Natural Resource Management and Policy
Series Editors: David Zilberman · Renan Goetz · Alberto Garrido

Harry de Gorter
Jill McCluskey
Johan Swinnen
David Zilberman *Editors*

Modern Agricultural and Resource Economics and Policy

Essays in Honor of Gordon Rausser

Springer

Natural Resource Management and Policy

Series Editors
David Zilberman, University of California, Berkeley, California, USA
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There is a growing awareness to the role that natural resources, such as water, land, forests and environmental amenities, play in our lives. There are many competing uses for natural resources, and society is challenged to manage them for improving social well-being. Furthermore, there may be dire consequences to natural resources mismanagement. Renewable resources, such as water, land and the environment are linked, and decisions made with regard to one may affect the others. Policy and management of natural resources now require interdisciplinary approaches including natural and social sciences to correctly address our society preferences.This series provides a collection of works containing most recent findings on economics, management and policy of renewable biological resources, such as water, land, crop protection, sustainable agriculture, technology, and environmental health. It incorporates modern thinking and techniques of economics and management. Books in this series will incorporate knowledge and models of natural phenomena with economics and managerial decision frameworks to assess alternative options for managing natural resources and environment.

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Modern Agricultural and Resource Economics and Policy

Essays in Honor of Gordon Rausser

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Preface

The half-century between 1970 and 2020 has witnessed fundamental political, environmental, and agricultural changes. These include the fall of the Soviet Union, the emergence of China, the formation of the Eurozone, the computer age and the internet, the environmental movement, the growing concern about climate change, the emergence of modern biotechnology, and several severe pandemics. These global changes contributed to the intensification and emergence of new approaches to economic research, especially the economics of agriculture and natural resources. These changes include the intensification of data availability and analysis; an increased reliance on experimentation; the introduction of large-scale simulations of the economy and the environment; and the emergence of environmental economics, behavioral economics, and political economics. These new tools strengthened the role of economic analysis in policymaking and intensified the use of and automated financial markets. Gordon Rausser was in the thick of many of these transitions of agricultural and resource economics and financial systems. Playing multiple roles, including professor, dean, policy advisor, and businessman, he has impacted the agenda of agricultural economics and multiple institutions and policies.

This book combines contributions by Gordon's students, colleagues, and friends. It aims to shed light on the lessons of his career and the modern literature of agricultural and resource economics to which he was a seminal contributor. Several of these contributions were first presented during a 4-day Festschrift on the occasion of Gordon's retirement. Two days were held at the UC campus and 2 days were held at the Rausser Ranch. The events held in Berkeley consisted of several panels, covering the broad reach and seminal contributions of Professor Rausser. The program is presented in Appendix 1 along with a preamble that was prepared by the university to motivate the Festschrift. This appendix also includes a poem written by Richard Just that was presented during the dinner celebration at the Berkeley Festschrift. Each panel's presentation and the interventions of former UC Davis and UC Berkeley Ph.D. students, former Harvard MBA students, and entrepreneurial partners of Professor Rausser were videotaped.[1] The second 2 days of the Festschrift focused on an active and ongoing research program organized by the four editors of this volume: Harry de Gorter, Jill McCluskey, Johan Swinnen, and David Zilberman. The actual presentations and the discussants for each session of this portion of the Festschrift are listed in Appendix 2. During this portion of the Festschrift, Julian Alston spontaneously led a group to prepare a song in Rausser's honor. The song is also included in Appendix 2. The program at the Ranch set in motion a yearlong effort to prepare each chapter that appears in this volume through formal reviews and evaluations.

A total of 19 chapters are organized into four major parts. The first part, *Gordon Rausser: Scholar, Leader, and Entrepreneur*, includes an introduction to Rausser and his career, presenting contributions by the University officials and based on the University's records by Ann-Marie Harvey and Kathryn Moriarty Baldwin. This is followed by David Zilberman's perspective on Gordon Rausser's academic and policy leadership, and then another chapter by David on how Rausser was instrumental in the transformation of agricultural economics from the 1970s to now. Stan Johnson highlights the many dimensions of Rausser's career that extends well beyond academic scholarship, including his consulting career, entrepreneurial activities, and editorial innovation. The remaining chapter in this part is authored by Jill McCluskey who documents the actual impacts of Rausser on the world food system.

Part II begins with a critically important contribution of Rausser and one of his most cherished colleagues, Richard Just, on the principles of policy modeling in food and agriculture. The original version of this paper was presented at the Federal Reserve Bank of Kansas City's Conference on Modeling Agriculture for Policy Analysis and we, the editors, believe that this paper never had the impact it deserved. The next two chapters turned to the future of food economics and food policies. In his chapter, building on foundations laid by Gordon Rausser with David Zilberman and other colleagues, Julian Alston discusses what he calls the "woke farm and food policy movement" and its economically destructive consequences for food producers and consumers and the natural environment—especially those that come from ill-conceived restrictions on technologies used on farms. David Just argues the proposed radical changes to the food system ignore the social and economic costs involved. The final two chapters in this part extend Rausser's many contribution to natural resource management and public policy. Yacov Tsur extends the many contributions of Rausser to water resource systems, Richard Howitt and Larry Karp investigate the current and ongoing efforts in the advancement of remote sensing technologies. A futuristic lens of what is possible in improving effective management through active learning, experimentation, and big data analytics is presented.

Part III presents the major developments in political economy that are directly traced to Rausser's research contributions over the years. In the first chapter, Jo

[1] The videos are available on YouTube: https://www.youtube.com/playlist?list=PLOyuQaVrp4qoepO-CxkRhvoytUPX8rJxk.

Swinnen uses the lens of special vs. public interests in drawing insights about potential improvements and reforms of agriculture and food policies. This chapter is followed by the work of Leo Simon and Jinhua Zhao to bring to bear of the role of political hyperbole and polarization along with the increasing importance of social media in public policy debates and elections. The next chapter turns to economic development where Alain de Janvry and Elizabeth Sadoulet, two of the major academic leaders in this field, investigate why sub-Saharan Africa has failed to perform in supporting agricultural growth and poverty reduction. de Janvry and Sadoulet use the political economic lens that Rausser developed on the potential use of "SMART" redistributive policies to achieve greater inclusiveness of the poor. The remaining two chapters of this third part turn to evolving institutions sourced with Rausser's work in designing public–private R&D partnerships in the emerging bioeconomy by Jill McCluskey and his many contributions to law and economics by Gareth Macartney.

In Part IV, a number of new research efforts extend Rausser's award-winning publications on future markets, macroeconomic linkages, and commodity price booms and busts. The Freebairn and Love chapter extends Rausser's earlier work on macroeconomic linkages to incorporate market concentration along with the agriculture and food supply chain in the United States. The next chapter by Carter and Revoredo-Giha update and extend much of Rausser's earlier work on futures markets, recognizing the fundamental contributions that resulted in futures market being included as an asset class for institutional portfolios. de Gorter summarizes his new theory of what caused the recent food commodity price boom and provides irrefutable empirical evidence that contradicts the massive literature on this topic. de Gorter then analyzes why Rausser is one of the few economists who changed his mind and adopted de Gorter's approach. He uses the lens of sociology and behavioral economics to explain the sclerotic thinking in the economics profession and how Rausser, who did not succumb, is a legend in our profession. The final chapter by Goodhue examines the continued evolution of spot and contract markets in agriculture, including recent developments in blockchain applications along witih food product supply chains. In the closing chapter, Foster, one of Rausser's former Ph.D. students, along with two of the co-editors, discuss how Gordon Rausser's work, insights, approaches to research and how he applies findings to the real world can serve as guides when addressing the multitude of wicked problems (see last chapter) that our profession will face over the course of this century.

Ithaca, NY, USA — Harry de Gorter
Pullman, WA, USA — Jill McCluskey
Washington, DC, USA — Johan Swinnen
Berkeley, CA, USA — David Zilberman

Appendix 1

Rausser Festschrift Preamble

Dr. Gordon Rausser is the Robert Gordon Sproul Distinguished Professor at the University of California, Berkeley, in the College of Natural Resources. He is a preeminent agricultural and resource economist whose contributions in academia, government service, business, and public policy are exceptional for their impact around the world. His leadership at Berkeley, including his exemplary service as dean of the College of Natural Resources, has had a critical and transformative effect in sustaining the College's strength and enabling it to achieve global stature and influence.

Dr. Rausser is proud to be a product of California's public education system: he received a B.S. in agriculture and statistics from California State University, Fresno, and an M.S. and Ph.D. in agricultural economics from the University of California, Davis, along with a post-doctorate at the University of Chicago in both general economics and statistics. Early in his career, he was a resident fellow at the Nonprofit Organization Resources for the Future, served as a Fulbright Scholar in Australia, and founded and served as president of the Institute for Policy Reform Fellowship Program in Washington, DC. In addition to his four decades at UC Berkeley, he has taught at the University of Chicago, Harvard University, Hebrew University, UC Davis, and Iowa State University in both economics and statistics.

Leadership at Berkeley

The effects of Gordon Rausser's leadership and achievement at Berkeley are broad and deep. During his years on the campus, he served on three separate occasions as chair of the **Department of Agricultural and Resource Economics** (ARE) at the College of Natural Resources. At the beginning of his first term as chair, the department was ranked eleventh in agricultural economics; at the end of his second consecutive term, it was ranked first in all such evaluations. His efforts as department chair to cultivate a cooperative spirit, set high expectations for tenured positions and faculty research, and recruited new faculty members who embraced a culture of excellence led to the ranking of ARE's Ph.D. program as the best in the country.

He was also a forward-thinking and inventive leader within the **Division of Agriculture and Natural Resources and California's Agricultural Experiment Station**—fundamental parts of the University of California's original charge as a land-grant university and important components of UC's continuing contributions to the state. He has served as director of the Giannini Foundation of Agricultural Economics, which supports efforts in agricultural and resource economics throughout the UC system, and he jointly prepared a seminal article on the social value of the Giannini Foundation.

After successfully serving as chairman of the Haas School of Business Siting and Architectural Faculty Committee in the mid-1980s, Dr. Rausser also had a pivotal role in **shaping and sustaining the Department of Economics and the campus-wide landscape for economics at Berkeley**. In the late 1980s, he served as chair of a high-level committee charged with evaluating the state of economics at Berkeley. This committee's findings and recommendations, presented in a document that became known as **the "Rausser Report,"** reversed a period of underinvestment and defined a path forward for the department and the campus, including increasing the size of the department's faculty, making faculty salaries more competitive, and establishing coordination and cooperation among areas of economics research and instruction across the campus. Today, Berkeley's Department of Economics and Department of Agricultural and Resource Economics are consistently ranked among the best in the world, and the campus produces renowned, innovative, and influential economics scholarship.

Gordon Rausser's imprint on the Berkeley campus is nowhere greater than at the **College of Natural Resources**, where his leadership as dean from 1994 to 2000 made a crucial difference. Faced in 1994 with a campus realignment proposal that would have significantly cut the College's faculty and discretionary resources, Dr. Rausser instead led a fundamental restructuring that substantively increased the quality of all of its programs.

At this critical juncture in the College's history, **Dr. Rausser's vision as dean laid the groundwork for transformative change**: revitalizing the College's research efforts, expanding its role in undergraduate and professional education, enhancing engagement in cooperative extension programs, and increasing administrative and budgetary efficiency. Under his watch, the CNR faculty and budget increased significantly, the number of faculty members appointed to chairs and professorships grew, both endowment and annual giving to the College increased dramatically, new undergraduate majors were introduced, and the number of graduate applications rose significantly.

J. Keith Gilless, who served as dean of CNR in subsequent years, has observed:

> Gordon Rausser assumed leadership of the College of Natural Resources at a point when the College's mission needed to be redefined and its structure realigned to deliver on that mission. The College and the campus were under tremendous financial stress. . . . Rausser was up to these challenges, reinvigorating a stalled academic reorganization of the college to achieve a departmental structure that was better aligned to support faculty in their exploration of cutting-edge research opportunities ….
>
> The new structure laid a sound foundation for the growth of the College's undergraduate programs, forward-looking faculty hiring, and the emergence of new and re-invigorated graduate programs that dominate in national rankings. … Without Rausser's ambitious and effective transformation of the College during his deanship, it is unlikely that it would have survived, much less become one of Berkeley's treasures.

Gordon Rausser also provided the intellectual leadership for the so-called **Berkeley-Novartis Agreement** (1998), the most creative public–private research and development agreement of its time, established in the face of much controversy about genetically modified organisms. The partnership brought Novartis's significant financial, intellectual, and technological resources together with Berkeley's strengths in plant genomics to advance research in the public interest. It also offered an important model: this agreement, along with an analysis of such public–private partnerships across the research university landscape, is presented in Dr. Rausser's award-winning book, *Structuring Public–Private Research Partnerships for Success: Empowering University Partners*.

In short, Gordon Rausser has made a critical difference across the Berkeley campus, and **his leadership as dean of CNR transformed the quality of its academic programs and their external rankings**: the College is now a world leader in all of its disciplines. The evolution of CNR has been documented on numerous occasions in the magazine, *Breakthroughs*, created by Dean Rausser as a branding vehicle for the College, which continues to flourish.

When Dr. Rausser was honored at the conclusion of his tenure as dean of the College of Natural Resources, Carol Christ—now Berkeley's Chancellor, and then Executive Vice Chancellor and Provost—made remarks celebrating his accomplishments. In describing his style as a leader, she evoked a distinction between "the fox and the hedgehog" inspired by the ancient Greek poet Archilochus and made popular by the philosopher Isaiah Berlin—"the fox knows many things, but the hedgehog knows one big thing." Carol Christ likened Gordon Rausser to both:

> He has brought an extraordinary variety of innovative ideas and strategies to his deanship—the personality of the fox. He knows many tricks. But his most characteristic strategy is to resort to first principles …. He has insisted on uncompromising standards of excellence …. It's a testimony to his achievement as dean that he is something of both the fox and the hedgehog.

Professional Achievement

In addition to leading transformative change at Berkeley and for the College of Natural Resources, Dr. Rausser has had an extraordinary impact as a professional in his field, within academia, in government and policy, and in entrepreneurship and business. Over the course of his career, he has made pioneering contributions to a number of fundamental areas of economic inquiry—in several instances, providing the seminal contribution that inspired others. **His creativity and productivity as a scholar have been recognized by no fewer than 25 merit awards to date** for original discoveries in the design and implementation of public policy, multilateral bargaining, collective choice and statistical decision theory, design of legal and regulatory infrastructure supporting sound governance, modeling dynamic stochastic processes, and the design of innovative environmental and natural resource economic analytical frameworks. Many of these acknowledgments took the form of awards for publications of enduring quality, quality of research discovery, and best refereed journal articles. He has published more than 250 articles and book chapters, along with 19 books and more than 100 commissioned papers, governmental reports, and working papers.

Gordon Rausser's exceptional contributions in his academic career and as a partner to the College of Natural Resources have been recognized by a unique distinction from the College. He was, until recently, the only member of the CNR faculty (composed of more than 130 tenure-track professors) to receive **both the College of Natural Resources Citation Award (2004) and the Career Achievement Award (2010)**. Each of these honors is awarded annually to a single individual: the Citation Award recognizes a friend of the College who demonstrates an exceptional commitment to CNR and its mission and has made a significant impact, while the Achievement Award honors a tenured faculty member for distinguished teaching and research through the course of a career. Along with these and numerous other honors, Dr. Rausser has been elected a fellow of the American Association for the Advancement of Science (1994), the American Statistical Association (1991), and the Agricultural and Applied Economics Association (1990).

As a luminary in both statistics and economics, Dr. Rausser has also played a crucial role in the **editorship of leading journals** in these fields. He has served as editor of the *American Journal of Agricultural Economics*; associate editor of the *Journal of the American Statistical Association* for almost a decade; associate editor of the *Journal of Economic Dynamics and Control*; and, most recently, for the past 15 years, founding editor of the prestigious *Annual Review of Resource Economics*, focusing on agricultural, economic development, environmental, energy, and resource economics. Equally important, he was selected (while still dean of CNR) as one of the two co-editors, 1998–2002, to prepare four volumes of the *Handbooks in Economics* series, focusing on agricultural and resource economics and designed as a definitive source for use by professional researchers and advanced Ph.D. students. In each of these roles, he has established the highest standards for peer-reviewed evaluations.

Beyond UC Berkeley and the University of California system, Dr. Rausser has played a **leadership role at Palo Alto University** (PAU), a private, nonprofit professional school focused on education and research in psychology for the greater good. Looking back on Dr. Rausser's service on the board (2000–2017) and as chair of the finance committee, PAU President Emeritus Allen Calvin wrote that Gordon provided "the kind of exemplary leadership, including the design of a critical financial template, required at that time for Palo Alto University to continue on its positive trajectory. We are in his debt forever."

Economic Policy Leadership and Reform

Among the most important of Gordon Rausser's professional achievements are his **leadership and innovation in economic policy**, an area in which the effects of his contributions have reverberated around the globe. He served as senior economist on the President's Council of Economic Advisors in the 1980s (responsible for agriculture, trade, and finance) and subsequently accepted a second federal government appointment, again on leave of absence from Berkeley, to become **chief economist of the US Agency for International Development** (AID) from 1988 to 1990. In this post, he managed over 500 economists working throughout the developing and emerging market world. During Dr. Rausser's tenure at AID, and subsequently as **president of the Institute for Policy Reform,** he developed new guidelines for the strategy statements that define the path to advance countries' economic development, while receiving a special State Department award for leadership. His research program began to focus on the importance of sound governance, government accountability, and political, civil, and economic freedoms.

With his 1990 article *A New Paradigm for Policy Reform and Economic Development*, and with dozens of further publications on the same theme, Dr. Rausser argued that international agencies (e.g., the IMF and the World Bank) and donor agencies (e.g., AID) should not make assistance conditional on outcomes or establishment of particular government policies. Instead, **his work made clear that decision-making about which countries are given priority for economic assistance should emphasize underlying constitutions and the design of institutions.** He wrote in 1992:

> These arrangements are usually overlooked in ideological debate and in scholarly research, and their importance is not generally appreciated in either the mature market economies or in the societies in transition…. [But] privatized enterprises will work well only after a society has established the institutions that are needed for an efficient private sector.

For example, he argued that democratic governmental and judicial institutions are critical to the enforcement of contracts, the security of private property, and the assignment of liability for wrongful conduct. Without sound constitutional structures, there is likely to be a maldistribution of political power[1], in which political

[1] Rausser, G., Swinnen, J., Zusman, P. (2011). *Political Power and Economic Policy: Theory, Analysis, and Empirical Applications.* Cambridge University Press.

agents are unencumbered in pursuing self-interest rather than the public interest. In essence, he argued that the underlying constitution must be designed to establish the credible guidelines and mechanisms for "rules by which rules are made." In a 1993 publication in *World Development*, he proposed that for the former communist regimes throughout Eastern Europe and the former Soviet Union, "The public sector must play a dominant role during the transition process and will be effective if and only if a well-designed constitution and an associated legal and regulatory infrastructure is first established."

Before Gordon Rausser's entry into this arena, policymakers largely held to the so-called Washington Consensus of the 1970s and 1980s, which emphasized allowing the free market to "get prices right." Yet his research and efforts as president of the Institute for Policy Reform demonstrated successfully that such an approach was misguided. Ultimately, in the mid-1990s, the IMF and the World Bank embraced his arguments and turned to supporting public-sector policies that reflect his insights into the essential importance of good governance in all of its aspects. At the time, IMF Managing Director Michael Camdessus remarked, **"Every country that hopes to maintain market confidence must come to terms with good governance."**

Following the Great Recession of 2008–2009, Dr. Rausser once again exerted a crucial influence on economic policy, this time in the United States. Based on his award-winning work on futures markets and derivatives, he took note of Warren Buffet's 2002 observation that "governments have so far found no effective way to control … the risks posed by these contracts," and that derivatives constitute latent "financial weapons of mass destruction." Motivated by this insight, Gordon Rausser and his colleagues designed a patent that focused on permissioning, counter-party risk, and avoidance of systemic risk, issued in 2010 and entitled *Integrated Electronic Exchange of Structured Contracts with Dynamic Risk-Based Transaction Permissioning*. This effort—along with numerous other publications, as well as consulting work with organized futures markets exchanges in the United States and England—formed part of **the intellectual foundation for the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010.**

Consulting and Entrepreneurship

Reflecting the themes of his research, Dr. Rausser's career also encompasses **remarkable contributions as an economic consultant to government agencies and private clients**, with a focus on applying economics and finance to complex legal and public policy disputes. His consulting experience includes issues associated with economic damage determination, economic feasibility studies, antitrust violations, unfair competition, market manipulation, class certification, risk valuation, and statistical and econometric modeling. On numerous occasions, he has provided expert testimony in matters involving pharmaceutical products, patent infringement and patent infringement damages, commercial success, new product introduction, and damages flowing from delayed entry or anticompetitive barriers to market entry. Many of Dr. Rausser's refereed journal publications reflect insights drawn from his expert testimony on matters related to ground water contamination, surface water pollution, air pollution, diminution of property values, superfund site remediation, attempted manipulation of commodity futures markets, merger and acquisition analysis, breach of contract in many agribusiness and commodity industries, food safety, false labeling, housing discrimination, environmental justice, lender liability, false representations, and market collusion.

In addition to his efforts as a consultant, Gordon Rausser has made **significant contributions as an entrepreneur**. These achievements include his role as co-founder and chairman of Emeryville-based **OnPoint Analytics**, which provides business consulting services specializing in expert testimony in economics, data analytics, finance, and statistics. He has served on the boards—in many instances, as chair—of at least 20 companies, both public and private. He was a co-founder with three fellow Berkeley faculty members and served as board member of LECG (the Law and Economics Consulting Group); the company was taken public in 1997.

Guiding Values and Commitment

In 2015, when the UC Davis Agricultural and Resource Economics program celebrated the 50th anniversary of its Ph.D. program, Gordon Rausser was honored as an inaugural recipient of the ARE department's outstanding Ph.D. Alumni Award. In speaking to his fellow alumni and UC Davis faculty about the formative experience of his years at Davis, Dr. Rausser articulated some of the lessons and values that underpin his life and work. He told the story of becoming a faculty member after only 2 years of Ph.D. coursework at Davis, while completing his dissertation, serving as Ph.D. director for six graduate students, stepping up to manage a family farm after his father's death, and raising his own young family. He spoke about how the chaos attendant on all of these demands helped teach him to set a high priority on the work he loves. At root, Gordon Rausser has been driven by a desire to seek out challenges, a sustaining passion for his work, and a profound sense of responsibility. As a leader, he has built communities grounded in **intellectual rigor, generative collaboration, and—in Carol Christ's words—"uncompromising standards of excellence."** These values are consonant with Berkeley at its core. We are fortunate that Gordon Rausser has enacted them through his leadership and achievements on this campus.

Dr. Rausser's accomplishments at Berkeley reflect his deep love and affection for the College of Natural Resources, where he has spent the past four decades serving the institution. That dedication and love are also expressed in his generosity as a donor to CNR. During the Campaign for the New Century (1993–2001), he established the *Gordon Rausser Endowed Scholarship Fund*. He has continued to add to the endowment, with his contributions matched through an incentive program for faculty and staff who give to Berkeley. Today, the market value of the fund is more than $620,000, and its payout supports exceptional Ph.D. students in the top-ranked Department of Agricultural and Resource Economics as well as undergraduates with financial need in the Environmental Economics and Policy major sponsored by CNR.

Appendix 2. Festschrift in Honor of Gordon Rausser

October 24th and 25th
Banatao Auditorium, University of California Berkeley
Randy Katz: Master of Ceremonies, Vice Chancellor of Research
Panel 1: University Entrepreneurship, Leadership, and the Fostering of Public–Private Partnerships|9:00–10:00 a.m.
Richard Lyons
Professor of Finance and former Dean, Haas School of Business (Moderator)
Paul Alivisatos
Executive Vice Chancellor and Provost, UC Berkeley
Carol Christ
Chancellor of University of California, Berkeley
Ann Harrison
Dean of the Haas Business School, UC Berkeley
Comments by former Ph.D. students
Panel 2: Public Policy and Market Reforms in Transition Economies|10 a.m.–11:30 a.m.
Gerard Roland
E. Morris Cox Professor of Economics and Professor of Political Science, UC Berkeley (leading theorist of political and economic analysis of transition economies) (**Moderator**)
Nicholas Stern
Chief Economist World Bank 2000–2003; 1st Chief Economist for the European Bank for Reconstruction and Development 1994–1999, Chair of the Grantham Research Institute, Chair of the Centre for Climate Change Economics and Policy, IG Patel Professor of Economics and Government at the London School of Economics and Political Science
Francis Fukuyama
Olivier Nomellini Senior Fellow and Mosbacher Director, Center on Democracy, Development and the Rule of Law at the Freeman Spogli Institute for International Studies, Stanford University; author of *The End of History*
Goran Buldioski
Director, Berlin Office and Co-Director, Open Society Initiative for Europe (OSIFE) at the Open Society Foundations
Stan Johnson
Former director of CARD at Iowa State University and former Chairman of the Board, Institute for Policy Reform
Joe Stiglitz
Nobel Laureate, Economics 2001; University Professor, Columbia University; Chief Economist of The Roosevelt Institute
Yang Xie
Assistant Professor, Department of Economics, University of California, Riverside

Panel 3: Political Economy in Elections and Public Policy Selection: New Implications of Narrative Control|11:30–12:30 p.m.
Jo Swinnen
Director-General of IFPRI, Director of LICOS Center for Institutions and Economic Performance and Professor at the University of Leuven in Belgium, Visiting Scholar, Stanford University (Moderator)
Julian Alston
Distinguished Professor, Department of Agricultural and Resource Economics, University of California, Davis
Leo Simon
Adjunct Professor, Department of Agricultural and Resource Economics, University of California Berkeley
Jinhua Zhao
Professor of Economics and Agricultural Economics and former Director Environmental Science and Policy Program, Michigan State University
William Foster
Distinguished Professor of Economics, University of Santiago de Chile
Panel 4: Law and Economics|2–3:00 p.m.
Rich Gilbert
Emeritus Professor of Economics and Chair of the Berkeley Competition Center, former Assistant Attorney General for Economics, Antitrust Division 1993–1995 (Moderator)
Jeff Perloff
Professor and Chair, Department of Agricultural and Resource Economics, University of California Berkeley
David Sunding
Thomas J. Graff Professor, University of California Berkeley (former chair of ARE)
Michael Hausfeld
Leading Class-Antitrust Attorney
Gareth Macartney
Chief Executive Officer and Director of Competitive Analysis, OnPoint Analytics
Martin Stuermer
Senior Research Economist, Research Department Federal Reserve Bank of Dallas
Panel 5: Macroeconomic Linkages, Hedge Funds, Derivative Markets, Futures, and Options|3–4:00 p.m.
Brian Wright
Professor, Department of Agricultural and Resource Economics, University of California Berkeley
(Moderator)
Vito Palmieri
Co-Founder, Equity Administration Solutions (EASi), Former CEO, Certent
Bill Balson
Economist and Risk Manager, Former CFO Opt4 Derivatives
Colin Carter

Distinguished Professor, Department of Agricultural and Resource Economics, University of California, Davis

H. Alan Love

Director and Professor School of Economic Sciences, Washington State University

Gordon Fallone

Co-founder and Managing Partner of OnPoint Analytics Capital Partners

Panel 6: Celebrating Gordon Rausser's CNR Career|4:15 p.m.

Dean David Ackerly

Dean of College of Natural Resources (CNR) and Professor, Integrative Biology, UC Berkeley (Moderator)

Carol Christ

Chancellor of University of California, Berkeley

Keith Gilless

Professor of Forest Economics and Dean Emeritus, UC Berkeley

Jill J. McCluskey

Distinguished Professor of Sustainability, Washington State University

David Just

Professor and Area Coordinator for Applied Economics and Policy Charles H. Dyson School of Applied Economics and Management, and Susan Eckert Lynch Professor in Science and Business, SC Johnson School of Business, Cornell University

Panel 7: Governance Structures and Agriculture's Role in Economic Development|9–10:00 a.m.

Alain de Janvry

Emeritus Professor, Department of Agricultural and Resource Economics, University of California, Berkeley (Moderator)

Michael Carter

Professor, Department of Agricultural and Resource Economics, University of California, Davis; Honorary Professor of Economics, University of Cape Town, South Africa

Marcel Fafchamps

Freeman Spogli Institute for International Studies; Senior Fellow at the Center on Democracy, Development, and the Rule of Law; Courtesy Professor, Department of Economics, Stanford University

Jeremy Magruder

Associate Professor, Department of Agricultural and Resource Economics, University of California, Berkeley

Panel 8: China US Trade Relationships: Agricultural Distortions and the Uruguay Round|10–11:00 a.m.

Doug Irwin

John French Professor of Economics, Dartmouth College; author *Clashing over Commerce: A History of U.S. Trade Policy*; Winner of 2019 Hayek Book Award (Moderator)

Hongbin Li

James Liang Director of the China Program, Stanford King Center on Global Development and Senior Fellow, Stanford Institute for Economic Policy Research

Daniel Sumner

Frank H. Buck, Jr. Distinguished Professor, Department of Agricultural and Resource Economics, University of California, Davis

Harry de Gorter

Professor, Charles H. Dyson School of Applied Economics and Management, Cornell University

Kym Anderson

George Gollin Professor Emeritus in the School of Economics, foundation Executive Director of the Wine Economics Research Centre, and formerly foundation Executive Director of the Centre for International Economic Studies, University of Adelaide

Panel 9: Big Data Analytics and Continuous Remote Sensing: Revisiting Optimal Control Methodologies|11–12:00 p.m.

Richard Howitt

Professor Emeritus, Department of Agricultural and Resource Economics, University of California, Davis (Moderator)

Larry Karp

Professor, Department of Agricultural and Resource Economics, University of California, Berkeley

Gordon Rausser

Robert Gordon Sproul Distinguished Professor, ARE UC Berkeley; Former Chief Economist of the U.S. Agency for International Development; and Founder of the Institute of Policy Reform, UC Berkeley

Joe Fargnoli

Chief Technological Officer, Theia

Solomon Hsiang

Chancellor's Associate Professor of Public Policy, UC Berkeley

Panel 10: Social Costs: Exhaustible and Renewable Natural Resources (with Emphasis on Water Resources)|1:00–2:30 p.m.

David Zilberman

Robinson Chair, Agricultural and Resource Economics; Director, Center for Sustainable Resource Development, UC Berkeley; 2019 Winner Wolf Prize in Agricultural (Moderator)

Brief comments by Nicholas Stern and Joseph Stiglitz

Michael Hanneman

Julie A. Wrigley Chair in Sustainability, School of Sustainability, Arizona State University; Professor Emeritus, Department of Agricultural and Resource Economics, University of California, Berkeley

Ariel Dinar

Distinguished Professor, UC Riverside

Yacov Tsur

Professor, Department of Environmental Economics and Management; Ruth Ochberg Chair, Hebrew University of Jerusalem

Susan Stratton
Associate Professor Department of Economics, Smith College
Rachel Goodhue
Department Chair and Professor, Department of Agricultural and Resource Economics, University of California, Davis
Panel 11: Social Value of the Giannini Foundation: 2:30–3:00 p.m.
Alex McCalla
Professor Emeritus, Department of Agricultural and Resource Economics, University of California, Davis (Presenter)
Discussant: Brian Wright
Current Director of the Giannini Foundation of Agricultural Economics
Discussant: David Just
Professor and Area Coordinator for Applied Economics and Policy Charles H. Dyson School of Applied Economics and Management, and Susan Eckert Lynch Professor in Science and Business, SC Johnson School of Business, Cornell University

Gordon Rausser

As a colleague, Gordon is the fiercest competitor,
Always to be the best, he is driven like a predator.
Yet as a competitor, he is the most supportive colleague.
Always ready to work together, never dampened by fatigue.

If he starts a consulting company, it must be the biggest.
If he founds a trading fund, it must grow the fastest.
If he chairs a department, it must be the world's best.
If the dean of a college, it must show where the future will rest.

If he joins a government agency, he must be the chief.
Always moving forward with vigor and without relief.
Even with grandchildren, he must have the most.
Oh well, there's one thing he cannot boast.

Giving more time in a day and more days at a time.
He has come to be one of the profession's prime,
He has achieved all, of these goals and more.
One can only imagine what the future has in store.

While this person's achievements are many,
His most unique characteristic beyond any,
Is his infectious charisma that energizes all,
Which expands vision and makes goals tall.

Through his ideas and visions he does conceive,
He has inspired many around him to believe,
That they can join and contribute with him,
To making something the best that there has ever been.

-Richard E. Just

One Gordon Rausser

words by Julian Alston

To be sung to the tune of Guantanamera (e.g., Trini Lopez version or Pete Seeger version)
with apologies to José Martí and Joseíto Fernández

Chorus

One Gordon Rausser
There's only one Gordon Rausser
One Gordon Rausser
There's only one Gordon Rausser

He was a young dairy farmer
Acting assistant professor
He was teaching and learning
Over-reaching and earning
Doing dynamics, PERTs and PESTs
Young Gordon Rausser rarely rests
(Excess begets excess)

Chorus

He wrote a fine dissertation
Was it the best in the nation?
It took him two years to write it
Then Ben and Gordy read and signed it
He had to stop at three volumes
He'd filled up all of their shelf room

Chorus

He came from Galt, that's just near us
He went to Fresno and Davis
He had three kids in a heartbeat
Tenure tracking, his life was so sweet
But still he could not settle down
Off to the mid-west upward bound

Chorus

From the mid-west to the east coast
And then back out to the west coast
UC Berkeley, Giannini
It was where he knew he should be
And for two score years he stayed there
All the while he plied his trade there

Chorus

He's an econometrician
And a financial magician
He's a top expert witness
And a builder of business
A merchant banking high-roller
And still a gentleman scholar

Chorus

He's a writer and a fighter
He's a career expediter
A most creative adviser
His many mentees left wiser
A builder of knowledge
He served as Dean of his College

Chorus

He led his colleagues at Berkeley
Thrice chaired his Berkeley Department
He saved his College at Berkeley
From other men who set out to harm it
When Rausser plays, he wins the game
And now the College bears his name

Chorus

Now Gordon's kids have their own kids
And one of them has his own kid
Now Gordon's grandpa to nine kids
And a great grandpa too
His greatest legacy of all?
The one he values most of all
(Fare the well Giannini Hall!)

One Gordon Rausser
There's only one Gordon Rausser
He's an envy arouser
There's only one Gordon Rausser

Chorus and Repeat

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Part III Major Developments in Institutional Economics and Political Economy

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About the Authors

Julian M. Alston is a Distinguished Professor in the Department of Agricultural and Resource Economics at UC Davis, best known for his work on the economics of agricultural and food policy. His recent projects have emphasized science and technology policy and the economics of innovation; food and nutrition policy, and the global challenges of poverty, malnutrition, and obesity; and wine economics. He has published hundreds of research articles, chapters, and books on these subjects. He is a Distinguished Fellow (or equivalent) of AAEA (2000), AARES (2004), WAEA (2009), AAWE (2012), and an Honorary Life Member of the IAAE (2015).

Colin A. Carter is a Distinguished Professor of Agricultural and Resource Economics at the University of California, Davis, where he served as Department Chair from 1998 to 2001. For 9 years, he served as Director of the Giannini Foundation of Agricultural Economics at the University of California. Colin's fields of interest include commodity markets and international trade. He has produced roughly 150 academic publications on topics including international trade, agricultural policy, futures and commodity markets, the economics of China's agriculture, and the economics of biotechnology adoption in agriculture. Colin was elected a Fellow of the AAEA in 2000 in recognition for his many contributions to the field of agricultural economics.

William Foster is a Professor in the Department of Agricultural Economics at the Pontificia Universidad Católica de Chile in Santiago. He received his Ph.D. in Agricultural and Resource Economics from the University of California, Berkeley, and his M.S. and B.A, from the University of Maryland. Before moving to Chile, he was an Associate Professor at North Carolina State University. His research interests include political economy, economic geography, rural and territorial development, land values, entrepreneurship, among other areas of study.

John Freebairn holds the Ritchie Chair in Economics at the University of Melbourne. He has Bachelor's and Master's degrees from the University of New England and a Ph.D. from the University of California, Davis, under the wonderful supervision of Gordon Rausser. Prior to joining Melbourne in 1996, his preceding career includes university appointments at the Australian National University, LaTrobe University, and Monash University, and periods with the NSW Department of Agriculture and the Business Council of Australia. John is an applied micro-economist and economic policy analyst with current research interests in taxation reform and environmental economics.

Alain de Janvry is a Professor of Agricultural and Resource Economics and Public Policy at UC Berkeley. His area of interest is international economic development, with expertise principally in Latin America, Sub-Saharan Africa, the Middle East, China, and the Indian subcontinent. His fields of work include poverty analysis, rural development, land reform, quantitative analysis of development policies, impact evaluation of social programs, technological innovations in agriculture, and the management of common property resources. He has worked with numerous international development agencies and foundations. He is a fellow of the AAEA and a member of the French Academy of Agriculture.

Harry de Gorter is professor in the Dyson School of Applied Economics and Management, Cornell University. His research focus is on agriculture and trade policy with recent work on food waste, biofuels, and agricultural trade reform and the Doha Development Agenda, especially the impact of subsidies and protection on developing countries. He has long been actively involved in advising many governments and organizations on issues related to agriculture trade policy including the EU, FAO, G-20, IMF, OECD, UNCTAD, World Bank, and WTO. He recently published a book on the causes of the great food commodity booms in the new millennium.

Rachael E. Goodhue is Professor and Chair in Agricultural and Resource Economics at the University of California, Davis. She earned her Ph.D. and M.S. from the University of California, Berkeley, and her B.A. from Swarthmore College. Her research interests include agricultural marketing and organization, agri-environmental policy, pest management, regulation, and contract design. She is on the editorial boards of *Agricultural and Food Economics*, *California Agriculture*, and *Review of Industrial Organization*. Currently, she teaches intermediate micro-economic theory for undergraduates in the Managerial Economics major and courses on agricultural markets and contracting and the economics of California agriculture for graduate students.

Richard Howitt is Professor Emeritus in the Department of Agricultural and Resource Economics, member of the Center for Watershed Sciences at the University of California, Davis. He has earned six national research awards and was made a Fellow of the Agricultural and Applied Economics Association in 2009. He has recently co-authored three books on the future of California water management and continues to serve on several advisory boards. His current research interests are: Disaggregated economic modeling methods; Using market mechanisms to allocate water resources; and Empirical dynamic stochastic methods used to analyze investments that are subject to dynamic stochastic inputs and irreversible costs or decisions.

Stanley R. Johnson, Ph.D is a Distinguished Professor of Economics-Emeritus Iowa State University, where he last served as the Vice Provost for Extension, after almost a dozen years as the Director of the Center for Agricultural and Rural Development (CARD). He may be best known for his hundreds of Ph.D. advisees as well as for his publications in econometrics, or about food, agricultural and environmental policy. In 1998, the American Agricultural Economics Association named him a Fellow. He has also earned numerous appointments to academies of science around the world and outstanding article awards. He has published 20 books, over 300 journal papers, and over 500 technical reports. He currently serves as the Chair of the Board of the National Center for Food and Agricultural Policy, Washington, DC.

David R. Just received his Ph.D. (2001) and M.S. (1999) degrees in agricultural and resource economics from the University of California, Berkeley, and a B.A. (1998) in economics from Brigham Young University. He is currently the Susan Eckert Lynch Professor of Science and Business in the Charles H. Dyson School of Applied Economics and Management and previously served as area coordinator for applied economics and policy in the S.C. Johnson College of Business at Cornell University. He is a fellow of the Agricultural and Applied Economics Association.

Richard E. Just is Distinguished University Professor Emeritus, University of Maryland, and previously Professor, University of California, Berkeley. He has authored hundreds of refereed journal articles and other publications and is the lead author of the two major textbooks on welfare economics. He has served as editor of the American Journal of Agricultural Economics and president of the Agricultural and Applied Economics Association (AAEA). He won more research awards from the AAEA in its first 100 years than any other person and ranks in the top 1% of all economists on RePEc in number of works, number of journal pages, and strength of students.

Larry Karp is Professor in Agricultural and Resource Economics at UC Berkeley. His current research projects include asset prices with overlapping generation; instrument selection under asymmetric information; the theory of International Environmental Agreements; and optimal social distancing policy in a pandemic. He has also worked on trade policy, industrial organization, and dynamic games. Recent books include *Lectures in Classical Trade Theory* (2021) and *Natural Resources as Capital* (2017). Recent publications include *Carbon Taxes and Climate Commitment with Non-constant Time Preference* (with T. Iverson), *Review of Economic Studies*, and *Provision of a Public Good with Many Dynasties*, Economic Journal.

H. Alan Love is a Professor in the School of Economic Sciences at Washington State University where he served as Director, 2011–2018. He received his Ph.D. in Agricultural and Resource Economics from the University of California, Berkeley, M.S. from the University of Minnesota, and B.S. with high distinction from the University of Kentucky. Before joining WSU, he held faculty positions at Texas A&M University and at Oregon State University. His research focuses on issues relating to empirical industrial organization. He has received a number of awards including Published Research Award, WAEA; Article of the Year, NAREA; and Quality of Research Discovery Award, AAEA.

Gareth Macartney is Senior Economist and Director of Competition at OnPoint Analytics, a consulting firm specializing in expert testimony. Macartney serves as an expert witness in antitrust, intellectual property, contract, and class action litigations. His research has been published in *The Review of Economics and Statistics* and *The Economic Journal*. He received a 2015 Antitrust Writing Award for his work on *Antitrust Proceedings—Then and Now*, an article about economic analysis in class certification published in Research in Law and Economics. His co-authored article *Economic Principles for Class Certification Analysis in Antitrust Cases* appeared in Antitrust Magazine.

Jill J. McCluskey is Regents Professor and Director of the School of Economic Sciences at Washington State University. McCluskey's research focuses on product quality and reputation, sustainable labeling, consumer preferences for new technology, and representation of women in STEM. An award-winning researcher, she is widely published and cited. Her research has been funded by private foundations, NSF, and USDA. An award-winning mentor, she has served as major professor to 41 Ph.D. students, many of whom are Professors at major research universities. She is an incoming *Editor of the American Journal of Agricultural Economics*. She is past President and Fellow of the Agricultural and Applied Economics Association and Fellow of the Western Agricultural Economics Association. She is a member of the Board on Agricultural and Natural Resources of the National Academies of Sciences, Engineering, and Medicine. Her research has been highlighted by various media outlets including the *New York Times*, *National Public Radio,* and *Newsday.* She received her Ph.D. in Agricultural and Resource Economics in 1998 from the University of California, Berkeley, with Gordon Rausser serving as her advisor.

Gordon Rausser is an American economist. He is currently the Robert Gordon Sproul Distinguished Professor Emeritus, Dean Emeritus "https://en.wikipedia.org/wiki/Rausser_College_of_Natural_Resources" Rausser College of Natural Resources and more recently, a professor of the Graduate School at the "https://en.wikipedia.org/wiki/University_of_California,_Berkeley" University of California, Berkeley. On three separate occasions, he served as chairman of the "https://are.berkeley.edu/" Department of Agricultural and Resource Economics, served two terms as Dean of the "https://en.wikipedia.org/wiki/Rausser_College_of_Natural_Resources" Rausser College of Natural Resources, and has served on the "https://en.wikipedia.org/wiki/Board_of_Trustees" Board of Trustees of public universities and one private university. Rausser has been appointed to more than 20 board of directors of both private and publicly traded companies, including chairman of several of such boards. His federal government service includes Senior Economist at the Council of Economic Advisers, Executive Office of the President, Chief Economist at the Agency for International Development and as President of the Institute for Policy Reform. His editorship contributions include serving as editor of the American Journal of Agricultural Economics, associate editor of the Journal of the American Statistical Association, associate editor of the Journal of Economic Dynamics and Control, editor of Agricultural Management and Economics, co-editor of four volumes of the Handbook of Agricultural Economics, and more than 15 years as the editor of Annual Review of Resource Economics. He is recipient of 34 professional awards, including Best Journal Articles, Annual Best Published Research awards, and Publications of Enduring Quality from the AAEA, and Outstanding Research and/or Leadership awards from other associations, such as the American Antitrust Institute, the European Association of Agricultural Economists, and the Agency for International Development. He was most recently honored by AAEA for named keynote addressed at the annual meetings from 2020 forward for exceptional intellectual leadership and his mentoring of leading scholars. He was also honored in 2020 by the permanent naming of the College of Natural Resources, UC Berkeley for his visionary leadership and philanthropic contributions.

Cesar Revoredo-Giha is Reader in Food Supply Chain Economics and Team Leader of Food Marketing Research at the Rural Economy, Environment and Society Research Group at the Scotland's Rural College (SRUC). He holds a Ph.D. in Agricultural and Resource Economics from the University of California, Davis. His research interests are in the areas of industrial organization of the food sector, international trade, commodity markets, and economic modeling.

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Leo Simon is a Professor in the Department of Economics, Monash University, and an Adjunct Professor in the Department of Agricultural and Resource Economics, University of California, Berkeley. His research interests include game theory, information economics, environmental economics, and political economy. His work on continuous time game theory and the theory of discontinuous games have proven to be seminal for the field. Current research projects address questions regarding dynamic games, polarization, confirmation bias, and Bayesian skepticism. He holds two Master of Science degrees from the London School of Economics, and his Ph.D. from Princeton University.

Johan Swinnen is Director General of the International Food Policy Research Institute (IFPRI). Earlier, he was Professor of Economics and Director of the LICOS Centre for Institutions and Economic Performance at KU Leuven and Senior Research Fellow at the Centre for European Policy Studies; Lead Economist at the World Bank and Economic Adviser to the European Commission; visiting professor at various universities; and adviser to OECD, EBRD, FAO, etc. He is a Fellow of the AAEA and the EAAE and former President of the IAAE. He has a Ph.D. from Cornell University and Honorary Doctorates from the University of Göttingen and Nitra University. His recent books include *COVID-19 and Global Food Security*; *The Political Economy of Agricultural and Food Policies*; *Quality Standards, Value Chains, and International Development*; *Political Power and Economic Policy*; and *From Marx and Mao to the Market*.

Yacov Tsur is the Ruth Ochberg Professor of Agriculture at the Department of Environmental Economics and Management, the Hebrew University of Jerusalem. His research deals with natural resource management under uncertainty and catastrophic threats, with a particular focus on water resources. He publishes widely in economic outlets and has been actively involved in advising Israel's Water Authority and the World Bank on issues concerning the use of market-based instruments in the management and regulation of water resources.

Jinhua Zhao received his PhD from UC Berkeley and is the David J. Nolan Dean and Professor of Applied Economics and Policy at the Charles H. Dyson School of Applied Economics and Management, Cornell University. He was a co-editor of the *Journal of Environmental Economics and Management* and served on the editorial councils of JEEM and the Review of Development Economics. He is currently on the editorial committees of *Annual Review of Resource Economics and Frontier of Economics in China*. He conducts research in the broad area of environmental and resource economics, with special interests in global climate change, water, technology adoption, and dynamic decision making under uncertainty.

David Zilberman is a Professor and holder of the Robinson Chair in the Department of Agricultural and Resource Economics, UC Berkeley. His areas of expertise include agricultural and environmental economics and policy, water, marketing, risk management, the economics of innovation, natural resources, biotechnology, and biofuels. He is the recipient of the 2019 Wolf Prize in Agriculture, and the 2018–2019 President of Agricultural and Applied Economics Association (AAEA). He is an elected member of the United States National Academy of Science, a Fellow of the AAEA, the Association of Environmental and Resource Economists, and Honorary Life Member of the International Association of Agricultural Economists.


Harry
de Gorter


Gordon
Rausser


Francis


Ann
Harrison


Alain


Gordon
Rausser


Hongbin
Li
Daniel
Sumner


Elisabeth
Sadoulet
Alain
de Janvry
RESERVED


Gordon's approach to NR analysis
• Static analysis is tractable and easy
– But to make a develop dynamic frameworks with adaptation and learning
• Political economic analysis is crucial
– To identify strategies – that are well timed efficient feasible and acceptable politically
• Quantitative analysis should allow to solve disputed figures
– Should be practical-Sophistication is a mean not an end.


PEOPLE, POWER, AND PROFITS
PROGRESSIVE CAPITALISM FOR AN AGE OF DISCONTENT
JOSEPH E. STIGLITZ


Michael
Hanemann


Ariel
Tsur

Part I
Gordon Rausser: Scholar, Leader and Entrepreneur

On the Essence of Leadership: Lessons from Gordon Rausser

David Zilberman

The BEAHRS ELP (environmental leadership program) started when Gordon was Dean of the College of Natural Resources. One of the biggest challenges initially was teaching leadership. We were able to develop good sessions on conflict resolution and development of personal and communication skills, but not on leadership per se, so we decided to bring several people who were leaders in different fields and let them speak about their life lessons. We found that when it comes to leadership, case studies can be inspiring. I realized later that Gordon Rausser's career and life provide excellent lessons on leadership. Furthermore, to me and others, he provided a model and showed how to manage a career and run an educational program. In this chapter, I summarize some of the lessons on leadership that I learned from working with and knowing Gordon. Gordon's life is an American success story, where a farm boy becomes a successful scholar, businessman, policymaker and leader, earning the admiration of his colleagues while building a strong and supportive family. It is a story of overcoming obstacles, surpassing expectations, learning from mistakes, and leaving his mark on many fields and lives.

Bryman's (2007) survey of literature suggests that academic leaders vary in their styles and methods and that effective leaders make a significant difference to their organization and society. Gordon's career led him to academic and business leadership positions. I will identify some of the characteristics that made him a leader and demonstrate how these characteristics led to his accomplishments as a scholar, department chair, dean and entrepreneur. I will conclude with some general lessons on leadership I have learned from observing Gordon Rausser.

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1 Gordon: A Born Leader Who Honed his Leadership Skills

In the introduction of each BEAHRS ELP session, participants discuss a basic question: are leaders born or made? After the discussion, they conclude that leadership is a combination of traits and continuous improvement. Gordon is a great illustration of this conclusion. From a young age, he didn't accept unsatisfactory situations, instead always fighting to improve them. Encountering violence as a kid, he became a competitive boxer, for self-defense and for self-esteem. He dedicated himself to boxing and even won the prestigious California-Nevada Boxing Association's Diamond Belt. But from a young age, he was good at benefit-cost analyses, and realized that the glory of boxing was not worth the price in terms of blood and tears. During his childhood, all of his available time, aside from sports and an amateur boxing career, was spent working on the small family farm, never choosing to open a book and complete any homework assignments. Later, he discovered that he was dyslexic, but he excelled at evaluating dairy cattle, which led him to be active in 4H and Future Farmers of America, indirectly preparing him for trading in financial commodities and thinking like an economist. With his photographic memory, ambition and recognition of the importance of education, he became an outstanding student and leader of his peers (Miller, 2020). As a junior in college, he became president of his fraternity and structured a financial agreement to construct a fraternity house for 65 members. He also became the president of the undergraduate executive council (equivalent to president of the academic senate); Greek man of the year; Senior class president; the president of his fraternity Alpha Zeta; and recipient of the Outstanding Graduating Leadership Award.

It seems to me that Gordon views himself and people he cares about as "works in progress." More than once, he prodded me to work on my accent (my wife often reminds me that I should have listened). I once asked him why he started trading in futures and other financial markets. He told me that while at Harvard, he realized that he needed supplemental income to support his children and alimony commitments. He did not pursue a private sector employment since he did not want to give up his primary passion of academic research and instruction. Since he had a relative advantage in understanding futures markets and it would be complementary to his academic research, he started trading and established a hedge fund.

He often discussed, with faculty members and staff, what has and has not worked in the department, trying to understand why. His capacity to manage meetings and build consensus has improved over time. He became a very efficient and considerate moderator and decision maker. He doesn't fight for lost causes and strives to reach the best compromise. He has made sure to show faculty members that he cared about them and was willing to fight for them, because for him, building a team was a major priority. His leadership was so effective because of skills that he has developed over his life, a few of which I highlight below.

2 The Ability to Multitask

By necessity, Gordon became very good at multitasking at a young age. The time management skills and capacity to work simultaneously on multiple issues that he acquired as a young man on the family farm served him well throughout his life. As a graduate student, he was able to work on the farm following his father's unexpected death, study, and be an engaged parent. As a young researcher, Gordon contributed to the economics of agricultural production, resource economics, the economics of dynamic systems, and econometrics. Later, he combined quantitative research, both theoretical and empirical, with policy work. In later years he continued to be engaged in research, served as dean, and co-founded a major publicly traded consulting firm.

Perhaps the most challenging and admirable expression of Gordon's multitasking talent was his ability to pursue a professional career while being supportive of and close to his children. Over the years I became close to the Rausser's, and like every family they have their ups and downs, but Gordon's children always came first. He gave up many opportunities at Harvard and other east-coast universities to be near his children in California (he was fortunate to be in Berkeley which provides as good academic opportunities as anywhere). Even in his busiest moments where he was less accessible to colleagues, he was there when his children needed him, and they grew up to be wonderful people in their own right. Gordon is proud of his family, and now enjoys playing the doting grandfather and great-grandfather. He was fortunate to establish a wonderful sanctuary for his family, a delightful ranch in Grass Valley that he designed and had built.

While excessive multitasking may prevent people from retaining information and learning (for example, people who text during class tend to get lower grades (Ellis et al., 2010)), Gordon was able to allocate his time to multiple tasks while concentrating fully on the task at hand. One of Gordon's most endearing qualities is that he gives people who speak with him his full attention and tends to remember the conversation and the context. Perhaps his sharp memory allowed him to multitask and excel in private pursuits and academic work at the same time.

The ability to multitask is a valuable leadership skill (Otto et al., 2012). Sometimes leaders need to integrate and negotiate between various perspectives and points of view. They need to fight multiple fires and be able to shift attention from one area to another. They need to be able to relate to various constituents and bring them together. Relating to each group requires a distinct approach with the added challenge of bringing the groups together. This type of effort embodies multitasking. Gordon has done it as a dean, when he served as a chair of the committee to evaluate Berkeley's efforts in economics, and as a business mediator.

3 Developing People Through Delegation and Building Partnerships and Institutions

One drawback of multitasking is that it may lead to over-commitment and failure to perform well on significant tasks. One remedy is the delegation of subtasks to others to reduce stress and improve performance. Leaders of organizations need to have the ability to identify talent, develop people, and delegate responsibilities (Kuhnert, 1994; Bennis, 1999). Gordon has been a successful team builder—assigning people responsibility and letting them grow. He invited Eithan Hochman to join him in writing a book on dynamic systems in agriculture, and their joint book (Rausser & Hochman, 1979) has won the prestigious Enduring Quality Award of the *Agricultural and Applied Economics Association*. In the 1990s, he invited Johan Swinnen to co-author a book based on Rausser's work with the late Pinhas Zusman and the product, *Political Power and Economic Policy: Theory, Analysis, and Empirical Applications* (2011), is a masterpiece on political economy.

As chair, he developed a strong committee structure to manage the essential functions of the department. He assigned me, a young Associate professor, a primary responsibility, to head the Graduate Advisory Committee (GAC) of the department. He set a target for me to increase the yield (percentage of students accepted to the department who join it) by 50%. I began calling the prospective students to convince them to join us and requested other faculty members to join me. This effort worked. Since then, we regularly speak with our prospective students before they come and we have enjoyed a relatively high yield, which allows us to maintain a large graduate program. Gordon also appointed Peter Berck as a vice-chair responsible for operational aspects of the department, which would enable Gordon to concentrate on more strategic objectives. In particular, getting more Full Time Equivalent (FTEs) faculty positions and increasing the profile of the department and its national recognition. Indeed, he was able to expand our program and our faculty. Moreover, before he became chair we were ranked number 11 among agricultural economics departments. During Gordon's first tour as chair, we had become the top-ranked department.

I remember that at the time, the conventional wisdom was that young faculty members should concentrate on research and shouldn't be assigned service responsibilities. When I was an assistant professor, I was largely left alone, but once I became an associate professor, Gordon had appointed me chair of the GAC and gave me other tasks as well. In retrospect, it was very smart. I don't believe it affected my research productivity, but it made me more dedicated to the department. It also gave me a better understanding of the university and of life. Gordon has a philosophy that almost from the beginning, faculty need to be involved in the activities of the department. While even though some may resent the responsibilities they are assigned, not having them is worse. During his time, he was a very inclusive chairman, and we had frequent faculty meetings and many retreats, which made us better citizens of the department. Over the years, I found that trying to protect young faculty too much from the day-to-day drudgery of university management actually makes them less involved and connected to the institution.

Going beyond delegation, Gordon has emphasized the importance of building partnerships, teams, and institutions. He partnered with Richard Just to become the editorial team of the *American Journal of Agricultural Economics*, where they expanded and changed the direction of the journal. With Stanley Johnson, he collaborated to develop the Institute for Policy Reform, a think tank that included a number of senior fellows, many of whom later became Nobel Laureates. The Institute's purpose was to introduce policy suggestions to develop an integrated global economic system, facilitate the smooth transition of the Soviet bloc countries into the market-based global trade system, and enhance economic growth. A few years later, Gordon and several partners started the Law and Economics Consulting Group, which was one of the pioneers in providing economic advising, mostly for high-stakes legal disputes.

While Gordon has been quite confident in his own abilities, he is well aware of the limitations of the abilities of any individual, and one of his strengths as a leader has been to recruit help and build economies of scale. This was apparent in his approach to research in the department. He supported research collaboration and joint authorship between faculty and students, expecting that students have a few papers published when they graduate. Indeed, a significant number of ARE students have published articles when they go on the job market, which helps their case. I was one beneficiary of this approach, both as a graduate student and as a professor. The prominent academic reputation of the department, the large volume of output despite being a relatively small department, and the excellent placement of students are partially due to the collaborative research within the department.

4 Having Clear Priorities and Implementing Policies to Pursue them

When Gordon first became chair of the department, its members included some very promising economists, such as Richard Just, Alain de Janvry, and Andrew Schmidt, as well as Michael Hahnemann and Peter Berck. I was finishing my Ph.D. at the time, and we presume that we were assessed for tenure and promotion mostly by our ability to publish in mainstream economic journals and to be excellent economists; papers that were rejected could go to agricultural economic journals. While obviously there was some awareness that we needed to address agriculture and natural resources issues, it was not the priority. If it was good for the AER, then it was good for ARE. Researchers in the school of agriculture are privileged to teach less because they had presumed responsibilities to produce relevant agricultural research for the experiment station. From the beginning, Gordon fit quite well in the economics world; he had a paper in the AER and he had come from Harvard after all. But he realized that it would be unsustainable and socially irresponsible to aim to be the second-best economics department at Berkeley. He took agricultural economics seriously and wanted contributions to agricultural economics to be our main focus. He had a broad conception of the field and expanded our focus to include resources, environment, and development, and instigated and supported the growth of the department in these areas. This was apparent in Gordon being a big supporter of renaming the department Agricultural and Resource Economics. He also strived for us to be the number one department in this area and to that end he introduced several changes.

First, he encouraged the young professors to be active in regional research projects sponsored by the USDA on various agricultural topics, including risk, water, and environmental valuations. Joining these projects, he increased the resource base of the department, made our faculty members known among the agricultural and natural resources community, and established our sustainable future as a leading innovative academic department.

Second, he insisted that resources from the agricultural experiment station and the Giannini Foundation be spent on projects that were well-aligned with the mission of the experiment station. For example, Richard Just and I had a project that planned to estimate the value of basketball tickets as a function of the location of the seats and the quality of the visiting team. Once he knew about it, he told us we could do it as long as we didn't use university and student resources and encouraged us to spend our time on more mission-oriented work. This really was one impetus for our work on risk management and productivity in the context of agriculture which later led to many research discovery awards.

Third, he encouraged individuals and faculty to submit papers to agricultural and environmental economics conferences and be involved in the relevant associations. Since Gordon became chair, I have been to every AAEA meeting. At his insistence, Richard Just and I started organizing symposia and other events at these meetings, which led each of us, over the years, to become President of the AAEA. Gordon and Richard Just became editors of the AJAE, which took significant personal sacrifice. All these activities together put Berkeley on the map and dramatically enhanced the quality of our Ph.D. program.

Fourth, while we hired people that came from major economics departments, Gordon made sure as chair that they became familiar with and emphasized agricultural and resource themes and topics in their teaching and research.

Gordon also changed the way that funding and research assistants were allocated in the department. He made sure that younger and new faculty members had priority in the allocation of new research assistants every year. He would send all the faculty members a list of incoming students, asked who they would like to work with, and then gave the youngest faculty members the first choice. Of course, he allowed people to shift among advisors and allowed students to choose with whom they wanted to work. But he broke the system of rule by seniority, which hindered the development of young faculty.

Gordon was very principled in his approach to his job as the dean. When Gordon became dean, there was still debate on a proposal to move many of the CNR faculty to Davis and keep only the economists and plant biologists in Berkeley. As a condition for accepting the job, Gordon demanded and received an assurance that the College would stay intact and have an increased number of positions. There was a lot of debate within the College about priorities for promotion and emphasis on research activities. Gordon emphasized the importance of excellence and rigor, as well as relevance, and pushed to hire people to help achieve this goal. One of the biggest challenges to this was obtaining resources. Gordon was aware that other units of campus, such as engineering and sciences, obtained large support from contracts with major organizations. The excellence of Berkeley in chemistry and physics were largely a result of association with Lawrence Berkeley and Livermore labs. The 1990s were a period when advanced molecular and cell biology technologies were evolving and the private sector was investing and developing immense capacities in this field. Both Gordon and leaders of the plant biology department realized that Berkeley needed support to stay on top of this area and the challenge was to obtain private support for research without compromising the University's values. Under Gordon's leadership and negotiating skills, the University signed an agreement to obtain support from the Novartis Agricultural Discovery Institute in exchange for providing Novartis access to the activities of the Department and in particular, first rights to some of its discoveries (Dalton, 1999). The Berkeley Novartis agreement was the first of its kind and encountered many resistance, but in retrospect, it provided the Department of Plant Biology and CNR $25 million and allowed CNR to become the leading plant biology department in the world without compromising the integrity of the Department or its research (Yang, 2004).

4.1 Drive, Big Ambition, Energy, and Courage

Kirkpatick and Locke (1991) reviewed studies that have found that intelligence, drive, energy, and ambition are traits of leaders. Gordon has these traits in abundance, as the poem by Richard Just indicates (xx). His multitasking, researching, teaching, farming, and parenting responsibilities required immense energy. He never hid his desire to move away from the cows and the farm, to be well off financially and be impactful as a scholar and leader. He accumulated multiple skills in his studies—and started his research career with a bang.

He had four papers published in the *American Journal of Agricultural Economics* (AJAE) in 1971—the year he graduated. Between 1971 and 1974, he had 8 papers in the AJAE and a paper in the American Economic Review, two papers in the *Journal of the American Statistical Association*, the Journal of Finance, the *Review of Economics and Statistics*, and two research winning articles that appeared in the *Annals of Economics and Social Measurement* (Rausser & Freebairn, 1974a, b; Rausser & Howitt, 1975), all cutting edge journals. This publication record allowed him get to know many leaders of the economics profession, and develop a network of collaborators and contacts. I got to know him in those days while I was working as a research assistant for Eithan Hochman, one of Gordon's collaborators. I realized that Gordon was the star of a circle of young agricultural economists; he knew how the system worked and had a good sense of what and where to publish. These early achievements allowed Gordon to attain a position at Harvard University and later at Berkeley. In Berkeley, Gordon assumed the role of department chair and continued to shape the department, but he slowly changed his research focus.

At the start of Gordon's career, he established a reputation as a quantitative modeler with skills in statistics, econometrics, and optimal control. But over the years, he reinvented himself to become interested in more issues of content and to become an expert on agricultural policy. The transition was gradual. At Davis, he wrote an excellent quantitative political economy paper with John Freebairn (Rausser & Freebairn, 1974a, b) assessing the influence of different interest groups on US beef import policy. At Berkeley, he taught a class on quantitative policy analysis and expanded his research on the political economy, distinguishing between transfer policies that are rent-seeking (that reduce social welfare, PESTs) and policies that improve social welfare (PERTs) (Rausser, 1982). However, to increase his visibility and impact on the policy process, he become a senior staff economist for the Council of Economic Advisors and later, chief economist at USAID. These positions introduced him to the institutional and practical challenges of implementing policies and provided him with the visibility to shape resource policy and to help found the Institute of Policy Reform. Over time, Gordon became a leading authority on agricultural policy, was asked to serve in high-ranking political positions, and coauthored an authoritative review of the development of the field (Anderson et al., 2013).

One of the challenges facing many scholars is that they distinguish themselves based on quantitative skills, but these skills may erode with age, while overall judgment develops. Gordon made an investment (by going to USAID and the Council of Economic Advisors) that enabled him to transition from being a methodologist and a quantitative analyst to being a policy analyst. Of course, his quantitative and analytic thinking helped him in this new direction and combining quantitative foundations with growing institutional knowledge has made him a more effective intellectual leader and decisionmaker.

Gordon's transition in his career path was risky. I consider Gordon not to be loss-averse nor risk-averse. I believe that his success as a businessman stems from his risk-management strategy; he was able to take risks in order to achieve higher average gains. This was quite apparent when he was department chair in his attitude towards budget or promotion requests from the administration. Some of our colleagues may be embarrassed when requests for promotion or new positions are rejected, and take a loss-averse strategy of trying to avoid rejections as a result. Gordon has a saying "If you are never rejected, it means that you didn't reach high enough."

As department chair, he fought to maximize the faculty members' wellbeing. He pursued excellence as the Dean. He strived to hire superstars and to expand the reach of the College, and both the College and the Department benefitted from this approach. Taking risks and trying to test the limits may sometimes be costly, and Gordon might have occasionally paid for overreaching, but in retrospect, his risk-taking has been key to a very successful career and life.

Gordon's "think-big" strategy inspired many of us in our publication strategy. He encouraged us to do our best and to try to reach the best journals for which the papers had a reasonable chance. He didn't treat rejection as a personal failure, but as a learning opportunity. Referee reports from a good journal allow you to improve your chances at another journal. In at least one case, he found a referee report to be wrong, and wrote a polite rebuttal that led to reconsideration and eventual acceptance. Watching him was empowering and helped me develop my own publication strategy. Speaking with him about publishing, I learned that he never sees editors or referees as absolute authorities to be pleased, but rather as colleagues with whom you co-learn and negotiate, while recognizing their authority. This approach wasn't limited to editors and publications, but extended to academic life more generally. He taught me not to treat deans and chancellors as imperious autocrats, but as enlightened arbiters who can be influenced. More than once, he reminded me to speak up if I didn't agree with him and to offer an alternative, even if he wouldn't take it. We are on the same team, and my role is to provide the best advice to the decision-maker.

More than once, Gordon mentioned in faculty meetings that not trying is often more costly than failing and emphasized that we shouldn't accept things as given but instead improve them where we can. The establishment of a senior fellow program at the Institute for Policy Reform is one example. Since the Institute's purpose was to address major global problems, IPR sought and disseminated ideas for institutional reform from leading scholars, including people who subsequently became Nobel Laureates like Akerlof, Deaton, Ostrom, Tirole, Stiglitz and Williamson. When Gordon mentioned this Institute to me, I doubted that he would be able to recruit these high-profile economists. He responded that if you provide the right motivation and modest incentives, leading thinkers would prefer to contribute and participate. Obviously, he succeeded. I followed this line of thinking when I initiated the establishment of the Galbraith Medal and Forum of the AAEA, and Gordon was one of the four speakers at the first Forum. I also remember when Gordon mentioned that he participated in the establishment of a company, Law and Economic Consulting Group, that would provide economic expertise in complex legal disputes. Firms of this scale were not common, and I didn't recognize that people are entitled to access the best economic defense of their case. Nor did I foresee the growing need for these services, and I wasn't alone. Gordon recognized the risks, but was convinced that the timing was right and the risk was worth taking. Finally, a few years ago Gordon mentioned that he was considering making a generous contribution to the University. When I heard about it from various members from the college, they assumed the contribution would be to the Department. He was bolder. His experience as dean convinced him that a large sum to the College would be transformative, providing the College greater freedom to operate. Indeed, that's what he did, and he walked his talk.

5 People Skills, Loyalty, and Judgment

A desired trait of leaders is the capacity to build strong human relationships (Kirkpatick & Locke, 1991). I believe that Gordon's capacity to connect with people is one of his greatest strengths. Even before I met him, people told me that when you spoke with this famous person he made you feel special and he paid full attention to you. Not long after we met, I was surprised that this academic superstar asked me, a beginning graduate student, detailed questions about my life, research, and career. I was even more surprised that he remembered those details years later when we met again. I realized that two of Gordon's most valuable traits have been his curiosity about people and his memory. Gordon would interact with many members of the profession and was able to find common topics and understand their interests, which helped him build a network and obtain resources. In addition to curiosity and memory, he has good humor and good manners, which allowed him to maintain personal relationships even when he might have had conflicting interests.

While Gordon holds very strong opinions, he is a good listener and he takes his time before expressing a strong view on a topic, especially when there is an active discussion or a debate. This tendency to listen before he speaks developed over the years as Gordon held more and more positions of authority. His capacity to interact with diverse sets of people helped Gordon as the dean and led him to higher leadership positions. For example, he chaired a committee that wrote the Rausser Report on the quality, design and structure of economics research at Berkeley in the 1980s. This report led to significant changes in hiring practices and resource allocation to the Economics Department and was likely a contributor to its rise in the ranking in the 2000s. He chaired another committee assessing the future of the Division of Agricultural and Natural Resources (DANR) at the University of California in the 2000s. This committee developed a vision for how to expand the scope of DANR, and secure its finances, to take advantage of advances in biology, to address the challenges of climate change, and to contribute to the transformation and modernization of California's agricultural and natural resources sectors.

Gordon has always tried to be a good and loyal citizen of his institution and groups. As a faculty member, he didn't take advantage of his senior position and he taught the demanding undergraduate introductory class for years. He was a highly regarded teacher of the demanding introductory classes, EEP1 and ECON 3, receiving very good teaching evaluations over the years (averages above 6 out of 7). In another instance, he set the standards far too high in an intermediate microeconomic class, ECON100A, and initially received low student evaluations. He took his students' criticisms to heart. Over time, he modified the class and the introductory economics class became still demanding but more accessible, and excellent to the benefit of the students. Gordon's loyalty was clear in the extra effort and resources he gave to the department. At the same time, he required loyalty from others. As I mentioned earlier, he always believed that the more you give, the more you will receive.

5.1 Telling It as It Is and Living in Reality

Gordon treasures the factual truth. When I speak with him, he always checks if I mean what I say, and if I'm sure that I'm right. It does not mean he will not be strategic. At times he may not volunteer the truth—but he lives in reality and doesn't try to ignore the truth. When it counts, he will tell you what he thinks—even though it may be painful or uncomfortable. He spoke with me, tactfully, about my accent- and what to do—or not to do about it. He has given me plenty of advice, mostly helpful but sometimes not, and he has admitted when he was wrong. When I applied for a job in the Department while a graduate student in the Department, he told me that it would be good for me and the Department for me to go elsewhere. I actually didn't remember this counsel, but he reminded me recently, suggesting he may have been wrong. The keys for his success as a trader and decision-maker, I believe, originate in his ability to live in reality all the time, to consistently observe and think clearly, and to accept reality for what it is. This reality-based decision making along with his outstanding analytical capacity lead him to make high rates of successful choices. Combine this with his capacities to accept and learn from mistakes and look for advice, and you have a very effective decider and leader.

6 Conclusions

Gordon Rausser is an outstanding scholar, among the best agricultural economists of the twentieth century. Much of this book is allocated to his scholarship, but he is much more than a scholar. His life lessons go beyond excellent research findings. He taught us how to manage our lives as people and as scholars. Those who pursue a scholarly career are challenged to pursue academic excellence while supporting and nurturing their family and contributing to a better world. This chapter aims to identify the qualities and patterns of behavior that have helped Gordon to meet these challenges.

Gordon's uniqueness as a person amazed and mystified many of us. Yair Mundlak, another great economist, once commented to me, "There are many great scholars, but only one Rausser," which led to a long conversation where he marveled at Gordon's balancing act and his capacity to be both part of the business world as well as a detached academic analyzing it. Mundlak and others suggested that most of us are good at one of the two, but the ability to excel at both is a unique gift. The real-world business involvement shaped Gordon's academic perspective, as I will show elsewhere (chapter 4, "Gordon Rausser and the Transformation of Agricultural Economics from the 1960s to the 1980s"), contributing to a transformation of our discipline. The ability to integrate research and practice is one of the greatest strengths of the United States. Much of the innovation in this country is the outcome of the educational-industrial complex (Graff et al., 2002), where university research is transferred to the private sector, resulting in new products and industries. Many of the leading industries originated from new research discoveries, and unique and talented scientists contribute to and even lead growing industries. Gordon's activities showed me that this mixing of innovative research and marketable applications is not limited to the natural sciences and engineering, but can also can be done by social scientists.

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Scholar, Entrepreneur, and Editorial Innovator

Stanley R. Johnson

1 Introduction

Upon his “retirement” (if there ever was one), Professor Gordon Rausser was honored with a Festschrift highlighting his major contributions as a scholar, academic leader, and entrepreneur. More specifically, Gordon’s (we refer to Gordon in this chapter) work in consulting, academic leadership, structuring public-private research partnerships, as well as his innovative efforts in the restructuring of the College of Natural Resources at UC Berkeley are simply remarkable. These efforts have provided a blueprint for future academic and entrepreneurial challenges that all universities and private sector companies face. More generally, Gordon has distinguishing himself as an academic trailblazer and a major leader in all dimensions of economic analysis and the development of public policy processes.

My focus on this chapter is on the first 30 years of Gordon’s professional career. I first met Gordon in 1969 when I was a visiting professor at UC Davis. When I arrived, there was this young, brash member of the faculty who had been hired after completing only 2 years of his PhD coursework. Whenever I met with him, there was a new researchable idea every 10 or so minutes and it was difficult to keep up. I discovered that six of Gordon’s fellow PhD students had selected him as their PhD director even though he has yet to complete his own PhD thesis. I was surprised to learn that in addition, he was managing a small family farm about 30 or so miles from the UC Davis campus. His idea generation and energy were very infectious. A mutual respect among the two of us intensified and I became one of his members of his dissertation committee. Ultimately, he completed his dissertation, which was

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composed of three volumes. I have long argued that I was the only member of his dissertation committee that read all 1200 or so pages (Rausser, 1971).

Our constant generation of new ideas for researchable topics led us to often work late in the office in Voorhies Hall at UC Davis. We also, on occasion, visited his family farm, where he often went to work over the weekends. At the time, Gordon had three young children and at least two of them would travel with us from Davis to his family farm's. I remember Gordon being very impressed that I could recognize and provide the common name and scientific name of many grasses that appeared on his family farm's pastureland. Gordon would often work manually during the day and work with me late into the night, pursuing the completion of our collaborative research papers. In contrast to many PhD students working on their dissertations, he had published at least ten or so papers in referred journals, some of which I was one of his co-authors.

Looking back on this academic year, 1969–1970, Gordon and I established a foundation for collaborative research work that stretched over the course of the next 30 years. At the outset, as long as our collaborative research did not detract from his time with his three children and his family farm responsibilities to his mother and sister, this may well have been among my most productive years in my professional and academic life. In addition to all the hard work, there was much banter that emerged that never detracted from the strength of our friendship, in large part, because of Gordon's intellectual capital and generosity of spirit. In one instance, I actually thought perhaps, I had gone too far. Near the end of my time at UC Davis, there was a departing celebration for a faculty member who had recently accepted the provost position at the University of California, Office of the President (UCOP). During this farewell separation, there were a number of gifts that were presented to the departing faculty member and as he was unwrapping the gifts, someone admonished him, that as an economist, he should conserve the wrapping paper. Gordon whispered in my ear that the honoree had never been an economist. I decided to entertain all of those attending the farewell party to repeat what Gordon had said to me in confidence and identified him as the source for the remark. The honoree asked what Gordon's title was and it was specified by a chorus of faculty attending that he was an acting assistant professor. The honoree suggested that Gordon would remain so for the balance of his career at UC Davis. Fortunately, this action on my part did not detract from our friendship or mutual respect for one another.

Our wives at the time convinced both of us to take a break from our collaborative research and travel to one of the finest restaurants in San Francisco. I was surprised to learn that Gordon never visited San Francisco even though he was raised in California. What is memorable about this particular event in addition to the extraordinary cuisine was the fact that Gordon brought along his briefcase with two of our unfinished papers. I recall telling him, "you don't expect us to work on this." No, he didn't. But he wanted to be prepared if the opportunity should arise. I then referred to his briefcase as his security blanket. Once again, Gordon took this observation with good humor.

2 Scholar

Within months after Gordon completed his dissertation, he was granted tenure and left for a postdoctoral fellowship at the University of Chicago. Since I was also located in the Midwest, we had an opportunity to continue our collaborative work. Later, when Gordon returned to California as a professor of agricultural and resource economics at UC Berkeley, he very quickly was selected as chairman of the department. I took another sabbatical of 1 year to work with Gordon. I was surprised to learn when I arrived that in addition to all of Gordon's academic scholarship and chair leadership for the department, he also established a futures market hedge fund while he was on the faculty at Harvard. I came to realize that among all academics, he knew more, from the theoretical, statistical, as well as from an operational standpoint about futures markets than anyone else in the profession. I wasn't surprised to learn that his futures market hedge fund was awarded the top commodity/futures hedge fund by E.F. Hutton in 1981. Academically, he had published a large number of papers on the behavior of futures markets. Many of these papers were published in statistical journals, the *Journal of Finance*, as well as the *Journal of Political Economy*. One of these papers won the Outstanding Journal Article published by the *American Journal of Agricultural Economics (AJAE).* Unfortunately, we never collaborated on all the scholarly and investment work he had done on futures markets. We instead, for much of the decades of the 70s and 80s, focused on the following research activities:

- creating quantitative research methods in agricultural economics (a joint authorship book with George G. Judge and Richard Day that was sponsored by the AAEA and published by the University of Minnesota Press) (Judge et al., 1977);
- collaborating with George Judge, providing advice and counsel to the United States Department of Agriculture, Economic Research Services (USDA ERS), on quantitative modeling (1974–1977);
- providing the conceptual framework and quantification of a Canadian agricultural policy model (1977–1980);
- jointly organized a major conference in Egypt on the agriculture sector and the critical importance of water resources in supporting the country's economic growth
- securing major funding to support a comprehensive quantitative evaluation of Uruguay Round GATT proposals (1988–1992); and
- establishing and operating the Institute for Policy Reform (IPR) (1990–1994).

In each of these efforts, whenever Gordon walked into the room, he commanded the attention of all the participants. This was certainly the case in each of the conferences we had jointly organized. For example, in the case of Egypt, he had developed a framework for pricing Nile River water given all its multiple uses; viz., as a source for recreation; as a source for critical irrigation to agriculture; as a source for waste disposal for major cities along the river; as a source for urban drinking water. Gordon made a captivating presentation at the conference and President Sadat's wife,[1] who was in attendance, was very impressed and invited Gordon to travel to Alexandria, Egypt, where President Sadat was then currently located. A few days later, many of the attendees, along with Gordon, rented a bus and travelled to Alexandria. When we arrived, Jehan Sadat greeted us at the presidential residence and walked Gordon into an extraordinary Arabian tent whose walls moved with the breeze from the Mediterranean Sea. Jehan introduced Gordon to President Sadat and requested that he made the same presentation that he had done at the conference. Gordon rose to the occasion and made an even more elegant presentation about the critical role of pricing the various uses of the rivers in Egypt. When he completed his presentation, President Sadat warmly came up, shook his hand and said, "I appreciate your insights, but you don't understand. In Egypt, water is free. Water has always been free and will remain free to all our citizens."

Our engagement in collaborating with the USDA ERS was entirely pro-bono. However, our work in constructing quantitative models for Canada and a number of other countries in subsequent years (e.g. Czech Republic, Russia, Ukraine) were commercial consulting engagements. In each of these efforts, Gordon's logical thought processes resulted in improved specifications of the models that we developed in collaboration with the staff of each of the governments. Much of this work is summarized in Gordon's book, *New Directions in Econometric Modeling and Forecasting in U.S. Agriculture* (Rausser, 1983). Gordon and I realized early in our work that institutional changes were major contributors to the functioning of agricultural sectors in the U.S. as well as the world agricultural economy.

With a clear understanding of agricultural sector modeling and the importance of the institutions, Gordon was able to develop new and insightful political economic frameworks. Gordon's emphasis on the critical roles of institution and public policy led to his pathbreaking paper on PERTs and PESTs (Rausser, 1982). This paper was actually presented as the major invited address at the annual summer meetings of the AAEA. In fact, I believe Gordon was the youngest member of the association to present such a major invited address. And this paper resulted in him being asked to present seminars throughout many of the land grant university departments related to agriculture and resource economics. To his political economy lens, he later, in an article appearing in *the Journal of Economic Perspectives*, provided a more detailed representation of the data that related to PERTs and PESTs (Rausser, 1992). In other collaborative work with his Berkeley Ph.D. students, he was able to demonstrate the complementary of PERTs and PESTs and the design of "smart PESTs."[2] The work on PESTs and PERTs, along with his work on rent-seeking behavior by powerful interest groups, set the framework for his seminal book publication with Jo Swinnen and Pinhas Zusman (Rausser et al., 2011). Perhaps unknown to most of us, while he was preparing for his invited address to the AAEA, the futures market and his previously developed analytical frameworks turned upside down, but he never lost

[1] Jehan Sadat became an international leader in women's rights, serving as honorary president of the Women's International Center.

[2] See Alain de Janvry and Elizabeth Sadoulet's chapter "The Puzzle of Lagging Sub-Saharan Africa Agriculture: Toward a Theory of Connectedness".

a step. His first priority was his academic research, not the performance of his hedge fund.

Over the years, of course, Gordon frequently used the most advanced econometrics techniques, including advanced time-series analysis to isolate the major distributive effects of institutions and public policy on the performance of the U.S. agricultural sector. One of his major award-winning publications on this topic was an insightful examination of the role of agricultural policies in the face of changing external economic linkages, including monetary and fiscal policy, resulting in major movements in interest rates and exchange rates (Rausser et al., 1986).

3 Government Service

Gordon's work on governance structures and their critical importance in selecting sound policies that serve the public interest began long before his political appointment as senior economist of the Council of Economic Advisers (CEA). In 1985, he was providing pro bono consulting services to the head of United State Trade Representative, Clayton Yeutter, a longtime friend. There was a great interest on the part of the Reagan administration to reform the huge subsidization of the U.S. agriculture and food sector. One proposal prepared by the Reagan administration in 1981 was announced by Congress as being "dead on arrival." Even a second attempt in 1986 was not expected to overcome the obstacles faced by the then political economic landscape in the U.S. Gordon provided a compelling argument to Ambassador Yeutter that other interests had to be represented within the political economic process. In particular, if agriculture could be included in the next round of GATT negotiations, there would be not only other rules but also other interest that could, in effect, counter the powerful commodity producer groups who carried much weight in the actual policymaking process within the United States (due largely to the configuration of the Senate). After many months of discussion, Ambassador Yeutter accepted this proposition and began to work within the administration by lobbying other cabinet members to support such an institutional action. It was recognized straight away that domestic producer interests would object to including food and agriculture in the next round. Ultimately, the 1986 Uruguay Round in Punta del Este was launched, including for the very first time, food and agriculture. It took nine long years before the actual Uruguay Round was concluded with major rules that had to be imposed by all signatory members of the GATT, subsequently renamed the World Trade Organization (WTO).

In the nine-year period, my institution, for which I was director of the Center for Agricultural and Rural Development at Iowa State University, and Gordon, with respect to his leadership in the Department of Agricultural and Resource Economics at UC Berkeley, were selected to evaluate the consequences of the reforms proposed by the Uruguay Round. I recall making a major presentation to the USDA and Gordon arrived with his colleagues, which I remember, at the time, I referred to as the "all-star team." He had, in his group, luminaries, such as Richard Just, Andrew

Schmitz, David Zilberman, Harry de Gorter and William Foster, among others. The foundation for much of this work was Gordon's and my earlier on quantitative modeling of the US agricultural sector. A large stream of publications emerged that were very informative to the U.S. government with regard to potential designs and principles of compensation for the "losers" under the proposed new "decoupling" policy frameworks. Much of this work resulted in Gordon being selected for the coveted AAEA Policy Award that is offered once per year and the Secretary of Agriculture Award for outstanding accomplishments in agricultural public policy research and formulation (See Appendix 1).

Over this period of time, 1988–1993, we must've attended ten major conferences, some of which were organized by the World Bank, some by the OECD, some by the AAEA, and some by the International Agricultural Economics Association (IAEA). In most instances, Gordon was a keynote speaker and always ended up presenting our results with great clarity. At all of these conferences, if they were held during school holidays and/or the summer, Gordon's three children would be travelling with him. Over time, his colleagues became very good friends with one or more of Gordon's children. I remember distinctly a trip to the Hague in which Gordon made a major invited address, a major conference in Budapest following the collapse of the Soviet Union, a major IAEA address in Buenos Aires and a number of such conferences in Israel, where all of his three children attended.

With his 1990 publication, "A New Paradigm for Policy Reform and Economic Development," and with dozens of further publications on the same theme, Gordon argued that international agencies (e.g., the IMF and the World Bank) and donor agencies (e.g., AID) should not make assistance conditional on outcomes or establishment of particular government policies (Rausser, 1990). Instead, his work made clear that decision-making about which countries are given priority for economic assistance should emphasize underlying constitutions and the design of institutions. He argued that democratic governmental and judicial institutions are critical to the enforcement of contracts, the security of private property and the assignment of liability for wrongful conduct. Without sound constitutional structures, there is likely to be a maldistribution of political power, in which political economic agents are unencumbered in pursuing their self-interest rather than the public interest. In essence, he argued that the underlying constitution must be designed to establish the credible guidelines and mechanisms for "rules by which rules are made." In a 1993 publication in *World Development*, we proposed that for the former communist regimes throughout Eastern Europe and the former Soviet Union, "The public sector must play a dominant role during the transition process and will be effective if and only if a well-designed constitution and an associated legal and regulatory infrastructure is first established" (Rausser & Johnson, 1993). To facilitate the transition, Gordon was also assigned the role of promoting the investment climate in Eastern Europe by helping design and implement private enterprise venture capital organizations in Poland and Hungary.

With regard to our modeling of the outcomes of various Uruguay Round type potential reforms, Gordon made a number of presentations to the ministerial meetings held at the OECD where cabinet secretaries from the 22 participating countries often were in attendance. His presentation provided compelling evidence of how the global economy might benefit from the major policy reforms that could be generated by an inclusion of food and agriculture in the GATT negotiations. Because of his keen observations and compelling presentations, after he returned to Berkeley, he was offered the position of Chief Economist of the Agency for International Development (AID) as well as the USDA, which was his for the taking. He ultimately chose the chief economist position at the AID because he wanted to broaden his horizons, looking at the role of improved infrastructure and ex-ante assessments of policies across all sectors of less-developed countries. In this role, he worked with 500 or so economists, many of whom were stationed in various missions of less-developed countries. During this time, Gordon also came to the conclusion early in his time at AID that much of the prior economic development literature offered little ex-ante value in improving existing policies or reforming those policies to serve overall social welfare.

While Chief Economist at AID, Gordon traveled to each and every AID missions in various developing countries. He formally met with each Mission Director and made major presentations about political economy, the need to pursue sound governance structures, and also the opportunities for offering compensation to powerful interest groups that blocked policy reforms that could serve to improve social welfare. He also held quarterly conferences in Washington D.C., making the same presentations to all of the large number of economists that served not only in Washington D.C. but in each mission throughout the developing world. Based on this experience, he rewrote the AID country strategy statements and had his new guidelines approved by all Missions Directors and the AID Administrator. Based on these efforts, he went to the Secretary of State and to the Administrator of AID to secure the funding for the established of an Institute for Policy Reform (IPR). He proposed that such an Institute would focus on ex-ante analysis of how countries might reform their underlying governance structures, underlying constitutions, and the public policies that might be promoted to sustain any major reforms given the unique political economic landscape that existed in each one of the developing countries.

4 Institute for Policy Reform

The founding of the Institute for Policy Reform (Gordon actually did it, and I came along) may well have been our major joint contribution. We established a remarkable board of directors for the Institute, including Yair Mundlak, Vernon Ruttan, Malcolm Gilles, Al Harbeger, Martin Bailey, Ron McKinnon, and political scientist William Riker. Gordon was able to secure major funding from the U.S. State Department to support the Institute and during its formation, the heady times of the Soviet Union collapse took place. As a result, there was much hope that the emerging liberalization of all Eastern European and former Soviet Union countries would transition to democratic, market-based capitalistic economies. All major multilateral institutions, including the World Bank, the newly formed European Development

Bank, and IMF, were focused on providing assistance and support for the transition of these economies.

He began his government service by seriously investigating the political economy of policy reform with his chapter in the Economic Report to the President entitled, "Towards Agricultural Policy Reform" (Rausser, 1987). Given his two government service roles, he began to focus much of his academic research on public policy reforms across the globe. His efforts in this respect were introduced to the entire profession at the winter meetings of the American Economic Association and the AAEA, while he was finishing his role as Chief Economist of the AID. In this major presentation, he laid out his views on reforms and the pursuit of economic policies that serve the public interest. Other presentations were made by the Chief Economist of the World Bank as well as the Chief Economist of the IMF. At this session, during the Q&A, Gordon explained why the so-called "Washington Consensus" should be rejected. Gordon organized this invited session, and the room was packed with hundreds of people standing outside of the room, hoping to be live witnesses to the debate that took place.

As it turned out, we were quite successful in recruiting academics and others in policy leadership positions to the study of institutions and governance structures that could precipitate economic and political policy reform. In fact, over a four-year period we recruited many conceptual economic leaders to engage as Senior Fellows of IPR. The roster of the engaged Senior Fellows included:

George A. Akerlof, University of California, Berkeley
Angus Deaton, Princeton University
Sebastian Edwards, University of California, Los Angeles
Stanley Fischer, Massachusetts Institute of Technology
Mark Gersovitz, University of Michigan
Partha Dasgupta, University of Cambridge
Bengt Holmstrom, Yale University
Richard Just, University of Maryland, College Park
Ann Kreuger, Duke University
Paul Krugman, Massachusetts Institute of Technology
Paul Milgrom, Stanford University
David M. G. Newbery, University of Cambridge
Charles Plot, California Institute of Technology
James Poterba, Massachusetts Institute of Technology
Paul Romer, Stanford University
Todd Sandler, lowa State University
Tom Sargent, University of Chicago
T. Paul Schultz, Yale University
Pablo Spiller, University of California, Berkeley
Nicholas Stern, London School of Economics
Joseph E. Stiglitz, Stanford University
Erik Thorbecke, Comell University
Jean Tirole, Massachusetts Institute of Technology; University of Toulouse

Robert M. Townsend, University of Chicago
Barry Weingast, Hoover Institution, Stanford University
John Whalley, University of Western Ontario
Oliver Williamson, University of California, Berkeley

The senior fellows[3] all held academic appointments at leading universities and worked for little direct compensation because they were interested in what could be done to update the institutions that set the basis for policy reform. The IPR created a fertile environment; fellows were paid a small stipend and travel reimbursements but there was fierce competition to write more thoughtful, analytical papers for our biannual meetings. The Senior Fellows joined the Institute frankly for reasons of intellectual prestige among their contemporaries. It became obvious during those years for which we had funding (1990–1994) that joining the Institute was very attractive for those academics interested in institutions, the political economy of policy reform, and ex-ante policy analysis. With these Senior Fellows, we were able to set the foundation for including the study of institutions and political economy of policy reform as a serious academic and operational undertaking. And much of the future economic policy literature was built in some way on earlier results or ideas that had been fashioned by all the IPR participants—we in fact left a real legacy for policy reform.

One of the major events[4] for the Institute and the Senior Fellows was an invitation to present our collective works at a major conference in Prague. Gordon arranged to have major political leaders to attend from Poland, Hungary, Romania, Bulgaria and Czechoslovakia. In fact, he arranged for the president of Czechoslovakia, Vaclav Havel, to attend and view the results of our research for his nation in transition as well as the other transition economies of Eastern Europe. Gordon made a great presentation of the Institute's work, with a focus on reforming public sector governance structures and the processes needed to privatize state-owned enterprises. The attending political leaders participated in the discussion of the papers offered by our Senior Fellows. Many themes came from the conference, but one of the hallmark themes was related to the bringing along the former Soviet Union populations of these nations. Here a subtle and recurrent point was made—"it is not possible to bring the former Soviet populations along with policy reform unless there is a clear narrative of what the consequences might likely be of the prospective transitions and policy reforms". Many of the leaders simply had asked these Soviet populations to come along with the "new" policies without an ex-ante evaluation of possible consequences.

[3] Eight of these fellows have subsequently been awarded the Nobel Prize in Economics.

[4] A special event at the Prague conference was a meeting with Shirley Temple, the U. S. Ambassador to the Czech nation. The meeting was very pleasant and informative, and generously hosted, with Ambassador Temple who was present and was talking earnestly and very capably with our Senor Fellows. She was actually quite interested in learning about our presentations at the Conference and about how institutions affected policy reform. I recall a very funny observation that she made to all of us, saying that the dim lights in the Embassy were good for both for her and the building: "both looked better in the dim lights."

There are many instances of how this collection of academics and policy professionals influenced the policy leaders at USAID, the World Bank, the IMF and other organizations where institutions and policy reform were becoming one of their major themes of transition economies. In fact, I will say that the IPR was at the beginnings of serious studies of policy reform for the disciplines of economics and political science. Examples of policy reforms and institutions that drew special interest were the US agricultural and European policies which resulted in large transfers from the national budgets to the food and agricultural sectors. Corruption was another topic studied by the Institute's collection of academics and policy professionals. How to deal with corruption in many countries was a major concern for the Senior Fellows. Transparency was the theme that also emerged. Asymmetric information was still another aspect of institutions influencing policy reform. How to make the different sides of policy reform known and understood to all participants in the political reform process was a serious challenge as was issues of equity and distributional outcomes as well. A book edited by Gordon and Chris Clague entitled, *The Emergence of Market Economies in Eastern Europe* was published based on the conference (Clague & Rausser, 1992).

The Prague Conference and the multitude of reports prepared by the Senior Fellows of IPR, including all of Gordon's ongoing work on governance structures, set the foundation for a formal review and evaluation as to whether the U.S. government should continue to fund the mandate of the Institute for Policy Reform. A formal review and evaluation were made by external peer-reviewed scholars, presentations were made by Gordon to various governmental officials, all of which were very positive, but unfortunately, a new administration arrived with little interest in Eastern Europe or the former Soviet republics.

Unfortunately, the collapse of Communism and throughout the former Soviet Republic and Eastern European countries turned not towards sound governance structures, market economies, and democracy; much of the privatization took place was orchestrated by crony capitalists and oligarchs in many of these countries. The privatization process that was designed and promoted by the Institute of Policy Reform, Gordon's many publications and his recommendations were largely swept aside by powerful economic interests and the oligarchs and the emerging political leaders.

5 Academic Leadership

In 1994, the College of Natural Resources (CNR) was searching for a new dean. The university was under considerable stress and the CNR was at serious jeopardy. There was a proposal from the University of California Office of the President to redirect resources away from Berkeley viz. CNR to the other components of the land-grant university, namely UC Davis and UC Riverside. As a result, Gordon's Deanship of the CNR came at an opportune time for him after serving, for a third time, as the chair of the Department of Agricultural and Resource Economics

(ARE). It was in a period of opportunity for restructuring of the College, due in part to the U.S. economic difficulties of the time and in part, to the changing fundamental nature of the agriculture, biology, environment, and natural resource professions. The profession was becoming more reliant on scientific endeavors and less so in traditional or professional fields; it was time for a major shift in the plan for an advancing leading academic institution. Gordon navigated this process skillfully, advancing biological and life sciences, downsizing those programs that could not likely be the best in the country, and introducing new life in the nutritional sciences and toxicology. In all of his leadership efforts, he was on course to achieve merit and excellence much the same as his strategic and tactical plans that resulted in moving ARE from 11th among U.S. land-grant universities when he first became chair in 1979 to unequivocally, the best in the country after his two tours of duty as chair. This was a real important contribution to the academic and professional life of the Berkeley campus and the future in the discipline of agriculture, resources, energy, and environmental economics.

Another aspect of Gordon's work was with the Deanship of the College of Natural Resources, which he took on during his other consulting obligations, was a path-breaking research on institutional change and his growing interest in political economy. This deanship came at a time that the University was taking stock of its investments in agricultural research broadly defined. A theme which he had or adopted as guidance was that the University needed to be more related to scientific work than traditional professional activities. The Deanship therefore involved making a major change in the College, reducing some programs and adding others always focusing on **merit**. The idea was to bring the College to the forefront in terms of science, reestablishing the foundations of the Berkeley campus in terms of the frontiers of fundamental science.

This was a major undertaking and not always favored by the faculty of the College. It involved restructuring what was formerly the Forestry School, taking nutrition and making it a more scientific department instead of a department that worked with nutritional status of the population of California and beyond, and integrating into CNR the Department of Plant and Microbial Biology. The latter was the most challenging and the most significant in terms of giving the College of Natural Resources strong emphasis in the scientific or life science of agriculture, food and natural resources.

Changing the College of Natural Resources in this manner took much fortitude and resilience, since it was not supported by a number of faculty. Of course, Gordon had negotiated these moves with the Chancellor and Provost of the University. But it was his job to get the significant changes made with the agreement of the faculty. In the process he reached out to other of the academics from leading universities for consultation about the changes he was about to administer or implement. At first, they had to be convinced about these changes in the structure of the College, which was a significant task in itself. Ultimately, Gordon convinced these and other doubters about the changes he was making and encouraged their participation in suggesting how he should go about making the changes and in fact, bringing along the doubting faculty.

The changes that were planned for the College were made successfully and Gordon retired from the Deanship after 6.5 years. He had made the changes to emphasis life science over professionalism and frankly brought the College to a new level of more harmonious focus on basis sciences—in many scholar's estimation where the College of leading institution should have its focus. In short, the mission for his deanship was accomplished and he wanted to return to his main academic issues of introducing institutions and the political economy into more general economic calculations. This is a trait that characterized Gordon's career, getting the job done and returning to his first love, bringing institutions and political science directly into the every-day modern economics of our profession.

As the dean, Gordon's scholarly work on governance structures, his work as chief economist of the AID, his efforts as president of the IPR, and his consulting experience and his intimate knowledge of the private sector, placed him in good stead to understand the strengths and weaknesses of the CNR. He was able to determine that many of the disciplines could, through the infusion of superstars and promising faculty members and graduate students, easily move to a #1 ranking among all universities in the United States. This, in fact, happened with the most recent NRC rankings that took place, establishing each of the departments as being #1 or #2 in their respective areas of instruction and research inquiry. Along the way, during his deanship, Gordon realized that the one department that was not in a position to achieve an excellent position, was the Department of Plant and Microbial Biology (PMB). They were facing dramatic difficulties in recruiting the very best PhD students due to the lack of having sufficient resources in the face of stiff competition from major Ivy League schools, as well as Stanford University.

Gordon sat on the Chancellor's Committee on Biotechnology and watched one of the premier programs on campus, the Molecular and Cell Biology program, try to create a foundation for private-public partnerships with funding from the private sector to support and advance their faculty and graduate programs. After observing their efforts, it was clear to Gordon that they were not going to be successful. In fact, their entire process and attempt to attract private funding while maintaining academic freedom, was miserable. Based on the knowledge he had accumulated as a prominent economic consultant, he realized that the competitive landscape in plant and microbial biology within the private sector could be the basis for structuring a major public-private partnership that would benefit the faculty and perhaps, even more importantly, would put them in good stead for attracting the very best PhD students that historically were not arrived at the doorstep of Berkeley.

Gordon saw an opportunity for combining the problems that the department faced with his knowledge of the competitive landscape among plant and biotechnology firms including Novartis, Monsanto, Syngenta, Pioneer, DuPont, and a number of foreign biotechnology companies. He worked with the PMB leadership to prepare a proposal that was sent out to 15 major plant and microbial global biotechnology companies, asking for their interest in pursuing a public-private partnership under certain conditions that are elaborated in Gordon's award-winning book, "Structuring Public-Private Research Partnerships" (Rausser et al., 2016). Over half of the firms approached were actively engaged in private R&D to advance biotechnology discoveries, focused largely on transgenic innovations. Gordon was intimately familiar with the institutions changes that had taken place prior to his becoming dean, namely the Bayh-Dole Act, which changed dramatically the ownership rights of any major discovery that could be codified in the form of a patent as well as the Supreme Court ruling that genetic innovation and seeds were, in fact, a patented utility due to its non-obviousness.

Of the 15 companies that received an outline of a possible public-private partnership with the constraint of protecting and enhancing academic freedom of faculty members and graduate students, eight companies responded with much interest. Gordon sat down with the PMB leadership and selected four of those companies were selected for further negotiations. These included: DuPont, Pioneer, Novartis, and Monsanto. Three key faculty members, along with Gordon, then travelled to the headquarters of each of these companies and made formal presentations over the course of a day-long seminar. In response, each company submitted a formal proposal which led to further negotiations led by Gordon. Ultimately, Novartis was selected after many negotiations and a formal contractual commitment was signed by the University and Novartis, which called for a $25 million contribution to the College. A portion was set out for overhead costs that went directly to the administration and the balance was available to the faculty for recruitment of graduate students and for funding research of individual faculty who chose to participate in the partnership. Only one faculty member chose not to volunteer but all other members decided to participants and the allocation of research funds was selected and administered by the department leadership. As a result of this program, the plant and microbial biology department suddenly found its way to be ranked as the best department in the country and perhaps more importantly, they were able to recruit the very best graduate students which were a critical component of the partnership and helped explain one of the major interests of the private industry partner. That is, the private partner was not only interested in any discoveries that might take place that might be patentable but as well learning about PhD students, their special skills and talents, and emotional makeup, and whether they wanted to work with them either going forward.

This innovative public private partnership, which is often referred to the Berkeley-Novartis Agreement, subsequently formed the basis for a number of such efforts by other research universities, as well as Berkeley itself (See chapter "Control of the Research Agenda in University-Industry Partnerships" by Jill McCluskey). In many of these agreements Gordon has been involved as a guiding light or directly. The shared governance structure on the Berkeley campus meant that Gordon had to not only negotiate with the Chancellor but as well as the academic senate and many CNR faculty which were ideologically opposed to private/public research, development agreements (PPRD), and biotechnology research. He found the right narrative*: the Berkeley/Novartis was a scientific experiment from which much could be learned*. The experiment turned out to be highly successful, maintaining and enhancing the academic freedom of Berkeley faculty. It also set the foundation for the PPRD agreement between Berkeley, the Lawrence-Berkeley National

Laboratory, the University of Illinois Urbana-Champaign, and the British Petroleum Company, funded by $500 million from the private sector partner.

At the end of Gordon's leadership at CNR, few or any resources transferred from the Berkeley campus to the other campuses. In fact, the allocation of faculty positions to the CNR at the end of Gordon's tenure as Dean, has increased by almost 50%. His other accomplishments were recognized in a special tribute for Gordon at the conclusion of this tour as Dean. I had the pleasure of making a major presentation in the program for his tribute. The actual program is attached as Appendix 2 along with concrete metrics of what was achieved during his Deanship.

6 Entrepreneur

Gordon served as the intellectual leader of IPR in his role as president. During the period following his position as chief economist of AID, he returned to the Berkeley campus and once again, was asked by his colleagues in his department to reassume chairman of the department from 1993 to 1994. I wasn't surprised to learn that he took another major responsibility in the entrepreneurial sphere by cofounding with three Berkeley colleagues, the company Law and Economics Consulting Group (LECG). This group started with only two staff members but grew from 1989 to 1997 to a with over 700 employees. Their original office was located to Berkeley and expanded throughout the US, being located in most major cities, as well as a number of foreign countries, including London, Brussels and Sydney, Australia. The firm ultimately filed for an IPO and there was a real buzz among our profession about the amount of value that was created by this consulting firm. In fact, it was the first major litigation consulting group that successfully orchestrated an IPO. There were others that followed but in 1997, this was the first major firm that had achieved this status.

Shortly after its IPO, LECG merged with another major consulting firm and Gordon became very concerned about the governance structured at the newly merged company even as he continued to serve on the board of directors. After attempting to change the governance structure without success, he resigned from LECG and was offered a major Senior Consultant role at one of LECG's many competitors, Charles River Associates International, another major consulting firm headquartered in Boston, Massachusetts that was led at the time by Franklin Fisher, a leading econometrician on the economics faculty at M.I.T. As a clear indication that Gordon had become a premier consultant in the United States, particularly, litigation consulting in antitrust, intellectual property, environmental remediation and contamination, quantitative measures of economic damages, and numerous analytical works for investigating competitive interactions across a number of industries, including food and agricultural, pharmaceuticals, base metals, attempts at manipulating futures markets, and others. As Charles Rivers stated in a press release when they attracted Gordon as a senior consultant:

> Charles River Associates Incorporated (Nasdaq: CRAI), a leading provider of sophisticated economic and financial consulting services, today announced the acquisition of a consulting business led by Dr. Gordon C. Rausser, a University of California, Berkeley agricultural and resource economics professor and former Dean of its College of Natural Resources. Professor Rausser brings to CRA loyal, established client relationships, as well as a network of experienced, senior-level experts in economics and quantitative finance (Charles River Associates, 2000).

This was documented in a followed 10-Q SEC filings by Charles River Associate:

> On October 18, 2000, CRA acquired the consulting business of Dr. Gordon C. Rausser for $4.75 million in cash. The acquisition price may increase based upon the business meeting specified performance targets over the ensuing three fiscal years. In addition, the Company loaned Dr. Rausser $4.5 million, on a full recourse basis, for the purchase of CRA stock. CRA has accounted for the acquisition as a purchase, and the results have been included in the accompanying statements of income from the date of acquisition (Charles River Associates, 2004).

In addition to this entrepreneurial and consulting work, Gordon served on numerous boards of directors and provided leadership as chairman for many of these boards, both public and private companies (see Appendix 3 for a listing of board of directors). After spending 5 years at Charles River, as a result of an exclusive lock-up, he turned to the establishment of a new economic and litigation consulting company for which he was the co-founder and has served as chairman of the board from its origination in 2005 until this very day.

He not only received honors from his own tribes, the AAEA and the WAEA, but from a number of other associations including leadership awards from the Department of State, the Agency for International Development, and the Antitrust Institute (see Appendix 1). He also was honored by serving on the board of trustees at UC Berkeley and for many years, Palo Alto University.

7 Editorial Innovator

Gordon's innovation and entrepreneurship did not end with what I have described thus far. He was also a major innovator as an editor of professional peer-reviewed journals. As noted in David Zilberman's chapter "On the Essence of Leadership: Lessons from Gordon Rausser", he and his esteemed colleague Richard Just transformed the *American Journal of Agricultural Economics,* upgrading the quality of publications and the standards by which empirical analysis would be conducted. He also served as associate editor of the *Journal of American Statistical Association* for almost a full decade, often combining authors with reviewers in upgrading the quality of the initial paper to make a joint paper far superior. This happened on numerous occasions and this is one of the reasons he was selected as a fellow of the American Statistical Association, a distinction that few economists hold. He also was selected along with another giant of our profession, Bruce Gardner to be co-editors of four volumes of the Handbook of Agricultural Economics. These four volumes are a seminal contribution to AAEA. He followed this with being the founding editor of the *Annual Reviews of Resource Economics* (ARRE), selecting a remarkable editorial committee, moving this journal in a period of ten short years to being among the most impactful journals now ranking first among all journals that focus, in part, on agricultural and resource economics.

8 Summary

In all of the various activities of Gordon there has been a strong work ethic. He has become one that can get the job done under sometimes the most difficult circumstances. In his academic work he has been a major publisher of novel ideas, and suggestions about how his research discoveries can be accommodated in every day economic and political economic life. This is an accomplishment that very few economists have achieved. In his Deanship he was committed to getting a major job completed and he was quite successful at this major institutional change. Frankly, most administrators would have taken much longer to complete this restructuring job and likely would have made many missteps. We cannot say enough about how Gordon went about the tasks given him—to take the College from professionalism to a more life scientific footing and one that in fact, made the way for other major changes in the structure is a real accomplishment. The fact that this set of efforts has given rise to the significant, if we might say "world-shaking change" at the University of California, cannot be dismissed. He has taken the University from a scientific pace where faculty address topics that are of interest for themselves to a place where the faculty is more directly engaged in strategies that are more attuned to economic and political economic progress is a subtle move.

Consulting was a second and in the long run, a major activity that in many ways contributed to his ability to frame the economic, institutional, and political economy issues for investigations in both public and private research. Learning about how the private sector really works, an unlikely point of engagement for academic economists, contributed to his understanding of political versus economic issues, which led to a number innovations in his scholarly work, and solutions to complicated structural problems for the firms and industry groups with which he was affiliated. It was in a way, what lead him to a better understanding of the forces within companies and industry groups that lead to support for universities creating improved outcomes for not only themselves but as well the academic institutions.

Private and public research has been a significant hallmark of Rausser's academic, entrepreneurial, and consulting work. The problems in the private sector do not all depend on the firms or organizations themselves, but on changing the entire environment in which a firm or organization is operating. Rausser was able to sense these underlying issues and develop mechanisms to solve them by looking to novel issues involving the broader aspects of the changing circumstances. By taking these different constraints and advantages into consideration, Rausser was able to develop, long-term strategies for companies. This is a real attribute of Rausser's innovative skills that he brought to each of the problems that he tackled. Gordon has done all of this academic and University restructuring work while at the same time making investments in his activity with private firms and in fact, the source of ideas that allowed him and future academics to make more significant progress at the university. This is a real special capacity or capability of Gordon and one that will not be duplicated by many academics in future years.

Through all of these different facets of his career, the energy of Gordon has been evident—no one works harder and is more resourceful and innovative then he! He approaches economics and political science from a decided advantage point—making the processes work in the university life and in his selected passions. This life in academics and entrepreneurship has been quite rewarding for Gordon, and he has selected this life path from several other alternatives he could have chosen. He will tell you that this work ethic is one of the major characteristics of his long and stellar career.

Gordon, you should see your accomplishments as especially noteworthy in your retirement or moves to even more significant types of changes. We both practiced what we preached, we both had interesting and novel experiences together. The thing is, it's soon time for us to leave it to future economists and political scientists. I was going to say that at the end, we grew old and matured together. But as I thought about this observation, I don't think we matured together, I think we just got old.

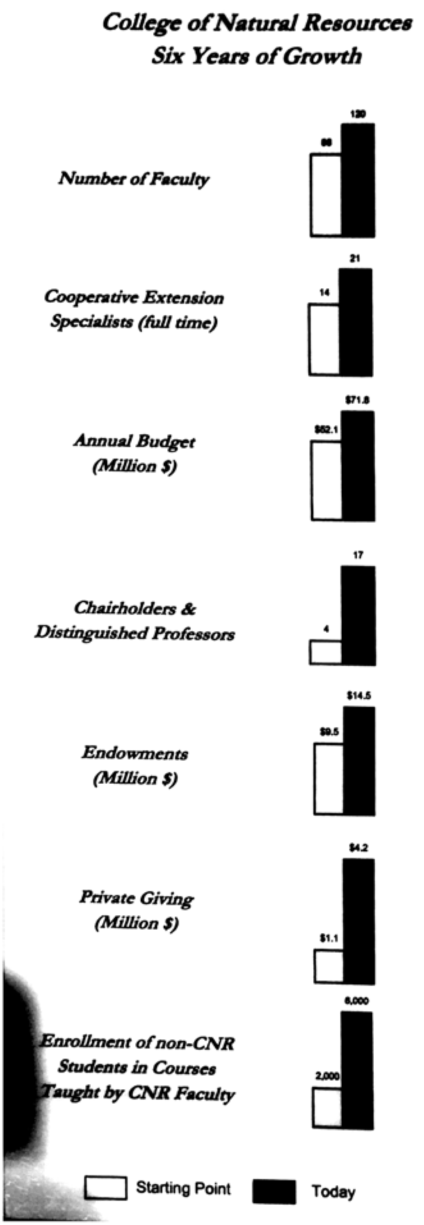
Appendix 1

- In 2021, Rausser was appointed the Edward A. Dickson Emeriti Professorship.
- In 2020, Rausser was awarded the Berkeley Fellowship, awarded to distinguished faculty and friends of UC Berkeley who have led exemplary careers at the top of their professions.
- In 2020, Rausser was selected as a Builder of Berkeley to honor his philanthropy donation to U.C Berkeley's Rausser College of Natural Resources.
- In 2020, U.C. Berkeley awarded Rausser with the U.C. Berkeley Citation and the Berkeley Fellowship, awarded to "distinguished individuals or organizations, academic or nonacademic, whose contributions to UC Berkeley go beyond the call of duty and whose achievements exceed the standards of excellence in their fields."
- In 2020, the Annual Meeting of the Agricultural and Applied Economics Association dedicates their Keynote Address to Gordon Rausser for his "lifetime research discoveries, publications of enduring quality, selected best referred articles, his phenomenal editorial work for four different journals, including the AJAE, and exceptional intellectual leadership of our profession."
- In 2019, a Festschrift was held in honor of Rausser. This four-day symposia composed of some of the world's leading economists on those most pressing topics facing society highlighted Rausser's pioneering research and policy.

- In 2018, Rausser was awarded the "Best Article Award" from the *American Journal of Agricultural Economics* for his article, "Commodity Storage and the Market Effects of Biofuel Policies."
- In 2017, Rausser was awarded the "Quality of Communication Award Honorable Mention" from the *Agricultural and Applied Economic Association* for his book, "Structuring Public-Private Research Partnerships for Success: Empowering University Partnerships."
- In 2015, Rausser was awarded UC Davis' "Outstanding Ph.D. Alumni Award Covering the First Fifty Years of the Program."
- In 2014, Rausser was awarded the "Best Private Enforcement Academic Article" from the *American Antitrust Institute.*
- In 2014, Rausser was awarded the "European Quality of Policy Contribution Award" from the *European Association of Agricultural Economists.*
- In 2014, Rausser was selected as an associate member of Nuffield College, Oxford University.
- From 2013–2014, Rausser was a visiting professor at Oxford University, Department of Economics.
- In 2012, Rausser was selected as a member for the International Scientific Council, LICOS Centre for Institutions and Economic Performance at the University of Leuven, Belgium.
- In 2012, Rausser was awarded the "National Excellence in Multistate Research Award" from the Southern Association of Agricultural Experiment Station Directors (SAAESD).
- In 2012, Rausser was awarded the "Distinguished Scholar Award" from the Western Agricultural Economics Association.
- In 2010, Rausser was awarded the Career Achievement Award from UC Berkeley's College of Natural Resources.
- In 2001, Rausser was awarded the "Quality of Research Discovery Award" from the AAEA.
- In 2000, Rausser was awarded the "Secretary of Agricultural Award" and the "Cooperative State Research, Education, and Extension Service Awards" from the U.S. Department of Agriculture for "outstanding accomplishments in agricultural public policy research and formulation."
- In 2004, Rausser was awarded the "Outstanding Publishing Research Award" from the *Western Agricultural Economics Association.*
- In 1993, Rausser was selected as a fellow at the American Association for the Advancement of Science. He was also selected as the chair of the Electorate Nominating Committee for the *American Association for the Advancement of Science, Section on Social, Economic, and Political Sciences* in 2001.
- In 1993, Rausser was awarded the "Publication of Enduring Quality Award" from the *Agricultural and Applied Economics Association*. This award is given for "contributions to environmental economics, statistical decision theory, and natural resource analysis."
- In 1993, Rausser was awarded the "Distinguished Policy Contribution Award" from the *Agricultural and Applied Economics Association.*

- In 1991, Rausser was selected as an American Statistics Association Fellow.
- In 1990, Rausser was awarded the "Superior Unit Citation Award" from the U.S. Agency for International Development (USAID) for his leadership.
- In 1990, Rausser selected as an AAEA Fellow.
- In 1989, Rausser served as Chief Economist of the Agency for International Development.
- In 1989, Rausser served as chair of the Intergovernmental Consultative Group on Indonesia, The Hague.
- In 1987, Rausser was selected as Fulbright Scholar in Australia.
- From 1986 to 1987, Rausser served as Senior Economist of the President's Council of Economic Advisers.
- In 1986, Rausser was selected as the Robert Gordon Sproul Distinguished Professor at UC Berkeley.
- In 1986, Rausser was awarded the "Best Published Research Award" from the *Agricultural and Applied Economics.*
- From 1983 to 1986, Rausser served as editor of the *American Journal of Agricultural Economics.*
- From 1984 to 1985, Rausser was a resident fellow at *Resources for the Future.*
- In 1982, Rausser was awarded the "Best Journal Article Award" from the AAEA for his article, "Commodity Price Forecasting with Large-Scale Econometric Models and the Futures Markets."
- In 1978, Rausser was awarded the "Best Published Research Award" from the *Western Agricultural Economics Association.*
- In 1976, Rausser was awarded the "Best Published Research Award" from the AAEA.
- In 1972, Rausser was selected as a Ford Foundation Visiting Scholar to Argentina.

Appendix 2



Program

Master of Ceremonies
Rod Park
The Vice Chancellor Emeritus

—

Robert Berdahl
Chancellor

—

Ted Briggs
Past Chair, CNR Advisory Board

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Peggy Lemaux
Cooperative Extension Specialist

—

Rachael Goodhue
Assistant Professor, UC Davis
and
Jill McCluskey
Assistant Professor, Washington State University

—

George Judge
Professor Emeritus

—

Richard Gilbert and Thomas Jorde
Professors and Co-Founders, LECG

—

Reg Gomes
Vice President – Agriculture and Natural Resources

—

Barbara Allen-Diaz
Professor
and
Rick Standiford
Associate Dean for Forestry

—

Nancy Lewis
Assistant to the Dean

—

Stan Johnson
Vice Provost for Extension
Iowa State University

—

Carol Christ
Executive Vice Chancellor and Provost

Appendix 3

Entrepreneurship, Private Company Board of Directors Service

Co-Founder, Chairman and Member of the Board of Directors, TriColor Line 1997–2004.

Co-Founder and Member of the Board of Directors, Law and Economics Consulting Group, Inc. 1990–2000.

Chairman, Board of Directors, Asthma and Allergy Prevention Co. 2011–.

Chairman and Member, Board of Directors, Certent (formerly Equity Administration Solutions, Inc.) 2007–2020.

Member, Board of Directors, Werqwise (UK) Limited 2020–.

Member, Board of Directors, Logic Source, Inc. 2020–.

Member, Board of Directors, Electric Cloud 2017–2019.

Member, Advisory Board, Rembrandt Venture Partners 2015–.

Member, Board of Directors, Connected Data, Inc. 2014–2015.

Member, Board of Directors, Great Maple Restaurants, LLC (aka Sycamore Restaurants, LLC) 2013–.

Member, Board of Directors, iVu Technologies 2011–2013.

Member, Board of Directors, Pacific Mercantile Bank 2009–2012.

Member, Board of Directors, Integrated Oncology Network 2009–2012.

Member, Board of Directors, Chicago Alternative Investment Partners 2007–2018.

Member, Board of Directors, OnCure Technology (formerly US Cancer Care) 1998–2003.

Member, Board of Directors, and Shareholders' Representative, Diversified Therapy Corp. 1997–2011.

Member, Board of Directors, U.S. Diagnostic Labs 1994–1999.

Member, Board of Directors, Source for Automation, Inc. 1988–96.

Co-founder and Member, Board of Directors, OPAC., LLC 2017–.

Chairman, Board of Directors, OTC Online 2007–2018.

Co-Founder, Senior Economic Consultant, and Chairman of the Board, OnPoint Analytics 2005–.

Co-Founder and Chairman, Board of Directors, Opt4 Derivatives 2000–2004.

Chairman, Board of Directors, Creston Commodities 1978–1986.

University Board of Trustees

Co-Founder and President, Member, Board of Trustees, Institute for Policy Reform, Washington, DC 1990–1994.

Member, Board of Trustees, University of California Berkeley 1994–2001.

Member, Board of Trustees, Palo Alto University (formerly Pacific Graduate School of Psychology) 1999–2018.

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Impacts on World Food Systems

Jill J. McCluskey

Gordon Rausser has a deep and long-term relationship with food and agriculture. He grew up on a small dairy farm near Lodi, California, instilling in him something many in the agricultural and food economics profession lack, a first-hand knowledge and respect for our food and where it comes from. He has since developed this relationship beyond the farm whilst staying true to these humble roots. Gordon attended U.C. Davis for his Ph.D. in Agricultural Economics and was asked to join the faculty at the end of second year of his Ph.D. program, a previously unheard-of appointment. While managing his work as a student, teaching underclassmen, and completing his dissertation, he continued to manage the family farm. Gordon completed his Ph.D. in 1971 but left soon after to broaden his experiences. Afterwards, he was appointed to a post-doctoral position in Economics and Statistics at the University of Chicago, before joining the Economics and Statistics faculty at Iowa State in 1973. His next major appointment was at Harvard as a Professor of Managerial Economics and Statistics. In 1978, Gordon returned to his home, California, to join the faculty at the University of California at Berkeley, where he has served ever since. In addition to his faculty service, Gordon's commitment to public service truly demonstrates his commitment to improving the livelihoods of agriculturalists.

From 1986 to 1987, Gordon served as Senior Economist at the U.S. Council of Economic Advisers. David Irwin wrote that this was a critical time for world agricultural policy: the Uruguay Round of trade negotiations under the General Agreement on Tariffs and Trade (GATT) was launched, and Gordon wrote a chapter in the 1987 annual *Economic Report of the President,* "Toward Agricultural Policy Reform." This chapter noted that the distortions that existed on world markets

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sourced with food commodity dumping activities across the globe concentrated in less-developing countries resulted from subsidy-induced excess supply from the United States and European Union which led to strong disincentives for agricultural productivity. Market distortions and damages imposed by European and U.S. agricultural policies are the direct result of political economic forces that ignore poverty, hunger, and malnutrition of low-income households around the world.

Clayton Yeutter, then the U.S. Trade Representative Ambassador and soon to be U.S. Secretary of Agriculture, singled out Gordon's contributions in getting agricultural issues on the negotiating agenda and orchestrating the ministerial meetings to move the Uruguay Round forward. Yeutter is reported to have said, "Food and agriculture might well have not been included in the Uruguay Round but for Rausser's contributions." For this leadership, Gordon Rausser received the USDA Superior Service award in 2000 for outstanding accomplishments in the areas of agricultural public policy research and formulation.

From 1988 to 1990, Gordon served as Chief Economist for the U.S. Agency for International Development (USAID). As Ambassador David Merrill wrote that Gordon's impact at USAID, but for Gordon's strategic-thought leadership and technical assistance, the Indonesian government would not have placed a high priority for food security or the implementation of particular measures for alleviating hunger for those identified as food security risks, including means tests for households and food vouchers for vulnerable groups. This was all changed as a result of Gordon's active involvement. The impacts of Gordon's work carried over in future years, materially improving the nutritional welfare of millions of Indonesian people who would have been at risk of food insecurity. In honor of his exemplary governmental service, USAID recognized him with a Superior Unit Citation Award from the Agency for International Development (1990) for his efforts to design food security regimes for less-developed countries.

While at USAID, Gordon developed the idea which would become the Institute for Policy Reform (IPR). The IPR was a unique organization composed of many future Nobel Prize winners whose mission was to guide public policy in lesser developed countries by improving the political economic landscape so as to achieve increased agricultural productivity and food security. From 1990 to 1994, the institute focused on promoting increases in the size of the economic pie, reducing food insecurity and correcting malnutrition of the most vulnerable segments of society. Ultimately, much of the effort was devoted to the revolutionary transition of the recently liberated economies of Eastern Europe and the former Soviet Union toward a systematic market reform, improved food production and the reduction of food insecurity. Gordon founded this organization and served as its President for the duration of its existence.

Gordon is one of the world-leading researchers on the economics of food and agriculture. In particular, he has distinguished himself in agricultural policy and designing structures that advance innovation in agricultural research. His legacy and ideas have had broad influence as the importance of strategic alliances in public-private research partnerships and the research agenda increases with each passing year. Following Gordon's ideas, public-private partnerships that seek to optimize societal welfare have been on consistently pushing agricultural research forward regardless of the swings in public funding. His impacts are multiplied with each new partnership, including lives saved from the resulting crop improvements and the enhanced food resources that naturally result from them.

As Gordon engaged in university leadership, he made seminal contributions to valuing research and the incentives of university-industry partnerships. He was a pioneer in building a university-industry partnership who thought carefully about control of the research agenda to optimize societal welfare. In 1998, in a challenging funding environment, Gordon, who was the Dean of Berkeley's College of Natural Resources, negotiated and signed an agreement with Novartis that provided \$25 million over 5 years to fund basic research in the Department of Plant and Microbial Biology. Under the terms of this agreement, Novartis gained a limited-time right-of-first refusal on commercialization of the department's discoveries while ensuring the academic freedom of plant sciences faculty and graduate students.

Gordon's Berkeley-Novartis Agreement is an exceptionally significant achievement. Other universities have followed his path-breaking work. The resulting agricultural research that comes from these strategic alliances has increased the quantity, quality, and availability of food for a large number of people. The Berkeley-Novartis Agreement was controversial at the time. Gordon recognized that his university's value is "enhanced, not diminished, when we work creatively in collaboration with other institutions, including private companies." Gordon was able to leverage his public resources with private money. In doing so, he moved research forward and set an example of how other public institutions can make progress, even in a time of university-budget turmoil. Gordon argued, "Without modern laboratory facilities and access to commercially developed proprietary databases… we can neither provide first-rate graduation education nor perform the fundamental research that is part the University's mission in support of agriculture and food systems throughout the world."

The research allowed the plant and microbial biology department access to state-of-the-art equipment and support of researchers that established it as a leading department in its field. An external review found that the fear of the "sell-out" of the university to the corporate sector never materialized. This joint effort was an act of leadership. It faced opposition from multiple directions, required negotiation skills and persistence, and had historical importance. Over the last 30 years, government support for research has unfortunately further declined, and the Novartis Deal was a *de- facto* model for much larger agreements between universities and companies that enable many valuable programs in the plant and biological sciences. The Novartis deal allowed Berkeley to maintain excellence in plant biology. Many were critical of forming a strategic partnership with a private company. Gordon wrote, "The question is not whether universities must deal with the outside world but how effectively they do so." But for the accomplishment of the Berkeley-Novartis Agreement, billions of dollars in private funding for public-good research would not have been available at public Land Grant Universities, setting the foundation for agricultural productivity and food security across the globe.

From the beginning of his research career, Gordon has served as a leader in the fields of agricultural, food, and resource economics by identifying new areas for research and pursuing them. His creativity and productivity as a scholar have been recognized for his discoveries in the design and implementation of public policy, multilateral bargaining, collective choice and statistical decision theory, design of legal and regulatory infrastructure supporting sound governance, modeling dynamic stochastic processes, and the design of innovative environmental and natural resource economic analytical frameworks. Many of these acknowledgements took the form of awards for publications of enduring quality, quality of research discovery and best refereed journal articles. He has published more than 300 articles and book chapters, along with 19 books and more than 100 commissioned papers, governmental reports, and working papers. His immense productivity along with the quality of his work culminated in October 2019, in which the University of California, Berkeley honored his tremendous career with a four-day Festschrift comprised of the world's most influential economists, along with selection as a member of the 100 member Berkeley Fellows.

He contributed to the emergence of a field of political economy in food and agriculture. His seminal book developed the foundations and significant findings of this field. He argued that special interests drive much of the agricultural policies, but he distinguished between policies that improve overall welfare and those that reduce it. Gordon's insights explained investment in research and the evolution of agricultural and natural resource policies. Gordon's major academic contributions began with his efforts to reform public policy as it relates to resources, agriculture, and price distortions that exist in food commodity markets. Then, he wanted to understand the nature of the political economy that makes our political leaders adopt certain policies and their consequences and, in many instances, avoid the societal problems of hunger, malnutrition, and food insecurity. Johan Swinnen, the Director General of the International Food Policy Research Institute (IFPRI) wrote, "Rausser has affected policies that benefited millions by influencing minds of scholars and policy-advisors and by personally getting involved in the policy-making processes." As Wolf Prize Laureate David Zilberman has noted, "[Rausser's] transformative work on political economics triggered policy changes that enhanced agricultural productivity and security, sustaining numerous lives."

Gordon has not only combined meritorious career in academia but also remarkably in business and public policy. His financial support for the undergraduate, masters', and PhD programs is unparalleled. The executive board of directors of the Agricultural and Applied Economics Association has voted unanimously to devote the opening keynote address at each annual AAEA meeting from 2020 forward to honor Gordon. This honor is attributable to his lifetime research discoveries, publications of enduring quality, selected best referred articles, his phenomenal editorial work for four different journals, including the *American Journal of Agricultural Economics* and his exceptional intellectual leadership of our profession.

Throughout Gordon's professional career, he has held leadership positions and through his own research, he concentrated on creating forces that promote agricultural productivity and the public good attributes of reducing poverty, hunger, and malnutrition, both in the United States and across the globe. He identified and pursued three major challenges to achieving food security: (1) resource funding for promotion of research and development, whether in the public sector or the private sector, that advances agricultural productivity; (2) identification of political economic forces that detract from food productivity or redistributive schemes that serve the public interest by increasing agricultural productivity and food security; (3) expand the people resources engaged in solving serious challenges of poverty, hunger, and malnutrition. For example, Gordon and David Zilberman initiated a two-year master's degree in development practice, following a summer program that has trained more than 800 students, which is targeted towards students from many developing countries, most of whom are passionate about reforming agriculture and food systems.

Finally, Gordon's impact on the profession of Agricultural and Resource Economics also includes his teaching and mentorship of Ph.D. students. He has advised more than 75 Ph.D. students who have thrived with his influence on their careers, including me. Gordon was my Ph.D. advisor from 1994 to 1998. His doctoral students were fortunate to receive the gift of his mentoring. Although I was a graduate student being mentored by an eminent scholar and Dean at UC Berkeley, Gordon always made me feel like a colleague. To him, ideas mattered more than positions. The merit of an argument or idea was more important than who was making it. It did not matter that I was female in a male-dominated discipline. He believed in me and pushed me to produce excellence. I endeavor to do the same with my own doctoral students, which means his impact is multiplied further.

1 Statement of Impact

Gordon Rausser has dramatically advanced global food availability through his integration of political economics with modern biotechnology discoveries resulting from creative research and development public-private partnerships. His legacy and ideas have had broad influence as the importance of strategic alliances in public-private research partnerships and the research agenda increases with each passing year. Following Gordon's ideas, public-private partnerships that seek to optimize societal welfare have been consistently pushing agricultural research forward regardless of the swings in public funding. His impacts are multiplied with each new partnership, including lives saved from the resulting crop improvements and the enhanced food availability that come from them.

His innovative negotiation processes and structural design granting access to private genetic material and company databases led to "crowding in" rather than "crowding out" of public good research, increasing food security and agricultural productivity while reducing poverty, hunger, and malnutrition. One of the groundbreaking public-private partnerships developed under his leadership became the foundation for plant biotechnology and other plant sciences collaborations that have led to more than a billion dollars of private company funding for university research.

His application of economics to forge better public policy and creatively deploy large-scale resources has quietly but efficiently transformed the global food landscape.

As Dean of the College of Natural Resources at the University of California, Berkeley from 1994 to 2000, he led a redirection of the college's and the system-wide Division of Agriculture and Natural Resources' vast resources to promote fundamental science capitalizing on recent biological discoveries. By every conceivable metric, the College flourished under his leadership; student enrollment, professorships and endowed chairs, cooperative extension specialists, total budget, extramural grants, and private giving all grew dramatically, and the College became the top ranked in the country sometime after his initial tour as the chairman of the Agricultural Economics Department, taking the department from a ranking of 11th to first nationally in just four short years.

In 1995, the U.S. government allocated only 2% of federal research and development (R&D) spending to agriculture and food, while private sector R&D funding to agriculture soared to 60%. The challenge was to place some portion of these private funding resources into the hands of university nutritional, plant, and microbial scientists. Following the groundbreaking alliance that Rausser negotiated between Berkeley and the Novartis Agricultural Discovery Institute, the researchers at Berkeley became incredibly productive with impactful results. For example, discoveries generated through that partnerships include (1) introduction into tomatoes of a naturally-occurring gene in peppers creating resistance to certain pathogens; (2) discovery of a protein in wheat and dairy that can be manipulated to make these products easier to digest and less allergenic; (3) genetic alteration of plants to produce larger seeds, harboring more starch and protein; (4) deploying a common form of algae to produce substantial amounts of hydrogen gas, a potentially major clean energy source for the future; and (5) frost-tolerant varieties.

The initial $25 million investment by Novartis has spawned countless other university partnerships in plant biotechnology and other plant sciences resulting in more than a billion dollars of private-sector funding to support research directed to agricultural productivity and food security. In essence, armed with the recombinant DNA technologies and the resources of the Berkeley campus, CNR plant and microbial biologists have continued to make new discoveries of nature's oldest and simplest plants, gene by gene.

At the completion of his Deanship in 2000, in comparison to when he first became Dean (1994), the number of faculty and cooperative extension specialists assigned to CNR has increased by 40%; the annual budget has increased from slightly over $50 million to $80 million; the number of endowed chairs, chancellors, professorships and distinguished professorships has increased from 4 to 23; the endowment at the college had increased by over 50%; private giving had been augmented by over 300%; and the undergraduate enrollment courses taught by CNR had increased from 2000 to well over 7000 students. The extramural grants awarded to faculty increased from slightly over $17 million per fiscal year at the beginning of Rausser's Deanship to almost $50 million in his last year of his Deanship.

Rausser's second major impact resulted from his role as the leading scholar of political economy of agriculture. He identified flaws in the previous self-interested global policies that distorted markets and endangered food security. He served as Chief Economist of the U.S. Agency for International Development (AID) during the period 1988 to 1990. While at AID, he succeeded in redirecting policy to focus more heavily on agricultural productivity and food access. In many impoverished countries, these efforts led to reversal of counter-productive policies that had favored powerful interests at the expense of feeding segments of the population. He founded and led the Institute for Policy Reform from 1990 until 1994, which worked to minimize institutionalized corruption and to improve production and distribution of food in former Soviet republics and Eastern Europe in the wake of the Green Revolution. Lives saved from his efforts as Chief Economist of AID in Afghanistan, Bangladesh, Indonesia, Pakistan, the Philippines, Thailand, Costa Rica, El Salvador, Guatemala, Honduras, Peru, Ecuador, and Sri Lanka number in the millions.

Rausser's third major impact is the inclusion of food and agricultural in the Uruguay Round of the General Agreement on Tariffs and Trade (GATT). Agriculture had traditionally been the most contentious area in trade negotiations. From 1986 to 1987, Gordon served as Senior Economist at the U.S. Council of Economic Advisers. Gordon wrote a chapter in the 1987 annual *Economic Report of the President,* "Toward Agricultural Policy Reform." This chapter noted that the distortions that existed on world markets sourced with food commodity dumping activities across the globe concentrated in less-developing countries resulted from subsidy-induced excess supply from the United States and European Union led to strong disincentives for agricultural productivity. Market distortions and damages imposed by European and U.S. agricultural policies are the direct result of political economic forces that ignore the resulting poverty, hunger, and malnutrition of low-income households around the world.

2 Conclusion

In sum, Rausser is one of the leading agricultural, food and resource economists of our time. His major accomplishment of establishing a public-private partnership that enhanced public-good research, resulted in increased agricultural productivity, and serves as a blueprint for others. Extending his influence are his policy impacts that directly affected international agricultural productivity and food security, including one of the nutritional policy centers he established as Dean that assisted in the formation of food banks throughout the U.S. and revolutionized the kinds of food offered. His students carry his legacy forward, and his policy contributions and institutional innovations have greatly contributed to increased food production, thereby reducing human suffering, and improving health and nutrition. His impact will endure. The appendix includes written statements from colleagues who interacted with Gordon Rausser in his impactful career.

Appendix

Written Statements from Colleagues.

David Zilberman, Robinson Chair and Wolf Laureate, University of California, Berkeley

Gordon is a farmer, scholar, entrepreneur, and intellectual leader. He is a polymath that excelled in multiple fields. He has had an immense impact on agriculture and food through numerous channels as delineated below. Gordon is one of the most important agricultural and resource economists of the twentieth century, and his work blazed several essential trails. His award-winning book with Eithan Hochman introduced dynamic modeling under uncertainty to the design of food and agricultural production systems and supply chains. This pioneering book taught a generation of scholars and students how to manage food inventory, to maximize its value and reduce food and economic losses. The introduction of dynamic inventory systems in agriculture all over the world, in both developed and developing countries, improved millions of lives benefiting from the lessons offered by this book.Gordon pioneered modern political economy research in agricultural systems. His work with Freebairn in 1974 was among the first to measure the relative weight that interests of different groups, such as consumers, producers, exporters, and government, have had in shaping agricultural policies. Gordon continued to provide new insights and develop new tools to assess the interaction of politics and economics, which are on display in agriculture in his seminal book with Zusman and Swinnen. Rausser was especially insightful in distinguishing between two types of political economic interventions, dispelling the notion every government intervention is harmful. He recognized the essential value of policies that expand the capability of agriculture through support to research or providing insurance against shocks, versus parasitic policies that reduce overall social welfare. His contributions influenced the thinking of agricultural policymaking, led to the introduction of decoupled policies, which aim to maintain efficiency while changing resource allocation to reduce vulnerability and provided intellectual support to interventions that increase the sustainability of agriculture. Rausser and collaborators' excellent overview piece in the *Journal of Economic Literature* (2013) provides evidence of how agricultural policy has become less wasteful over time, owing to some extent to the contributions of agricultural policy scholars, including Rausser and his disciples.

Rausser's work expanded the range of issues covered by agricultural economists. He was among the first to study the linkages between macroeconomic policies and the well-being of agriculture. In particular, his work analyzed the behavior of commodity futures markets, the economics of commodity booms and busts, and how to reduce the adverse effects of instability. Rausser was a pioneer in studying the economics of entrepreneurship in agriculture, in particular, public-private partnerships, technology transfer, and the emergence of startups. His book with Ameden provides both theory and case studies based learning.

Gordon has been among the most important leaders of agricultural research in the last century as well. When he became the chair of agricultural and resource economics at Berkeley, the department was ranked number 11 nationally. He made smart hires and, more importantly, changed the direction of the department to emphasize agricultural food policy, and the nexus of agriculture, the environment, and development. Berkeley became the leading department of agricultural economics and, through its publication and alumni, modernized the field. Rausser's scholarship on research partnerships between the public and private sectors relied on his experience as Dean of the now Rausser College of Natural Resources at UC Berkeley. When he became Dean, he negotiated an end to a proposal to reduce the size of the college and instead implemented a plan to emphasize research agricultural biotechnology environmental and resource issues. He backed establishing the world's leading program in plant and microbial biology that spawned some of the most significant and most essential innovations in the use of genetic engineering in agriculture.

I consider Gordon the father of the modern collaboration between research universities and major companies. The Berkeley-Novartis deal that he ushered and the publications and books that he wrote provided the blueprint for the rapid evolution of arrangement where the private sector finances basic research at universities, gains access to intellectual property and knowledge, which leads to the implementation of new agricultural technologies. Gordon initiated this effort, working with a new department of microbial and plant biology in order to finance the research in this area. The department needed expanded capacity to implement modern tools of molecular biology. Developing this capacity required resources. Gordon led the Berkeley-Novartis deal that gave the department vital resources in modernization and student support in exchange for providing Novartis with preferred access to university knowledge and intellectual property under cooperative terms. While the deal was very controversial at the time, in retrospect it did not compromise university research but strengthened Berkeley's capacity and led to significant discoveries. These include the first application of agricultural biotechnology (frost tolerant variety) and several plant disease control and yield improving traits. The Novartis deal was a model of university-industry collaboration and inspired the establishment of the Energy and Biosciences Institute (EBI) and Integrated Genomic Institute (IGI) at Berkeley. The EBI led research on second-generation biofuels and the discovery of multiple enzymes that increase agricultural productivity. The Integrated Genomics Institute, headed by Jennifer Doudna, is applying gene editing to various fields, including crop protection. Now, institutions both in developed and developing countries are linking with private enterprises to obtain extra resources and modernize agricultural research to take advantage of new tools and to have closer links with organizations that can apply this knowledge.

The establishment of collaboration between universities and industries that has led to innovations and startups around the world was inspired by Rausser's research and leadership. Graff et al; documented that venture capital firms and hedge funds have been allocating billions of dollars to agricultural research around the world in the last decade. Despite burdensome regulations, university research discoveries have led to widely adopted private sector agricultural biotechnology applications, which increased the supply of soybeans and corn and enhanced food security globally. With the availability of gene-editing technology, the potential benefits associated with the modernization of agriculture, taking advantage of the public-private sharing of knowledge can be immense. The multiplier effect of Rausser's initial innovation and institutional design is enormous. As my own research on agricultural biotechnology indicates, it expanded the supply of soybeans by about 15% and the supply of corn by about 10% and made protein affordable to numerous poor people, reducing malnourishment and saving lives. I mentioned Gordon's contribution as a scholar and as a visionary leader in Berkeley. When he was Chief Economist of USAID, he started the Institute of Policy Reform and engaged the leading economic thinkers on the problem of reform in Eastern Europe and developing countries and revolutionized development economics by introducing modern microeconomics to the field. When Gordon retired, Nobel Laureate Joe Stiglitz emphasized that Gordon's efforts were crucial in building a world-class department at Berkeley that enlisted world-class economists to work on agriculture and development.

Gordon made numerous contributions as a mentor. He was crucial to my career as well as Jo Swinnen and Jill McCluskey. Rausser mentored Richard Howitt, who became a world-leading scholar of water systems and policy, and John Freebairn, who is a leading agricultural economist and policy analyst in Australia. He nurtured Colin Carter, a leading scholar on the agricultural economics of China and futures markets and Kostas Stamoulis, who led many FAO initiatives, among others.

Gordon's career has not been traditional. It went through multiple directions, but wherever he went, he had the Midas touch. He turned our agricultural economics department at Berkeley from #11 to #1. He made the College of Natural Resource at Berkeley a leading center for biotechnology research. He pioneered the collaboration between universities and the private sector that led to numerous technological breakthroughs with many more to come. He transformed research on agricultural policy from a simple application of economic principles to a sophisticated integration of economics, technology, and politics, that impacts the real world. He trained a generation of students that changed the world on their own. His transformative work on political economy triggered policy changes that enhanced agricultural productivity and food security, sustaining numerous lives.

Johan F.M. Swinnen, Director General, International Food Policy Research Institute

Dr. Gordon Rausser has made so many contributions to improving agricultural productivity, the food system and reducing hunger and malnutrition that it is hard to identify a single contribution as a crucial part. Others have emphasized his very important contribution through entrepreneurial innovations in agricultural and food research design. I would like to focus on his work on political economy of agricultural and food policy and the implications for food policy and policy reform globally—and thus the impact on the lives of numerous poor food consumers and poor farmers around the world.

It is abundantly clear that public policy has a vast impact on food and nutritional security—and more general the lives—of billions of poor people in the world. Improving public policy can have huge impacts on these billions of people. However, improvements in public policy are often difficult because they not only affect the welfare of many, they often also affect the vested interests intrinsic in the status quo. And those vested interests may block welfare-enhancing public policy reform. Understanding these "political economic mechanisms" and how to overcome them is crucial for enhancing public policy—and thus global welfare improvements—in the world. Dr. Gordon Rausser has played a leading role both as academic researcher and as policy advisor in improving the lives of many by identifying and measuring these mechanisms and integrating them explicitly into public policy.

Throughout his career, from his early work as academic researcher through his later positions as senior advisor inside public policy institutions, Dr. Rausser has focused on the importance of understanding, integrating, and alleviating political constraints in public policy improvements. His early work focused on the political economy mechanisms of policies that were explicitly targeted to benefit specific sectors in the economy, such as commodity programs, and why those programs often caused unnecessary distortions in the economy while benefiting the few and not the many. These vested interests typically tried to block welfare-enhancing policy reforms. His later work showed that not only such "distributive policies" (e.g. subsidies, tariffs, etc.—or "PESTs" as he defined them) but also public policies that were explicitly targeted to enhance public goods (or PERTs in his work) were subject to similar political economy mechanisms.

He and his collaborators showed that massive underinvestment in public goods, such as public agricultural research, resulted from the redistributive implications of changes in public policies—again bringing the importance of considering vested interests explicitly into policy design. A crucial contribution has been the integration of both perspectives. He showed that in many aspects of the world, such as agricultural policies, food security and nutrition, public good policies and redistributive policies not only existed at the same time, but interacted with each other—sometimes in "good ways" (as redistributive policies can help the political process of policy reform by compensating losers of the reform); sometimes in "bad ways" (as the distortions caused by the redistributive policies are made worse by productivity-increasing public investments).

Key implications of these insights for enhancing food security and the lives of the poor are (a) the need to create a proper governance structure for policy reform; (b) the importance of using non-distortionary policy instruments; (c) better targeting in public policy; and (d) minimizing negative interactions between different public policies and using positive interactions to stimulate policy reform. Gordon has applied these insights to a large number of public policy issues related to food security and nutrition, such as food subsidies, agricultural protection, trade policy reform, water policy, R&D investments, land reform, property rights and incentive structures, etc. (as documented in the various chapters in his book "*Political Power and Economic Policy: Theory, Analysis and Empirical Applications*" published by Cambridge University Press). These insights—through his academic work and by his role on the Council of Economic Advisers—influenced the integration of food and agriculture into the WTO and, as a consequence, the reform of agricultural policies in many countries (as documented in his 2013 article in the *Journal of Economic Literature*).

Dr. Rausser has received numerous awards for his academic work on this. Gordon later in his career used these insights to advise on and contribute to effective policy reforms in a variety of important policy arenas and issues, during his time on the Council of Economic Advisors, as Chief Economist of USAID and as President of the Institute for Policy Reform. As Ambassador Merrill in his letter documents his work has impacted the food security of many lives and poor in countries such as Indonesia. This was true in other countries as he advised on policy in a variety of countries in Africa and Asia in his time at USAID and later on Eastern Europe and Central Asia at the Institute of Policy Reform. His contributions at the Council of Economic Advisors to integrating agriculture in the GATT (now WTO) have contributed to a significant reduction of distortionary subsidies in rich countries which benefited millions of poor farmers in developing countries.

In summary, Dr. Rausser's research and policy advisory work and policy vision contributed importantly to policy reforms in a variety of areas that enhanced global food security. He relentlessly argued that is not possible to design policies that counter hunger, poverty, and malnutrition unless the public sector is actively involved. The primary obstacle to such effective intervention is a political-economic structure based on a faulty governance structure that largely serves the self-interest of the powerful. Hence, to improve food security and enhance the welfare of the poor, it is crucial to integrate political economy into the policy analysis and policy design. With his seemingly limitless energy, he has affected policies that benefited millions by influencing minds of scholars and policy-advisors and by personally getting involved in the policy-making processes.

Ambassador David N. Merrill, President, United States-Indonesia Society

My [statement] is based on over 30 years of knowledge of Dr. Rausser's intellect and his ability to get to the analytical core of an issue, frame it in its wider political and policy reform context, and communicate it to others. It principally covers the period Dr. Rausser was USAID's Chief Economist in the late 1980s and his work together with USAID in the 1990s as Head of the Institute for Policy Reform, which he founded to convey his insights more widely. During this time, I was a Senior

USAID Foreign Service Officer, serving as USAID's Mission Director in Indonesia in the late 1980s and then as USAID's Senior career official in charge of emergency transitional assistance to Central and Eastern Europe, 1990–1993. From 1994 to 1997, I was U.S. Ambassador to Bangladesh.

For the past 12 years, I have been President of the United States-Indonesia Society. In 1989, when Dr. Rausser was USAID's Chief Economist, I invited him to visit the USAID Mission in Jakarta to help us with our new economic strategy for assistance to Indonesia, as well as to meet with our senior economic and agricultural staff and to deliver a speech to the Indonesian Economics Association. Dr. Rausser helped us reformulate our entire thinking. First, he helped us put all our economic strategy in the context of political economy and policy reform. He helped us see that it was not dollar resources *per se* we should be looking at, but using our resources for analyzing and dealing with the policy constraints on economic development. This was critical to understanding the winners and losers from the policy reforms that might be implemented, and how to counter the large and consequential constraints, with the improved knowledge of all the political and economic forces at play.

Dr. Rausser's lecture to the Indonesian Economics Association created much excitement and a different lens on how to achieve major policy reforms. He outlined the current political/ economic landscape in Indonesia, and how the internal governance structure would have to evolve to sustainably implement food security objectives. He outlined desirable governmental intervention programs, including cash transfers linked to children's school attendance, nutritional training, and means-tested food vouchers. Recognizing the difficultly of restructuring the political/economic landscape to enable these measures, he showed how this could also be altered by the external donor community, and by the emerging Uruguay Round on liberalization of trade in food and agriculture. He convincingly argued such liberalization could lead to significant reforms of the Multi-Fiber Arrangement (MFA) that could ultimately benefit low-income households being lifted from poverty and hunger through textile manufacturing employment and the principle of comparative advantage. Dr. Rausser's presentation dramatically deepened our AID mission's relationship with Indonesian economists.

I used Dr. Rausser's insights on how to overcome resistance to change within my own Mission. USAID was a world of technical assistance projects only, reluctant to transfer resources even for policy change. Discussions with Dr. Rausser fortified me to press ahead with new techniques such as temporary resource transfer programs to ease resistance in the Indonesian government to support new policies for the agricultural sector. New Integrated Pest Management (IPM) controlled pests without the use of pesticides. The Indonesian government was resisting not only because of budget issues but also because of pressures from politically connected chemical insecticide companies. We started a demonstration program to provide budgetary resources to the government to hire IPM staff on an experimental basis. It worked. The government received favorable attention for its environmentally-sound new practices and started to pick up these costs on its own.

Because of Dr. Rausser's technical leadership, respect, and persuasive ability, I sought him out to lead the U.S. delegation to the Inter-Governmental Group for Indonesia's ("IGGI") annual donor meeting at the Hague in 1989. There was a fiscal deficit which the Indonesian government wanted donors to fill. We were providing U.S. aid of around $75 million per year; moreover, the U.S. voice was listened to attentively owing to our world role and economic expertise. Dr. Rausser wrote and gave the USG statement. He conditioned the U.S. pledge on the Indonesian government's implementing a higher priority for food security, specifying measures for alleviating hunger for those identified as food security risks, including means tests for households and food vouchers for vulnerable groups. This was accepted and carried over in future years, materially improving the nutritional welfare of millions of Indonesian people who would have been at risk of food insecurity.

In 1990, Dr. Rausser wrote USAID's guidance to all missions for their economic development strategies. It concentrated on creating broad-based sustainable growth, including environmental protection, avoiding misuse of pesticides, protecting ecosystems, protecting the natural resource space, and of course, addressing the political and institutional context so as to improve economic growth and the degree of food security among lower-income households. That document is the most impressive strategy guidance I have ever seen. It improved the strategies of dozens of USAID assistance programs, with broad impact.

By 1990, I had returned to Washington. Soon after the countries of Central and Eastern Europe began their historic break from communism, I was made the senior career USAID officer responsible for U.S. assistance to Eastern Europe. My political level supervisor and I reported to the Deputy Secretary of State, who had policy direction of the assistance because "Eastern Europe was too important to be left to AID." Dr. Rausser, then at his Institute for Policy Reform, prepared several papers to guide USAID through the process of Eastern Europe's sudden privatization. They were helpful in guiding me to avoid rent-seeking behavior and helping special interests and leaning toward an open economy.

The sector grant techniques we pioneered in Indonesia were able to be used to deliver assistance to Czechoslovakia in environmental programs support. In Romania, these same techniques were used for agricultural program assistance, including our firm avoidance of supporting vested political interests, despite strong pressure from the country to do so. Dr. Rausser has a rare combination of an extraordinary mind and being a natural influencer of practical results. If the problem requires technical econometrics, he can do that easily. But his gift is in immediately grasping the essence of a problem in its real-world context to guide the rest of us in how to deal with it and achieve broad impact.

He has been a seminal force who has inspired those he has touched to improve their own results. He has materially enhanced the environmental, natural resource, and food security of millions of people over 30 years. Without his presence and persuasiveness, this would not have happened.

Douglas Irwin, John French Professor of Economics, Dartmouth College

There is no better way to ensure food availability and accessibility than to eliminate the policy distortions that stand in the way of countries trading their agricultural output with one another. By reducing trade barriers that force local self-sufficiency, countries can take advantage of the gains from specialization, including higher incomes for food producers in exporting countries and lower prices for poorer households in food importing countries. By that standard, Gordon Rausser had made critical contributions in a range of activities to further that goal. Many of the other nominating letters will talk about his academic and entrepreneurial contributions to the cause of food security. I will focus on his role in public policy.

In the 1970s and 1980s, world agricultural markets were in "disarray," as the great University of Chicago economist D. Gale Johnson noted at the time. The United States, Western Europe, and Japan heavily subsidized their domestic farm producers, leading to overproduction and further export subsidies to eliminate the surpluses. Those subsidies depressed world market prices, harming farmers in developing countries and leading to a proliferation of counter-subsidies and trade barriers around the world. When the Reagan administration proposed reforms to U.S. policies, it was considered "dead on arrival" on Capitol Hill.

Clayton Yeutter, then the U.S. Trade Representative (chief U.S. trade negotiator) and later Secretary of Agriculture, asked Gordon for his advice. Gordon suggested that reform would only work if all major countries agreed to curtail their subsidies and reduce their trade barriers; that unilateral action would fail for political reasons. Yeutter agreed with and took this advice and the United States insisted that agriculture be a key component of the next global trade negotiating round under the General Agreement on Tariffs and Trade (GATT).

Shortly thereafter, Gordon became the Senior Economist on agricultural at the Council of Economic Advisers in the Executive Office of the President during the administration of Ronald Reagan (1986–1987), where I worked with him. This was a critical time for world agricultural policy. The Uruguay Round of trade negotiations under the General Agreement on Tariffs and Trade (GATT) was launched that fall. And, for the first time in the history of post-war trade negotiations, agricultural trade policy reform was a key item on the agenda. Prior to that period, the contracting parties to the GATT had refused to discuss or negotiate lower trade barriers in agriculture because of domestic political sensitivities. The Reagan administration made it a priority to reduce trade barriers—tariffs, quotas, export subsidies, and price supports—in this area to ensure a freer flow of agricultural goods around the world.

In his White House position, Gordon played a key role in crafting the U.S. position in the agriculture negotiations. He worked extensively with officials at the U.S. Trade Representative's Office and the U.S. Department of Agriculture in helping to identify the key foreign trade barriers that blocked U.S. exports and the distortions of trade and production around the world, identifying both their impact on trade and economic welfare for consumers and producers. For example, at this early stage, the Organization for Economic Cooperation and Development was just formulating the producer subsidy equivalent (PSE) metrics that proved to be so useful in quantifying the magnitudes of government support for producers (subsidies) in various countries for many commodities.

Gordon's written work during this period was also important in communicating the importance of policy reform. In February 1987, the Council of Economic Advisers released the annual *Economic Report of the President* that included the important chapter "Toward Agricultural Policy Reform." This chapter noted that the benefits arising from U.S. agricultural policy programs did not reach those most in need. Moreover, the distortion that existed on world markets and the food commodity dumping activities across the globe concentrated in developing countries, resulting from subsidy-induced excess supply from the United States and European Union, resulted in strong disincentives for agricultural productivity. The market distortions and damages imposed by U.S. agricultural policies are the direct result of political economic forces that ignore the resulting poverty, hunger, and malnutrition of low-income households around the world.

This chapter was singled out by members of Congress for its important contribution when the chairman of the CEA presented the report before Congress. The chapter gained wide circulation as making an effective case of the need to reform agricultural policies in the United States and around the world. In addition, Clayton Yeutter, then the U.S. Trade Representative and soon to be Secretary of Agriculture, singled out Gordon's contributions in getting agricultural issues on the negotiating agenda and orchestrating the ministerial meetings to move the Uruguay round forward. (Yeutter is reported to have said that "that food and agriculture might well have not been included in the Uruguay Round but for Rausser's contributions.")

Based on his work at the CEA with the USTR, Gordon was asked to provide the coordination leadership to orchestrate the OECD 1987 ministerial meetings. Those meetings, attended by seven U.S. cabinet secretaries, were critical to pushing the agricultural reform agenda forward. Because of Gordon's critical work in this area, Yeutter later sought to have Rausser become the chief economist at the Department of Agriculture. Instead, Rausser's prominence among policymakers and commitment to food security resulted in his being selected as Chief Economist of the Agency for International Development in early 1988. There he continued his work on policy reform and agricultural food security that has proven to be so important. Other colleagues of his can attest to this phase of Gordon's career, but it is clear that his leadership at the Council of Economic Advisers made possible these later accomplishments. (In addition, it should be noted, the Uruguay Round was successfully completed in 1993 and the Agreement on Agriculture is one of the crowning achievements of that agreement.)

The efficient allocation of agricultural resources across countries is a vital factor in ensuring adequate food production and distribution and an importance means of increasing food availability and accessibility to those most in need. Throughout his career, but certain at these critical moments in the late 1980s and early 1990s, Gordon made important contributions to making this a reality.

Gordon Rausser and the Transformation of Agricultural Economics from the 1960s to the 1980s

David Zilberman

1 Introduction

Agricultural economics emerged from a merger of farm management and farm economics. The farm management side emphasized practical resource allocation problems at the farm level, and the farm policy side emphasized issues of agricultural markets as well as policy (Zilberman, 2019). The farm management field emphasized normative analysis: how to run a more efficient and profitable farm. Farm economics was more interested in understanding farmer behavior and developing policies that would improve the wellbeing of farmers. While the distinction between normative and positive analysis has always been an important feature of economics, economists tend to emphasize understanding behavior and less often prescribe choices. Management science is much more normative. Agricultural economics has retained both a strong positive and normative emphasis, first for farms and later for agricultural, agrifood and natural resource systems. Namely, they aimed to explain reality and suggest solutions to manage it better. This management perspective led to a multidisciplinary emphasis in agricultural economics, as well as an agenda more anchored to reality than to theory. Thus, agricultural economics has evolved as a distinct discipline, closely linked to economics but with its own agenda and modes of operation.

Over the last century, the discipline that began as farm economics has expanded as the US and much of global society has become less rural and agriculture has become part of a larger food sector that occupies much of the global resource base. The name of the discipline (as reflected by department and association names) has changed, becoming agricultural and resource economics, agricultural and food

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economics, and even agricultural and applied economics. Many of these changes occurred between the late 1960s and the 1980s. Gordon Rausser was a major leader of the transition as a scholar and administrator. In this chapter, I will trace the evolution of agricultural economics from its inception to the present, with particular emphasis on the transition and Gordon's contributions to it. I will distinguish between the earlier period from the inception of agricultural economics till the 1950s, the transitional period from the late 1950s to the 1980s, and the modern period since. The next section overviews the main features covered by agricultural economics prior to the 1950s. This will be followed by a section identifying the main features of the transition toward modern agricultural and resource economics. We will have sections dedicated to the two stages of the transition. Schultz and Griliches were the major figures of the early transition of the 1950s and 1960s, while Gordon was prominent in the larger transition from the later 1960s to the 1980s. A concluding section will assess the implications of this evolution towards the future.

1.1 Traditional Agricultural Economics

Agricultural economics emerged as a discipline from the integration of two groups of scholars and practitioners. Those interested in farm management emphasized agricultural practices, understanding costs and returns for different crops, farm marketing, and finance. The second group consisted of agricultural economists, many linked to the USDA, who were interested in agricultural trade, pricing, and policy. This integration was formalized when the American Farm Economic Association (the predecessor of the American Agricultural Economics Association, today known as Agricultural and Applied Economics Association) was established in 1919. As the excellent review by McCalla et al. (2010) suggests, research in agricultural economics was inspired by the challenges of US agriculture and the global agrifood economy, both at the micro and macro levels. These included studies on productivity, technology adoption and the role of extension, and the economics of family farms and farm labor. Pricing analysis was very detailed and emphasized the importance of transportation costs on profitability of agriculture as well as allocation of resources over time. A key issue is competitiveness and power of the farm sector in the food supply chain. There was a recognition that the market power of individual farmers is limited and of the need for cooperation to counter the power of buyers. That led to analysis of the performance and management of cooperatives. The agricultural economics literature was responding to economic and political realities, namely, policies and measures to improve productivity during the First World War and adjustment after the war. In the 1930s, the emphasis was on alleviating the hardships associated with the Depression and the Dust Bowl. The 1940s saw an emphasis on the rural economy, the food security in Europe, and the post-World War II arrangements and adjustments. The economics of policies to address the farm problem (low prices and excess supply) were emphasized in the 1950s.

The methodology of agricultural economics evolved with that of economics. In the beginning of the twentieth century, it was more conceptual and graphical, applying the concepts of neoclassical economics and providing major contributions to the development of a quantitative understanding of production functions and supply and demand. The leading journal of agricultural economics, the AJAE (originally Journal of Farm Economics, then American Journal of Agricultural Economics) published some of the leading papers in economics. The survey of AJAE publications by Lybbert et al. (2018) lists the outstanding article from every year. These include Waugh's article that was one of the first presentations of the notion of hedonic pricing (1928), Peterson and Galbraith's work on the concept of marginal land (1932), Working's article on the theory of futures markets (1948), Stigler's study of the minimum cost diet (1945), and Ciriacy-Wantrup's study of the value of soil conservation activities (1947). These papers were visionary, launching original ideas and opening new avenues for research.

John Kenneth Galbraith was one of the most prolific agricultural economists in the early days. He was the second most prominent economist in the US government during the Second World War (after Simon Kuznets), overseeing price control programs, and he became a public intellectual after the war. Galbraith's notion of countervailing powers and consumer behavior in "The Affluent Society" were affected by the realities of agricultural supply chain and consumer behavior as documented by agricultural economists. Galbraith and other agricultural economists played important roles in government economic analysis. In addition to Galbraith, the first head of the Council of Economic Advisors was an agricultural economist, Edwin Nourse, who wrote a dissertation on the Chicago Produce Market and was once vice president of the Brookings Institution.

Agricultural economists were quantitatively compared to most economists of this era, mostly because of the availability of agricultural data assembled by the USDA. Before the Second World War, agricultural economists led much of the quantitative research in economics. The 1950s and 1960s saw the introduction of computers, the mathematization of economics, the emergence of agribusiness, and significant transitions in the farm sector, and agricultural economics evolved and adapted to these developments.

2 The Transition of Agricultural Economics after the 1950s

2.1 Overview

Surveys of agricultural economics show that the discipline underwent a transition from the 1950s to the 1980s (Gardner, 1992). As the survey by Debertin and Pagoulatos (1992) indicates, prior to the 1950s the majority of papers in the AJAE were not quantitative, and after the 1970s the majority were quantitative. The transition had many dimensions, as Table 1 indicates.

Table 1 The transition of agricultural economics in the 1960s

From	To
Farm-centric	Agrifood system centric
Sectoral	Economy-wide
US	Global
Numeric	Statistics
Statics	Dynamics
Descriptive/narrative	Quantitative
Production and consumption (goods)	Resources and environment
Market	Political economy

2.2 *Early Stage: 1950–1970*

The transition was gradual, and it coevolved with analogous developments in economics and other disciplines. Most importantly, it evolved with the increased capacity of computers. Samuelson's work popularized the use of calculus in economic analysis in the 1950s and 1960s, and game theory became mainstream in economics in the 1970s; these methods quickly diffused across agricultural economics (Debertin & Pagoulatos, 1992). The transition to more quantitative analysis started in Berkeley, the University of Chicago, and Iowa State, and then spread elsewhere. Agricultural economic research was at the frontier of econometrics, evidenced by the prominence of Griliches's work on productivity and diffusion, Nerlov's work on adaptive expectations, and Mundlak's work on fixed effects. This period of applied agricultural economics research inspired the comments made by Nobel Laureate Leontief assessing agricultural economics as "an exceptional example of a healthy balance between theoretical and empirical analysis".

Theodore Schultz was a towering figure throughout this period of transition. Much like Keynes, Schultz was a keen observer of the real world and introduced different conceptual frameworks to address gaps in theory. One is the notion of human capital and the difference between worker and allocative skill. A related notion is the ability to deal with disequilibrium. Schultz and Lewis won the 1979 Nobel Prize for their work on the agricultural sector. Lewis addressed issues of economic development, while Schultz's work was more relevant for developed economies. Another major contributor to the understanding of US ag policy and development was Willard Cochrane.

Cochrane was influenced by Schumpeter's notion of creative destruction. He introduced the technology treadmill concept where innovation benefits consumers and early adopters, but leads to structural changes and punishes laggards. However, most of their analysis was theoretical, conceptual, or descriptive. Earl Heady was a pioneer in the use of experimental data to estimate production functions and various applications of operation research, which he applied to agricultural markets, later leading to a quantitative emphasis in policy analysis.

The transition was also affected by the prominence of macroeconomic and agricultural policy and the challenges of trade management during the Cold War era.

2.3 Later Stages of the Transition 1970–1990

The transition intensified in the late 1960s and 1970s, just as Gordon Rausser became a major contributor to agricultural economics. This was the beginning of drastic reductions in the cost of computing power, and personal computers were introduced. Another important development was the emergence of the environmental movement, inspired in part by the publication of Silent Spring. It led to the establishment of the EPA and the passing of the Clean Air and Clean Water Acts. While the interest in environmental issues increased in the 1970s, the rural population declined. Because this decline reduced the demands for traditional agricultural training, land grant colleges shifted emphasis to natural resource issues. For example, the College of Natural Resources in Berkeley (later to be called the Rausser College of Natural Resources) was established in 1974 with the integration of the College of Agriculture and the School of Forestry. Other issues that affected the agenda of agricultural economics was the expansion of agribusiness, and the later fall of the Soviet Union, the opening of trade with China, globalization, and concerns about climate change. Several major lines of research emerged in agricultural and resource economics during the 1970s and 1980s and were impacted significantly by Gordon Rausser's work and leadership.

3 Rausser and His Contributions to the Transition

Rausser started his academic career in the late 1960s and 1970s, and from the start, he was an agent of change. His early contributions were more methodological, but very soon he started changing the focus and research agenda of agricultural economics. We will identify only a few areas where he made a major difference, complimenting the other overviews of his contributions in this book.

3.1 Dynamic Modeling

The economics of natural resources has emphasized dynamic considerations since the work of Hotelling. Analysis of water projects using dynamic models was an important area of agricultural economic research, and Burt and Cummings (1970) developed a conceptual framework to analyze investments in natural resource management that was applied to water problems, pest control problems, and soil management problems (Lichtenberg et al., 2010). However, many dynamic problems have strong random (stochastic) elements and developing realistic solutions require adjustments to unexpected events. Rausser has developed several important applications of dynamic control to natural resource problems. Rausser and Freebairn (1974a) introduced the first application of dynamic control for international trade policy. The paper is important methodologically because it developed methods to assess decision rules based on multiple criteria for adapting decision-making given new information. It shed new light on the determination of beef import quotas, estimating the weight given to consumers, producers, and tax payers' wellbeing in the development of the quota and how the quota was adapted as policymakers learned from the past. Rausser and Howitt (1975) developed a dynamic stochastic framework to design policies (e.g. taxes) to control externalities (e.g. pesticide damage). The paper was among the first to recognize the stochastic nature of externalities and the problems of incomplete information regulators face. It developed methods for updating policy designs as information accumulates. The award-winning book by Rausser and Hochman (1979) was a seminal contribution that expanded the range of analytical tools applied by agricultural economists. It compares alternative methods for policymaking under dynamic systems over time, and introduced a notion of adaptive learning to agricultural economics, where policymakers may engage in active learning by experimenting with alternative solutions. This approach allows to more accurately assess the parameters of the system they manage and improve policy choices. The methodological part of the book imported and explained new dynamic tools developed by electrical engineers to the context of economic systems. It provided several examples of important applications for policy design and inventory management. Over time, stochastic dynamic analysis has become a major line of agricultural and natural resources research, applied to problems of fisheries and forest management, as well as management of livestock and agricultural supply (Lichtenberg et al., 2010).

3.2 Quantitative Policy Analysis

Much of the advanced thinking on policy analysis in agricultural economics, in the 1950s and 1960s, was descriptive and based on partial microeconomic models that were adjusted to reflect features of agricultural markets and properties of agricultural products (Brandow, 1977). Edward Schuh (1974) recognized that agriculture is affected significantly by macroeconomic policies, and that has to be considered in the design of agricultural policies. Rausser realized that policymaking requires establishing quantitative policy parameters and the ability to predict possible outcomes based on the fundamentals of the agricultural sector and the agricultural economy, the feedbacks from the macroeconomy, as well as random shocks. The award-winning paper by Rausser et al. (1986) developed an econometric model to assess how agricultural sector outcomes (agricultural prices, farm income, etc.) are affected by various policies, including monetary policy (interest rates), international trade conditions (exchange rates), fiscal policy (tax rates), as well as agricultural policies such as price supports, deficiency payments, and export subsidies. The model suggested that high interest rates and a strong dollar affect agricultural incomes negatively. Furthermore, the agricultural market's fast response to changes in macroeconomic conditions can cause farm incomes to fluctuate significantly, at times leading to crisis situations. Traditional agricultural policies tend to expand supply, exacerbating the vulnerability of agricultural markets to macroeconomic shocks, and transfer much of the losses to the public sector. Rausser et al. (1986) suggest that government intervention in agriculture tends to be excessive and leads to inefficiencies and distorted international trade patterns. It can be justified to counter the excessive instability brought by macroeconomic policies on agricultural markets. These findings were very influential in justifying the emphasis on decoupled agricultural policies, that stabilize income without affecting production, throughout the world.

Rausser's quantitative agricultural policy analysis has contributed to blazing several paths of research and policy analysis. Over the years, quantitative agricultural and natural resource policy analyses have become more common. Researchers have applied computable general equilibrium, programming and econometric approaches,[1] and we expect these trends to further expand with the availability of BIG data sources and tools (Weersink et al., 2018). Distorting government interventions in agriculture have declined over time (Anderson et al., 2013). While governments aimed to pursue decoupled policies, doubts were raised as to what extent such policies were feasible, because of farmers' risk aversion and other considerations (Goodwin & Mishra, 2006; Serra et al., 2006). Rausser and others suggested that government intervention in agriculture is justified to reduce excessive risk and instability, but economists are often disappointed with actual policies. From his work over 4 years in Washington and elsewhere, Rausser experienced firsthand the political process that precedes policymaking, and he contributed to an emerging literature on political economy in general and in agricultural and resource policies in particular.

3.3 Political Economy

Griliches (1958) pioneered the use of welfare economics to assess the impacts of government policies, e.g. investment in agricultural research. Schmitz and Seckler (1970) illustrated the power of welfare economics to assess distributional outcomes, showing that while consumers and industry gained from the introduction of the tomato harvester (developed with public funding), farm workers lost, leading to political and legal confrontations (Martin & Olmstead, 1985). Rausser and Freebairn (1974b) developed econometric techniques to analyze the distribution of a policy's benefits across groups and thus, estimate how much weight policymakers give to the interests of different groups. While welfare economics has been used to assess the impacts of government programs, especially in providing public goods that improve social welfare, the literature on rent-seeking behavior (Krueger, 1974) emphasized

[1] See for example Khanna and zilberman (2012) review of alternative approaches to model Biofuels and their implication of land use and greenhouse gas emission.

that government officials may enact self-serving policies that reduce social welfare. Rausser argued that the political economic literature recognized that political and economic systems coevolve. Politicians and policymakers are modeled as economic agents that develop an agenda to pursue votes and financial resources. Rausser's seminal 1982 paper distinguished between self-serving policies (PESTs) and policies that aim to correct market failures and improve welfare (PERTs). The land grant system, support for research, and investments in agricultural infrastructure are examples of PERTs, while some commodity programs are clearly PESTs. Resource-owners out of self-interest may manipulate the political system to produce policy interventions that are PESTs. The challenge for society is to develop a political system and institutions conducive to enacting PERTs rather than PESTs, and Rausser's research addressed this institutional design challenge. For further details on the complementarities of PERTs and PESTs, their inherent complementarities, please see chapter "The Way Forward" in this volume.

Rausser's magnum opus on political economy is the book "Political Power and Economic Policy" (2011), which he coauthored with Jo Swinnen and Pinhas Zusman. It contains a rich and creative theory and with multiple applications to important agricultural and resource management problems, building and expanding upon the game theoretical framework of Nobel laureate John Nash and John Harsanyi (1977). Rausser and his coauthors model political systems as a central player (the government) and many interest groups which bargain in negotiating policy parameters. The power of the different parties varies, and groups with stronger political power prod for the implementation of policies that secure self-interest. The policy parameters, as well as random events, affect the economic outcomes (for example, income distribution). The modified economic outcomes affect subsequent political power distributions, that in turn, affect policy parameters, and so on. The performance of the system is strongly affected by governance structure, namely, the basic rules of the game that constrain political operators and may be specified by a constitution. This framework is used to analyze the political economy of public investment in R&D and public goods, land reforms, economic transition (as in Eastern Europe in the 1980s and 1990s) and European commission agricultural policies, and to develop and apply econometric approaches to estimate the power distributions for a few applications. The book suggests that political economy analysis is crucial for designing institutions that will enable the introduction of sustainable, welfare-improving policies and markets. In particular, it emphasizes the importance of developing effective transfer arrangements to reduce resistance to initiatives that enhance overall social welfare, including developing safety nets to compensate potential losers and developing effective representations of entities that may be affected by policy changes (e.g. the environment).

The ideas presented in the book were influenced by Rausser's experience as the Chief Economist of the US Agency for International Development (AID). They led him to suggest that international agencies (e.g. the IMF and the World Bank) and donor agencies (e.g. AID) should make assistance conditional on effective constitutions and the design of institutions rather than on immediate outcomes or establishment of particular government policies (Rausser, 1990). For example, he argued that democratic governmental and judicial institutions are critical to the enforcement of contracts, the security of private property and the assignment of liability for wrongful conduct. Analyzing the transition of former communist regimes throughout Russia and Eastern Europe, Rausser and Johnson (1993) suggested "The public sector must play a dominant role during the transition process and will be effective if and only if a well-designed constitution and an associated legal and regulatory infrastructure is first established." This perspective contrasts with the Washington Consensus of the 1970s and 1980s, which emphasized allowing the free market to "get prices right." Over the years, however, government agencies and economists have embraced the emphasis on good governance and effective institutional design. Major economic thinkers have emphasized the importance of institutional design for economic growth (Acemoglu et al., 2005). The analysis of the transformation become a major area of research in agricultural economics (Reardon et al., 2009).

Agricultural economics has always emphasized methods that allow practical policy design. Rausser's co-authored paper with Richard Just "Principles of Policy Modeling in Agriculture," captures the key elements that Rausser has attempted to incorporate to the science and practice of policy modeling. These include an emphasis on clarity in defining objectives and policy tools, a holistic (general equilibrium) rather than a partial approach, incorporating both markets and political considerations, understanding and redesigning institutions, and an evolving dynamic perspective where the policy makers experiment and adapt their polices based on the accumulating evidence. Xie and Yang (2017) studied the evolution and design of China's market reform in the 1970s. They argue that the de-collectivization of agriculture in China by Deng Xiaoping was gradual and began with experiments in a few regions, an example of the principles presented by Rausser and Just (1981).

3.4 Futures Markets

When Gordon was at Harvard, much of his work was in agribusiness. Over the years, his activities in the futures market led him to become a leading expert on agricultural finance and the economic literature on the futures market. One area Rausser was interested in was the quality of prediction of future prices by future markets. He was able to obtain historical predictions data from professional forecasting models of organizations like Wharton Econometrics, USDA and others. The award-winning paper by Just and Rausser (1981), showed that futures markets forecasted future prices more accurately than commercial, large-scale econometric models. This contributed to the reduced reliance of these models by agribusiness firms. However, his work also pioneered and applied statistical approaches to identify situations where models can predict future prices better than futures markets and thus to assess the likelihood of gains from reliance on predictive models in speculating in future markets (Cargill & Rausser, 1975; Rausser & Carter, 1983). These works led to further research on futures market performance and profit opportunities by hedgers and speculators (Myers et al., 2010; Carter & Revoredo-Giha, this book).

3.5 Environmental and Resource Economics

Environmental and resource economics became major areas of growth in agricultural economics. Gordon's work on dynamic systems was very important for resource economic research, and he also wrote some important papers in this field. As chair, he emphasized environmental economics research at Berkeley, where Michael Hanemann and Anthony Fisher became leaders in the field. Gordon contributed to environmental economics through his work as an expert witness, recognizing the importance of financing environmental projects and developing mechanisms for environmental mediation. Furthermore, he was one of the leading scholars on the economics of biodiversity. In an award-winning study, Rausser and Small (2000) showed that bioprospecting is a source of finance for biodiversity conservation. Their analysis emphasizes the heterogeneity of ecosystems in terms of the potential for pharmaceutical discoveries, and the existence of "hot spots" with valuable therapeutic bio-resources, that may generate significant rent. There is much uncertainty about the locations of valuable biodiversity resources, but the uncertainty can be reduced with improved search technologies. Using simulations, they show that, under plausible conditions, the bioprospecting value of certain genetic resources could be large enough to support market-based conservation of biodiversity. This work was an important contribution to the growing literature on payments for ecosystem services, and the development of financial mechanisms to achieve environmental objectives that became a major element of the environmental economics literature (Wunder et al., 2020).

3.6 Economics of Research and Innovation

Agricultural economists have long highlighted the importance of research and innovation to economic growth, documenting high rates of return to public research, especially in the context of agriculture (Griliches, 1958; Alston et al., 2009; Huffman & Evenson, 2006). Alston and Pardey emphasized the complementarities between public and private research and the need for continuous support of public research to stimulate private sector applied research and development. However, there was minimal understanding of how to develop the linkages between public and private research and to increase the resources available for university research. The major innovative scholarly work of Rausser has been on the design and implementation of private-public research development and partnership. As dean, he was the first to design such a partnership that enhanced resources for basic research in Berkeley (see chapter "On the Essence of Leadership: Lessons from Gordon Rausser" of this book). The award-winning book (Rausser et al., 2016) presents the lessons from this experience and a general framework on the basic principles for partnership between the private and public sectors that will lead to increased knowledge and new technologies.

The introduction of genetically-modified crops led to drastic changes in the structure of the seed industry. In particular, biotechnology companies that hold the rights to genetically modified traits develop alliances and took over seed companies. Graff et al. (2003) quantified and explained this evolution, emphasizing that innovation in agricultural biotechnology and related fields require companies to have access to multiple markets which requires either alliances or the integration of seed companies with biotechnology companies.

The work by Rausser and his collaborators contributed to and often preceded a growing body of research on the economics of biotechnology and innovation. Policy debates on the role of biotechnology and the future of agriculture have been shaped by the significant body of research by agricultural economists on the relationship between public and private research, intellectual property management, biotechnology regulation and acceptance, and the structure of the biotechnology sector.

3.7 Building the Canon of Agricultural and Resource Economics

While agricultural and resource economics have active and dynamic journals, it is important to take stock of the literature and create resources that will provide an overview and assessment of the major findings of the discipline and assessing its direction. The Handbook of Economics is a prestigious series that has presented authoritative reviews of the state of knowledge in major economic fields. Gordon Rausser and Bruce Gardner and later Robert Evenson and Prabu Pingali were entrusted to be the editors on the Handbook of Agricultural Economics starting around 2000. Comparison of these six excellent volumes from the previous version of the Handbook of Agricultural Economics (Martin, 1977) shows the drastic progress and transition of the discipline. It emphasizes the rise of quantitative analysis and econometrics, the emphasis on global issues and agribusiness, the importance of political economy, and the growing emphasis on environment and development. Rausser's leadership in recruiting the author and identifying many of the themes were quite apparent and the large number of citations of these volumes are evidence for the relevant.

When the Annual Review series decided to expand into the field of economics, they recognized the richness of the field and decided to have three series: the Annual Review of Economics, whose founding editor was the Nobel laureate Ken Arrow; the Annual Review of Finance, whose founding editor was Nobel laureate Robert Merton; and the Annual Review of Resource Economics, whose founding editor was Gordon Rausser. This series became a top-cited journal in agricultural economics and serves both to refine and communicate ongoing research and to suggest avenues for future research.

4 Conclusions

The Agricultural and Applied Economics Association has established creative arrangements to honor its outstanding members. It holds the Galbraith Forum during its annual summer meeting, the Schultz memorial lecture in its winter meeting, the Gardner award for best policy research, and the Sylvia Lane mentorship, as well as numerous appreciation clubs. The association decided to name the keynote speech in the opening session of its annual meeting beginning 2020 after Gordon Rausser, recognizing his contributions as a transformative scholar and leader.

Rausser has also been a transformative leader of his department and his college. This mirrors his research emphasizing dynamic adaptation and change. His research has an element of opportunism, identifying new phenomena and tools and utilizing these to provide original yet rigorous and relevant outcomes. As discussed in this chapter, he contributed to the redefinition and agenda of the agricultural and resource economics discipline. The Department of Agricultural and Resource Economics at Berkeley has been to some extent his laboratory, and he led changes in emphasis that spilled over to the profession. As dean of the College of Natural Resources that is now named after him, he successfully spearheaded the transition from a traditional agricultural school to an integrated natural resource college with leading programs in environmental science, bioeconomy, food and nutrition, as well as agricultural and resource economics. He views agricultural and resource economics as providing integrated knowledge for policy and entrepreneurship and as dean, contributed to linking the College's research with industries that apply it and together, contribute to changing the world. The unique feature of Gordon is that he is both a scholar and a practitioner of economics, and his career emphasizes this combination. His lessons and achievements in business nourished his research, and he strives to transform his College and discipline to maintain excellence while staying relevant.

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Part II
Major Developments in Agricultural, Food and Resource Economics

Principles of Policy Modeling in Food and Agriculture

Gordon Rausser and Richard E. Just

1 Introduction

To address the complexity of the agriculture and food sector in policy formulation, models have long been viewed as a potentially valuable aid to the evaluation and selection of alternative policies. Such models can be employed to generate quantitative forecasts and to evaluate the effects of alternative decisions or strategies under the direct control of policymakers. In essence, models can offer a framework for conducting laboratory experiments, without directly influencing the agricultural and food economy. They also potentially offer a basis for sharpening the judgments of analysts and policymakers alike.

Many models of the food and agricultural sector have been constructed. Some have been constructed for descriptive purposes, some for explanatory or causal purposes, some for exploratory purposes, some for forecasting purposes, and others for the express purpose of decision analysis. The latter group of models, of course, is of direct interest in policy formulation. Such models require at a minimum (a) the performance or target variables considered important by the policymakers, (b) the instruments or policies available to policymakers, and (c) a set of behavioral, identity, and physical relationships that link (a) and (b). This group of models is, indeed, the most demanding. The development of useful models for dynamic stochastic systems of the type represented by the agriculture and food economy requires the construction of conditional policy forecasts. In many situations, the construction of forecasting frameworks requires as a prerequisite the development of descriptive as

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well as explanatory models. To ascertain the effect of alternative policies in terms of performance measures, causal relationships between the decision variables and relevant performance measures must be captured.

By examining the elements of policy models in terms of their conceptualization, specification, estimation, and use, the unfulfilled promise of modeling as an aid in support of policy analysis begins to take shape. While the anticipated costs of policy modeling have been incurred (and often exceeded) over the past few decades, the anticipated benefits have not yet emerged. This observation is, of course, not new. Reasons such as insufficient model validation, insufficient linkage and feedback relationships, and insufficient communication between model analysts and policymakers have been advanced for the failure of quantitative models to attain their promise. This chapter argues, however, that the reasons underlying this failure run deeper and span a broader set of concerns.

Architects of policy models have too often followed the principles of model formulation that are generally appropriate for other purposes of models such as descriptive, explanatory, causal, exploratory, and forecasting purposes (Rausser & Hochman, 1979). A close examination of problems arising in the use of quantitative models in policy formulation or decision analysis suggests the need for a set of principles to emphasize the tradeoffs that must be considered in the construction and use of agricultural and food policy models. The assessment of tradeoffs for descriptive, explanatory, or forecasting models differ measurably from assessments for policy models. This paper attempts to develop such a set of principles or a code of conduct specifically relevant to modeling for policy decision analysis. The 11 basic principles along with their various subprinciples and associated tradeoffs that are justified and discussed through the course of this chapter are as follows:

1. The purposes and goals of policy models should be explicitly defined at the outset with a view to the policy decisions that will be evaluated.

   (a) *The distributional impacts of agriculture and food policies can be completely examined only through their indirect effects on input and asset markets.*
   (b) *For multidimensional policy problems with noncomparable objectives, the analyst and policymaker should evaluate alternative weights or equity schemes.*

2. The experimental role of policy models should be exploited.

   (a) *Potential users should be involved in the process of model design and development.*
   (b) *Development of policy models must be treated as a process, as opposed to just the creation of the product.*

3. Post-Bayesian analysis should guide the design, estimation, and use of policy models.

   (a) *Alternative model specifications for the same problem imply different decompositions of systematic and nonsystematic components.*

4. Policy models should be designed to accommodate and track structural change.
5. The degree of imposed theoretical structure in policy model specification should depend on the amount and age of available data and its variability.

   (a) *The number of variables employed to reflect policy instruments is crucial for interpretation of historical data.*
   (b) *Summary variables rather than representative variables should be emphasized in policy models.*
   (c) *Functional and alternative distributed lag structures must be evaluated constantly as more information is obtained.*
   (d) *Relative rather than absolute specifications enhance policy model longevity and degrees of freedom in estimation.*

6. General equilibrium rather than partial equilibrium relationships should be emphasized in the structure of a policy model.

   (a) *In policy model analysis, the emphasis should be on obtaining the most accurate conditional probability distributions for the relevant performance measures after accounting for complexity costs.*

7. Policy modeling should provide for the use of intuition, both in model development and in updating; strong intuition should override causal implications of coincidental data in model development.

   (a) *Ample opportunities should be given for judgmental inputs, especially those provided by commodity specialists, especially for less-observed policy instruments.*

8. Use of greater weight on more recent data in policy model estimation should be seriously considered.

   (a) *Model maintenance and updating are continuous processes for which explicit expertise must be fostered.*

9. General purpose data sets rather than general purpose models should be emphasized.

   (a) *The principles of post-Bayesian analysis are also appropriate in governing the design and maintenance of a general-purpose data set.*

10. Policies should be formulated with an appropriate degree of learning in mind.

   (a) *Policy alterations should be imposed whenever possible by revising existing policy instruments rather than by determining a new set of policy instruments, subject to political feasibility.*
   (b) *Depending on administrative costs, policy instruments should be exercised in a smooth and continuous fashion based on market conditions.*

11. Major structural reforms of current policies in the face of concentrated political power requires modeling of alternative compensation schemes and potential changes in the existing governance structure

(a) *If no feasible mechanism exists for altering the historical governance structure to completely support policy reform and there remains powerful interest groups who can block any potential reforms, then compensation schemes become necessary.*
(b) *Potential pitfalls of compensation schemes must be recognized and effectively managed.*
(c) *Wherever possible, compensation schemes should be designed to promote economic growth in other linked sectors of the economy.*

2 Principle 1. The Purposes and Goals of Policy Models Should Be Explicitly Defined at the Outset with a View to the Policy Decisions that Will Be Evaluated

An overwhelming number of policy models have been developed that are well-specified technically but fail to address the relevancy and implementation of any proposed policy actions; in other words, these policy models contain elaborate but irrelevant details. Far too frequently, researchers construct policy models under the premise "that the goal of economic modeling is to provide helpful information to decisionmakers that will improve the likelihood of their making a sound choice when confronted with a set of possible actions unknown to the researcher during the construction of the model" (Hughes & Penson Jr, 1981). This perspective places the researcher in a world of uncertainty, gambling with odds heavily stacked against success. Answers to the following questions provide guidelines to alleviate such uncertainties:

- What policies or decisions are the model results designed to influence?
- For whom is the output information intended?
- Consequently, what information must the model provide to the user?
- What input variables shall be used to test alternative assumptions?
- How often will the model be used?

The second point may be particularly relevant when political debates or pending elections cause political preference uncertainty or changes. The answers to these questions define the model operationally and, in turn, they become the marching orders for the model architect to implement.

To illustrate the importance of model purpose, consider the effect or the design of policies to influence the structure and control of agricultural production. As noted by Gardner (1980) long ago, agricultural economists have made little progress in determining the distributional effects of price supports, acreage set-asides, deficiency payments, and public stockholding policies. One possible reason for this observation is that most models concentrate on output markets; and, certainly, the vast majority of agricultural sector models address only these markets. However, to measure the distributional impacts of various policies both qualitatively and quantitatively calls for dealing squarely with dynamic interactions, feedback, and linkage effects as well as equity and efficiency impacts. This general observation leads to the following subprinciple.

2.1 Subprinciple 1.1: The Distributional Impacts of Agriculture and Food Policies Can Be Completely Examined Only Through Their Indirect Effects on Input and Asset Markets

If distributional issues are not under examination, a model does not need the complexity associated with input and asset markets. However, if such issues are crucial, the general equilibrium effects on these markets are exactly what must be examined. A number of conceptual papers by Floyd (1965), Kirwan (2009), and Rausser et al. (1984, 1986) demonstrate how input flow and asset stocks can be altered indirectly by changes in economic policies. For example, a sampling of the implications of these theoretical frameworks are as follows:

- An increase in deficiency payments and a reduction in acreage set-aside requirements leads to increased concentration measured by the average land size of commercial farms.
- An increase in deficiency payments and a reduction in acreage set-aside requirements encourages the adoption of output-increasing technologies and discourages the adoption of cost-reducing technologies.
- Restrictive monetary policy tends to reduce the ratio of land prices to rental rates and to encourage participation in voluntary governmental programs.

Without the explicit consideration of these indirect effects of policies on assets in agricultural systems, discovery of these implications would not have been possible. It is, indeed, important to be alerted to such potential effects in the selection of actual policy instruments. For example, a desire to increase farmers' income by reducing output through acreage set-aside policy settings could lead to an increase in the relative price ratio, thus reducing the shadow price of credit and making new investments more attractive. The resulting adoption of new technology, especially output increasing technology, can make various policy mixes of target prices, loan rates, and acreage set-asides in the short run quite different from the long run.

2.2 Subprinciple 1.2: For Multidimensional Policy Problems with Noncomparable Objectives, the Analyst and Policymaker Should Evaluate Alternative Weights or Equity Schemes

In the case of many agricultural policy problems, we are faced with multiple objectives, including such loosely defined measures as increased income of farmers, increased consumer welfare, improved distribution of income, self-sufficiency, price stability, improvement in the balance of payments, decreased public expenditures, stable flow of supply, and so on. On both normative and positive grounds, criterion functions based only on efficiency may be inappropriate in many operational applications. For this subprinciple, at a minimum, settings on the policy instruments that maximize welfare under social welfare criterion functions with a variety of provisional weights should be considered. This may be useful when pending elections raise contingencies in political preferences and may lead to choosing policies more robust in uncertain political climates.

In the face of multiple concerns, the continued use of single attribute, objective-criterion functions will result in analyses that often fail to address actual policy problems. Hence, multiple objectives must be considered. The definition of a multidimensional objective function neither creates nor resolves conflicts associated with policy issues; instead, it identifies them. The identification of conflicts are, of course, an important first step in their resolution. Many advancements in specification, identification, and assessment of multidimensional objective functions were developed by Keeney and Raiffa (1976).

Because unique single-attribute objective criteria are often not appropriate for policy analysis, one approach is to determine the effects of alternative policies on each objective and then allow the political process to select among the alternatives. Policy model experimentation with alternative weights can provide some important information for this process. In a "normative" or prescriptive setting, the 1976 Keeney and Raiffa multi-attribute utility function approach can be used, while, in a more "positive" setting, revealed preference has been employed to determine weights associated with various objectives. In any event, as Steiner (1969, p. 31) argued some years ago, "we now accept in principle that the choice of the weights is itself an important dimension of the public interest."

In the first application of a revealed preference framework to agricultural policy interventions, Rausser and Freebairn (1974) argued that the importance of the bargaining process and the resulting compromises between different political groups, the range of preferences of these groups, and the lack of an explicitly stated, unambiguous value consensus suggest construction of several criterion functions. They argue that these functions should reflect the extreme viewpoints and preferences of various policymakers actively involved in the policymaking process as well as the preference sets lying between these extremes. A parametric treatment of the resulting set of preferences will provide decisionmakers with rational policy outcomes, conditional on the representation of policy preferences. Accordingly, the results obtained from such an approach should contribute to the efficiency of the bargaining process and in reaching a consensus.

3 Principle 2: The Experimental Role of Policy Models Should Be Exploited

In essence, policy models offer a framework for conducting laboratory experiments without directly influencing the system. Since these experiments can be conducted with a model rather than the real system, mistakes that may result in costly consequences can be avoided. This experimental perspective forces analysts or others interested in a particular system to be precise about their perceptions and to examine possible inconsistencies in those perceptions.

Experimentation with policy models has often been inhibited because of inabilities to solve complex dynamic stochastic systems. However, the continued development of a number of numerical methods (Judd, 1998) facilitates the experimentation of the sort envisaged here. All of these methods are faced with a problem of multiple local optima. Analysts frequently deal with these problems by employing incomplete or partial multiple-objective criterion functions. The limitation of such partial analysis is that superior solutions often lie in "inferior" regions. Given the limitations of operating with complete, as well as incomplete, multiple-objective criterion functions, analysts should attempt to generate alternative weightings or trade-off relationships in accordance with Subprinciple 1.2.

Most policy models are structured to investigate specific policy instruments. The emphasis on the experimental role of policy models requires, however, more originality in the selection of policies that are evaluated. For example, the results from policy models for predetermined instruments should be used in part to gauge the design of other policies not previously considered.

To facilitate originality in the policies selected for evaluation, econometric methods, operations research, systems analysis, and simulation should not be viewed as mutually exclusive approaches. The use of multiple approaches is often more desirable (Brill Jr., 1979) to develop, evaluate, and elaborate alternative solutions. This increases the likelihood of tailoring available algorithms to provide significant insights rather than just answers. With this perspective, policymakers and analysts are not wedded to the first design, and implicit incentives are provided to pursue other distinct alternatives. In this environment, artificial intelligence and heuristic methods will prove particularly worthwhile. This reduces the answer-seeking mentality and increases learning and inductive inference.[1]

3.1 *Subprinciple 2.1: Potential Users Should Be Involved in the Process of Model Design and Development*

One effective means of facilitating the effective use of policy models and the explicit definition of the goals of a policy model is to involve the users of the model results in the development process from very outset of model development. As recognized on many occasions and in an early study by McKinsey Co, Inc. (1968), one of the principal factors explaining the failure of a large number of private corporations

[1] To facilitate learning and inductive inference, analysts investigating various policy issues in agricultural systems will have to develop an experimental response surface procedures. Relevant experimental designs must be sequential (Anderson) and squarely address "policy improvement." Such sequential designs involve an extensive search via exploratory experiments that converge toward some peak (or valley) on an objective surface and then switch to an intensive search as the optimum approached. To implement such improvement methods, the appropriate response surfaces must be constructed. Fortunately, an excellent survey is available for analysts to familiarize themselves with response-surface investigations from the standpoint of sequential analysis and optimal design (Chernoff).

planning and decision models is the lack of user involvement in the development process. Of the 36 large corporations surveyed in their study, the report concluded that the neglect of user involvement is, indeed, costly.

Undoubtedly, users should play an important role in determination of the objectives of a policy modeling effort. When designing the model, substantial attention should be paid to users' perceptions of the environment under examination. In general, both modelers and users tend to trust and use something they have had a hand in developing; developing confidence in something must be accepted on faith proceeds slowly only with experience. Equally important, the involvement of users during development enhances their understanding and decreases the educational effort required after the model is constructed. Obviously, involvement of the ultimate users must be managed judiciously, given their perceptions about the opportunity cost of their time. If the ultimate users cannot allocate time for such efforts, then at a minimum their trusted deputies should be assigned the task.

3.2 Subprinciple 2.2: Development of Policy Models Must Be Treated as a Process, as Opposed to Just the Creation of a Product

Unfortunately, this is a subprinciple that often fails to guide the actual construction and use of policy models. The product approach is the more usual situation. The typical goal is to create a working model, and those involved in the construction fail to see beyond that stage of their efforts. For the process approach, the creation of the model is the means along the way toward using the model to affect policy analysis favorably. The longer run view of the process approach fosters a give-and-take relationship between the analyst and user in model design, and improvements that usually continue beyond the first implementation. This interaction assists everyone involved in the process of model construction to behave non-myopically and to consider how the model will be used in the future and how the organization is likely to respond to its use. The process approach anticipates the need for education and organizational change to effectively utilize the model for policy evaluations.

4 Principle 3: Post-Bayesian Analysis Should Guide the Design, Estimation, and Use of Policy Models

As argued by Faden and Rausser (1981), neither the "Bayesian" nor the "classical" school of thought related to the foundation of statistics is adequate. The nature and purpose of current statistical foundations need to be reexamined. An adequate theory should be compatible with the way science develops. Moreover, the conceptual base should be consistent with the way in which we casually accumulate knowledge in everyday life. It should also be "axiomatically" satisfying.

The Bayesian approach to statistical inference and knowledge accumulation would, in fact, be acceptable if analysts and policymakers had unlimited and costless information-processing capacity. A rigorous Bayesian would need superhuman abilities—a perfect and infinite memory, perfect deductive powers including faultless and instantaneous calculating ability, and the wherewithal to understand questions of arbitrary complexity. Hence, due to human limitations, more or less serious departures from the strict Bayesian approach are warranted. In particular, the cost of information collection, processing, and interpretation should be recognized.

Formally, the post-Bayesian criterion for inference is to minimize loss or costs. It is, therefore, consistent with the general framework of decision theory; inferences are "Bayes" decisions with respect to some prior distribution. However, the criterion stresses two major cost categories that do not appear in the early work of Wald or his successors. The first is associated with complexity, namely, those costs that emanate from information processing, which include constructing models, gathering and storing data, solving models, communicating results, and the like. The second component is associated with inaccuracy. Hence, the approach explicitly evaluates the tradeoff between accuracy and complexity. In essence, the benefits and costs associated with alternative policy models dictate construction and use strategy.

As many modelers have recognized, the complexity of a model is measured by such characteristics as the number of equations in a model, the nonlinearity of a model, and number of "families" to which the equations belong. Similarly, *ceteris paribus*, deterministic models are simpler than stochastic models, static models are simpler than dynamic models and lump-parameter models. In general, complexity rises with the number of free parameters. The complexity of a policy model is not measured by model size or the number of endogenous variables (Powell, 1978).

To indicate how complexity costs can be assessed, consider the problem of alternative regression models aimed at, say, predicting a certain variable of interest. Complexity costs generally rise with the number of explanatory variables. Cost may take the form of money, time, resources, or effort used in model development and analysis. Certain aspects of cost rise linearly with the number of variables (e.g., tabulating the data); some go up quadratically (e.g., printing the covariance matrix); some rise cubically (e.g., inverting the moment matrix). These are not the only costs, but they suggest that a cubic polynomial in the number of variables may require to measure complexity costs.

In addition, differences in complexity costs result from sample survey design, sequential analysis, and other data selection criteria. Thus, even tractable models differ considerably in complexity. The consequences of incorporating complexity costs—or, equivalently, the value of simplicity—can be a major factor in implementing and using such alternative models (Faden & Rausser, 1976).

Turning to the second important cost component associated with inaccuracy, the more accurate a model is, the more benefit is accrued from employing it to resolve various policy issues. In other words, inaccuracy is costly. The cost of an inaccurate model depends on how it is used. That is, for models used as guides in making decisions, inaccuracy tends to degrade the quality of the decision. To assess the cost of forecast inaccuracy, one must embed the model in a more complete policy framework. This embedding can be done in several ways, all leading to a different inaccuracy cost function. No absolute “metric” for inaccuracy is available.

4.1 Subprinciple 3.1. Alternative Model Specifications for the Same Problem Imply Different Decompositions of Systematic and Nonsystematic Components

The balancing of inaccuracy with complexity is particularly crucial in the selection of explanatory variables. Somehow, a selection of “significant” explanatory variables (or “appropriate” policy variables) must be made from a large pool of variables, and the proper estimates or settings must be made for each. The post-Bayesian approach makes this selection in a structured fashion that involves the weighting of alternative costs and avoids the inappropriate tests that are inherent from conventional statistics. To illustrate the implementation of Subprinciple 3.1, consider the case of supply response for some of the major feed grains where weather conditions are important. Owing to complexity costs, the coefficients on weather variables in an estimation context may be set to zero. For feeder calf supply, range conditions play a role; nevertheless, they are sometimes excluded as an explanatory variable because of complexity costs associated with data acquisition, the increased ability to identify other coefficients and the inability to forecast weather. Such potential explanatory variables are subsumed in the error process. To the extent that movements in these variables can be represented by autoregressive, moving average processes, their influence on endogenous variables of interest can be ferreted out through time series representations of the error or disturbance terms. Moreover, if the purpose of constructing a policy model is to evaluate, say, alternative feed grain reserve policies vs. meat import quotas, the explanatory variables that must appear in systematic components (variables whose coefficients assume values other than zero) vs. nonsystematic components (disturbance terms) may differ among policy evaluation problems.

One of the major problems with conventional policy models that have been constructed to date emanates from their failure to recognize complexity costs and the accompanying need to balance those costs against the cost of inaccuracy resulting from abstraction. Balancing of these costs leads to what we have characterized as the post-Bayesian approach and requires a reexamination of procedures of model construction. Admittedly, however, because accurate estimates of complexity costs and inaccuracy costs are not possible, Bayesian procedures must often be implemented with crude estimates of such costs. Nevertheless, for a number of illustrative applications (see Faden & Rausser, 1976), it is possible to use very crude estimates of these costs to motivate procedures that should prove to be superior to conventional treatments.

5 Principle 4: Policy Models Should Be Designed to Accommodate and Track Structural Change

By their very nature, models are abstractions involving simplifications imposed by available data, research time, and budget as well as by the necessity of achieving tractable results. Such simplifications and abstractions often result in misspecifications that, in turn, influence the accuracy of conditional probability distributions. As demonstrated in Rausser et al. (1981), the effects of such misspecifications can be countered by introducing appropriate parameter-variation structures that may be theoretically or empirically based. The most important types of misspecifications that arise in the construction of policy models include omitted variables, proxy variables, aggregated data, and simplified functional forms.

In addition to the misspecification rationale for varying parameter formulations, economic theory can be advanced to justify their potential relevance. In many situations, the very nature of economic theory leads to relationships that change over time. For example, Lucas (1976) has argued that the constant parameter formulation is inconsistent with economic theory. He notes that a change in policy will cause a change in the environment facing decisionmakers; under the assumption of rational decision-making, this will result in shifts in the equations representing their behavior.

One of the better examples of the points raised by Lucas (1976) occurred as a result of the U.S. economic stabilization program during the period 1971–1974. Price ceilings were imposed on red meats at the end of March 1973. When combined with the biological nature of various red-meat animals, these ceilings led to distorted and clouded price signals, which resulted in strategic errors on the part of numerous decisionmakers. These signals led to instability in the expectation-formation patterns of decisionmakers along the vertical commodity chain in beef, pork, and poultry. During that period, the cattle cycle, which was poised for a sizable liquidation, was substantially altered. In fact, for a short time, price ceilings appeared to become the expected prices of producers. This had dramatic implications for dynamic supply responses, ultimate market realizations, and cattle inventories. Under such circumstances, a model which includes a particular price expectation formation pattern as part of its maintained hypothesis would thus be subject to structural change in the face of governmental price ceilings.

In essence, this principle recognizes the importance of distinguishing between the “local approximation” accuracy and the “global approximation” accuracy of a model structure. In attempts to achieve global-approximation accuracy with abstract models, specifications that readily admit structural change are a necessity. The importance of this principle has been illustrated on numerous occasions during decades dating back to the 1970s, involving neglect of linkages with the international economy through exchange rates and international capital markets (Rausser et al., 1986; Ardeni & Freebairn, 2002). Models that fail to track and accommodate these significant changes will fail to achieve sufficient credibility and thus will not be seriously entertained by policymakers. Similarly, linkages with the general economy (especially with interest rates reflecting monetary and fiscal policies) will force a shift from one local approximation to another. Models that fail to accommodate structural changes that result from significant movements in interest rates (via their effect on exchange rates, export demand, stockholding behavior, and investment) will fail many credibility tests.

The issue of accuracy is particularly important when the structural model representation is nonlinear in the variable space. In agricultural systems that address dynamic, linked, and feedback relationships, model representations often involve simultaneous interactions of large systems. For nonlinear representations in these model forms, obtaining a unique reduced form is not possible. In computing the necessary derivatives to represent this form, issues of approximation and round-off error naturally arise. More importantly, reliability statistics for highly nonlinear models cannot be derived. Analysts operating with such models often "sweep under the rug" the problem of measuring the variability (or risk) associated with the various policies under examination. Rausser et al. (1981) show that these problems frequently can be avoided by specifying models that are linear in the variable space but are, in essence, nonlinear in the parameter space. This requires the specification of models in which the parameter effects are not constant but are treated as time-varying and random. This approach allows forecasts of probability distributions, conditional on alternative actions, to be generated for particular points in the parameter space.

6 Principle 5: The Degree of Imposed Theoretical Structure in Policy Model Specification Should Depend on the Amount and Age of Available Data and Its Variability

The proper degree of imposed structure, as well as the extent of accommodation for structural change, depends upon whether the model is used to evaluate policies for which there is much prior experience or little or no experience. The latter situation arises in evaluating new institutional designs. In other words, a greater amount of prior experience on the effects of a particular policy allows greater accuracy in estimation with less imposed ad hoc structure. On the other hand, more specification is needed if new policy controls or instruments are under examination in order to allow parameter identification. In some instances, highly structured programming models may be the only possibility for evaluating policies for which no prior observations are available. However, if prior observations are available, a less structured model may be more appropriate and may provide a better level of flexibility in ascertaining from observed data the effects of alternative policy instruments.

Where sufficient data are available, reasonable fits are often obtained with the econometric approach. But even under these circumstances, predictions often quickly go off course as explanatory forces move outside the range of data used in the sample period for estimation. Some of the main approaches to combat this problem have involved adding further structural specification such as theoretical restrictions based on consumer utility theory or producer profit maximization. Some of these approaches are based on a neoclassical theory which entails full flexibility at least as an approximation. But the cost of such flexibility can be that the numerous resulting parameters may not be identifiable when few observations are available. This problem is mitigated to some extent by making further ad hoc assumptions with respect to functional forms of preferences and technologies. But this approach leads to costs of inaccuracy associated with erroneous ad hoc assumptions.

At the other extreme, programming models can make more efficient use of data to estimate input-output coefficients and resource availability when only one or a few observations are available, but very poor predictions of producer behavior are often obtained from programming models. This is apparently principally due to three sources of inaccuracy. First, producers' objective criteria may differ from that used in the programming model; second, farmers' subjective distribution of prices and yields may be different from that reflected in the programming model; and third, the linearity often imposed in a programming model may be inappropriate. At the end of the day, the appropriate balance between use of econometric estimation vs programming will depend crucially on the availability of data reflecting the observed effects of relevant policy instruments (Howitt, 1995).

Moreover, the fact that U.S. agricultural policy change is often a mixture of both institutional and policy instrument change further suggests that policy model specification can, in some cases, be enhanced by a proper blend of the two seemingly very different approaches. An effective merger of the conventional econometric and programming approaches centers on the distinction between discrete (qualitative) and continuous (quantitative) choices. Institutional choices or selection of particular policy instruments correspond to qualitative choices, while changes in policy specific instruments correspond to quantitative choices. Programming formulations can easily handle the former, while conventional econometric models focus on the latter. Moreover, inequality constraints found in programming models are not admitted in conventional econometric formulations. However, both discrete and continuous choices and inequality constraints can be admitted in behavioral models estimated by qualitative econometric methods (Greene, 1990).

6.1 Subprinciple 5.1: The Number of Variables Employed to Reflect Policy Instruments Is Crucial for the Interpretation of Historical Data

Government policies are often changed from time to time in a way that seemingly involves a switch to a new set of policy instruments. For example, U.S. wheat was regulated by price supports and strict allotments with marketing quotas in 1950 and from 1954 through 1963; by price supports alone in 1951 through 1953; by voluntary allotments, diversion requirements, and price supports in 1964 through 1970; and by set-asides with target prices and deficiency payments in the following 1970s. Furthermore, the set-aside program has at times required cross-compliance among crops and in other times not. In the 1985 Farm Bill, processes were established for decreasing target prices in the late 1980s and incentives were established for the Conservation Reserve Program (CRP) that motivated removing environmentally sensitive land from wheat production. During this period, the export enhancement program provided subsidies to move wheat stocks through export markets.

In the 1990 Farm Bill, additional flexibility was introduced that allowed wheat farmers to reallocate up to 15% of their base wheat acreage to other commodity production without losing any of their base acreage allocations. In 1996, following the conclusion of the Uruguay Round, the Farm Bill replaced price support and supply control (acreage set-asides) with deficiency payments based on historical production. More flexibility was introduced, allowing farmers to allocate their previous base acreage to other potential commodities. The main feature of this particular bill was to provide decoupled income support over a period of 7 years for those farmers who entered into production flexible contracts.

In 1998–2000, additional payments were provided to wheat farmers as part of an emergency market loss assistance program. These nonrecourse marketing assistances provided loans or loan deficiency payments on all or part of their eligible production. With the emergence of the new century, the Federal Crop Insurance Corporation provided additional subsidies, offering alternative options triggered by yield-based protection as well as revenue-based protection. The subsequent 2002 Farm Bill established a national loan rate at $2.80 per bushel during the years 2002–2003, which fell to $2.75 for 2004–2007. This policy instrument was combined with counter-cyclical payments in the form of subsidies from the U.S. government if the national average market price fell below the established target price for wheat.

In the next three Farm Bills, the focus of governmental support turned largely to crop insurance. The 2008 Farm Bill allowed wheat farmers to make a choice between revenue-based, market-oriented protection versus subsidy protection based on target price policy instruments. The 2014 Farm Bill moved more dramatically in the direction of strengthening the crop insurance program by introducing optionality on the type of insurance products that could be selected. In the 2018 Farm Bill, wheat producers were once again allowed to select among three commodity revenue support programs. With these frequent policy revisions, often only a very small number of years of data have been available in which the effects of a given set of policy instruments could be observed.

Given this policy environment, econometric and statistical reliability can be greatly enhanced if ways can be found to represent alternative instruments as different levels of the same set of instruments. If adequately implemented, both degrees of freedom can be saved in estimation and more information can be gained by comparison of the effects of alternative policy regimes. For example, in moving from a policy period with strict allotments to one of voluntary allotments, one would expect that those farmers who continued to participate would behave in much the same way as when allotments are strictly imposed. Similarly, one would expect those farmers who do not participate to behave much like they would when no allotment program was exercised. By making this minimal assumption, one can reduce the number of variables needed to reflect the alternative policy regimes in an econometric model (Just, 1974).

Similarly, the roles of diversion requirements and set-aside requirements are quite similar as are the roles of wheat certificates and deficiency payments. By appropriately considering the similarity of these controls from one policy regime to another, one can often gain more information on the effects of policy instruments from historical data. These considerations also lead to greater simplicity in policy models and, thus, the complexity costs can be reduced accordingly. In reducing the number of variables used to represent policy instruments, however, one must bear in mind the approximations that are introduced.

6.2 Subprinciple 5.2: Summary Variables Rather than Representative Variables Should Be Emphasized in Policy Models

A common practice in econometric application has been to consider as many variables in model construction as may seem intuitively important but then to prune that set of variables based on their apparent statistical importance. In doing so, variables may be excluded which intuition implies should clearly play a role. A justification for this practice usually goes as follows: either (1) the variables are truly unimportant or do not play a role, or (2) they are sufficiently closely related to variables that are retained in the model that multicollinearity prevents estimating with accuracy o a separate effect. The implication is that a similar multicollinearity is assumed to persist in the forecast period. When intuition is sufficient, a more appropriate practice would be to construct summary variables that include the effects of perhaps several colinear variables, possibly with weights that can be justified from extraneous information. This is particularly true in policy modeling where distinct changes in policy controls may cause collinearities observed in a sample period to cease. An obvious example is where the cost of factor input costs is represented by a single price versus an index of input prices.

Many models have used price indices to represent the effects of many exogenous prices. However, relatively few models make use of price indices including endogenous prices. Similarly, relatively few models use quantity indices which embody the effects of several quantity variables which may be too highly correlated to be included separately in an econometric model.

The case of estimating demand prior to 1970 may serve to illustrate the importance of this principle. In data generated prior to 1970, the prices of beef, pork, and poultry all tended to move together so that the resulting multicollinearity prevented estimation of commodity-specific cross-elasticities. As a result, many modelers tended to exclude all but one of the “cross” prices so that, for example, beef demand would not be sensitive to pork prices, etc. Many of these models, however, ‘performed poorly in forecasting the events of the 1970s because huge feed-price increases caused a change in the relationship among livestock prices. For example, hogs began to sell at a premium relative to beef cattle. These events thus led to failure of the models which had followed the practice of excluding collinear variables. Alternatively, if summary variables had been used to include the prices of all commodities which theory clearly dictated were important, then the associated models might have been able to predict the associated consequences of high feed prices, at least to some extent. If summary variables are used rather than excluding variables which are clearly important, then a model may not flounder as soon or to the extent when existing multicollinearity ceases to hold. Of course, these arguments are also consistent with the need for constant consideration of model revisions and the importance of subjective information in model development and data interpretation.

6.3 Subprinciple 5.3: Functional and Alternative Distributed Lag Structures Must Be Evaluated Constantly as More Information Is Obtained

This subprinciple simply recognizes that all maintained hypotheses must remain tentative (Rausser, 1973). In other words, various elements of conventional maintained hypotheses must be relaxed and reevaluated as the modeling process continues. The imposed structure must be constantly reassessed. In essence, to the extent possible, the imposed structure should remain in a fluid state.

6.4 Subprinciple 5.4: Relative Rather than Absolute Specifications Enhance Policy Model Longevity and Degrees of Freedom in Estimation

In the infancy of econometric modeling, the objective of policy modelers was to determine a linear relationship between two or more variables in nominal form. Further experience, however, particularly in inflationary times, suggested that models tended to lose their tracking ability after sufficient inflation when variables were used in nominal form. In response to this problem, prices began to be used in relative or deflated form for econometric modeling purposes. This specification was justified by the fact that economic theory under certainty implies that both producers and consumers respond directly to changes in relative prices rather than changes in nominal prices. But the imposition of such specifications is debatable since economic theory under risk implies that decisionmakers may respond to nominal prices as well as absolute prices. Nevertheless, the use of relative or deflated prices for econometric purposes has persisted because experience with deflated price models has tended to dominate nominal price models, particularly in post-sample periods.

One may question, however, whether this use of relative vs. absolute specifications has been carried far enough. The practice of deflating prices by some general price index has become quite common (although it is not clear that use of a general price index in the denominator of a price relative always outperforms the use of a price of a closely related good or index of closely related good prices). But the use of quantity relatives in policy models is a much less common practice. The use of quantity relatives, as well as price relatives, can often better facilitate comparisons both across time periods and economic units (decisionmakers, counties, states, countries, etc.) and often reduces the number of coefficients that must be estimated. In addition, when alternative policies are actually evaluated, relative measures ("ratios" or "differences") will simplify the comparisons.

By specification in terms of relatives, models often turn out to be independent of units of measurement and are thus formulated in terms of the basic conceptual unit of economic measurement-elasticities (quantity as well as price elasticities). In this context, the estimated structure of the model is likely to have greater longevity of application. This has been borne out by experience with respect to the use of price relatives. When all prices tend to increase together with inflation, the use of price relatives removes the effects of inflation on several prices in order to increase comparability across time periods. However, in a growing economy, all quantities also tend to increase together with the expansion of the economy. Thus, the use of quantity relatives should also tend to increase comparability of several quantities across time periods in a growing economy. The same considerations for both prices and quantities also make sense in comparing across economies (counties, states, countries, etc.) and also appear to offer even greater advantages in the context of cross-section data where units of measurement may not be comparable or where general price levels or economy sizes may greatly differ.

Experience in some preliminary work on the effects of the International Sugar Agreement may serve to illustrate this point in the context of time series data. In data over only a 10-year period from 1970 to 1980, the size of the world sugar market in terms of production and consumption increased from around 70 million metric tons to around 90 million metric tons. A change in stock levels of, for example, 5 million metric tons is often more crucial in a market with 70 million metric tons of consumption than in a market with 90 million metric tons of consumption. To reflect this difference, a model stated in terms of quantity relatives is more effective. With this approach, we found that a model may be stated in terms of fewer estimable coefficients without losing statistical tracking power. Furthermore, we found that post-sample predictability was improved through the use of quantities as well as prices.

As a precaution in applying this principle, however, one must bear in mind complexity costs which may be related to certain nonlinearities that may be introduced into a system (depending upon functional forms). That is, if a model is stated in terms of price and quantity relatives involving several equations, then the use of any identity relating quantity variables may make the resulting system of equations nonlinear and, thus, increase associated complexity costs. One way to avoid this problem is to specify quantity relatives so that denominators are exogenous variables. This is essentially the traditional approach that has been used with price relatives. In addition, if general equilibrium relationships (rather than partial equilibrium relationships) are estimated, then it may not be necessary to use groups of equations together with identities for policy impact purposes (see Principle 6). As a result, some of the complexity costs associated with the use of quantity relatives may also be outweighed by the associated benefits of accuracy and model longevity.

7 Principle 6: General Equilibrium Rather than Partial Equilibrium Relationships Should Be Emphasized in the Structure of a Policy Model

In the early days of econometric modeling, researchers attempted to estimate single-equation relationships describing supply or demand in a particular market. Following a traditional Marshallian approach, the supply or demand relationship was conditioned upon all of the determinants (*ceterus paribus* conditions) which were econometrically discernible. The problem with such simple models is that they reflect behavior only in the market in question and ignore possible repercussions of policy changes which may take place in other markets. Also, they ignore possible feedback effects in the market in question from repercussions in other markets. For example, when a price support is increased on a feed grain, one may obtain an estimate of the increase in feed-grain production based on a simple feed-grain supply equation. However, an increase in feed grain prices may have substantial effects on livestock producers through higher feed prices, and the higher feed prices may lead to a reduced quantity demanded by the livestock sector. These effects cannot be captured in a single-equation model conditioned only on variables that directly affect feed-grain producers. Alternatively, a single-equation model conditioned on all external variables that affect the entire feed-grain-livestock-consumer demand complex can possibly capture the general equilibrium effects on a particular endogenous variable but would not reflect the individual behavior of either feed-grain producers, livestock producers, or consumers (Just et al., 2004). However, the number of such variables may exceed identification possibilities with common data limitations.

In response to this problem, policy modelers began to add additional equations describing effects on other markets. The search for all of these effects has at times seemed endless as policy models have grown to hundreds of equations. Conceptually, these models are appealing since they allow for the feedback effects of repercussions in other markets. However, the cost has been high. Large, complex models require simultaneous solution techniques to assess the potential effects of policy changes. Also, a serious error in estimating an equation even in a market other than the one in which the policy changes are imposed can invalidate all of the results forthcoming from the model.

To exemplify the distinction between general and partial equilibrium approaches to policy modeling, consider the case where one wishes to model the beef-marketing sector to determine the effects of grain price policy and conceptualizes the problem (simplistically, for purposes of exposition) as follows. Consumers decide how much beef to consume, Q_b^d, based on the retail price of beef, P_b, and income, Y:

$$Q_b^d = Q_b^d\left(P_b, Y\right). \tag{1}$$

The beef-marketing industry (meat packers and retailers) decide how much beef to supply, Q_b^s, based on retail price, the price they pay for fat cattle, P_f, and the wage rate of labor, P_L:

$$Q_b^s = Q_b^s\left(P_b, P_f, P_L\right). \tag{2}$$

The beef-marketing industry likewise decides how many fat cattle to buy, Q_f^d:

$$Q_f^d = Q_f^d\left(P_f, P_b, P_L\right). \tag{3}$$

Feedlots decide how many fat cattle to sell, Q_f^s, and how many feeder calves to buy, Q_c^d, based on the price of fat cattle, the price of feeder calves, P_c, the price of grain, P_g, and the number of cattle placed on feed in a previous time period, $N_{(-1)}$:

$$Q_f^s = Q_f^s\left(P_f, P_c, P_g, N_{(-1)}\right) \tag{4}$$

$$Q_c^d = Q_c^d\left(P_c, P_f, P_g, N_{(-1)}\right). \tag{5}$$

Finally, cow-calf operators' supply of feeder calves, Q_c^s, depends on the price of feeder calves, P_c, and the price of hay, P_h:

$$Q_c^s = Q_c^s\left(P_c, P_h\right). \tag{6}$$

In addition, the system of supply and demand equations is closed by equilibrium relationships:

$$Q_b^d = Q_b^s, Q_f^d = Q_f^s, Q_c^d = Q_c^s.$$

Using the partial approach, the above six nonidentity equations would be estimated directly as specified. In the context of this system of equations, however, one can solve for general equilibrium specifications in each market. In doing so, one must keep clearly in mind the difference in true general equilibrium specifications and general equilibrium specifications in the context of a particular model specification. It is the latter possibility which offers advantages in policy modeling. In reality, the true general equilibrium demand for beef may depend on factors underlying production conditions of many other commodities, influences on tastes and preferences for other goods, and a seemingly endless host of other factors, which would require an endless host of equations to capture. In the context of examining policies using the model above, however, the equilibrium effects obtained by solving the system of equations under several alternative policies (say, high grain prices and low grain prices) would not depend on such a wide array of factors; in point of fact, the effects could depend only on Y, P_L, P_g, $N_{(-1)}$, P_h (or such changes as have well-defined effects in the context of a market model, e.g., a tax or quota that drives a well-defined wedge between prices) since those are the only exogenous factors in the system. Following the abstraction of reality set forth in the above system of equations, the general equilibrium demand and supply for beef at the retail level are of the form

$$Q_b^d = \overline{Q_b^d}\left(P_b, Y\right) \tag{7}$$

$$Q_b^s = \overline{Q_b^s}\left(P_b, P_L, P_g, N_{(-1)}, P_h\right). \tag{8}$$

Respectively, the general equilibrium demand and supply of fat cattle are of the form

$$Q_f^d = \overline{Q_f^d}\left(P_b, Y\right) \tag{9}$$

$$Q_f^s = \overline{Q_f^s}\left(P_f, P_g, N_{(-1)}, P_h\right). \tag{10}$$

Respectively, and the general equilibrium demand and supply feeder calves are respectively of the form

$$Q_c^d = \overline{Q_c^d}\left(P_c, Y, P_L, P_g, N_{(-1)}\right) \tag{11}$$

$$Q_c^s = \overline{Q_c^s}\left(P_c, P_h\right) \tag{12}$$

To clarify some of the advantages of estimating equations in the general equilibrium form, suppose one is attempting to determine the effects of a grain price policy (with explicit effects on grain price) on the market transactions of consumers of beef. Using the partial approach and assuming all equations are specified linearly with constant terms (for simplicity of exposition), one must estimate 24 coefficients in six equations, whereas using the general equilibrium approach would require estimation of only nine coefficients in two equations (Eqs. 7 and 8). Estimation of Eqs. 9–12 would not necessarily be required. Solving for equilibrium prices and quantities is thus much simpler in the latter case because of the reduced dimensions of the problem (therefore corresponding to the guidelines of Principle 3). Finally, Just et al. (2004) show that examining policy objectives, such as consumer and producer surplus using equilibrium supply and demand relationships in a single market, attains the same results in theory as summing results over all relationships in a system of partial specifications. Hence, policy analysis can also be simplified greatly (although with loss of distributional detail on the producer side in this case) while making the results subject to errors of estimation in fewer parameters.

Admittedly, the model specified above is quite simple but, nevertheless, illustrates the advantages of the general equilibrium approach to specification, estimation, and policy analysis. In the context of any specification of a system of equations describing a number of markets, however, one can, in principle, solve for equilibrium supply and demand equations for a particular market which describe, say, equilibrium supply price, demand price, quantity demanded, and quantity supplied as a particular policy instrument (e.g., a price support, quota, subsidy, etc.) is altered in the market if those variables are represented in the complete system on which the general equilibrium equations are based. In practice, these relationships may or may not be simple to estimate as illustrated above depending on the number of exogenous variables introduced in the complete model specification. If not, however, it is often practical to estimate semi-equilibrium relationships which correspond to equilibrium specifications of sub-models.

For example, in the above example one may be considering effects of grain price policy in a larger model which also describes behavior in the grain market according to the equations:

$$Q_g^d = Q_g^d\left(P_g, P_c, P_f, N_{(-1)}\right) \tag{13}$$

$$Q_g^s = Q_g^s\left(P_g, A_{(-1)}, I_g, P_n\right) \tag{14}$$

$$Q_n^d = Q_n^d\left(P_n, P_g, A_{(-1)}, I_g\right) \tag{15}$$

$$Q_n^s = Q_n^s\left(P_n, P_p\right) \tag{16}$$

where Q_g^d, quantity of grain demanded; Q_g^s, quantity of grain supplied; Q_n^d, quantity of nitrogen demanded for fertilizer; Q_n^s, quantity of nitrogen supplied for fertilizer; $A_{(-1)}$, acreage planted to grains in a previous time period; I_g, inventory of grain; P_n, price of nitrogen used for fertilizer; P_p, price of petroleum.

In this case, the general equilibrium demand and supply of beef in the context of the entire model composed of Eqs. 1–6 and 13–16 and supply-demand identities $Q_g^s = Q_g^d$ and $Q_n^s = Q_n^d$ are

$$Q_b^d = \widetilde{Q_b^d}\left(P_b, Y\right) \tag{17}$$

$$Q_b^s = \widetilde{Q_b^s}\left(P_b, P_L, N_{(-1)}, P_h, A_{(-1)}, I_g, P_p\right), \tag{18}$$

respectively, whereas the equilibrium specification for the beef market in Eqs. 7 and 8 is a semi-equilibrium specification which considers only equilibrium adjustments in the beef-marketing sector for given grain price. If, because of complexity (too many coefficients to estimate in a single equation) Eq. 18 is impractical to estimate, then the entire model in Eqs. 1–6 and 13–16 could be replaced by one containing several semi-equilibrium relationships, e.g., Eqs. 7 and 8 plus the following semi-equilibrium representation of the grain market above:

$$Q_g^d = \overline{Q_g^d}\left(P_g, P_b, P_L, N_{(-1)}, P_h\right) \tag{19}$$

$$Q_g^s = \overline{Q_g^s}\left(P_g, A_{(-1)}, I_g, P_p\right) \tag{20}$$

Thus, the model becomes a reduced from one with 10 nonidentity equations with 42 coefficients to one of four nonidentity equations with 20 coefficients (assuming linearity with constant terms) while still reflecting the same phenomena. The complexity of the empirical model is thus greatly reduced although the underlying conceptual model does not involve any greater degree of abstraction. Alternatively, depending on the policy objective, one could examine general equilibrium specifications for a different market. For example, the general equilibrium specification of demand and supply for the grain market in the context of the overall model in Eqs. 1–6 and 13–16 is

$$Q_g^d = \widetilde{Q_g^d}\left(P_g, Y, P_L, N_{(-1)}, P_h\right)$$

$$Q_g^s = \widetilde{Q_g^s}\left(P_g, A_{(-1)}, I_g, P_p\right),$$

respectively, and is apparently no more complex than the semi-equilibrium equations in (19) and (20). As implied by the work of Just et al. (2004), estimates of these equations are appropriate for examining aggregate welfare effects associated with any standard intervention in the grain market for the entire group of decisionmakers whose behavior is reflected by Eqs. 1–6 and 13–16.

7.1 Subprinciple 6.1: In Policy Model Analysis, the Emphasis Should Be on Obtaining the Most Accurate Conditional Probability Distributions for the Relevant Performance Measures After Accounting for Complexity Costs

This subprinciple is consistent with and implied by the principles of the post-Bayesian approach. The criteria used in estimating a model often do not correspond appropriately to the policy goals of interest in predicting the effects of alternative policies. For example, in an econometric model, each of the equations is usually estimated with the criterion of minimizing the sum of squares of errors in a sample period. That is, in the feed grain livestock case, one may minimize the errors in forecasting the quantity of feed grains produced given the level of a price support in one equation, minimize the errors in forecasting the quantity of feed grain consumed by livestock producers given the price of feed grains in another equation, etc. For policymaking purposes, however, one may be more concerned with the effects of the price support on the real income of feed-grain producers, livestock producers and consumers. Since the criterion in conventional estimation does not focus on accuracy in the latter forecasts, the value of the policy model may be far less than is potentially possible.

As a possible means of overcoming these problems as well, greater emphasis on estimation of general equilibrium relationships rather than partial equilibrium relationships offers promise. Simulation and forecasting in a model with many partial equilibrium relationships allow errors to propagate through a system of equations upon solution of the model, whereas the statistics of fit in the criterion of estimation of a general equilibrium relationship are more directly applicable to the forecasting mode and to measuring the overall welfare effects.

8 Principle 7: Policy Modeling Should Provide for the Use of Intuition, Both in Model Development and Updating; Strong Intuition Should *Override Causal Implications of Coincidental Data in Model Development*

Data use in policy models can never be allowed to become a substitute for sound, hard thinking about assumptions and alternative courses of action. To enhance the believability of policy models and their effective use by policymakers, new, potential local approximations must be continually investigated and evaluated. Prior information facilitates this investigation and evaluation. To accommodate structural change and track new and changing developments, the weighting of prior information must be revised constantly in policy models.

The relative weightings on prior information vs. sample information must depend upon the degree to which relevant policy instruments have been observed. When no prior experience (data) is available on the effects of particular policy instruments, even greater weights must be placed on intuition. New institutional designs involving discrete choices across alternative policy sets will lead to greater weights on intuition than will policy evaluations for instruments that have been applied under continuing and well-observed institutional designs. In this setting, the following subprinciple arises.

8.1 Subprinciple 7.1: Ample Opportunities Should Be Given for Judgmental Inputs, Especially Those Provided by Commodity Specialists, Especially for Less-Observed Policy Instruments

Subprinciple 7.1 suggests that the expertise and software must be developed for cost-effective interactions of policymakers and commodity specialists regarding a policy model. The basic premise for introducing information from commodity specialists into the analysis provided by policy models is given in Johnson and Rausser (1982). To facilitate these interactions, experimentation with alternative information bases and various weightings across prior intuition and sample data must be accomplished easily. Interactive software must be developed and maintained which allows policy scenarios to be developed both with and without the subjective input of commodity specialists. The sensitivity of such policy scenarios to the subjective input of commodity specialists should be valuable for a number of purposes. To the extent that the information provided by commodity specialists is separable from other information sources for the constructed policy model, improved or more precise conditional policy distributions will be obtained for relevant performance measures.

9 Principle 8: Use of Greater Weight on More Recent Data in Policy Model Estimation Should Be Seriously Considered

The intuition of Principle 4 dictates that we are living in a world with constant structural change. We must accept the premise that models used for policy purposes are abstractions and approximations of reality. Thus, as the economy changes from time to time, one may find that not only should the structure used in the abstract model be changed but also, and perhaps more often, the models should be calibrated more closely to recent data. That is, to accommodate structural change and to track new and changing developments, the weighting of sample data must be revised constantly to update policy models. In a world in which underlying forces change in an unpredictable way from time to time, this principle is formally supported by the results of Kalman filtering and adaptive stochastic control theory. In this framework, one does not view the world as having discrete structural changes between reasonably long periods of constant structure. Rather, structural change is viewed as a process which takes place constantly but with small and subjectively random increments. In this context, recent observations are far more valuable in predicting the future than are observations in the distant past, although distant observations are often still useful. This consideration also emphasizes the importance of continual maintenance and updating of policy models.

Principles 7 and 8, when combined with 3, 4, and 5, have some direct implications for assessment of the tradeoffs between the use of information from (1) economic theory, e.g., homogeneity, symmetry conditions, etc., (2) non-sample information, such as expert judgment, (3) recent sample data, and (4) the entire sample. The assessment of these tradeoffs must be determined in large part by the purpose for which a policy model is constructed (Principles 1 and 2). In general, however, the credibility of policy models will be enhanced by giving the most serious considerations to (1), followed by (2), (3), and (4) in that order. This ordering follows from currently available data support systems and the "local approximating" nature of quantitative models.

9.1 Subprinciple 8.1: Model Maintenance and Updating Are Continuous Processes for Which Explicit Expertise Must Be Fostered

Maintenance and updating must take place not only for growth and continual quality enhancement of policy models but also to avoid deterioration of the information in a policy model. Again, these arguments underscore the importance of viewing development and use of policy models as a process and not as the creation of a product.

10 Principle 9: General Purpose Data Sets Rather than General Purpose Models Should Be Emphasized

The use of the post-Bayesian approach, the need for constant revision of the weighting of sample information vs. intuition in model specification, the need to incorporate summary variables in policy models, and the need to evaluate new and different policy problems from time to time all dictate the need for an all-purpose data set rather than an all-purpose model. Two of the greatest problems policy modeling has faced historically have been the extreme complexity needed in a model in order to be able to address a wide set of issues unforeseen at the time of model construction and the extreme costs imposed by this complexity in model development and use. As evidenced by the experience of the Forecast Support Group in the USDA and the failure of commercial general purpose econometric models of agriculture in the 1970s, complex models take years to build. Such models can often not be brought to fruition before some of the pressing issues have passed. Furthermore, even though a model may be made very large and complex, it may still not include the appropriate focus to evaluate a specific policy issue unforeseen at the time of the model development.

An alternative approach is to develop small policy models with specific policy focus at the time that specific policy issues surface as suggested by Principle 1. In order to pursue this approach, however, models must be developed rapidly if they are to have bearing on current policy considerations. Rapid model development can be facilitated by the maintenance of an all-purpose data set. One of the largest costs both in terms of money and time involved in model construction is the acquisition of data and development of a data-management system and appropriate software for estimation. With the existence and maintenance of an all-purpose data set, a data-management system, appropriate estimation software, and a portfolio of previously constructed specific purpose models, a policy analyst can sit down at a computer terminal and develop a model with specific focus on the issues at hand in a matter of a few days. This has been borne out by the authors' own experience in which a model of moderate complexity (34 equations with 52 variables) was developed in less than a week through the use of a general-purpose data set.

The maintenance of an all-purpose data set is also important in facilitating the use of summary variables in policy model construction. With the maintenance of an all-purpose data set, the means of constructing price or quantity indices as the need arises is readily available. Thus, a policy analyst is less likely to be forced to use only representative variables in policy model construction.

No matter how general a general-purpose model is, questions always seem to arise that are beyond the scope of the model. Moreover, what some would define as general purpose models, others would argue are specific purpose models. The essential point, however, is that actions which result in increasingly more general-purpose models place insufficient weight on complexity costs. In this regard, the experience of the U.S. Department of Agriculture policy modeling effort speaks for itself.

10.1 Subprinciple 9.1: The Principles of Post-Bayesian Analysis Are Also Appropriate in Governing the Design and Maintenance of a General-Purpose Data Set

The design and maintenance of an all-purpose data set requires that some frameworks be developed to determine which variables should be initially included in such a data set and which variables should be added or deleted from a data set as additional experience is gained. Formally, these problems can be solved using the principle of pre-posterior analysis. That is, data base inclusions, augmentations, or deletions should be based upon intuition and judgment as well as experience in assessing the cost of maintenance vs. the potential policy modeling benefits. In the case of data set maintenance, however, these issues must be decided based on the entire collection of policy models and potential policy models rather than on the basis of a single policy model.

11 Principle 10: Policies Should Be Formulated with an Appropriate Degree of Learning in Mind

If policy models are to become an important source of information in policy selection, then, in some instances, the policies should be determined so that a greater amount of information can be ascertained from observation of their effects. Principle 10 is supported formally by adaptive control theory which places some emphasis on the value of experimenting with an economy. However, the cost of such experimentation may be more than recovered by the benefits of setting the policy controls taking into account the potential value of improved understanding of the system under examination.

Principle 10 is also related to the earlier discussion on the form and shape of much of governmental intervention in the agricultural and food economy. The form of this intervention in effect has made policy modeling difficult. Moreover, policies resulting from such intervention have placed, as expected, little value on information that might be generated from quantitative models. However, the "tidal wave" effect and the importance of path vs. magnitude can be effectively managed by implementation of Principle 10 and the following subprinciples.

11.1 Subprinciple 10.1: Policy Alterations Should Be Imposed Whenever Possible by Revising Existing Policy Instruments Rather than by Determining a New Set of Policy Instruments, Subject to Political Feasibility

Currently, historical agricultural policies generally result in instruments which are imposed only if certain fixed barriers or trigger points are reached. For example, acreage allotments and price supports represent fixed quantity and price barriers; set-aside requirements are imposed depending on whether the Secretary of Agriculture determines that some theoretical trigger point has been crossed. With such policy instruments, the effects of various policy controls may be observed in some years and not in others. Hence, less information is gained than if policy instruments were effective in varying degrees over the complete sample record. Data generated from such policy regimes call for analysis by means of qualitative econometrics thus greatly increasing the complexity costs of model construction and analysis, and reducing the value of information forthcoming.

11.2 Subprinciple 10.2: Depending on Administrative Costs, Policy Instruments Should Be Exercised in a Smooth and Continuous Fashion Conditioned on Market Conditions

Greater value of feedback information from policy modeling would result from the implementation of Subprinciple 10.2. For example, government price-supporting operations for, say, wheat could be carried out by means of government purchases of one million bushels of wheat for every 1 cent per bushel the market price is below some target price (or, conversely, selling one million bushels of stock for every 1 cent per bushel the market price is above the target price). Similarly, a 1% set-aside could be required for every 20 million bushels of wheat in government reserves. Such policies are generally more consistent with economic efficiency in contrast to the form of existing policy instruments which are conditioned on fixed barriers and trigger points. They have the additional benefit of reducing policy risk and allowing farmers to reduce allocative inefficiencies. In other words, farmers are more able under such policies to correctly anticipate government actions based on their own assessment of market conditions. Too often, analysts concentrate on instabilities and distortions in the private sector and offer policies which, when implemented, lead to instability of the political administration system. In essence, the risk faced by individual farmers is transferred from economic markets to political markets.

As most agricultural policy instruments have been exercised historically, their effectiveness is largely dependent on market conditions. Thus, under many market regimes, no information is generated on the effects of the policy instruments. However, when policy instruments are exercised in a smooth and continuous fashion, governmental actions behave much as a demand or supply curve that can be observed in every time period. Thus, information on the effects of policy instruments can be compiled with less empirical difficulty.

12 Principle 11: Major Structural Reforms of Current Policies in the Face of Concentrated Political Power Requires Modeling of Alternative Compensation Schemes and Potential Changes in the Existing Governance Structure

Perhaps the major reform of agricultural policies in the United States emerged with the GATT Negotiations during the Uruguay Round. For the first time in the history of GATT (subsequently renamed WTO), agriculture was included as one of the industries for which trade liberalization would be pursued. In all prior GATT negotiations, there was never a sufficient coalition for the inclusion of agriculture. In other words, a sufficient number of individual countries did not want to give up their sovereign rights to pursue protectionism of their agriculture and food policy programs. In the case of the United States, powerful interest groups benefiting from governmental subsidizations had lobbied to exclude the agricultural sector from the Uruguay Round. However, a crisis of huge surpluses that existed among many commodity systems led to a prisoner's dilemma scenario between the E.U. and the U.S. that resulted in driving world prices to unacceptably low levels (Rausser, 1987). In the case of both the E.U. and the U.S., this crisis was caused by "coupled subsidies" that created strong incentives for overproduction. The resulting supply surpluses were offered up on export markets with another dimension of policy instrument subsidies from a new policy program entitled, "the export enhancement program." The implementation of this new policy program meant that major commodity trading firms could purchase these surpluses on U.S. markets at artificially elevated prices driven by government support and in turn, dump them on developing countries at artificially deflated prices while receiving a subsidy from the U.S. government for the difference. The E.U. pursued the same actions with regard to managing their surpluses, which meant that whenever a developing country put in a bid at very low prices, the competition between the U.S. and the E.U., in their desire to eliminate surpluses, resulted in in even lower prices. The international commodity trading firms had no incentive whatsoever to eliminate this prisoner's dilemma outcome (Rausser, 1987) because their incentives were to move large volumes and both the E.U. and the U.S. would ensure that they would be fully compensated.

The above scenario resulted in an array of prices, none of which, reflected basic market fundamentals. Other trading countries (for example, Australia, Thailand, and New Zealand) were justifiably upset with the steadily declining prices for their food-related exports. These market externalities of E.U. and U.S. government actions led to diplomatic efforts across major exporting countries to seek some global rationality in agricultural and food product trade. In conjunction with this crisis, a new narrative emerged within the agricultural economics profession in the E.U., the U.S., and the OECD. This narrative argued that the reform of existing policies should move in the direction of "decoupled policies" (Rausser, 1987).

The executive branch of the U.S. during the Reagan administration had attempted to domestically reduce governmental involvement in a number of program-based commodities. In 1981 as well as 1985–1986, the Reagan administration proposed major legislation to eliminate much of the subsidization, but in both instances were dead on arrival. Powerful interest groups prevailed and defeated these attempts to reform U.S. agricultural policies by exercising their influence in the second branch of government, the Congress. Given these two dead-on-arrival proposals by the executive branch, it was no surprise that the Reagan administration found very attractive the inclusion of agriculture in the Uruguay Round that was kicked off on Punta del Esse in 1986. Many of the countries in the E.U. also supported the Uruguay Round because they too experienced the crisis and had begun to embrace the narrative.

As emphasized by Rausser (1995), "essentially, Reagan administration officials seized upon an opportunity to sidestep the domestic political economic forces, specifically, the commodity interest groups and well-established supporting institutions (e.g.

the Senate), which have always dominated the design of U.S. agricultural policies. As a result, if the Uruguay Round could be successfully concluded, the domestic governance structure would have a far different interest group landscape, which would then include the interest of global liberalization of trade. Ultimately, after seven long years of negotiations among all member countries of the WTO, the net result was a transition towards decoupled policies, the core narrative underlying the entire process. Without the inclusion of agriculture in the Uruguay Round, the U.S., as well as the E.U., would have continued to face their respective political-economic governance structures.

The above historical illustration of what took place to motivate the Uruguay Round makes clear that the interest group landscape for agricultural and food policies throughout much of the world depends critically on the relative influence and political power of interest groups. Up until 1995, beginning with the Great Depression in the 1930s, the principal interest groups were producers or commodity groups with little or any influence of other major non-agricultural interests, such as taxpayers or consumers. Since 1995, with an increasing focus on decoupled policies, the emergence of environmental interest groups supporting land conservation and reduction of chemical uses in agriculture, the introduction of ethanol subsidies and the resulting involvement of energy interest groups, that have expanded the number of organized interest groups who were engaged in active lobbying efforts (Rausser & de Gorter, 2015). Still, other interest groups associated with food safety, nutrition, obesity, and poverty have increased their lobbying and educational efforts and thus, their influence over the actual policies that are designed and implemented.

As recognized by Rausser (1990), Rausser and Johnson (1993), Rausser and Goodhue (2002) and Rausser et al. (2011), empirical governance structures involve some weighting across each of the traditional interest groups, as well as those who have emerged over the course of the last decade or so. In the context of major structural policy reform, the first step is to extend Subprinciple 1.2. In other words, instead of operating with a governance structure that implies an objective function that seeks to maximize social welfare, a governance structure that is consistent with a political preference objective function must be quantified. In this context, modeling efforts must focus on self-interest objectives of the various organized interest groups (Rausser & Zusman, 1992). Such an analysis begins with a specification of policymakers attempting to pursue the public interest but, through the lobbying of various interest groups, the resulting governance or political preference structure accounts for effects of organized self-interest groups that drag policymakers away from a pure public interest.

12.1 Subprinciple 11.1: If No Feasible Mechanism Exists for Altering the Historical Governance Structure to Completely Support Policy Reform and There Remains Powerful Interest Groups Who Can Block any Potential Reforms, then Compensation Schemes Become Necessary

When a policy reform is socially preferable but not politically feasible, the groups that benefit from the reform are typically not sufficiently organized to represent their economic interests relative to the interest groups that are harmed by the reform.

Often, this outcome arises because the interest groups benefitting from the reform face significant transaction costs of organizing their interest groups (Just et al., 1995a, 1995b). A common explanation for this result is that large groups that benefit have small individual gains. In much of the political economic literature, this is characterized as the "power of the few."

As this brief description suggests, total transparency is required in any quantitative modeling exercise to reveal who are the winners and losers of existing policies as well as the potential reformed policies. In the case of U.S. agriculture, the reform of coupled subsidization policies has the obvious benefits of reducing taxpayer exposure and dramatically increasing aggregate consumer social welfare. Movement towards decoupled policies and trade liberalization has the obvious additional benefits of eliminating deadweight costs, which allows world prices to rise and price uncertainty on world markets to contract. In turn, this makes farming operations far less land-intensive and utilizes less variable inputs that often have environmental impacts through less utilization of fertilizers and pesticides (Rausser & Irwin, 1989). This creates more incentives for innovation, global competition and the support for PERTs, or policies that increase the size of the economic pie (Rausser, 1982).

The principal reason for modeling compensation schemes is quite simply that they may be needed to pursue the public interest, which is expected to arise as a result of policy reform. When optimally designed, compensation can be regarded as a PEST payment necessary to achieve a Pareto-efficient outcome. However, if the compensation scheme is poorly designed, potentially introducing a moral hazard, then the compensation scheme may promote rent-seeking that distracts from economic efficiency.

The arguments in favor of compensation include the potential legitimate property rights that emerge from long-standing policies that have subsidized a particular interest group—in the case of food and agriculture, the program crop farmers. Based on this long-standing policy of coupled subsidization, economic agents have shifted their resource allocation to take advantage of the rents that are generated by current policies. These resource allocations largely take place because the government is viewed as credible with regard to continuing to pursue current policies from one period to another. In essence, public policy is often viewed as a contract with special interest groups, that is, a set of rules governing economic activity. As a result, any change might be interpreted as a "breach of contract" for which compensation is required. If major policy reforms are beneficial for the economy as a whole, then some means must be found to placate the obstructionists to such reforms. Thus, compensation can be seriously considered as an attempt to mitigate opposition.

There are, of course, many alternative mechanism or compensation schemes that can alter the distribution of benefits and costs from a particular policy reform. Once all such compensation schemes and mechanisms are identified and evaluated, an envelope frontier can determine what represents the best welfare redistributions given all of the compensation possibilities. Such an envelope frontier represents the efficiency boundaries of what is institutionally and politically feasible. When this compensation envelope frontier is determined, it can be combined with either a socially welfare objective function consistent with Subprinciple 1.2 or a political preference function reflecting political feasibility to determine whether a particular policy reform with compensation is welfare-improving as well as politically feasible. The roadmap for this analysis has been presented by Just and Rausser (1992) that examines the policy reforms resulting from the decoupled policy targets of the Uruguay Round to the coupled subsidization policies that existed in the United States, in one form or another, for the prior six or more decades. In this analysis, a transition period of 10 years was investigated where the direct payments of compensation for lost profits that would be incurred by crop producers required a compensation of \$72.2 billion in 1985 discounted value from the U.S. government. An operational approach was recommended to distribute these direct payments in a series of annual payments over the transitional period rather than to make lump sum compensation available at the beginning of the period. A lump sum payment would, of course, invite producer lobbying groups to return to coupled policies. The only losers as a result of the proposed reforms were, in fact, crop producers. Other interests of politically unorganized groups, such as consumers, taxpayers, those seeking environmental sustainability, all benefited from the proposed reforms.

While compensation of losers may be required to prevent obstructionist tactics by interest groups that suffer dramatic losses, winners from the reform that will emerge must also be recognized. To the extent that winners are concentrated and can be identified, they should share in the financing of compensation. In the practical implementation of compensation and in promoting private sector adjustments, both intra-country compensation as well as international compensation should be considered. On the intra-country front, one solution is for taxpayers to be required to bear the burden of financing compensation as in the Just and Rausser (1992) modeling effort. However, from an international perspective, there are also clear winners in world markets from reforms of coupled subsidizations. These winners are generally concentrated and have comparative advantages in a range of products. To the extent that they gain from agricultural reform in other countries, they might well be prepared to bear some of the compensation burden.

12.2 Subprinciple 11.2: Potential Pitfalls of Compensation Schemes Must Be Recognized and Effectively Managed

If compensation schemes are badly designed, they can merely introduce other distortions into the economic system. Determining the true value of policy-induced change in asset values is especially difficult when changes in these values have multiple sources of causality. Such assets also have the possibility of moving from their current use into other activities that generate a positive rate of return. This supports the notion of partial compensation in contrast to complete compensation. If ethical justification for full compensation is not accepted, a desire arises to minimize the necessary payment in order to politically support the proposed reforms of existing policies. Not all losers need to be fully compensated in order to reduce the effort of a blocking coalition to a proposed reform. Moreover, the financial resources offered for compensation also have opportunity costs such as excess tax burden of governmental tax debt that also provide further justification for partial compensation.

In the context of partial compensation, a question of moral hazard may arise even if policy reform is achieved with paid compensation if there are no barriers to well-organized losing groups reentering the political economic market to secure rents once again. This means, of course, when a policy reform is put into place and compensation is implemented, it must be combined with an active effort to prevent "compensation-seeking." The political economic capacity of well-organized interest groups to accept compensation and then devote new resources to seeking other forms of compensation or to once again establish coupled policies that serve their self-interest should never be underestimated.

In the context of pure compensation-seeking, for example, an announcement at time t that those producing sugar at time $t + 1$ will receive compensation in exchange for loss of import protection can be expected to dramatically increase sugar production acreage at time $t + 1$ compared to time t. This reallocation of production is not related to market generated signals, but to compensation seeking.

12.3 Subprinciple 11.3: Whenever Possible, Compensation Schemes Should Be Designed to Promote Economic Growth in Other Linked Sectors in the Economy

Any displaced resources resulting from major policy reforms can be effectively countered by new opportunities for resource mobility and asset diversification. As shown by Rausser and Zusman (1992), if there is asset diversification across all economic agents and active mobility among all resources, there will be no incentives for rent-seeking and/or the pursuit of political power in the economic policy-making process. For example, the results of trade liberalization have been documented to generate gains for winners that far outweigh the losses of those that are harmed by such policy reforms (Fernandez & Rodrik, 1991). For the agriculture and food sector, this certainly took place with regard to policy reforms in the textile industry as well as the sugar industry. The compensation that would be offered for such displaced resources, particularly labor resources, is worker retraining to upgrade their skills to achieve greater mobility in moving to other economic sectors supporting overall economic growth. With regard to asset diversification across economic agents in an economy, the economic self-interested incentives for acquiring political power will not exist (Rausser et al., 2011, Chap. 14). Accordingly, compensation schemes should be designed and implemented to promote more mobility and more asset diversification. Both of these two outcomes support public sector governments that are seeking reductions in wasteful rent-seeking activities on the part of potentially powerful interest groups.

13 Conclusion

We have offered a number of principles that may be interpreted as rules or a code of conduct that will allow the potential for quantitative policy models to be realized. They emphasize the tradeoffs that should be examined as more conventional models (those with descriptive, explanatory, or forecasting purposes) are replaced by operational and usable policy models.

In the final analysis, of course, major benefits from modeling public policy problems depend critically upon the sound judgment and experience of governmental policymakers and the analysts involved. Only through such judgment and experience can the proper balance, simplicity and accuracy be possible. Given the appropriate balance, the principal benefits of quantitative modeling are achievable. These benefits include (1) inter *alia,* forcing the users or governmental policymakers and analysts to be precise about perceptions of the system they are attempting to influence, (2) testing these perceptions with available evidence, (3) providing structure to the analysis, (4) extending policymaker's information processing ability, (5) facilitating concept formation, (6) providing cues and insights to policymakers, (7) stimulating the collection, organization, and utilization of data, (8) freeing the policymaker and analysts from a rigid mental posture, and (9) creating effective tools for negotiation and bargaining and as a basis for persuasion. These benefits can accrue to policy models, provided that the obstacles to achieving such potential benefits are avoided—obstacles such as timeliness, solving the wrong problem or solving the right problem too late, allowing improper expectations to form by not clearly delineating what the model can and cannot accomplish (the role of modeling efforts should always supplement rather than supplant the normal policymaking processes), and failure to differentiate the characteristics of the policymakers or users from the analysts (these are often very different types of people with different roles, responsibilities, expertise, cognitive style, etc.). The rules or principles advanced in this chapter are an attempt to facilitate avoidance of the major obstacles in capturing the promised benefits of policy modeling efforts.

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Woke Farm and Food Policies in the Post-truth Era: Calamitous Consequences for People and the Planet

Julian M. Alston

The great enemy of truth is very often not the lie – deliberate, contrived and dishonest—but the myth—persistent, persuasive, and unrealistic. Too often we hold fast to the clichés of our forebears. We subject all facts to a prefabricated set of interpretations. We enjoy the comfort of opinion without the discomfort of thought.

—John F. Kennedy

In June 2017, the Oxford English Dictionary (OED) announced it had added *woke* and *post-truth* as new words (public.oed.com/blog/june-2017-update-new-words-notes/).

"The original meaning of adjectival ***woke*** (and earlier *woke up*) was simply 'awake,' but by the mid-twentieth century, *woke* had been extended figuratively to refer to being 'aware' or 'well informed' in a political or cultural sense." I use it here in this broader sense rather than the more recently popularized ways related to racism and sexual misconduct.

Post-truth was Oxford's 2016 word of the year. It is defined as "relating to or denoting circumstances in which objective facts are less influential in shaping political debate or public opinion than appeals to emotion and personal belief." (Perhaps "post-trust" would be better, but this has not yet made it into the OED.)

The same update also included a new last word: *Zyzzyva*, the name of a genus of tropical weevils native to South America and typically found on or near palm trees, supplanting *zythum*, a kind of malt beer brewed in ancient Egypt.

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1 Introduction

In January 2019, in a highly-orchestrated launch, the EAT-Lancet Commission published its manifesto—on what's wrong with the world food system and how to fix it—titled "Food in the Anthropocene: The EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems" (Willett et al., 2019).[1] In April of the same year, Rausser et al. (2019) published an article in the *Annual Review of Resource Economics* titled "The Economics of the Naturalist Food Paradigm," building on the earlier article in the same journal by Rausser et al. (2015) titled "An Alternative Paradigm for Food Production, Distribution, and Consumption: A Noneconomist's Perspective." These articles by Rausser and his colleagues anticipate (given publication lags) and respond to many of the issues raised in the EAT-Lancet report.[2] In this chapter, I provide some personal perspectives on the same issues.

Before getting into the substance, some semantics: Rausser et al. (2015, 2019) refer to a "naturalist" (sometimes "naturalization") paradigm for food and agriculture versus an industrial food and agriculture paradigm. They define the "naturalist" paradigm in relation to the growing consumer demand for goods having "credence attributes, including organic, locally produced, and raised using humane livestock and poultry practices" (p. 217). However, in conventional usage "naturalist" refers to people who study natural history, such as Charles Darwin or David Attenborough (as in the UC California Naturalist Program conducted by UC Agriculture and Natural Resources), whilst in more specialized usage, it might refer to devotees of "naturalism" as a school of philosophy or art. It is not so easy to hijack an existing word to good effect.

I acknowledge that finding the right word for this purpose is difficult. I prefer "woke" because I think it better captures the broader aspects of the policy context and issues, beyond the attributes of the farm production system alone, and it connotes the sense of a presumption of enlightenment among the woke, which seems apt for what I have in mind here. Another, perhaps more subtle issue relates to false dichotomies. Proposing a dichotomy between two alternative paradigms is potentially useful as a didactic device, but we should not forget that what we really face is a multidimensional continuum of consumer (and broader societal) perspectives on and preferences regarding farms and food and related policies.

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[1] See, also the related report from The Lancet Commission by Swinburn et al. (2019) on "The Global Syndemic of Obesity, Undernutrition, and Climate Change."

[2] To be sure, these items represent just a sampling of the most recent contributions to a very busy scholarly and public policy literature across these topics, some of which will be drawn out in the pages that follow.

2 Woke Perspectives on Agriculture and Food

The woke farm and food policy reform movement—as exemplified by the EAT-Lancet Commission—blames the agricultural and food industry generally, and the industrial food and agriculture paradigm, in particular, for various societal ills.[3] The movement's protagonists prescribe personal choices and propose public policies, in many cases based on misguided perceptions of cause and effect connections and consequences that contradict scientific and economic evidence (see, e.g., Rausser et al., 2019). The costly consequences of this movement in driving individual choices and public policies restricting them provided the motivation for the articles by Rausser et al. (2015, 2019) and this chapter.

Rausser et al. (2015) set the stage by tabulating five categories of issues in this context, namely: obesity; food safety; contribution of agriculture to climate change; agricultural production structure; concentration of agribusiness. This is a familiar-looking list to those of us who study and teach agricultural policy.[4] As economists, we might contemplate these issues in terms of the potential for market failures associated with market power of firms; information asymmetries in the food chain; provision of public goods; environmental externalities; other distortions (e.g., externalities in the health-care system); or socially unacceptable poverty; we might also think about government failure in this context (see, e.g., Rausser, 1982, 1992). Against that background, we might identify potential for policy changes that would yield net social benefits, one way or another, and we might even propose enlightened policy reform, accordingly.

This is standard fare for economists who work on agricultural policy and, broadly speaking, agricultural economists will concur on the broad facts, analysis, and policy implications in each instance—but this mainstream economics consensus view tends to be at odds with the woke perspective and agenda. These differences in perceptions of the issues and policy positions might reflect differences in understanding of the facts, and the deeper cause-and-effect relationships, as well as more fundamental differences in ways of thinking about government policy and its purposes—perhaps including whether this is a subject for "thought" (as opposed to received dogma).

Even if we all were to agree that the government should do something, economists might disagree with others about the appropriate extent and form of intervention, with due allowance for opportunity costs and the value of matching policy

[3] The EAT-Lancet Commission is itself only an example, a manifestation of the woke food movement, not the focus of this chapter. Some other prominent individuals and groups advocate policies with more concerning economic implications—for example, proponents of "agroecology" seek to radically transform agricultural systems.

[4] To these we can add a few more that might fit on the woke agenda, such as air and water pollution (beyond greenhouse gases); food-related health and nutrition (beyond obesity); animal welfare; conservation of scarce natural resources, including endangered species; rural landscape amenities; farm worker safety and health; rural poverty; food security of the poor; globalization. Rausser et al. (2019) consider a broader range like this, which goes beyond traditional agricultural policy topics.

instruments well to targets. A crucial point to which we will return is a widespread failure—even by some economists—to appreciate the "Tinbergen rule," stipulating that for economically efficient policy, the number of policy instruments must be at least as great as the number of targets.[5]

At least some proponents of the woke agenda are engaged in a political process and, as well as food industry participants and policymakers, their messages are targeted to individual citizen-consumers—seeking both to induce individuals to change their own behavior and to recruit them as supporters in the political process aimed at causing (or obliging) others to change.[6] We can think about this in terms of two elements: first, promoting the demand for (and supply of) food with certain desired process and product attributes, some of which may not be readily apparent and thus are credence attributes (e.g., organic, non-GMO, Fair Trade, local, vegan, humane, sustainable); and second, pursuing policies to encourage production and consumption of food with the same desired attributes, or to discourage (or even ban) production and consumption of food with attributes that are deemed undesirable (e.g., GMOs in Europe; Roundup).[7]

Why do we (or I) care? At issue is whether the woke farm and food policy reform movement is causing misguided and costly changes in supply and demand for farm products and food, and the related policies. This concern is relevant at two levels. First, we can be concerned at the level of the geopolitical unit at which policies are applied that impinge on individual choices about what to consume and produce and how to produce it; significant individual and social costs can come from policies that are ill-informed or misguided in terms of either the choice of a policy instrument or the rate at which it is set. Second, a related concern applies at the level of individuals who, even in the absence of government policies, might be led to make ill-informed choices that make them worse off—e.g., to consume raw milk in the mistaken belief that it is risk-free to do so; or to eschew GMO foods in the mistaken belief that in doing so they help reduce the environmental footprint of agriculture. A review of the EAT-Lancet recommendations puts some meat on the bones of these ideas.

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[5] As Arrow (1958, p. 91) explains: "The analytic problem is to solve for the targets and other variables the terms of the instruments; the policy problem is to fix the targets and solve for the instruments, eliminating the other variables in the process. If a linear model is assumed, it is immediately clear that the number of instruments must—except for special cases—be at least as great as the number of targets."

[6] Leading luminaries and self-styled authorities on the issues in this context include journalists and food writers who are active in the popular press (such as Michael Pollan and Mark Bittman), television personalities (such as Bill Maher and Dr. Oz) nutritionists and public health policy types (such as Marion Nestle, Barry Popkin, Walter Willett, and Kelly Brownell), as well as professional muckrakers (like Raj Patel and the now born-again, now repentant Mark Lynas – e.g., Patel 2012, Lynas 2018) and snake-oil merchants. Rausser et al. (2015) cite many of these and more. I hesitate to identify anyone specifically as a deliberate fraud or a charlatan, but at least some people active in this context have skin in the game and take policy positions that are otherwise hard to explain.

[7] Many of these attributes of products or processes used to produce them may be credence attributes, some of which might be confirmed after purchase and consumption as in the case of experience goods, but the woke agenda also includes attributes that are readily apparent to an interested consumer—such as beverages containing sugar, or non-ruminant meat.

2.1 The EAT-Lancet Commission Report

The EAT-Lancet report (Willett et al., 2019) points to a range of concerns for the health and sustainability of people and the planet that can all be addressed by a substantial shift in food consumption patterns toward a "healthy" diet (see Box 1). As the report explains (p. 448):

> Healthy diets have an appropriate caloric intake and consist of a diversity of plant-based foods, low amounts of animal source foods, unsaturated rather than saturated fats, and small amounts of refined grains, highly processed foods, and added sugars.
>
> Transformation to healthy diets by 2050 will require substantial dietary shifts, including a greater than 50% reduction in global consumption of unhealthy foods, such as red meat and sugar, and a greater than 100% increase in consumption of healthy foods, such as nuts, fruits, vegetables, and legumes. However, the changes needed differ greatly by region.

Box 1 "Key Messages" from the EAT-Lancet Commission (2019, p. 448)

1. Unhealthy and unsustainably produced food poses a global risk to people and the planet. More than 820 million people have insufficient food and many more consume an unhealthy diet that contributes to premature death and morbidity. Moreover, global food production is the largest pressure caused by humans on earth, threatening local ecosystems and the stability of the earth system.
2. Current dietary trends, combined with projected population growth to about 10 billion by 2050, will exacerbate risks to people and planet. The global burden of non-communicable diseases is predicted to worsen and the effects of food production on greenhouse-gas emissions, nitrogen and phosphorus pollution, biodiversity loss, and water and land use will reduce the stability of the earth system.
3. Transformation to healthy diets from sustainable food systems is necessary to achieve the UN sustainable development goals and the Paris agreement, and scientific targets for healthy diets and sustainable food production are needed to guide a great food transformation.
4. Healthy diets have an appropriate caloric intake and consist of a diversity of plant-based foods, low amounts of animal source foods, unsaturated rather than saturated fats, and small amounts of refined grains, highly processed foods, and added sugars.
5. Transformation to healthy diets by 2050 will require substantial dietary shifts, including a greater than 50% reduction in global consumption of unhealthy foods, such as red meat and sugar, and a greater than 100% increase in consumption of healthy foods, such as nuts, fruits, vegetables, and legumes. However, the changes needed differ greatly by region.
6. Dietary changes from current diets to healthy diets are likely to substantially benefit human health, averting about 10.8–11.6 million deaths per year, a reduction of 19.0–23.6%.

7. With food production causing major global environmental risks, sustainable food production needs to operate within the safe operating space for food systems at all scales on earth. Therefore, sustainable food production for about 10 billion people should use no additional land, safeguard existing biodiversity, reduce consumptive water use and manage water responsibly, substantially reduce nitrogen and phosphorus pollution, produce zero carbon dioxide emissions, and cause no further increase in methane and nitrous oxide emissions.
8. Transformation to sustainable food production by 2050 will require at least a 75% reduction of yield gaps, global redistribution of nitrogen and phosphorus fertilizer use, recycling of phosphorus, radical improvements in efficiency of fertilizer and water use, rapid implementation of agricultural mitigation options to reduce greenhouse-gas emissions, adoption of land management practices that shift agriculture from a carbon source to sink, and a fundamental shift in production priorities.
9. The scientific targets for healthy diets from sustainable food systems are intertwined with all UN sustainable development goals. For example, achieving these targets will depend on providing high-quality primary health care that integrates family planning and education on healthy diets. These targets and the sustainable development goals on freshwater, climate, land, oceans, and biodiversity will be achieved through strong commitment to global partnerships and actions.
10. Achieving healthy diets from sustainable food systems for everyone will require substantial shifts towards healthy dietary patterns, large reductions in food losses and waste, and major improvements in food production practices. This universal goal for all humans is within reach but will require adoption of scientific targets by all sectors to stimulate a range of actions from individuals and organizations working in all sectors and at all scales.

According to the EAT-Lancet report, the worldwide adoption of the recommended healthy diet promises a significant improvement in human health (averting about 11 million deaths per year); reductions in greenhouse gas emissions from agriculture, in particular those associated with livestock—especially ruminants (dairy and beef cattle, buffaloes, sheep, and goats);[8] and reduced demand for land, water, and other natural resources for agricultural production, yielding benefits for achievement of sustainable development goals; in other words, a "Win-Win-Win" solution! The main ideas in the report are quite intuitive—essentially an elaboration of Michael Pollan's (2007a, 2007b) dictum: "Eat food, not too much, mostly plants," with a twist: "preferably non-ruminant"—and the arithmetic is straightforward

[8] FAO (Gerber et al., 2013) estimated that global livestock production emitted 7.1 Gigatonnes of CO_2 equivalent per year, representing some 14.5% of all anthropogenic GHG emissions; cattle accounted for two-thirds of this total.

based on the latest relevant science. If people generally were to shift to that diet, we might reasonably expect their nutritional and health outcomes generally to improve in the ways indicated; likewise, eliminating ruminant livestock production would reduce both greenhouse gases and the demand for resources to grow their feed. What could possibly be wrong with any of this?

Much has been written since the launch of the EAT-Lancet report, commenting on the process and how it was funded, as well as the substance of the report and its recommendations. One set of critical questions concerns how the world's consumers could be induced to change their consumption so radically (presuming they can afford to do so). Willingness may be an issue. When it comes to diets and nutrition, consumers have never been closely compliant with official dietary recommendations—such as the USDA recommendations, captured in "MyPlate" or its various predecessors, as taught in schools to most Americans.[9] In this context, people might not do what they are told by government experts, even if they agree with the wisdom of the recommendations and wish they could comply. Diversity among nutritionists and dietitians in what they recommend, and a history of big changes in their consensus recommendations have contributed to skepticism about dietary dictates (see Box 2).

Box 2 Dietary Guidelines: The Octopus

Referring to diversity of dietary recommendations, my friend and mentor John Quilkey once said to me (pers. comm. Circa 1975) something like: "In the world of the two-handed economist, the nutritionist is an octopus."

Sometimes a broad consensus emerges even if it might not last. As described by Berge and Ann (2008), nutritionists and other public health professionals demonized dietary fat in the 1980s and 1990s (see, e.g., Willett, 1994), but the mainstream understanding has evolved (see, e.g., Forouhi et al., 2018), and the same authorities have now switched to demonizing dietary sugar, in particular in the form of sugary sweetened beverages (see., e.g., Brownell et al., 2009).

Even so, there is more consensus among nutritionists than the octopus analogy might convey. From their global review of food-based dietary guidelines (FBDG), Herforth et al. (2019, p. 590) conclude:

> Some guidance appears nearly universally across countries: To consume a variety of foods; to consume some foods in higher proportion than others; to consume fruits and vegetables, legumes, and animal-source foods; and to limit sugar, fat, and salt. Guidelines on dairy, red meat, fats and oils, and nuts are more variable. Although WHO global guidance encourages consumption of nuts, whole grains, and healthy fats, these messages are not universally echoed across countries. Future frontiers in FBDG development include the *incorporation of environmental sustainability* and increased attention to sociocultural factors including rapidly changing dietary trends. (emphasis added)

Sources:

Forouhi, N. G., Krauss, R. M., Taubes, G., & Willett, W. (2018). Dietary fat and cardiometabolic health: Evidence, controversies and consensus for guidance. *BMJ*, *361*, k2139. https://doi.org/10.1136/bmj.k2139.

[9] See a "Brief History of USDA Food Guides" at https://www.choosemyplate.gov/brief-history-usda-food-guides

Herforth, A., Arimond, M., Álvarez-Sánchez, C., Coates, J., Christianson, K., & Muehlhoff, E. (2019). A global review of food-based dietary guidelines. *Advances in Nutrition, 10*(4), 590–605. https://doi.org/10.1093/advances/nmy130.
Berge, L., & Ann F. (2008). How the ideology of low fat conquered America. *Journal of the History of Medicine and Allied Sciences, 63*(2), 139–177. https://doi.org/10.1093/jhmas/jrn001.
Walter, W. (1994). Diet and health: What should we eat?" *Science, 264*(5158), 532–537. http://www.jstor.org/stable/2883698.

It's not so easy to stick to a healthy diet even if you want to. Two-thirds of Americans are obese or overweight even though they mostly wish they could lose weight and keep it off. Obesity is a complicated problem that cannot be cured simply by providing dietary advice and encouraging people to exercise more will power (see, e.g., Alston & Okrent, 2017).[10] People eat (and drink) for reasons that go beyond nutrition and health, and obtain utility from other attributes of food and food consumption such as taste and other sensory elements, and not just those but also social dimensions, as discussed by Veblen (1934) and Goldstein (2019), for instance. Apparently, the members of the EAT-Lancet Commission appreciate this aspect of the problem, otherwise they could have taken a much stronger position by recommending an even more significant dietary shift, with even greater benefits to the environment and the economy—e.g., George Stigler (1945) devised a least-cost diet for a working man, which would have cost less than $40 in 1939 (about $690 per year in 2016 dollars) to provide 3000 calories and other nutrients (see Box 3).

Box 3 Stigler's Least-Cost Diet for the Working Man

Stigler (1945) posed the question:

> For a moderately active man weighing 154 pounds, how much of each of 77 foods should be eaten on a daily basis so that the man's intake of nine nutrients will be at least equal to the recommended dietary allowances (RDAs) suggested by the National Research Council in 1943, with the cost of the diet being minimal?

Stigler's 1939 diet		
Food	**Annual Quantities**	**Annual Cost**
Wheat flour	370 lb.	$13.33
Evaporated milk	57 cans	$3.84
Cabbage	111 lb.	$4.11
Spinach	23 lb.	$1.85
Dried navy beans	285 lb.	$16.80
Total Annual Cost		$39.93

[10] Knowledge is not sufficient. For example, Kelly Brownell is a Professor of Public Policy, a Professor of Psychology and Neuroscience, and Director of the World Food Policy Center at the Sanford School of Public Policy at Duke University, who is known for his work on obesity and food policy. Yet even Kelly Brownell struggles with his weight (as described here: https://www.activistfacts.com/person/1289-kelly-brownell/); as does Julian Alston.

Table of nutrients considered in Stigler's diet	
Nutrient	**Daily Recommended Intake**
Calories	3000 calories
Protein	70 g
Calcium	0.8 g
Iron	12 mg
Vitamin A	5000 IU
Thiamine (Vitamin B_1)	1.8 mg
Riboflavin (Vitamin B_2)	2.7 mg
Niacin	18 mg
Ascorbic Acid (Vitamin C)	75 mg

Sources:
Stigler, George J. "The Cost of Subsistence." *Journal of Farm Economics* 27(2) (May, 1945): 303–314. https://www.jstor.org/stable/1231810
https://en.wikipedia.org/wiki/Stigler_diet

This brings us to the question of ability to pay. Hirvonen et al. (2020) evaluated the cost of the EAT-Lancet diet. To do so they obtained retail price observations used by the World Bank to measure poverty and identified the most affordable foods to meet EAT-Lancet targets. They compared total cost per day to each country's gross national income, computed the fraction of people for whom the most affordable ELC diet exceeds household income, and measured affordability relative to a least-cost diet with only essential nutrients. They found that the most affordable EAT-Lancet diets would have cost a global median of $2.84 per day in 2011, of which the largest share was the cost of fruits and vegetables (31.2%), followed by legumes and nuts (18.7%), meat, eggs and fish (15.2%) and dairy (13.2%). This diet might cost a small fraction of available resources in high-income countries, but is not affordable for the world's poor: it exceeds household income for at least 1.58 billion people, and it is also more expensive than the minimum cost of sufficient nutrients; on average, by a factor of 1.60.

While interesting and informative, these estimates are potentially misleading, owing to a fallacy of composition (see, also, Springmann et al., 2018). If the world as a whole were to adopt the EAT-Lancet recommendations, the relative prices of food—held constant in this analysis—would change in ways that could considerably condition the computed costs, potentially making the target diets more attainable for some and less attainable for others. This is reminiscent of the question: how would U.S. agriculture meet the demand for fresh fruits and vegetables if Americans were to eat according to USDA recommendations (an even harder problem if we are to use exclusively organic techniques as some food woke folk would wish)?

Given the consumer cost implications, and the fact that people do not seem likely to willingly adopt the EAT-Lancet diet any time soon, even if it were not more expensive, how might the change be brought about? The EAT-Lancet report proposes five strategies to adjust what people eat and how it is produced, under the rubric of "transforming the global food systems," while leaving it to individual governments to decide the details. The list of possible policies includes three main types: regulation (command and control); incentives (taxes and subsidies; cap and trade); or public persuasion programs (information, education, and promotion). Even the most vocal advocates of the woke food policy agenda do not seem to favor "command and control" methods (though they might wish to do so), nor even heavy-handed taxes, which I imagine would probably have to significantly exceed the Pigouvian optimum to shift consumption far enough to meet the EAT-Lancet targets—at least in rich countries where food is cheap. Rather, the recommendations are expressed in much softer language, many of them focused on influencing producers, in the first instance (Box 4).

Box 4 EAT-Lancet Commission—Strategies for Transforming the Global Food System

The commission proposes five strategies to adjust what people eat and how it is produced, under the rubric of "transforming the global food system."

- Firstly, policies to encourage people to choose healthy diets are needed, including improving availability and accessibility to healthy food through improved logistics and storage, increased food security, and policies that promote buying from sustainable sources. Alongside advertising restrictions and education campaigns, affordability is also crucial, and food prices must reflect production and environmental costs. As this may increase costs to consumers, social protection for vulnerable groups may be required to avoid continued poor nutrition in low-income groups.
- Strategies to refocus agriculture from producing high volumes of crops to producing varied nutrient-rich crops are needed. Currently, small and medium farms supply more than 50% of the essential nutrients in the global food supply. Global agriculture policies should incentivise producers to grow nutritious, plant-based foods, develop programmes that support diverse production systems, and increase research funding for ways to increase nutrition and sustainability. In some contexts, animal farming is important to nutrition and the ecosystem and the benefits and risks of animal farming should be considered on a case-by-case basis.
- Sustainably intensifying agriculture will also be key, and must take into account local conditions to help apply appropriate agricultural practices and generate sustainable, high quality crops.
- Equally, effective governance of land and ocean use will be important to preserve natural ecosystems and ensure continued food supplies. This could be achieved through protecting intact natural areas on land (potentially through incentives), prohibiting land clearing, restoring degraded land, removing harmful fishing subsidies, and closing at least 10% of marine areas to fishing (including the high seas to create fish banks).

- Lastly, food waste must be at least halved. The majority of food waste occurs in low- and middle-income countries during food production due to poor harvest planning, lack of access to markets preventing produce from being sold, and lack of infrastructure to store and process foods. Improved investment in technology and education for farmers is needed. Food waste is also an issue in high-income countries, where it is primarily caused by consumers and can be resolved through campaigns to improve shopping habits, help understand 'best before' and 'use by' dates, and improve food storage, preparation, portion sizes and use of leftovers.

Source:
The Lancet, 2019. "Diet and food production must radically change to improve health and avoid potentially catastrophic damage to the planet." Press release, 16 January. https://www.eurekalert.org/pub_releases/2019-01/tl-pss011419.php

This emphasis on producers and the supply side gives rise to a specific concern. When push comes to shove—given tight government budgets that limit the scope for subsidizing sustainable and healthy production directly, and political constraints on the scope for taxing consumption of unhealthy foods produced using unsustainable methods—one thing that is comparatively easy to do, politically, is to redirect agricultural R&D toward the woke agenda. This has already happened to a significant extent in high-income countries, including the United States, in spite of economic evidence and arguments against the idea.[11] It is one element of the EAT-Lancet recommendations that is within the capacity of national governments to do, and politically safe. Unfortunately, it is also likely to be ineffective for the purpose and to entail a very high opportunity cost (e.g., see Alston et al., 2016b on agricultural R&D as an instrument for reducing social costs of obesity).

This example illustrates a more general problem with proposals to use farm and food policies as means to address diverse and generally wicked social and economic problems such as human health, poverty, and climate change—as proposed by the EAT-Lancet authors and other proponents of the woke farm and food policy agenda. The problem arises because the proponents conflate what may be a very reasonable fundamental purpose (such as human health or environmental sustainability) with less-reasonable ideas about what may be useful and effective (let alone economical) means for achieving the purpose (such as agricultural R&D policy as a way of reducing American obesity). Mis-matching of instruments to targets in these ways

[11] Alston and Pardey (2008) concluded that the available evidence did not support claims that R&D into specialty crops was underfunded. Nonetheless, today's USDA Specialty Crops Research Initiative (SCRI) was introduced in 2008 (based on an initiative in the 1998 Farm Bill), with significant funding dedicated for research into specialty crops, motivated in significant part by a desire to improve American diets. More recently, Pardey et al. (2013a, 2013b) present data documenting the shift of U.S. public agricultural R&D funding away from farm productivity enhancement and towards other topics, many of which are better aligned with the woke agenda, such as climate change, animal welfare, endangered species protection, and environmental pollution.

reflects a more general misunderstanding of the economics of policy design, which can be made worse if combined with other misinformation—such as false perceptions of cause-and-effect connections or a misunderstanding of side effects, behavioral responses, and the law of unintended consequences.

We can find many examples of misbegotten farm and food policy ideas that reflect these forces at work, reminding us that good (i.e., well-intentioned and well-informed) policy design often calls for specialized expertise and processing of complex detailed information that may not be available to everyone. Citizen-consumers recruited to and pushing the woke agenda (and likewise those on the other side of any particular issue) might not have access to the relevant information and expertise and might not realize the error of conflating a worthy objective with an unworthy means. Absence of trust in authorities, experts, and one another makes a happy and sensible solution less likely. Some selected examples illustrate the issues.

Box 5 Natural Wine

In expressing his personal view of natural wine, Nossiter (2019) exemplifies a widespread phenomenon in which moral and ethical perspectives are tangled up with romantic (and inaccurate) notions about science, viticulture, farmers, and enology, and untested claims about the sensory quality of the wine itself; and in this case wrapped in emotive and defamatory language.

> *"The natural wine movement has led many city dwellers like me to see it as the (most chatty) ambassador for the culture of the countryside at a moment in history when the fate of our species may depend greatly on reinventing the urban-rural relationship."*
>
> *"What distinguishes a natural wine? Like organic wines, the vineyards are worked without any herbicides, pesticides or chemical interventions of any kind, with only a tiny amount of copper sulphate. Unlike many organic wines and almost all so-called conventional wines, the yeasts that magically transform the grape sugar into alcohol, enabling the mineral salts to create flavour do not come chemically engineered (often from a lab in Denmark) but spontaneously from the local population of yeasts."*
>
> *"Today it's virtually impossible for me to drink a so-called conventional or traditional wine with any pleasure, especially since what is presented as "conventional"…. is in fact in the most violent rupture imaginable with the conventions of any era, so disfigured by chemicals are their lands and so technically manipulated are the finished wines."*
>
> *"Natural winemakers have confronted their own world of agriculture, a land crushed as if in a totalitarian regime by the transnational megaliths practicing the law of the strong, the principal agents for the murderous abuse of scientific ethics. They have confronted their own craft, the world of wine, transfigured by the mechanisms of big agro on the one hand and disfigured by the cultural lies of the consumer society of the spectacle on the other.*
>
> *And yet in a joyous and pacific but unquestionably insurrectional fashion, they fight. They struggle so that agriculture can once again become culture, what it had been until the era of chemical warfare, speculatory financial orgies, and the anthropocentric arrogance of man as 'artist.'"*

Source:

Nossiter, J. (2019). A manifesto for the agriculture and natural wine: Natural wine challenges Viticultural and cultural norms by being unapologetically connected to nature" *Newsweek*. Retrieved from https://www.newsweek.com/manifesto-agriculture-natural-wine-1455321

2.2 Food Non-Sense and Fallacies

In his 2015 Fellow's Address to the AAEA, titled "Economic Consequences of Food Non-Sense" Daniel Sumner reviewed numerous examples of food markets and policies gone wrong as a result of misbegotten notions about farming and food production—whether related to the water used to grow almonds, the happiness of egg-laying hens, the nature of "pink slime," or the implications of COOL (country of origin labeling requirements) for border trade with Canada in feeder cattle, among others. Sumner (2015, p. 2) defined "non-sense" in this context as meaning "not being sensible as in not being linked to accepted notions of fact or reasoning." He went on to say "Much food non-sense is related to violation of basic facts and reasoning of economics, food and agricultural science or basic arithmetic … things that simply do not add up are non-sense." Defined this way, food non-sense is not something you would expect to see spouted by reasonable, well-informed, and open-minded individuals.

Sumner (2015) presented numerous recent examples of pervasive non-sense in American farm and food policy debates. Apart from errors of facts, basic knowledge, or simple reasoning, some of these examples entailed more subtle errors. In the example of California drought non-sense, many policy commentators made simple errors of fact and arithmetic about which types of water are used to grow almonds, and how much; even worse, however, their obsessive focus on the water content of products implied a "water theory of value"—defying the progress in economic thinking since John Stuart Mill, Alfred Marshall (and others) put paid to the *labor* theory of value proposed by Adam Smith, David Ricardo (and others), and should have done likewise to all such theories.

In his example of California legislation for egg laying hens, Sumner (2015) pointed out that by voting for and passing Proposition 2—a law restricting how hens may be housed in California—in 2008, voters and the legislature in California revealed their misunderstanding of the implications of that decision, which would not change *how* hens were caged but rather *where*; the industry would simply move to other states to avoid the costly restriction. Additional legislation was subsequently passed in a "whack-a-mole" process of policy adaptation to suppress the unintended side-effects of an ill-conceived law, the ultimate upshot of which remains still to be seen. For now, Malone and Lusk (2016) estimate that, because of Proposition 2 and related policies, consumers in California pay between \$0.48 and \$1.08 more per dozen eggs, suggesting an annual loss of consumer surplus of between \$400 million and \$800 million, with no apparent increase in demand for eggs reflecting consumers' valuation of the improved welfare of hens.[12] However, this measure does not include the consumers' perceived benefit from the improved welfare of hens, which may nonetheless be large.

Commenting on this law, Rausser et al. (2019, p. 229) write:

> "…65% of voters favored a ban on products consumed by 95% of Californians who chose to consume conventional eggs over the considerably costlier cage-free eggs. Markets allowed consumers to express their preferences and their values in their egg consumption decisions. For the most part they chose not to express those values in their consumption but rather to express them at the ballot box and impose their values on the majority of other Californians who also overwhelmingly preferred conventional eggs."

However, if the happiness of free-range hens is a public good, individuals might vote to provide such goods publicly (and help pay for them collectively) even if they would not pay the same amount privately to consume only one-nth of the same public good benefit (as discussed by Bovay & Sumner, 2019). By the same reasoning, consumers might not choose personally to switch to free-range and pay much more per dozen eggs if they obtain only a very small benefit per dozen. But they might still vote to pay this premium if doing so means they will receive the same small benefit on *every* dozen, not just the ones they buy. In a similar spirit, even though only a very small number of Americans declare themselves to be vegetarian or vegan—5% and 3% respectively in a recent Gallup Poll (Reinhart, 2018)—a much larger percentage may be willing to support imposing food policies consistent with vegetarian or vegan ethical principles.

Various other, perhaps more persistently popular fallacies, myths, and misconceptions also qualify for the term farm and food "non-sense" in that they seem impossible to dispel even though they should be easy to debunk if simple facts, readily available evidence, and reason were the relevant criteria. For example, many opponents of GMOs claim that genetically engineered crop varieties impose greater risks to human health and a larger environmental footprint compared with conventional varieties. The global scientific consensus disagrees; in fact, the converse is true. Nevertheless, the governments of many countries actively prevent or otherwise heavily discourage GMO crop production. Many Americans subscribe to the same misguided views of GMOs, the most recent manifestation of which is the poorly conceived and economically expensive U.S. GMO labeling law (see, e.g., Bovay & Alston, 2016, 2018). This law requires labels that could only be valuable to subscribers to GMO food non-sense.

Similarly, proponents of organic food production systems may claim that organic food is safer to eat, and organic agriculture has a smaller environmental footprint compared with conventional agriculture. However, while organic farming does use less synthetic pesticide, available evidence does not support the view that organic food has a meaningfully lower food safety risk or is otherwise healthier: Brantsæter et al. (2017, p. 307) conclude "the beneficial health effects of vegetables and fruits

[12] Some of those who supported Proposition 2 might also be surprised to learn that the while some hens now are allowed more movement, those hens have to live with more disease and violence and have higher mortality rates (see, e.g., Sumner et al. 2010).

and other foods recommended in a balanced diet are well documented, but the jury is still out and not ready to conclude whether choosing the organic alternatives would provide additional benefits." Meanwhile, other evidence *does* show that genetically engineered insect-resistant maize has lower food-safety risk from mycotoxins (Wu, 2006)—but reflecting woke food forces at work, GMOs are not allowed in organic farming systems, even though they might help organic farmers in these and many other ways. Moreover, because it is lower yielding, organic farming uses more land and reduces soil organic matter over time—it contributes less to biodiversity (Kirchmann et al., 2016; Kirchmann, 2019).

Various myths about organic products also apply to "local" products—a "food miles" theory of value? As discussed by Sexton (2009), for example, having traveled fewer miles does not mean a product is fresher and has a smaller carbon footprint, nor that it was produced by a small family farmer using desired production practices, or anything like that (see, also, Coley et al., 2011). Nonetheless, in spite of abundant evidence to the contrary, many consumers will pay a premium for food products labeled as local or organic, apparently in the belief that they are buying products that have desirable environmental attributes (see, also, Winfree & Watson, 2017).

The same phenomenon is apparent in the market for craft beer, where consumers seem to conflate small-scale, local, and artisan attributes of beer production systems in "craft," the antithesis of which is a macro-brewery owned by one of three multinational conglomerates. Though it need not, "local" could be construed to imply "fresh" which is a valuable attribute in beer, but if freshness is important it can be best communicated by a "brewed on" date on the label. Jarrett Hart (2019) has shown that these aspects are valuable to consumers, while Robin Goldstein (2019) has shown that beer and wine consumers are not well able to discriminate among different brands of similar beverages (e.g., different European lager beers) in blind tastings; label claims are a crucial part of the value chain.

A final example pertains to food policy and obesity. In spite of abundant and clear economic evidence to the contrary, it is still commonly claimed at public health conferences and in the media that farm subsidies constitute a major cause of the American obesity epidemic, and that changing farm policy would contribute significantly (and economically) to reducing the problem. That perspective is entrenched in the views of at least some of the significant public policy commentators in this context and embedded in the EAT-Lancet report, which is no surprise since its lead author, Walter Willett, is a persistent proponent of the farm subsidy theory of obesity. We shall return to this issue.

Sumner (2015) discussed several others, and I could raise many more examples of food policy non-sense. Rather than do that I will note that these kinds of issues have been targeted in a growing mythbuster literature that includes the articles by Rausser et al. (2015, 2019) and books and other writings by Jayson Lusk (2013, 2016, 2017, 2018) among others. Given this growing attention from agricultural economists, a natural question to ask is whether this problem of food policy non-sense is becoming worse. And we can also ask if, as my title suggests, the woke food policy movement is contributing to that worsening state in ways that are exacerbated by increasingly ill-informed (post-truth) policy decision-making.

3 The Best of Times, the Worst of Times?

Are we going to hell in a handbasket? Some food policy advocates sometimes seem to be suffering from a sentimental romantic reminiscence of a lifestyle that may never have existed, except in their imaginations. I have many fond memories of life growing up and working on a "small family farm," but no desire to return to an occupation of mostly hard, often boring, and sometimes dangerous work for highly uncertain but generally low returns—especially as I grow older and less physically able to do those things. Conscious of this tendency in others to romanticize the past, and perhaps more so as we grow older, I wonder if I, too, might be wearing rose-colored nostalgic glasses as I reflect on the evolving nature of the discourse surrounding farm and food policy, the institutions, and the policies themselves.

It does seem to me that—compared with, say, the 1970s and 1980s—we are living in a time when, broadly speaking, facts and evidence, knowledge and expertise, are becoming less relevant in public policymaking and in many respects farm and food policies are getting worse. But is it really so? I don't think I can provide a good general answer. I can however offer some potentially thought-provoking examples, and I can suggest that in at least one or two important areas that I care about, "things" do appear to be getting worse in ways that I can document. And I can (try to) connect these aspects to the woke food movement. Before I begin to do that, however, I want to record some reasons for questioning my pessimistic perceptions.

In their excellent book, "Factfulness" Rönnlund et al. (2018) illustrate how we tend to be too pessimistic about the rate of progress in reducing the incidence of poverty, improving human health and life expectancy, and other aspects of the human condition. It is a persuasive story that can also be seen in various video presentations from Gapminder, available online (https://www.gapminder.org/), featuring Hans Rosling. (What about rising income inequality and its implications for social strife?) Similarly, in his book "The Better Angels of our Nature," Steven Pinker (2011) documents how we tend to be too pessimistic about other aspects of civil society—grossly underestimating how much violence has declined. Likewise, in his books and other writings Matt Ridley (2010, 2015) provides an optimistic view of progress in the human condition. These various writings belie more pessimistic perceptions that may come from within our nature as well as from a tendency for the mass media to emphasize bad news (see, e.g., Mullainathan & Shleifer, 2005; McCluskey & Swinnen, 2011; McCluskey et al., 2015). So, perhaps we should not trust our subjective perceptions too much and should rather try to find some evidence on these questions.

One obviously pertinent example is measures of economic distortions associated with farm price and income support policies. Have these policies generally got better or worse over time? Are they currently tending to get better or worse? Anderson et al. (2013) present a comprehensive analysis of these questions. The answers are not simple because, as their work reveals, as countries become richer they tend to switch from taxing agriculture to subsidizing it. So, the trends are diverse, though there would appear to be some convergence. And the instruments of support change, too. Policies have tended to shift over the past 50 years or so toward more open international trade in farm products and generally less trade-distorting instruments of farm price and income support (e.g., tariffs rather than quantitative trade restrictions), though they might be sliding back.[13]

The authors appear to conclude affirmatively about both policy and the prospects for economists to contribute to it:

> "In conclusion, we find that our profession has made material progress in the political-economic analysis of agricultural and food-policy distortions across the globe. … [B]ased on enlightened political-economic analysis, sustainable policy reform can be implemented, inter alia, by sound advice in the face of crises, changes in governance structures, political entrepreneurship, provision of information and mass media, effective compensation to counter recalcitrant interest groups, and breaking up powerful coalitions that detract from the public interest. Moreover, understanding the forces that drive agricultural-policy choices can ultimately contribute to designing policy options to address a number of current global concerns, such as food security, energy security, and climate change." (Anderson et al., 2013, p. 469)

However, though the quoted passage in itself is indisputable, the sentiments expressed could be interpreted as a prayer rather than a prediction or a promise, and they do not say whether the prospects for economists to contribute usefully to policy are waxing or waning.

3.1 Sin Taxes and Related Regulations

Some stories about U.S. experience with sin taxes and related regulations offer some different insights into how policies are made and the potential roles of activists versus expert analysts. In the early 1980s, Daniel Sumner and Julian Alston conducted a study on behalf of some anti-tobacco activists to evaluate the consequences of the farm program for U.S. tobacco. Sumner and Alston (1984) found that, compared with (hypothetical) deregulation, the tobacco program discouraged smoking, increased U.S. overall economic surplus (perhaps as much as possible using tobacco quotas), and did not cost U.S. taxpayers anything. These findings contradicted common perceptions (and some experts: see U.S. Government, Council of Economic Advisers, 1987, p. 159) and disappointed the activist clients who had imagined that the farm program for tobacco was encouraging production of tobacco and smoking, when in fact the opposite was true.

[13] Conversely, Malik et al. (2013 p. 13), assert that "The worldwide increase in obesity and related chronic diseases has largely been driven by global trade liberalization, economic growth and rapid urbanization."

This is reminiscent of recent commentary on U.S. farm programs as a contributor to obesity. Contrary to widespread commentary by food writers and other promoters of the woke food agenda, U.S. farm program policies on the whole make food more expensive and, if anything, discourage consumption of calorie-dense foods and reduce obesity (see, e.g., Alston et al., 2008; Alston et al., 2016a; Alston & Okrent, 2017). These findings been widely publicized but the alternative (misguided) viewpoint is stubbornly persistent, and misguided positions on policy are likely to result (see, e.g., Malik et al., 2013; Rodgers et al., 2018; Ludwig & Rogoff, 2018). The same people most likely have it wrong on policies for taxing sugar-sweetened beverages, too, but this is a case where the issue is more nuanced: many economists have conducted analysis that would appear to support such policies (see, e.g., Allcott et al., 2019a, 2019b). The anti-sugar lobby is pushing hard for ever-stronger measures against today's bête noir beverage, and some might even favor banning it altogether.

America's experience with Prohibition offers some lessons about such policies. Temperance was a "woke" (in the sense I use the term) activist movement, personified in Carrie Nation and the Anti-Saloon League, dedicated to reducing the social harm from alcohol by banning its sale, especially by saloons. They succeeded. As described by Daniel Okrent (2010) in "Last Call: The Rise and Fall of Prohibition" it took a concentrated, dedicated, politically astute effort over a period of eight decades, combined with some considerable serendipity, to accomplish this seemingly impossible purpose. Critical elements included (1) the introduction of the income tax via the 16th Amendment to the Constitution in 1916, which was necessary to provide a source of revenue to replace the alcohol excise tax income that would be foregone; (2) America's entry to World War I in 1917, and the ethnic connections of the U.S. brewers to Germany; (3) temperance serving as an issue of focus and a galvanizing force for women's suffrage (enacted in the 19th Amendment to the Constitution in 1920), since women and children were the main victims of alcoholic excess by their husbands and fathers; and (4) a Gerrymander resulting from lags in adapting electoral boundaries following massive rural-urban migrations, which meant dry rural voters were over-represented prior to substantial congressional "reapportionment" in 1920. The movement created and seized the opportunity and succeeded in winning the required super-majorities in the Senate and among the states just in time. The National Prohibition Act (the 18th Amendment to the Constitution), aka the Volstead Act, was passed in October 1919, and held force until Repeal in 1933 (the 21st Amendment to the Constitution), which seemed to be an even less likely prospect given the required supermajorities.

Stories abound about the consequences of Prohibition. To many of us it may seem obvious that it was a misguided policy that did not work and had many woeful unintended consequences. This is the conventional wisdom. However, scholarly work suggests that speakeasies and bootleggers notwithstanding, Prohibition had immediate effects on reducing alcohol consumption, destroying the liquor industry, and closing the saloons; and, even after Repeal, long-lasting effects on alcohol consumption patterns and culture in the United States (see, e.g., Blocker et al., 2006). It was at least partly successful. In hindsight, perhaps a different approach might have worked better—as in the efforts of the anti-tobacco movement, which focused on punitive taxation and public education programs rather than an outright ban—but such counterfactuals are difficult.

Another interesting comparison is between Prohibition (and Repeal) and the "War on Drugs" declared unilaterally by President Ronald Reagan in 1986, building on a foundation laid by President Richard Nixon in the 1970s. The former came about through decades of political pressure by "woke" activists and was enacted only by overcoming formidable Constitutional hurdles; the latter by a stroke of the Presidential pen. The War on Drugs, like Prohibition, has had many unintended and regrettable consequences, and many pundits would call it a failure; but this is another case where cost-benefit analysis is challenging. Nevertheless, with many states, including California, now having legalized marijuana it is easy to look back and wonder about the wisdom of having imprisoned young people for years for the possession of small amounts of weed. Neither of these two ways of making laws concerning sin taxes and related regulations seems totally satisfactory. Both could benefit from a greater use of evidence on likely consequences as a foundation for informed policy choice, as we might imagine would be part of normal business in effective representative government, addressing complicated social policy problems. Looking forward, issues come to mind about the sources of information—about policy alternatives and their likely consequences—available to today's woke activists and their constituents, and for elected representatives and theirs, and how information is used in policy decision-making.

4 Post-truth Policy Problems

Informed perspective on farm and food policy issues often calls for detailed, sometimes technical understanding of complicated biophysical and economic relationships. In an ideal world we might rather delegate decision-making on such issues to trusted elected representatives who could draw on relevant sources of detailed advice. Much of the focus of many woke food activists is on difficult, complex issues of this nature, where they demonstrably do not have the relevant technical expertise or detailed knowledge. Yet many people seemingly trust these activists more than they trust traditional official sources and other experts.[14] The term

[14] Perhaps in the past people were more willing to trust authorities and experts than they are today. Or perhaps they simply reject the idea of expertise. This is the thesis of the book by Tom Nichols (2017a) "The Death of Expertise: The Campaign Against Established Knowledge and Why It Matters." The "death of trust" is another topic worthy of attention, if we had time and space. So, too, is the related issue of the rise of "managerialism" in the public sector whereby subject matter experts have been systematically replaced with professional bureaucrats. This systematic reduction in the stock of technical, subject matter expertise in the public sector gives grounds for citizens to have less confidence in the reliability of the authorities to make well-advised choices. The COVID-19 pandemic provides myriad examples where mismanagement, at least in part owing to ill-qualified managers, has resulted in poor public policy design and implementation—such as in Melbourne in 2020 (see, e.g., Sheridan, 2020).

"post-truth" entered the lexicon to describe this phenomenon. It is defined as "relating to or denoting circumstances in which objective facts are less influential in shaping political debate or public opinion than appeals to emotion and personal belief."

4.1 Failure of Markets, Institutions, and Government

Part of the story with food policy "non-sense" is that people are simply ill-informed. Facts matter. Where people get their information is changing and this can have implications for what they "know" and therefore what positions they take in relation to farm and food policy. The rise of mass media and electronic communications generally has no doubt been an enormous economic boon. Markets generally work better and at much lower cost using these modern means. Crowd sourcing is an effective way of learning about products and prices, and buyers and sellers are able to connect and communicate better than ever at much lower cost. Many lives have been highly enhanced by Facebook, RateBeer, Zillow, Tinder, and Autotrader, to name just a few personal favorites. However, it also seems clear that the same tools have facilitated the rise of clearly and demonstrably false ideas such as the canard that vaccination causes autism, that GMOs threaten human health and the environment, or that Donald Trump is fit for public office. As Nichols (2017b, p. 3) says (in a section titled "Welcome to the Idiocracy"): "Information technology, however, is not the primary problem. The digital age has simply accelerated the collapse of communication between experts and laypeople by offering an apparent shortcut to erudition. It has allowed people to mimic intellectual accomplishment by indulging in an illusion of expertise provided by a limitless supply of facts."

This rise of "alternative truth" would be less of a concern if the consequentially ill-informed views were not playing a role in policymaking. This can happen in various ways. One way is directly through the ballot box. As discussed by Nichols (2017a, 2017b) a well-informed electorate is important for the effective functioning of representative government, and for other democratic institutions. Several of our finest examples of food policy non-sense in California were created through the system of Propositions, by which plebiscites substitute for representative government. As exemplified by Proposition 2, which passed in 2008, and Proposition 37, a proposal for mandatory labeling of genetically engineered food that (barely) failed in 2012, these processes can be heavily influenced by media advertising campaigns, funded by vested interests, and increasingly through social media, where the food movement may have some advantages compared with the food industry.[15] It is not clear that voters understand the issues or are expressing preferences over them per

[15] Joseph Mercola, a prominent funder of Proposition 37 revealed: "Personally, I believe GM foods must be banned entirely, but labeling is the most efficient way to achieve this. Since 85 percent of the public will refuse to buy foods they know to be genetically modified, this will effectively eliminate them from the market just the way it was done in Europe." (http://vtdigger.org/2012/04/17/wanzek-genetically-modified-food-is-perfectly-healthy/)

se, rather than responding to other political factors in this context (see, e.g., Alston & Sumner, 2012, Bovay & Alston, 2016, and Bovay & Sumner, 2019).

A second way in which the woke food movement can influence outcomes is through activism designed to influence individual citizens, elected representatives, and industry participants. A well-organized vocal minority can have a disproportionate effect on policy outcomes, as illustrated for example by the remarkable effectiveness of two NGOs, Greenpeace International and Friends of The Earth International in persuading the world largely to oppose genetically-engineered food (see Paarlberg, 2014; Qaim, 2016; Lynas, 2018)—an example of the tyranny of the Greens![16] They can accomplish this purpose without necessarily persuading a majority of producers or consumers to agree with their position if they can persuade market intermediaries or other regulators that it will be in their interest to comply. Persuasion could entail an implicit or explicit threat of political action against food manufacturers or retailers who opt not to toe the line. This appears to be the story with GMOs in Europe and the United States, where the industry has declined to adopt or has disadopted technologies because food manufacturers and retailers have found it expedient to declare that they will not use or stock the products—such as milk produced using rBST. Many other examples can be found where market intermediaries are crucial determinants of food policies.

Saitone et al. (2015) ask: what happens when—responding to pressure from food activists—market intermediaries require farmers to adopt restrictive production practices, such as antibiotic-free (AF) pork? This is a growing trend and more insidious than the referendum process that led to Proposition 2. Saitone et al. (2015, p. 1022) discuss examples of buyer restrictions on animal production practices, including requiring cage-free eggs and pork products produced without the use of gestation crates and with specific limits on the use of antibiotics. These authors reported that Burger King, Hyatt, and Sodexo were planning to sell only products made from cage-free eggs; that Chipotle sells only pork that it claims is "all-natural," and "antibiotic-free," and other major restaurant chains were contemplating related standards for their suppliers; and that key buyers embarking on a program to eliminate gestation crates from their pork supply chains included restaurant chains such as Applebee's, Denny's, and grocery retailer Safeway. The same authors also listed examples of restrictions on products made from plant materials: General Mills requiring non-GMO inputs for its Cheerios cereal, Post doing the same for its Grape-Nuts cereal.

These "woke-washing" private standards are tantamount to technological regulations, albeit imposed by private agents. Woke food forces are also active in advocating direct government regulation of agricultural and food technologies. In addition to the examples related to animal welfare, food safety, and GMOs, mentioned above, other recent examples include tighter regulations or total bans in Europe and in some U.S. jurisdictions on the agricultural use of the herbicide glyphosate (the

[16] Taleb (2016) discusses situations in which a "minority rule" can prevail, including various food examples (kosher and non-kosher food, GMO and non-GMO food) if the majority is largely indifferent, the minority has a strong preference, and it may be costly to segregate products.

primary ingredient of Roundup), because of unsubstantiated concerns over cancer risks, and several neonicotinoid insecticides because of unsubstantiated concerns over environmental risks, especially to pollinators. These technological regulations add to costs of food and farming without necessarily yielding the benefits imagined by the activists and their supporters. Similar types of consequences follow from woke-induced distortions of agricultural R&D policy, another way of limiting technological possibilities available to farmers and food manufacturers.

4.2 Agricultural R&D as an Instrument of Social Policy

Mechanism design calls for specialist skills that are sadly lacking in populist policymaking by plebiscite. This is well illustrated by the examples of food policy nonsense in which factual errors are combined with a lack of basic economic understanding. Common mistakes include misunderstanding of opportunity cost, the "Nirvana fallacy" of comparing imperfect actual situations to idealized hypothetical alternatives (Demsetz, 1969) and failing to grasp the basics of counterfactual comparisons. A more subtle but important issue is the idea that we want to have at least one policy instrument per objective, and we want to match instruments closely to targets—i.e., the Tinbergen Rule. Even specialist economists can miss this point, as is illustrated by the case of taxation of sugar-sweetened beverages (SSBs).

Clearly, taxing a narrow subset of the class of foods containing added sugars, which is itself a narrow subset of the class of calorie dense, obesogenic foods, must be an nth-best policy for reducing obesity and diabetes. Yet this point is rarely noted even by economists who report the salutary health effects and social benefits from soda taxes. (see, e.g., Wilde et al., 2019). It is interesting to compare a soda tax against the alternative of no policy, but surely the more relevant comparison should be with alternative policies that are obviously more likely to be closer to first or second best—such as taxing all foods containing sugar, according to their sugar content, or all sources of calories, or obesity itself—and why not "cap and trade," which could be less regressive on the poor?[17]

Economists writing on the issue have not complained nearly enough about the fact that beverage taxes per ounce of beverage are less-well-targeted than beverage taxes per ounce of sugar content, let alone policies that are well-designed, taking into account all relevant contributors to obesity, and chosen with a view to minimizing social cost of distortions. A significant recent example is Allcott et al. (2019a,

[17] Alston and Okrent (2017) compared food taxes based on content of various nutrients such as fat and sugar and total calories, finding as expected that calorie taxes are more economically efficient at reducing consumption of calories. In an article titled "The case for taxing sugar, not soda" Dewey (2016) refers to U.S. studies that have made the point, and reports that (unlike their U.S. counterparts) Britain and South Africa have adopted SSB tax policies that more heavily penalize drinks with higher sugar content.

2019b) who present a partial equilibrium analysis of the consequences of a tax on SSBs, drawing on the extant evidence. They conclude with a list of guiding principles for policymakers. In that list, number 3 is "tax grams of sugar, not ounces of liquid," which is a good point. But immediately before that list is their bottom-line recommendation: "an optimal tax of about 1.5 cents per ounce." Furthermore, they do not make the point that taxing sodas is inferior to a broader-based tax, even if the optimal rate of taxation may be higher for soda than for other sources of externalities and internalities from food consumption.[18] Nor do they compare to other narrow-based taxes.[19] Policymakers could be forgiven for inferring that economists say (even agree!) it is socially optimal to tax SSBs.

This brings me—at long last—to my main point, which is that many if not most food policy pundits, and not just the leading lights in the woke food policy movement, have missed the point about targets and instruments, especially in the context of agricultural R&D (or innovation) policy. Too many people propose to use agricultural R&D as an instrument of social policy, an objective for which it is ill-suited and awfully expensive.

The economic rationale for government involvement in agricultural R&D (of which public investment in agricultural R&D is a major element) is to correct market failures giving rise to an underinvestment in agricultural R&D, and a rate of agricultural innovation that is consequently too slow. Given this narrow purpose, the optimal intervention would result in a combination of public and private investments in agricultural and other R&D whereby the marginal social rate of return is equal to the marginal opportunity cost of the funds invested at the margin, a marginal benefit-cost ratio (BCR) of 1:1. On all the available evidence, on top of market failure we have government failure. Even though the relevant BCRs are very high, on the order of 20:1 and higher (e.g., see Alston et al., 2010), we see shrinking investments in public agricultural R&D. And we see a progressive shifting of the balance within the U.S. public agricultural R&D portfolio away from the types of topics that have historically yielded the highest payoffs towards topics that fit better with the woke food agenda and do not clearly promise comparable payoffs (see, e.g., Pardey et al., 2013a, 2013b).[20] Some of this might well be described as

[18] Taxing SSBs almost surely encourages the consumption of diet sodas, and the findings by Allcott et al. (2019a, 2019b) and others on taxing SSBs have turned on the assumption that diet sodas are safe to drink with no adverse health consequences. However, Mullee et al. (2019, E1) found otherwise: "In this population-based cohort study of 451,743 individuals from 10 countries in Europe, greater consumption of total, sugar-sweetened, and artificially sweetened soft drinks was associated with a higher risk of all-cause mortality. Consumption of artificially sweetened soft drinks was positively associated with deaths from circulatory diseases, and sugar-sweetened soft drinks were associated with deaths from digestive diseases."

[19] Moore and Fielding (2019) cite Scheelbeek et al. (2019) suggesting taxes on high sugar snack foods might be more effective than taxes on SSBs at reducing obesity rates in the U.K.

[20] In the 2018 Farm Bill, for instance, the budget for agricultural R&D is essentially flat in nominal terms, but it includes increased funding for the Specialty Crop Research Initiative and the Organic Research and Extension Initiative—the budget for the latter growing to $20 million to $50 million per year from 2019 through 2022.

agricultural R&D non-sense, attempts to use agricultural R&D as an instrument for reducing environmental externalities, or obesity, or for achieving some other social purpose.

A prime example is agricultural R&D as an instrument of health policy: as a means of combatting obesity. This is an implicit (if not explicit) recommendation in the EAT-Lancet report and in other places where people propose increased public support for production of "healthy" foods to encourage an improvement in diets. Alston et al. (2016b) evaluate this idea, specifically. They conclude that redirecting agricultural research priorities is a generally ineffective and highly expensive way of fighting obesity, other approaches are likely to be more effective and more economic. They show it would require a very significant reduction in agricultural research investments and thereby in productivity growth to achieve a significant reduction in obesity rates. Such a policy would have a huge social opportunity cost because reducing research spending would exacerbate an already serious underinvestment.

As Alston et al. (2016a) explain, for example, a 10% increase in past public funding for fruit and vegetable R&D with a concomitant decrease in past public funding for other farm commodity R&D would have resulted in a reduction of 6 calories per day per adult, implying a 0.79 lb. reduction in steady-state U.S. adult body weight. However, to reduce body weight using this approach would cost consumers \$60–\$90 per pound of weight lost, which would hugely outweigh the savings in public health-care costs of about \$4.35 per pound. Moreover, this is an extremely expensive way to reduce obesity compared with more-closely targeted policies. For instance, a tax on food according to its caloric content would cost consumers only \$0.86 per pound reduction in their body weight, and would yield a net social benefit. Moreover, given the very long lags involved (e.g., see Alston et al., 2010), it may take 20 years or longer until a change in research spending would have its full effect on farm commodity prices and thus food prices and obesity, which seems far too long relative to the current concern.

A similar argument can be made about environmental science, especially policy-oriented environmental science, as discussed by Pannell et al. (2018). Environmental externalities may call for environmental policy, such as Pigouvian taxes on carbon emissions, and imposing a carbon tax may suffice to incentivize industry both to adopt emissions-reducing technologies and to undertake R&D to develop those technologies. But, absent those taxes, undertaking environmental science in the public sector to develop emissions-reduction technology may be totally worthless if industry is not incentivized to adopt the innovations. In other words, R&D policy is no substitute for environmental policy though it can be complementary to it. This type of thinking is not clearly present in the minds of those who control the R&D purse strings.

Agricultural R&D is a powerful instrument for reducing poverty around the world. With that in mind, should agricultural R&D resources be focused more heavily on technologies for resource poor farmers on marginal lands? Or should the research portfolio emphasize those parts of agriculture where the potential total payoff is greater and leave it for other policy instruments to be used to tackle income distribution concerns? At least some development agencies are leaning in the direction of focusing on poor farmers. But in thinking about this question, we should perhaps pay attention to the fact that R&D takes time to take effect, perhaps 20 years or longer, and by 2050 the majority of the world's poor will be living in cities. For these people, the greatest benefits may come indirectly from agricultural R&D that makes staple foods cheaper, regardless of who grows them or where (Byerlee, 2000; de Janvry & Sadoulet, 2002). As well as having a high opportunity cost in terms of overall welfare, diverting resources away from that type of R&D may also exacerbate poverty among the urban poor, while other policy instruments that have a lower opportunity cost might be more effective at reducing poverty among subsistence farmers.

In a similar vein, also mainly to help the poor, some propose that public R&D priorities should be designed to help reduce malnutrition by promoting production and consumption of food with a better micronutrient profile. For example, genetic research could focus on biofortification, such as in golden rice, which expresses β-carotene, a vitamin A precursor; or for food crops containing more iron or zinc. The relevant question, once more, is whether such an approach will be effective and economically efficient compared with other instruments for reducing malnutrition, given the high opportunity cost of foregoing public R&D focused simply on maximum total social benefit.

5 Calamitous Consequences for People and the Planet

Along with other elements of agricultural technology policy, public investments in agricultural R&D and innovation have consequences for global public goods associated with poverty, health and nutrition, climate change, and peace. These investments matter. Over the past half-century, while the world's population more than doubled, the quantity and real value of agricultural output more than trebled, even though land in agriculture increased by only about one-tenth (Alston & Pardey, 2014). Much of these past gains can be attributed to organized agricultural R&D, mainly conducted in today's high-income countries.

Defying the dark neo-Malthusians prophecies of the 1960s, food has become much cheaper in real terms despite us having a much larger and richer global population to feed. In the second half of the twentieth century, in particular, global food supply grew faster than demand and real food prices fell significantly, alleviating hunger and poverty for hundreds of millions around the world. The recent significant slowing of the long secular decline in real food commodity prices stimulated a renewed interest in questions about the long-term path of agricultural productivity. Has the "golden age" of agricultural productivity growth ended? Can the recent past pattern, or anything like it, be sustained in the twenty-first century, given that global demand for food is projected to grow by 70% from 2010 to 2050 (Pardey et al., 2014)? The answers will depend fundamentally on the future path of farm productivity growth, driven primarily by organized agricultural R&D, filtered by technology policy.

In some senses we are at a crucial turning point, because the main players on this stage have changed roles. Sixty years ago, on the eve of the Green Revolution, today's high-income countries dominated both agricultural production and agricultural science. These countries provided the technologies that helped lift billions from poverty in Asia and Latin America. More recently we have witnessed a rise in the relative importance of the middle-income countries, especially China and Brazil, and to a lesser extent India, both as producers of agricultural products and as investors in agricultural R&D: China and the United States have switched roles (see Alston & Pardey, 2019; Pardey et al., 2013a, 2013b, 2016). This changing world order in agricultural R&D reflects slower (or negative) growth in real spending by the high-income countries contrasted by rapid growth in real spending by China and Brazil, in particular.

At the same time, and partly for the same reasons, growth in agricultural production and productivity has slowed considerably in the high-income countries. The world has come and is coming increasingly to depend on the middle-income countries both to produce most of the world's food and to conduct the science and technology to enable that food to be produced more efficiently. What remains to be seen is whether these countries will continue to invest at the current growing rates, and if they will make the resulting technologies broadly available to the lower-income countries, which will continue to depend on technology spillovers from richer benefactor nations. These are the key elements of the turning point we face, which will determine the time path of the world food equation and food poverty patterns.

The woke food movement can be held responsible for at least part of the slowdown in both farm productivity growth and spending by the high-income countries on agricultural R&D to enable it. Farm productivity growth and affordable food are not high on the agenda for many of the food activist groups in high-income countries. These groups can potentially make matters much worse by continuing to press for a diversion of research resources away from farm productivity growth towards other topics—for which public agricultural R&D is not clearly the right policy instrument—and by continuing to press for technological regulations that prevent the development and adoption of productivity-enhancing technologies.

Of particular concern in this context is the widespread opposition to both chemical technologies (synthetic pesticides, fertilizers, hormones, and the like) and the genetic technologies that might replace or complement them. Much of the great potential in agricultural science today lies in crop and livestock genetics, if only we can make full use of the complete tool kit of modern biotechnology.[21] But NGOs

[21] Around the world "organic" rule-makers arbitrarily preclude genetically engineered varieties, and they seem likely also to opt to preclude gene-edited. This is a shame. Genetically engineered (or gene-edited) varieties would enable organic farmers to use a lot less pesticide, and if permitted in organic production would enable many more farmers to qualify as organic. The wine-grape industry exemplifies these issues especially well. Genetic solutions could save great expenditures on fungicides that impose a considerable environmental burden—even among organic farmers that

and other woke food advocates are extending their opposition to genetic engineering to encompass gene-editing, and some are even opposed to marker-assisted selection. This is indefensible in the face of the relevant scientific evidence and unconscionable in light of its implications. If these groups succeed in blocking gene-editing (and other, related technologies) to the same extent as they have blocked genetic engineering, the consequences for people and the planet will be calamitous, indeed. Preventing (or slowing) productivity growth and thereby denying the poor access to affordable food can be expected to have many undesirable consequences beyond the immediate and obvious increases in poverty, hunger, and misery of the world's poor; also more strife, more demand for scarce natural resources, faster climate change.

Similar things may be said about some other aspects of the woke food agenda, but to do so usefully requires a case-by-case discussion. Rausser et al. (2019) make a start on this, but much remains to be done. As noted above, we all might well agree with many of the objectives, but it matters also that we understand the facts of each specific situation and match the means well to the purpose. In many cases activists propose and press for ill-conceived farm and food policies that will do more harm than good. This is perhaps especially so when we are dealing with the types of large, interconnected global issues that are the focus of the EAT-Lancet report: poverty, malnutrition, climate change.

6 Conclusion

The woke food movement is a relatively recent phenomenon, more prevalent in high-income countries where food is comparatively abundant, and, within those countries, more associated with rich liberal elite groups than others. Perhaps this movement is doing some good, by generating interest and discussion about issues that matter. But it is easy to find instances where they have done harm and to see possibilities for more harm to come. This happens because the movement is essentially intolerant, insisting on imposing its views on others even if those views turn out to be ill-informed (or simply silly), and even if a majority may disagree with them.

We have already seen calamitous consequences from misguided policies initiated by such interests—witness the global opposition to genetically engineered food, and particular examples such as golden rice, with their consequences for the poor—as well as a multitude of more minor instances of food policy non-sense that collectively may loom large in terms of their overall social cost. Of current concern is the possibility that these forces are becoming more influential as we are all coming to depend more on social media and non-traditional sources for information

use great quantities of sulfur and copper, which are permitted (see, e.g., Alston & Sambucci, 2019; Sambucci et al., 2019). It seems incongruous for the "greens" to rule out technologies that would facilitate a "greener" production system.

about issues that are sometimes complex. When farm and food policies are made by plebiscite, and voters are ill-informed, policy non-sense seems more likely. Some further harm can be done, even without the involvement of government, given the role of market intermediaries as gatekeepers in the food chain, imposing private policies as de facto technological regulations at the behest of activist groups.

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Future of Food Economics

David R. Just

1 Introduction

A decade wise search of the newspaper archives housed online by the Library of Congress reveals a long-standing concern with hunger and malnutrition in the United States.[1] This ranges from concerns about food riots in the mid-1910s to more specific concerns about southern blacks facing hunger in the early 1960s. There are the occasional pieces detailing the opening of new stores, but few articles concerned with food that are not also linked to a food scarcity issue. This is in stark contrast to the food-related headlines that are common in our day that cite myriad concerns. This includes concerns about the links between specific foods and disease or mental health, concerns about the impact of food and food waste on the environment, concerns about specific ingredients or production methods and perhaps most prevalent are concerns about obesity.

A similar decade wise search of Google Scholar for articles dealing with food policy finds an overwhelming predominance of papers concerned with food scarcity, and its human, micro, and macro-economic toll from the earliest covered dates. A few articles examining obesity appear along the way, but a substantial shift began around 1980. In that year, Paarlberg (1980) in a piece attempting to anticipate the farm issues of the coming decade, notes that due to rising farm incomes and reduced food prices, there were a much wider set of constituents beginning to influence food policy. This included organizations that were concerned with environmental impacts

[1] See https://chroniclingamerica.loc.gov/.

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of farming, food safety and nutrition, among a handful of other causes. Each of these was championed by specific lobbying groups and engaged directly with policymakers.

Indeed, one could have extrapolated the trends that Paarlberg identified to reasonably predict the world in which we live some forty years later. The number of constituencies influencing food and food policy have only multiplied. Perhaps in part due to the Internet and its ability to amplify small groups, food issues have become democratized like never before. To many, food is now a tool to engage the grand challenges that face society: oppression, war, climate change, systematic failures of capitalism, sustainability, diet related disease, obesity, and hunger. The list of causes that now intersect food policy in important ways is seemingly endless. This has led to policy discussions that are ever more radical in their tenor even among those originating from large and respected policy or research institutions. In compiling this chapter, I was asked to discuss the future of food and food economics. At the moment, there is no shortage of commentary on how food will (or rather should) evolve over the coming decades. Hence, I have taken as my purpose to both highlight the major proposals that have attempted to set the agenda for food policy going forward, but also to critically examine their underpinnings from the lens of an applied economist. As we have moved away from simple questions like "how do we increase the availability of food?" we have also found ourselves with contradictory and perhaps unattainable goals. Moreover, many of the biggest and best funded policy movements in food are now so disconnected from applied economics that they may fail to realize the substantial (perhaps cataclysmic) risks and costs involved in their proposed policies. While food assistance policies in the past were motivated by a rising tide that would help both consumers and producers (Natural Resource Council, 2013), these newer policies are apt to produce substantive losers with costs, potentially saddling them with costs that are not possible to overcome. How do we meet these competing goals? Or, at very least, how do we approach them and prioritize them?

In what follows I will discuss the research that is fueling the major movements in food policy in the context of agricultural and food economics. While one cannot predict the future, it appears clear that these movements and their policy goals will play a major role in shaping food policy, and perhaps the food crises in the coming decades. Much of this recent research supports the view that drastic and immediate change is desirable, but largely ignores the historic and sociological role of food that makes such change not only costly, but also risky. The social implications of food are an important component and one that if ignored will make serious conflict inevitable. Thus, I begin in the next section by discussing the important social aspects of food that are often glossed over when considering food policy at a global scale. I then outline the research calling for vast and drastic changes to the food system. This is not the first attempt at making such massive changes in food systems. With many past successes and failures to learn from, it is important to characterize the changes that were successful and those that were not. I use a discussion of such changes in history as a backdrop to discuss the potential dangers of such change, as well as how we could mitigate risks while still attempting substantive change.

2 Food Is More than Food

Humans, perhaps by nature, develop a close relationship with food. Food is one of the first touchstones we identify with any culture. We not only take food into our bodies—already a very intimate action—but food literally becomes part of us through the physical process of digestion. We are what we eat. It is perhaps no surprise that food became the subject of religious beliefs even from the earliest recorded history of man (Palmer & Van Der Veen, 2002).

The symbolism of ingestion has not been lost even on our earliest ancestors that would ritually consume sacrifices as a symbol of becoming holy (Norman, 2012). The act of sacrifice sanctified a food and made it holy, while ingestion internalized that which was holy. This tradition is alive today as religious people have a tradition of blessing and sanctifying food prior to eating and is more pointedly observed in the Christian practice of communion. Consumption of food sacrificed and sanctified before deity has held a place both in Abrahamic religious traditions, as well as early pagan traditions (Freidel & Reilly, 2010). Religions in the Abrahamic tradition designate some foods as clean and others as unclean and therefore forbidden (Feeley-Harnik, 1995). Similarly, many religions throughout history have designated some foods as polluted and thus restricted as to who could eat them and when (e.g., leading to the prevalence of modern vegetarianism on the Indian sub-continent). Thus the consumption of food can have significant personal and religious meaning that for many would supersede their feelings even for country (Kay et al., 2010).

Food has cultural in addition to religious meaning. Specific foods are associated with holidays around the world: the dumpling during the Chinese New Year, rice pudding at Christmas in Scandinavia, turkey for Thanksgiving or hotdogs for the 4th of July in the United States. Birthday cakes and Valentine's day chocolates help define how we relate to one another, marking important relationships and milestones. Many still cite family dinners as both sacred and among the fondest symbols of family relationships.

This special and sacred nature of food makes it particularly ill-suited to reductionist economic modeling. Our models may suppose that foods are simply a collection of nutrients commodified and exchanged on markets, with consumers seeking to optimize the mix of nutrients given a specific budget constraint (LaFrance, 1983). Rausser contributed to the critique of this model that it excludes taste in addition to the time inputs necessary to create meals (Gawn et al., 1993). Perhaps deeper, these models sidestep the cultural meaning of meals. Indeed, the fact that we consume traditionally formatted meals from recipes handed down over generations (or even found on the internet after a simple search) rather than collections of nutrients demonstrates the importance of meaning in food. Beyond this clash with our ability to model, the social meaning of food makes it at once a poor target for command-and-control policies, and the likely target of such policies. There are many recent examples of how government influence on food choice stirs backlash. Clear pushback has been seen in recent efforts to limit the choice sets of both adults (Debnam, 2017) and children (Just & Gabrielyan, 2016). Threats to perceived consumer choice and freedom with respect to food often takes on a sentimental tone, as seen in the case of the pink cookies of Elyria schools that were banned under the 2010 Healthy Hunger Free Kids Act. The cookies had been in schools for generations, and both students and alumni were outraged by the removal once the cookies were no longer allowed by Federal law. This led to town legislators pleading with the Federal government for an exception—the cookies clearly had meant much more to the town than the simple nutrients that had barred them from the menu. This same attachment to food often draws food into the spotlight of regulation as consumer groups push for foods that meet their social, cultural, religious as well as physical needs. This has been seen, for example, as Kosher regulations have been enshrined in law (Judd, 2003).

As western society has begun to drift from traditional religions (Lim et al., 2010), it is perhaps no surprise that many have sought a substitute hierarchy of both transcendent and social meaning in food. This trend has been noted by many, but most prominently by Rausser et al. (2015) who detail the movement to promote foods that are perceived as more natural. This includes an aversion to processed foods, large scale farming, pesticides, hormones, antibiotics and genetically modified organisms. This movement (or really collection of movements) has also spawned more recent resistance to foods containing gluten among many other simple ingredients.

The primary pillars of this movement are concerns regarding human health, labor rights, the environment, climate change and animal welfare. Interestingly, there is often conflicting evidence regarding how foods targeted by these movements actually impact the issues claimed. For example, consumers of organic foods perceive them as being more nutritious (Shafie & Rennie, 2012), yet to date there is very little evidence of such a benefit (see Williams (2002) for a review). Studies have found that individuals not only believe organic foods to be more nutritious, but also to taste better overall (Lee & Yun, 2015). Blind tests find no such general difference (Fillion & Arazi, 2002), suggesting that such perceptions may be the results of halo- effects whereby the consumer generalizes their positive feelings for the production practice to their perceptions along several dimensions. A general assessment of the naturalist food movement (which encompasses many of these behaviors) was presented by Rausser et al. (2019). Rausser et al., 2019 demonstrates that many of these movements are self- defeating when indirect impacts and externalities are taken into account. For example, avoiding the products of large-scale agriculture may be harmful to the environment as well as to less food- secure populations due to the general impact on food prices and land productivity.

This collection of popular food movements has led to regular boycotts of foods over humanitarian issues or issues related to perceived global responsibility of food producers. For example, a brief movement in 2019 called for a boycott of Starbucks to end the use of nutmeg in their holiday drinks (Brockell, 2019). While Starbucks was the target of the short-lived (and rather ineffectual) boycott, the purpose was ostensibly to punish the Dutch for the genocide perpetrated in the 1700s on the Banda Islands in order to obtain a monopoly on nutmeg produced there (Aubrey, 2012).

Clearly, such a boycott could not bring justice to such a situation—but that seems beside the point. The *symbol of the food choice* in this and many cases is more important than the *real effect of the food choice*. For this reason, many of the food movements seem to push solutions that could make the targeted problem worse. Organic farming may be less efficient (Kumbhakar et al., 2009; Madau, 2007) and thus more resource-intensive than conventional means. Nevertheless, eating organic is a symbol of environmental values. A push for local production may lead to use of lower-quality land, perhaps requiring greater land use than specialized larger-scale farming. Nevertheless, eating local is a symbol of a fight against climate change. Farmers' markets offering local produce may make regulation of food sanitation difficult, leading to greater incidence of foodborne illness (Bellemare & Nguyen, 2018).

Nevertheless, patronizing the farmers' market is a symbol of valuing health. These social values cannot easily be separated from feelings about food choices—even among academic researchers.

3 Food Revolution

Obesity rates in western countries saw dramatic increases beginning at least by the 1970s (Parikh et al., 2007; Rodgers et al., 2018), with developing countries following closely thereafter. This phenomenon and its causes have been hotly debated for decades (Ross et al., 2016) with the two prime culprits being a sedentary lifestyle (Martínez-González et al., 1999) and a western diet (Manzel et al., 2014). Rausser finds convincing evidence that processed foods, which are so prevalent in the western diet, play a significant role in contributing to childhood obesity (MacInnis & Rausser, 2005). With diet implicated, there have been several different calls for changes in the diet, first through education (Contento et al., 1995), then regulation and taxes (Nakhimovsky et al., 2016). These calls may be seen as using somewhat traditional tools to address a single policy goal by making marginal adjustments to the food system. A new and deeper criticism of the food system have emerged based on a loose connection between a collection of results in the science literature and the broader set of social movements noted by (Rausser et al., 2015) that seeks instead to make dramatic changes to the whole diet.

The Global Burden of Disease (GBD) is a large-scale academic effort to document the impact of all types of disease across the globe with the goal of informing international policy on disease treatment and prevention. The 2019 GBD focused on the burden from diet-related disease, finding diet to be linked to approximately 11 million deaths annually and an annual reduction of 255 million disability-adjusted life years (DALYs, a measurement of quality of life). They find that high intake of sodium, low intake of whole grains, fruits and nuts are the largest contributors to disease-related death as well as reduced quality of life. They estimate that achieving the "optimal" diet could prevent approximately 20% of deaths annually, making diet the leading risk factor for death globally.[2] They suggest that these findings highlight “the urgent need for improving human diet across nations.” Further, they argue there is a “need for comprehensive food system interventions to promote the production, distribution, and consumption of [whole grains, fruit and vegetables] across nations.” In their conclusions, they lament that while conventional interventions (e.g., taxes and subsidies) have been found to be both effective and cost-effective, they cannot achieve the scale of change necessary to attain the “optimal diet globally”—the diet which maximizes observable longevity and health.

In sum, the GBD 2019 calls for extensive changes to the food system at virtually all levels. This includes the need for vast changes in agricultural practices, though they warn of the potential for impacts on climate, biodiversity, soil quality, and freshwater. Drawing on other studies (Auestad & Fulgoni III, 2015; Heller et al., 2013; Sabate & Soret, 2014; Tilman & Clark, 2014), they suggest a dramatic change in the food system to replace animal- based foods with plant-based foods. The reasons claimed for considering such a change are based in both nutrition and sustainability arguments. First, there is ample evidence that individuals fail to consume enough plant-based foods for optimum health, leading to increased rates of cardiovascular disease among other diet-related disease (Hu, 2003). Second, the evidence they cite suggests that raising plant-based foods have a smaller impact on the environment, leading to reduced CO_2 emissions, reduced land use and reduced water use. This analysis generally assumes that individuals eat solely to impact health and longevity, ignoring the many social and cultural functions of food that may supersede marginal changes in health or longevity in the utility for many consumers. Beyond this, while the analyses and statistics in the report are primarily based on results from the health sciences, the conclusions are heavily influenced by the climate literature. The health and diet literature has a history of recommendations based on results that are both noisy, and often not directly causal to health outcomes (Fischer et al., 2020; Mente et al., 2009).

However, this study by the GBD research group was not the only major research team to call for a radical overhaul of the global food system. Just a few months earlier, the non-profit organization EAT released their report on healthy diets and sustainable food systems (Willett et al., 2019). Their report is, if anything, more aggressive than the GBD report, calling repeatedly for a “Great Food Transformation.” Indeed, the stated goals of their report are somewhat broader than that of the GBD, with environmental sustainability being perhaps the primary target. In their framework, environmental sustainability considerations include greenhouse gas emissions, nitrogen and phosphorus pollution, biodiversity, land use, water use, input waste, chemical pollution from fertilizer and pesticides, and food waste. In addition to addressing these diverse and complex issues, the authors also wish to reduce hunger and improve the nutrition and health of food consumers globally. This includes

[2] Of course, their definition of “optimal” differs substantially from that used by economists generally—depending

only on the observable impact on health and longevity, and ignoring other potential drivers of utility.

not only reducing cardio-vascular diseases, diabetes and obesity, but addressing the prevalence of cancers that are found to be related to diet. In short, they wish to solve a vast number of problems through the use of food as a single lever. Their overall targets are driven by the UN Sustainable Development Goals (Lu et al., 2015), which are stated primarily in terms of more traditional outcomes (e.g., ending hunger, eliminating poverty, etc.) and not specific actions required to achieve said goals.

The EAT report proposes specific policy solutions to address each of these issues. These proposals are aggressive, requiring cooperation from "all sectors and at all scales." Achieving the desired change would have a dramatic impact on everyday life. The shift in global consumption of foods required is dramatic. Red meat consumption would need to be cut by about 2/3, as would potato and starchy vegetable consumption. Whole grain consumption would need to more than quadruple, and nut consumption would need to increase by several hundred percent. These numbers (which already sound large) are measured on a global scale and necessarily mask even larger changes that would need to occur on a regional basis. For example, North America would need to reduce red meat consumption to about 1/7 of current levels. In addition to dramatic changes in diets, the EAT report calls for a 75% reduction in yield gaps and a "global redistribution of nitrogen and phosphorus fertilizer use." They anticipate that adopting this diet would reduce annual deaths by 23.6% (about 11.6 million fewer deaths per year). Again, their recommendations treat food without regard to social and cultural implications, or the potential utility one might derive from these connections that could supersede a desire for marginal improvements in longevity or health.

The report concludes by noting how important it is not only to dramatically change all aspects of the food system, but the great urgency with which we should pursue these changes. They readily admit "[h]umanity has never aimed to change the food system so radically at this scale or speed." While their work demonstrates that feeding the growing population of the Earth is possible, they warn against two major calamities that might result from failing to take immediate action: failing to achieve the UN Sustainable Development Goals and failing to achieve the goals of the Paris Agreement. It should perhaps be pointed out that the vast majority of consumers do not consider these among their top priorities in making food choices. As such, these goals might be considered as representing externalities at the point of food choice. However, the solutions proposed are normative and are made with a total disregard for private value from the experience of consuming food beyond the attainment of calories. While this private meaning is ignored, many of the arguments for radical change are couched in terms that are familiar within the new food movements.

3.1 Food Revolution and the Broader Public

The GBD and EAT research groups are perhaps the highest profile research efforts calling for a radical shift in diets and agricultural practices, though such calls are not rare. The link of poor diet to environmental degradation is a common theme that undergirds such calls (Springmann et al., 2016). For example, some link climate change and perverse incentives of food manufacturers to issues as wide ranging as obesity, malnutrition and pollution (Mendenhall & Singer, 2019). Many have credited the current food system built on international trade and relatively rapid innovation with lifting large portions of the world's population out of poverty, and easing the burden of poverty for many others (Brown et al., 2017; Stordalen & Fan, 2018). Nonetheless, these same researchers express fear for the ability to provide for future populations if certain issues are not managed properly. This includes maintaining free trade in food stuffs and consumer and government acceptance of biotechnology as well as issues of environmental degradation. Rausser has been at the forefront in demonstrating the value of trade liberalization and wider use of biotechnology in alleviating poverty and improving welfare in developing countries. Trade liberalization was key to improving welfare and farm incomes in the former Eastern Bloc (Janda et al., 1996; Janda & Rausser, 1998). In addition, Rausser et al. (2000) lament the growing disparity between developed and developing countries in agricultural research (specifically agricultural biotechnology). Following on the model put forth by Rausser, the authors advocate for public-private partnerships that help draw on cutting edge innovations from the private sector to address perplexing issues in developing countries. Such areas might not otherwise attract essential resources. Such policies seek to improve the functioning of markets through important changes that are very unlikely to upend what is already working well.

While research advocating for radical changes in the food system has been largely fueled by what might be termed "grand challenges", activists have often been motivated by much more narrow interests. This includes a long list of politically active groups such as the Non-GMO Project, People for the Ethical Treatment of Animals, Green Peace and many more. Many of these groups propose boycotts or seek to ban specific foods to achieve specific goals (such as eliminating certain forms of animal handling, or the elimination of very specific ingredients or chemicals). Anti-GMO efforts have been among the highest profile, with groups lobbying both for the labeling and the banning of foods containing genetically modified materials. The rationale for such changes can be disparate (e.g., banning GMOs is motivated both by a food safety fear and several arguments about environmental sustainability). Notably, the science behind some of the claims from food activists is at times found wanting (Kuntz, 2012). Often high-profile documentaries such as Supersize Me, Fed Up, Cowspiracy and GMO OMG have fueled or at very least documented a brand of activism led much more by anecdote and emotion than critical evaluation of evidence.

4 Consumer Behavioral Drivers of Food Trends

Food and nutrition policy in much of the world has long been organized around the notion of a rational consumer who makes decisions to trade off current pleasure from consumption with future impacts on health and consumption. Such a consumer can be influenced by changes in prices and budget, the availability of foods on the market, as well as informational content regarding health and nutrition they may not yet have been aware of. Unfortunately, there is very little support for this model of food consumption in the literature. Rather, food consumption is typified by strong behavioral reactions to trivial changes in the environment or the framing of information presented (Just & Gabrielyan, 2018). Thus, while consumers appear to respond to the introduction of nutrition information (Spiteri Cornish & Moraes, 2015), they cannot differentiate between credible and unreliable sources of information and often lack the skill to make use of basic nutrition information. Given the number of attributes on a typical nutrition label and the dizzying number of food decisions one must make, this is not surprising. This lack of ability to use nutrition information leads to heuristic decision-making. Such heuristics might explain apparent puzzles. For example, informing individuals that a bag of potato chips are fat free leads them to overcompensate, consuming more fat than if they had eaten full-fat chips (Miller et al., 1998). They understand the absence of fat reduces calories and believe this should give them license to eat more. They just don't have the capacity to calculate how much more they can eat without and maintain the health benefit.

Poor ability to use nutrition and other information is likely connected to some of the major trends in food consumer behavior. With the rise in obesity, consumers have a stated preference for healthier and more sustainable consumption. This has driven increases in the US demand for organic foods, non-GMO foods, gluten free foods, as well as a preference for refined sugar over high fructose corn syrup, and poultry over red meat. Note that while each of these trends are associated with consumer desire for better nutrition (e.g. Hoefkens et al., 2009) the scientific literature does not support the notion of any specific nutritional benefit for organic, non-GMO or gluten free foods for the vast majority of consumers. Moreover, the evidence for using refined sugar over high-fructose corn syrup is noisy and inconclusive (White, 2008), and the switch to poultry over red meat masks a general trend toward higher meat consumption overall.

How do such biased perceptions become established in the minds and culture of consumers? Behavioral economics provides some suggestions. Fuzzy trace theory (Reyna & Brainerd, 1995) posits that when consumers are faced with complicated information structures, they will prefer to simplify the information before decision-making. The information is simplified by extracting the perceived gist. Thus, instead of using the collection of all nutrition information contained on a nutrition facts panel (referred to as verbatim information), the consumer will make relatively quick judgments categorizing the food, for example, as "healthy" or "unhealthy". The resulting judgment will rely on a combination of the attributes that the consumer is seeking and those that are observable to the consumer. To be used in judgment a trace must both be available and accessible. Thus, while the nutrition facts panel is available, it is probably not the source for many decision-makers in a store setting as it would require picking up the package and inspecting the numbers, which is time consuming and inconvenient. Instead, consumers will make use of front of package information such as "low fat" health claims, or in many cases the increasing number of badges and certifications: "gluten-free", "GMO-free", etc.

While these claims are not directly related to nutrition, if consumers are seeking improved nutrition and perceive some correlation between the badge and items that are nutritious, it will contribute to an overall perception of health as the gist of the product. This fuzzy trace model has four key implications in food consumer demand: (1) When the most accessible information has only noisy relationships with the most valuable attributes, consumer will make extreme decisions based on poorly related information, (2) If accessible attributes correlate with only a subset of valuable attributes, consumers will focus on these (3) Producers will be strategic in making positive attribute signals more available and negative attribute signals less available (perhaps moving negative attributes from consideration), (4) Policy may inadvertently overcorrect by making only negative signals more accessible. In general, consumer trends may arise as different signals of underlying attributes become more or less ascendant in the food choice environment. In other words, consumers may be fully aware that they are not particularly interested in gluten-free foods, but they don't have many other signals that would inform them about what they do care about. When we place simple signals in the food choice environment, such as signs reminding consumers that produce has health benefits, we can see marked increases in the purchase of nutrition dense foods (Payne & Niculescu, 2018; Payne et al., 2014, 2015, 2016).

Interestingly, the fuzzy trace heuristic I have proposed here leads to consumers conflating food attribute causes and potential outcomes. Items that are potentially good for reducing environmental degradation (e.g., organic foods) will be treated as if they will address both environmental and health issues. This misperception creates a confluence of desired outcomes that seem to be addressable with similar approaches. Moreover, many in the academic and activist communities are now picking up on this thread of thinking and considering its use for public policy goals. As Rausser has posited that food and agriculture policy arises endogenously creating distortions (Rausser et al., 1982), here I am suggesting that academic research and activism are arising endogenously to amplify consumer decision bias. The implications of this endogeneity in public policy approaches are troubling as it undermines the neutrality needed for trust in academic research to thrive.

5 Food as the Focal Point

The list of issues that a confluence of activists and researchers wish to address through a transformation of the food system is vast in its scope and reach. Indeed, it would be hard to imagine that achieving the stated policy goals of the larger efforts such as EAT or GBD or any number of food activist groups would not touch the lives (for better or worse) of every individual on the planet—and perhaps that is the main point of the effort. Here I provide a partial (and clearly overlapping) list of the issues that have received broad support in the research literature as a basis for radically changing the food system. To be clear, each of these issues is important and clearly worth addressing. Activists have combined these issues in a way that often ignores details and nuance specific to individual issues to create some overriding social meaning beyond the hard science. This confluence makes the problems not only more difficult to grapple with in terms of assessing economic implications, but vastly expands the potential for unintended consequences in policies that are designed to address multiple targets at once.

Sustainability: Several have raised the issue of whether it is possible to sustain the level of production needed to feed the growing population of the world. We have seen dramatic increases in yield and productivity in most areas of the world. However, these gains are seen as coming at the expense of depletion of environmental resources. For example, agriculture is one of the two leading causes of threatened species (Maxwell et al., 2016), and many have (perhaps wrongly) associated high yielding technologies such as Bt corn with the decline in natural bee populations (Malone & Pham-Delègue, 2001). Continued conversion of forest into agricultural land in much of the developing world both threatens wildlife habitat, and threatens the stability of rainforest (Moraes et al., 2002). Even domestically, the recent conversion of grasslands in South Dakota to corn fields has threatened to eliminate the pheasant that had been a prime attraction for tourists.

Climate Change: Given that plants are thought to be one of the most effective carbon sinks (Lovett, 2002), and that animals are considered one of the largest producers of greenhouse gases (Fiala, 2008), agriculture and the food system are thus integral to addressing climate change. It is estimated that about one fifth of all greenhouse gases are emitted by agricultural production (McMichael et al., 2007). On the other hand, a substantial literature notes that climate change is a particular threat to agriculture, with yields expected to decline as a result of increased frequency of weather events (Gregory et al., 2005) and increased temperatures (Asseng et al., 2015; Peng et al., 2004; Wheeler et al., 2000). There is substantial uncertainty regarding the overall impacts on agriculture and the costs of adaptation to potential changes. This is all the more complicated by the apparent feedback between climate and agriculture.

Health: While the connection between diet and health is nothing new, the types of health threats associated with diet have changed dramatically. The primary concern is with diet related diseases such as diabetes and heart disease (Popkin et al., 2001).

However, concerns about the connection between diet and various cancers (Greenwald et al., 2001) and even mental health (O'Neil et al., 2014) have come to the fore. Many of the associations that have been found (e.g., between red meat consumption and colorectal cancer) are relatively modest (Bouvard et al., 2015). In the case of heart disease, the apparent advice regarding specifics in the diet have often changed (Schmit & Kaiser, 2003), sometimes dramatically. Studies often come to conflicting conclusions (Burr et al., 2005).

Some of this may be due to differences in local conditions or contaminants in specific foods. Some may also be due to the potential that effects of diet on such diseases themselves may be relatively small and thus difficult to isolate. There is clear evidence that micronutrient deficiencies can lead to very acute health problems such as blindness (Sommer, 2001) or anemia (Choi et al., 2011) that can be relatively more prevalent in developing countries. As more of the developing world has begun to adopt western diets (Popkin et al., 2001), considerations of obesity, diabetes, heart disease and cancer have taken much of the focus worldwide.

Waste: While waste can be somewhat difficult and controversial to define, there is wide agreement that more food and feed is wasted than is efficient (Katare et al., 2017). It is claimed that up to 40% of food in the U.S. is never eaten (Gunders & Bloom, 2017), with similar numbers being cited across the globe in both developed and developing contexts (Parfitt et al., 2010). The problem among developed nations appears to be primarily at the point of consumption, whether in the home or at an away- from-home establishment. Among developing nations, the problem is primarily an issue of post- harvest loss, transportation infrastructure, packaging and handling causing major losses.

Hunger: The prevalence of undernourishment worldwide (and in almost all regions) has been on the decline for many years with approximately 10.8% of the world's population suffering from undernourishment (Roser & Ritchie, 2013). However, the rate of decline has slowed substantially since 2015, and indeed due to population increases there are now 50 million more undernourished in the world than there were just a few years ago. The highest prevalence of undernourishment is in Sub-Saharan Africa and Southeast Asia. Hunger has long been studied with potential improvements requiring changes in agricultural practices, improved infrastructure and markets, and specific changes in government regulation and programs (Leathers & Foster, 2017). More recent work singles out a "predatory food industry" limiting the types of nutrient rich foods that are available in order to maximize profits (Mendenhall & Singer, 2019). While this may be a plausible explanation for undernourishment among urban poor, it misses the mark for the vast majority of the malnourished that are among the 2 billion involved in subsistence farming.

Pollution: The tremendous gains in agricultural productivity over the last century drew substantially on an increase in the use of nitrogen fertilizers (Davidson et al., 2015). These fertilizers, while essential to attaining the sustained yields necessary to feed the planet, have become the source of significant pollution. Runoff contributes to "dead zones" where large areas of the sea become uninhabitable for many native species. These are of course issues that have been widely studied in isolation. Moreover, the production and trade of nitrogen fertilizers has the effect of concentrating nutrients in areas of high agricultural productivity, leaving other areas with a paucity of nutrients (Sutton et al., 2013). Approximately 75% of crops in the world are raised as feed (Lassaletta et al., 2016), with agricultural products including meat on net being shipped from agricultural producing areas to urban centers, suggesting a net flow of nitrogen into urban centers. Recent interdisciplinary work suggests a cocktail of solutions requiring improved cooperation between government and producers, along with incentives to tie downstream pollution to farmers' profitability (Davidson et al., 2015).

More radical solutions have been suggested. For example, reducing the production of livestock can cut the overall amount of nitrogen required, while increasing the trade of nitrogen instead of agricultural products could diversify agricultural production and conserve nitrogen (Lassaletta et al., 2016).

Poverty: Agriculture has long played a central role in alleviating poverty (Pinstrup-Andersen & Pandya-Lorch, 1994; Tsakok & Gardner, 2007). Economic growth in agriculture is key to reducing poverty perhaps because of the relatively wide reach of agricultural employment in developing areas (Cervantes-Godoy & Dewbre, 2010). Many studies have found that agricultural development is key to alleviating the deepest poverty, though other sectors may play an important role for alleviating less severe poverty (Christiaensen et al., 2011).

That is to say, with all of the many goals and constraints placed on agriculture in this expanding cocktail of policy goals, we must remember that agriculture is the engine for addressing poverty. While some of the policy goals that have arisen can perhaps improve the functioning of agriculture in this role, many will quite clearly present tradeoffs. Assessing these tradeoffs is key.

6 Fomenting a Global Food Revolution

The general policy goals we have discussed come with a cocktail of recommended solutions. The majority of the work calls for a significant reduction in animal-derived foods (with a small fringe calling for complete elimination). These animal fats and proteins are to be replaced at least partially by increased consumption of legumes (including soy) and nuts. The intent is to decrease the overall area in agricultural use. This would necessarily require some conversion of pastureland to agricultural production, and a dramatic rise in land devoted to both legumes and nuts, but also to fruit and vegetable production. Using FAO statistics on current land use worldwide, this would suggest increasing land in nut production from a current 43 million hectares, to almost 1 billion hectares. Land area for grains in human consumption would increase by nearly 1.5 billion hectares, though this could be taken from land currently being used to produce feed.

Calculating the impacts of such massive changes in consumption necessarily requires extrapolation that is wildly out of sample. There are some areas of the world that are already producing near the ideals set out by groups such as EAT. However, those regions also happen to be those that have the highest rates of food insecurity—perhaps resulting from production systems that are inherently riskier. Unfortunately, most of the calculations used to determine the feasibility of the proposed changes presume no diminishing returns and do little to take account of heterogeneous land suitability. In particular, much of the pastureland (which is the vast majority of land in production of red meat) is of low productive value for other uses. It is not altogether clear that the changes called for in world production and diets are within the feasible set. Perhaps more troubling is the potential for misspecification in the production models employed, leading to vastly different land requirements than purported. It is very possible that the marginal reduction in land use reported by groups such as EAT may actually require a significant increase in land use under their recommended changes once unforeseen obstacles or nonlinearities in scaling are accounted for.

While the challenges enumerated in this literature are real, the research outlining solutions leaves much to the imagination. Besides questions about whether the methodology is capable of demonstrating physical feasibility, the solutions proposed are an aggregate consumption bundle—not the policies necessary to achieve that bundle. The situation is complicated (as are most things related to climate change) by the necessity of cooperative action across vast numbers of nations—both those with powerful government control of production and markets and those that provide broad economic freedoms to their citizens. Because the proposals involve large numbers of policy goals, and because they stop short of policy, it is very difficult to grapple with the potential welfare and economic impacts. Clearly, if taxes, quotas, or bans were used to obtain these goals, the well-known welfare economic results would apply, requiring a comparison of the economic burdens of the policies on consumers (which could potentially account for cultural and social value and heterogeneity) with the potential external benefits. However, barring a behavioral analysis, one would have to exclude any perceived value of leading the consumer to a revealed inferior consumption bundle (for example from improved health from choosing a diet that was already available but had been passed over). Thus, one would expect the majority of the external benefits to be derived either from environmental and climate improvements, or from the social value of reductions in hunger and poverty.

Consider a thoughtful and rigorous approach to addressing this confluence of issues. One approach is suggested by Gordon Rausser when addressing a thorny and nuanced (albeit somewhat more manageable) set of policy issues. Rausser and Yassour (1981) detail a method in which a decision tree enumerates all possible actions by all actors, and policy options are evaluated based upon a utility function that considers inputs from all involved. Such a sweeping set of policies that would require dramatic change on the part of nearly every earthbound creature would render any such reasoned approach empirically infeasible. Rigorous welfare analysis of policy options must be considered on a micro level and would need to take account of potential policy interactions from multiple externality targets (for example, dealing with only a piece of the decision-tree at a time). Such an analysis could clearly address the desirability of policies but would not address the underlying dogma of radical and immediate change. Indeed, very few economic tools have been developed to consider whether radical change would be better than marginal change (though the option value literature comes close), or whether immediate policy implementation is better than gradual (though some transactions costs or fixed cost of capital work approaches the topic). The latter is usually more of a consideration of political feasibility. Absent a rigorously defined policy instrument that would allow for welfare analysis, or an economic model of immediacy and radicalness, one alternative approach is to compare the current effort with similar historical efforts for radical and immediate change to determine what sorts of efforts have been successful and also what types of unforeseen issues might arise (e.g., the approach of Tsakok and Gardner (2007)). The remainder of this paper does not allow for a large sample of examples. Hence, I choose specific examples of unsuccessful and successful change as something of a parable from which we can draw ad hoc intuition.

Schweinemord: The Great German Swine Massacre. The discovery of potential production inefficiencies in livestock production is not recent. It has long been understood that we could raise more calories for direct human consumption if we were to cut out the middleman (or middle-pig) and choose grain consumption over meat consumption. This was the basic insight that led Germany to order the slaughter of nearly 10 million pigs (well over a third of all holdings) in 1915 (Stocks, 1916). The setting was the opening phases of World War I. As hostilities were escalating, academics and policymakers considered how Germany (which had relied heavily on imports of food) could supply their needs over the course of the war. German academics had made the argument that they could increase total production of potatoes and other crops, more than meeting the need if crops now devoted to swine (the predominant meat in the German diet at the time) were reduced or eliminated. The order was given to slaughter 35% of the swine population and preserve the meat, with the goal that the abundance of meat and the decrease in demand for potatoes and grain for fodder would lead to lower prices for human consumption. The decision not only backfired comically in the near term, but set up perhaps the greatest tragedy of World War I. As is predictable, prices for pork skyrocketed leading to swift implementation of price controls, and the official market for pork nearly disappeared entirely (Stocks, 1916). A black market for pork arose with very steep prices of 6 Marks per pound (it had been around 0.80 Marks previously) (Blum, 2011). Such results reflect the resilience of cultural and social preferences in the face of utilitarian policy changes.

Less predictable was the impact on grain markets and the eventual impact on population health. Swine had been an important source of fertilizer and the prices for fertilizer also increased, leading to substantially lower yields. Though certainly other factors played a role, some have speculated that the reduction in fertilizer use was key in the approximately 2000% increase in the price of grains. The situation was exacerbated as the British blockade of German ports was tightened and the war continued to drag on. Abbott (2013); Cox (2013, 2015) and Blum (2011) have well documented how the blockade—together with the reduced livestock population contributed to widespread hunger. The evidence comes from child and adult height statistics which shows a dramatic rise in stunting and malnutrition over the course of the war (for example, it appears a typical 8-year-old male in Stuttgart did not consume enough calories to grow even a centimeter in 1918). Though effects were differentiated by class and other socio- demographics, impacts reached to all classes.

Clearly there are few positives to take away from the German experience. While the outcomes of this decision to reduce meat consumption were exacerbated by a first-of-its-scale war, there are several warnings that must be heeded. First, markets can be more complicated and linked than the economic and biological models used to describe them—well-meaning scientists can be tragically wrong. While current efforts make attempts to account for how fertilizer and nutrients are linked to production, it is entirely possible that other important co-products have been omitted. Second, while the German government correctly identified that meat production was less land-efficient than direct consumption of grains, they neglected the historical role livestock plays as insurance against poor yields (Hänke & Barkmann, 2017).

Livestock can provide much needed diversification in the event of local threats to crops, providing a key response to agricultural risk. By reducing the livestock population dramatically, the government also dramatically limited the population's ability to adapt to future calamities that were eventually realized. Events will inevitably happen in the future that we cannot now predict (such as the recent pandemic), and which may dramatically change the desirability of our current goals. Third, and perhaps most important, dramatic changes move us far enough away from our current data that unforeseen consequences are inevitable. If the government had gradually subsidized the slaughter of swine while monitoring markets, many of the consequences would have been noticed before they became serious and could thus be avoided. By making dramatic changes rapidly, there was no way to go back once the negative impacts were known.

US Attempts to Change Diets during WWI and *WWII.* The German's were not the only country to seek dramatic and rapid changes in the population's diet in wartime. The US led campaigns to change the US diet at home with a goal of preserving supplies for troops. This effort was conducted by the U.S. Food Administration headed by future president Herbert Hoover. The goal of the policy was to dramatically reduce consumption of meat and wheat so that larger shipments could be sent to Europe. Europe had been devastated and food was scarce, which placed deployed US troops in danger of food scarcity. Rather than implement the strict rationing and price controls that had typified the European response (and that had contributed to hunger in at least some cases), Hoover chose to rely on voluntary efforts by Americans, writing "Our conception of the problem in the United States is that we should assemble the voluntary effort of the people…We propose to mobilize the spirit of self-denial and self-sacrifice in this country." This was to be accomplished through a two-pronged effort: first a massive media campaign with slogans such as "Food will win the war" or "Save a loaf a week and help win the war." The campaign encouraged the use of corn, oats, potatoes, fish and poultry, but a reduction in consumption of meat (especially pork) and wheat. The posters were clearly designed to make an emotional appeal to help the soldiers who were making much larger sacrifices. Thus, Hoover sought to use the social and cultural norms regarding concern for family to fuel rapid changes in diet. In addition to the media campaign, local boards were formed to help determine appropriate substitutes, educate, and provide locally appropriate recipes—all actions that acknowledged and sought to address heterogeneity. The combination of an emotional appeal and a program that was adapted to local conditions was widely regarded as successful, resulting in a 15% decrease in food consumption, and a doubling of food shipments to Europe. The program was continued after conclusion of the war to supply the recovering peoples of Europe.

The voluntary approach was deemed insufficient several years later as the U.S. entered World War II. Instead, the U.S. implemented rationing and price controls across a wide spectrum of foods. Individuals were issued books of red and blue stamps. In order to purchase rationed items, one would need to both pay the regulated price in dollars, and the regulated number of stamps of the proper color (blue for certain processed items and red for meat, fish or dairy).

Consumption of sugar and coffee were among other items cut by as much as 50%. As the war progressed and availability of items shifted, the stamp system became much more complicated. Consumer responses to the rationing were predictable. Whenever it became clear that an item was threatened to be rationed, consumers would begin to hoard the item, accelerating the shortages. Moreover, robust black markets arose for all of the rationed items. This again signals substantial cultural and social resistance to imposed changes.

Rationing was accompanied by a national media campaign educating consumers about the need to reduce consumption at home to support the troops, again seeking to tap into social norms to help ease the changes. Additional campaigns (similar to those in World War I) encouraged the use of substitutes—organ meats in particular. Organ meats had been seen as inferior meat that only those who were poor would eat prior to the war. Government promotions sought to encourage consumption of organ meats (that wouldn't be going to Europe anyway). It was promoted as a way to include variety in the meal and a way to demonstrate your patriotism. These efforts which arose from the National Research Council, really had the goal of changing diets permanently, and not just over the course of the war. Efforts to change American diets during World War II were largely viewed as successful, with some exceptions. The rationing was successful at freeing supplies to be shipped to Europe. Moreover, consumers actually viewed rationing somewhat positively (even complaining when some foods came off of rations prematurely, worried about potential hoarding). This positive view was largely due to the emotional appeal of continued promotions. Americans did dramatically change their diets through the duration of the war—though most changes were made marginally and over time.

Nonetheless, robust black markets took substantial resources from the effort, as did enforcement. There is some evidence that receiving stamps for specific goods increased consumption of those goods by some individuals (for example, a Washington Post article laments that stamps for shoes led to a "shoe purchasing orgy"). Additionally, the more aspirational policies that sought permanent changes in American diets had little lasting impact.

In contrast to the German effort, the American effort in WWI was marginal and relied entirely on persuading individuals to voluntarily substitute away from their preferred meals. This led to a relatively successful effort. To the extent that households faced extenuating circumstances or unforeseen consequences, they had the freedom to adjust their compliance. The American effort to change diets in WWII was much more aggressive and less flexible, but still relied on market components to drive production and consumption restrictions. These mechanisms allowed adjustments to be made at the normal pace of market equilibrium rather than through an immediate and irreversible edict. Consumers were given additional constraints on consumption—with some of these constraints being quite severe. Consumers were nevertheless relatively receptive to these efforts as they were connected closely with goals and aspirations they shared—protecting their family members who were fighting.

6.1 Saturated Fat and Trans Fat

In the 1950s and up until the late 1980s, much of the research from the medical literature associated saturated fat intake with cardiovascular disease among many other undesirable outcomes (Hoenselaar, 2012). By 1993, the FDA required saturated fat to be labeled so consumers could identify and avoid it. This led food companies to seek for a substitute to lard, butter, tropical oils and other animal fats as public pressure rose to respond to what was perceived as a health crisis. The most natural substitute was to use margarine or other trans-fats which widely replaced saturated fats. By the end of the 1990s, evidence began to accumulate that trans-fats were in fact *worse* than saturated fats (Hu et al., 1999). This led to an additional public outcry with the eventual labeling of trans-fats and the banning of artificial trans-fats by 2018.

Through much of this fight, consumers do not appear to have had strong preferences for one source of fat over the other but were rather responding to the health warnings provided by researchers and the government. While the changes to the food system in both cases were rather rapid, and not costly enough to register widespread complaints on the part of food companies, the entire episode demonstrates a significant problem with rapidly developed food policy: we often fail to recognize the substitution effects. In this case, the substitutions were more harmful.

While these examples are clearly cherry-picked to demonstrate themes, the lesson is both clear and important. Policies are often based on false perceptions and can only be labeled as wrong-headed *after* implementation makes this clear. Preserving option value and flexibility in consumer choice can thus provide great public value. This is despite the fact that the value may not be easily quantified a priori via bio-economic modeling. For this reason, providing consumers flexibility can preserve significant value. The very value of this flexibility is in allowing consumers to fix policy mistakes. Moreover, gradual change can allow the identification of unforeseen risks before they overwhelm all intended benefits. Finally, appealing to social and cultural norms in making changes can have substantial benefits in that it can reduce costly pushback and reduce both the cost of enforcement and noncompliance. While these principles may not provide directly for a solution to the long list of global challenges currently under debate, they do argue that a radical and immediate approach is at the very least unwise and potentially catastrophic.

7 Technology as a Potential Solution

One potential way to address the pressing issues enumerated by the food revolutionists is the development of new food technologies. A wide variety of technologies show promise in addressing each of the conflated crises. GMOs and more recently CRISPR, have the potential to push the boundaries of the crops and animals used for food. Though these technologies face (as yet unknown) biological limits, they promise higher yielding varieties, resistance to pests, longer shelf lives and better nutritional value. New crops are currently being developed that could help provide increased exposure to nutrients that are commonly deficient among developing country farmers (De Steur et al., 2017). Food scientists have worked on developing new food formulations and packaging technologies specifically to address waste and hunger (Buckle, 2015). Establishing public-private partnerships in the grand tradition of Gordon Rausser (McCluskey, 2021) can help to ensure innovations that both address public needs, but also economically viable new technologies. Such research with a purpose was the vision behind the landmark collaboration between the University of California and Novartis that has led the way among top research universities. Surely advances in transportation and environmental resource management also hold promise to help address many of these issues. Technological innovations have a history of overcoming the food and production issues we have faced over the last centuries. Beyond lessons from the Green Revolution, significant successes came from fortification efforts throughout the world addressing common diet related diseases (Zimmermann, 2004).

But our recent history tells quite a different story. Consumer resistance to GMOs, CRISPR, and other food technologies paints a bleak picture. In many ways, these responses sidestepped the science in favor of social and political meaning (Stephan, 2015). Some opposition is couched in terms of science (though at times abusing or misconstruing the science). Other opposition is couched in terms of religious, cultural or value-based language. In either case, consumer acceptance of food related technologies place significant limits on our ability to address each of the issues that are now attached to food—and this resistance now contributes to the series of crises.

This resistance to technological solutions should be the object of significant social science research. Much of the resistance to GMOs was tangled up in opposition to Monsanto and their very strenuous and public defenses of their intellectual property. To the extent that such resistance is due to the framing or marketing of a new technology, or the parties who are perceived to profit from its marketing, these problems are not inherent to the technology itself.

These are clearly behavioral factors that could be studied, managed and addressed to ensure that consumers are prepared for technologies that can substantively address the global challenges we face. To the extent that consumer opposition is rooted in the technology itself, we need to understand the depth, limits and hinge-points of such resistance to know how we can work within the boundaries to address the challenges. Either requires a robust research agenda among social scientists and one rooted not in prescribing or predicting based on rationality and efficiency but based in acknowledgment of the inherent behavioral nature of our plight. It is in understanding the confluence of human psychology and economics that we can chart a technological path forward.

8 The Path Forward

In this chapter I have outlined a pattern of association between broad global challenges facing all humans on the planet with the production and consumption of food. Among the general public, this has led to the beginning of several overlapping movements that imbue food with social meaning beyond the simple collection of nutrients. Often these movements can be confusing to outsiders in that their objectives in many cases are undermined by their means. These movements are behavioral by nature and require a broader set of social science methods and techniques to measure, predict and understand.

Connected with these broad and visible public movements, we are beginning to see an analogous academic push to conflate the global challenges and lay the charge to address these in the global agro-food system. The call has been for dramatic changes, at near immediate pace, affecting all players in the global food system. I have argued that such an approach is unwise and could have catastrophic effects. Robust solutions to these problems can only be found by implementing marginal and reversible changes that respect the sovereignty, heterogeneity and social nature of the consumer. From an engineering perspective, moving slowly and allowing consumers freedom to adapt to changes to their circumstance may be allowing challenges to unnecessarily persist. From an economic perspective, this approach allows unforeseen consequences to arise before they may do significant harm, and allows consumers to innovate in their adaptation, perhaps finding more efficient solutions. In addition to taking the small approach, it seems clear that many of the challenges we face are behavioral in nature and require a much broader set of tools than simply technology or neoclassical modeling would allow. At the center of all these issues is not just food, but humans. Understanding our behavior and specifically our food choices is one of a few keys to saving the world from ourselves.

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Closing the Gap Between Water Needs and Renewable Water Supplies: Global Perspective, Local Lessons

Yacov Tsur

1 Introduction

Water scarcity indicates the extent to which the supplies of renewable (natural) water available on a sustainable fashion satisfy human and environmental needs. It is a fuzzy concept because the available renewable water supplies vary seasonally and spatially, and human needs vary across locations (with population and living standards) and across climates (due, e.g., to evapotranspiration). Moreover, water scarcity depends also on water management and on the capacity to transfer water across time and space (from water-abundant periods or locations to water-scarce periods or locations), requiring, inter alia, storage and conveyance facilities. These qualifications notwithstanding, a common index of a region's water scarcity is based on the relation between average annual supply of renewable natural water vis-à-vis human and environmental needs, both measured in units of cubic meter per person per year (CMpy).

The "needs" side of the relation consists of (1) basic water needs (drinking, cooking, washing, hygiene), (2) water needs for food and fiber production, and (3) water needs for ecosystems support. Rough average estimates of the first two components are 100 MCpy for basic needs (Gleick, 1996; Mekonnen & Hoekstra, 2011) and 1700 MCpy for food and fiber production (Falkenmark et al., 1989; Rijsberman, 2006).[1] Accordingly, regions in which renewable (natural) water supplies fall below

[1] Based on Mekonnen and Hoekstra (2011), actual water used for food and fiber production range from 1000 to 1100 m^3 per person per year (CMpy) in India and China via 1600–1700 CMpy in France and Turkey to 2400–2800 CMpy in Spain and the USA (see the data in http://www.waterfootprintassessmenttool.org/national-explorer/).

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1700 MCpy are considered *water stress*. Likewise, regions with renewable water supplies below 1000 CMpy or 500 CMpy are said to experience *water scarcity* or *absolute scarcity*, respectively (Rijsberman, 2006). Regions with renewable natural water supplies below 100 CMpy are considered as experiencing *subsistence scarcity*. By 2050, about 6.2 billion people in 80 countries will live under water stress conditions, 5.6 billion people in 65 countries will live under water scarcity and 2.9 billion people in 47 countries will live under absolute scarcity conditions (Dinar & Tsur, 2014).

As surface water sources (stream flows, lakes, reservoirs), when accessible, are often cheaper than groundwater sources (aquifers), they are utilized first, with groundwater serving to supplement water supplies when surface water fails to satisfy water demand. Consequently, groundwater depletion, measured by extraction over and above natural recharge, indicates water shortage or, more precisely, the gap between water needs and renewable water supplies. I begin by providing a global overview of groundwater depletion trends. The data reveal widening trends in many regions. I then discuss how to manage the water gaps associated with these trends. The Jordan River basin (JRB), comprising the water sources of Israel, Jordan and the Palestinian Authority (PA), which experiences extreme (subsistence) water scarcity conditions, serves as a case in point.

2 Freshwater Trends

2.1 Global View

Freshwater occurs in the ground (soil moisture, aquifers), on the surface (streamflow, lakes, reservoirs) as well as in snow and ice. Rodell et al. (2018) define the stock of these components in any point of time (year) as terrestrial water storage (TWS). Advances in remote sensing technologies, such as the Gravity Recovery and Climate Experiment (GRACE) satellite system, enabled measurement of TWS trends. Rodell et al. (2018) use GRACE observations to estimate such trends. The authors divide the world into 34 regions and measure the TWS trend for each region over the period 2002–2016. Their data Table 1 in Rodell et al. 2018 reveal negative TWS trends in 24 out of the 34 regions. In 20 regions, the negative TWS trends are due to groundwater depletion.[2]

Richey et al. (2015) developed a groundwater depletion index, called RGS (Renewable Groundwater Stress), based on water withdrawal above natural recharge. Using GRACE observations for the period 2003–2013, the authors calculate RGS values for the world's 37 largest aquifers and classified the groundwater stress conditions of each aquifer as *low*, *moderate*, *high* or *extreme*. Aquifers with

[2] In 4 regions (Antarctica, Greenland, Gulf of Alaska Coast, and Canadian Archipelago) the negative TWS trends are due to melting ice sheets induced by global warming.

Table 1 Major aquifers under extreme or high stress conditions, i.e., with RGS index above 0.2 in Table 3 of Richey et al. (2015)

Continent	Aquifer
North America	Great Plains
	Ogallala
Africa	Nubian Aquifer System
	Northwestern Sahara Aquifer System
	Murzuk-Djado Basin
	Senegalo-Mauritanian Basin
	Upper Kalahari-Cuvelai-Upper Zambezi Basin
	Lullemeden-Irhazer Aquifer System
Asia	Arabian Aquifer System
	Indus Basin
	Tarim Basin
Australia	Great Artesian Basin

high or *extreme* stress conditions undergo depletion at alarming rates, which means that their exploitation has been, or soon will be, limited due to vanishing water stocks or quality deterioration triggered by the declining water head (e.g., seawater intrusion). The (major) aquifers identified by Richey et al. (2015) under high or extreme stress conditions are listed in Table 1.

Konikow (2013) use data on groundwater withdrawal and natural recharge during the period 1900–2008 to estimate groundwater depletion for all main USA's aquifers. The total groundwater depletion (extraction above recharge) in 2008 was 25 billion cubic meter (m^3), which amount to 70% of total USA's domestic water consumption during that year.

These studies reveal a highly non-sustainable situation: some aquifers have already reached the brink; others will do so soon. We turn to describe in a much higher resolution the water situation in the Jordan River basin.

2.2 Natural Water Sources and Water Needs in the Jordan River Basin

The Jordan River Basin (JRB) comprises the water sources of Israel, Jordan and the Palestinian Authority (PA)—see Fig. 1. The renewable freshwater supplies in the region are detailed in Weinberger et al. (2012) and MWI (2009)—the former for Israel and the PA, and the latter for Jordan. According to these sources (see Tables 1 and 2 in Tsur 2015), the average freshwater supplies available on a sustainable fashion (i.e., average annual natural recharge) west of the Jordan River (Israel and the PA) and east of the Jordan River (Jordan) are, respectively, 1680 and 745 million cubic meter per year (MCM/y).

Fig. 1 The Jordan River Basin. The Upper Jordan River extends between its headwater (at the confluence of its three main tributaries—Dan, Banias and Hasbani) and the Sea of Galilee (Lake Tiberias). The Lower Jordan River extends between the Sea of Galilee and the Dead Sea. (Source: United Nations Environment Program)

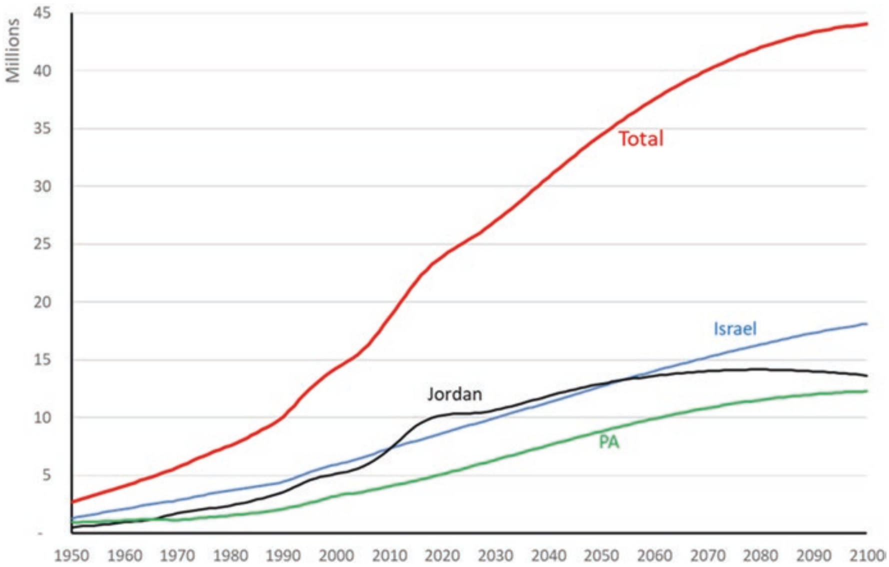

Fig. 2 Population trajectories in the JRB. (Source: United Nation's World Population Prospects 2019 (https://population.un.org/wpp/Download/Standard/Population/). Data are actual until 2018 and estimated (medium variant) from 2019 through 2100)

While natural water supplies are on average constant (with possibly a slightly negative long run trend due to climate change), the water needs grow with population and living standards. Figure 2 presents population trajectories of the JRB's three parties. The growing population give rise to increased diversions and exploitation of the natural water supplies. When exploitations exceed the average natural water recharge, depletion of natural sources arises.

The water level in the Dead Sea (DS) is an informative indicator of the depletion of freshwater sources in the JRB. This is so because the DS is the lowest point (in the region as well as on Earth) and loses water only via evaporation. While evaporation depends on (the annually stable) solar radiation, the water inflow into the DS depends on upstream diversions minus recharge, i.e., on depletion. As a result, the DS level trajectory is highly correlated with the depletion trajectory.[3] Figure 3 presents the trajectory of the DS water level during the period 1930–2018. The decline in the DS level becomes obvious during the 1960s, when Israel started to divert water from the Sea of Galilee via the National Water Conveyor, and has strengthened later with the shrinking flows of the Yarmouk River due to upstream diversions by Syria and Jordan. Diversions from side Wadies, including the Zarqa (Yabok) and the Mujib (Arnon), further exacerbated the DS's water level decline. All in all, about

[3] Note that declining DS water levels are associated with smaller surface area, hence smaller evaporation, which in turn reduces the evaporation rate. Thus, the rate of decline of the DS level is lower than the increase in the rate depletion (diversions minus recharge).

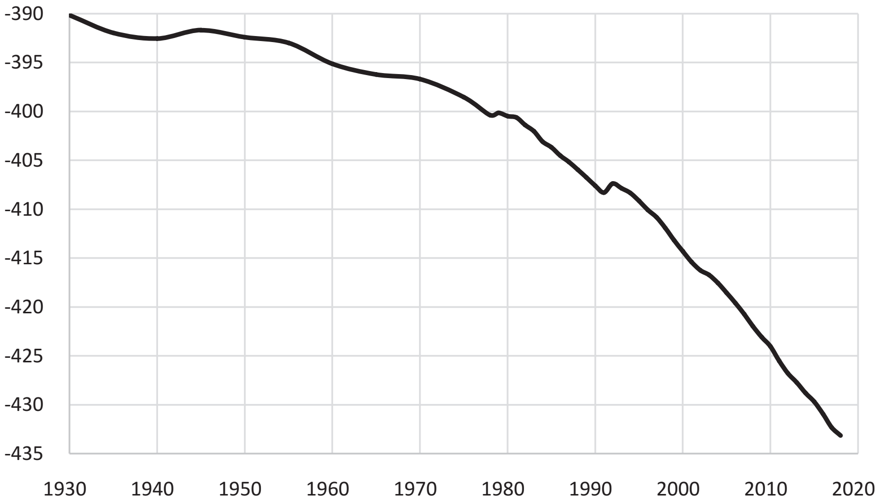

Fig. 3 Dead Sea level (meter below sea level). (Source: Israel's Central Bureau of Statistics (https://www.cbs.gov.il/he/subjects/Pages/%D7%90%D7%99%D7%9B%D7%95%D7%AA-%D7%94%D7%9E%D7%99%D7%9D.aspx))

1.6 billion cubic meter a year, that used to flow into the DS, has been diverted upstream—a flow reduction equal to average annual freshwater recharge in Israel and the PA combined (Tsur, 2015; Malkawi & Tsur, 2016). In the past 20 years, the DS's water level has been declining by more than 1 m a year.

Depletion (extraction above recharge) gives rise to shrinking water stocks and is therefore non-sustainable. It ends when water stocks are depleted or when the declining water stock triggers quality deterioration. A case in point is Israel's Coastal aquifer—one of the two main groundwater sources in the basin, the other being the Mountain aquifer. Prolonged depletion (extraction above average recharge) of the Coastal Aquifer has reduced the water head level, giving rise to seawater intrusion and salinization of the aquifer to the extent that certain sections have become unusable (Weinberger et al., 2012). Figure 4 shows average chloride concentration in the Coastal aquifer during 1958–2018.

2.3 *Water Scarcity in the JRB*

As discussed in the introduction, water scarcity relates to freshwater supplies available on a sustainable fashion, i.e., average annual natural water recharge per person per year. We saw above that the natural recharge in the JRB equals 2428 million cubic meter per year (MCM/y) on average (1683 MCM/y in Israel and the PA plus 745 MCM/y in Jordan). Dividing this annual recharge by total population gives freshwater supply per person per year (CMpy) available on a sustainable fashion. The CMpy trajectory in the JRB is depicted in Fig. 5. Figure 5 also shows the

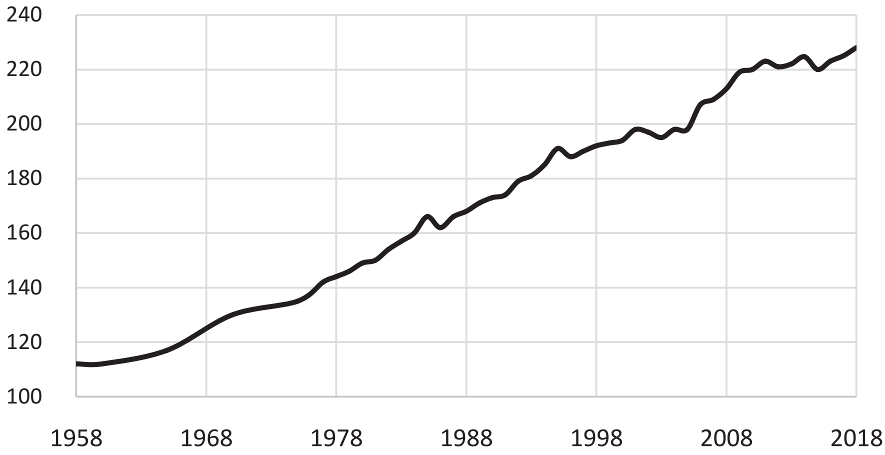

Fig. 4 Average chloride concentration (mg/L) in the coastal aquifer during the period 1958–2018. (Source: Israel's Central Bureau of Statistics (https://www.cbs.gov.il/he/subjects/Pages/%D7%90%D7%99%D7%9B%D7%95%D7%AA-%D7%94%D7%9E%D7%99%D7%9D.aspx))

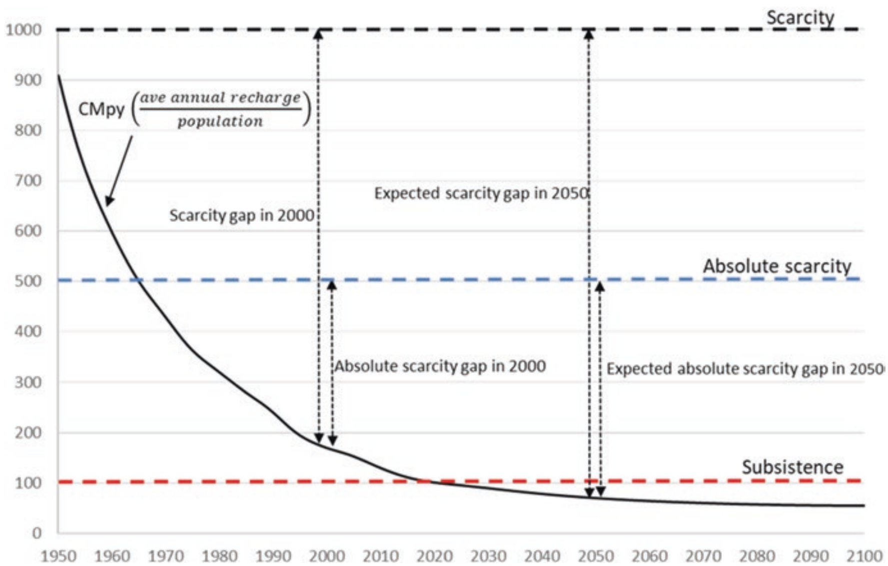

Fig. 5 Sustainable freshwater availability, measured in cubic meter per person per year (CMpy), in the JRB during 1950–2100. The CMpy trajectory is the average annual recharge divided by total population, where the latter is based on the actual population until 2018 and expected population from 2019 to 2100 (see Fig. 2). The scarcity and absolute scarcity gaps are the distances between the CMpy trajectory and the scarcity (1000 CMpy) and absolute scarcity (500 CMpy) thresholds, respectively

scarcity gap and absolute scarcity gap, defined by the distance between the actual CMpy and the scarcity (1000 CMp/year) and absolute scarcity (500 CMp/year) thresholds, respectively. Notice that these gaps increase over time due to the declining MCpy trajectory (associated with the growing population).

The CMpy trajectory in Fig. 5 represents the three parties combined (i.e., the *total* annual average natural water recharge divided by the *total* population). Of these, Jordan suffers the most severe water shortage. Moreover, while the bulk of Israel's and the PA's populations reside near the Mediterranean sea at low elevation, the bulk of Jordan's population resides in the Amman area at about 1000 m above sea level and more than 300 km away from Jordan's only sea access (the Gulf of Aqaba). These properties are relevant for the choice of policy aimed at closing the water gap in the JRB, to which I now turn.

3 Closing the Water Gap

The interventions available for water policymakers fall into two main categories: demand management and supply management. Demand management instruments aim at water conservation and improved efficiency of water use. Supply management policies seek to increase the available supply of natural water by increasing natural recharge (e.g., by diverting floodwater to recharge ponds) and developing recycling and desalination sources. I discuss demand management and supply management policies in turn.

3.1 Demand Management

Affecting water demand relies in one way or another on prices and/or quotas. Both tools require some form of water metering and I consider cases in which such metering allows volumetric pricing. Regulating water via volumetric pricing entails setting the "correct" water prices and letting suppliers and consumers determine water allocations based on these prices. The optimal water prices reflect the cost of supply and vary across sources and users. Detailed derivations of optimal prices are presented in Tsur and Zemel (2018), Tsur (2020) and Dinar and Tsur (2021).

I use data from Israel's water economy to demonstrate the efficacy of water pricing in affecting water demands. Consider first domestic users. Figure 6 presents domestic water consumption in Israel during 1996–2016. It is seen that domestic water consumption increased (more or less with the population growth) until 2007, reaching a local peak of 767 MCM/y, then decreased to 665 MCM/y in 2011—a decline of about 13% or 100 MCM/y (the equivalent of a large scale desalination plant). As population continued to grow along its secular trend, per capita water consumption, measured in cubic meter per person per year (CMpy), has decreased even more drastically. Figure 7 presents per capita domestic water consumption

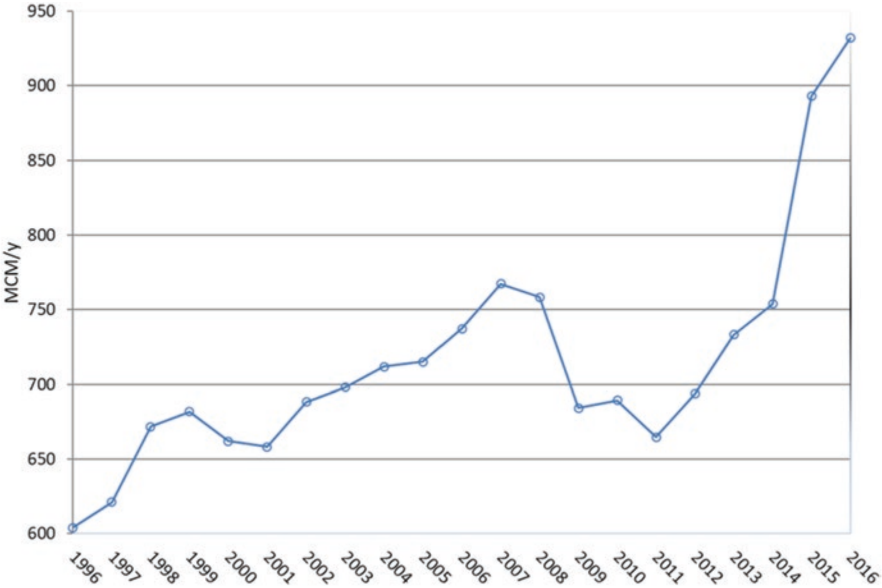

Fig. 6 Israel's domestic water consumption in million cubic meter per year (MCM/y) during the period 1996–2016. (Source: Israel's Water Authority (http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/20164/thrich%20lfie%20matarot%201998-2016.pdf))

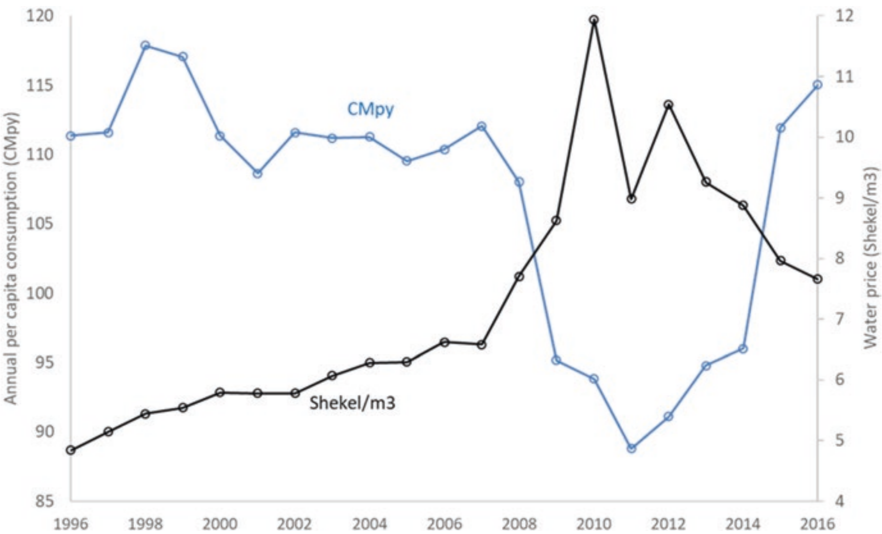

Fig. 7 Per capita domestic water consumption (cubic meter per person per year—CMpy) and domestic water prices (shekel per cubic meter) in Israel during 1996–2016. Domestic prices consist of a lower rate, applied to predetermined subsistence amount, an intermediate rate and a higher rate, applied for consumption above a certain amount. The higher rate, which includes also the cost of sewage collection and treatment, is adjusted periodically. The prices in Fig. 7 are the annual averages of the higher rates (obtained from Amir Shakarov of Israel's Water Authority)

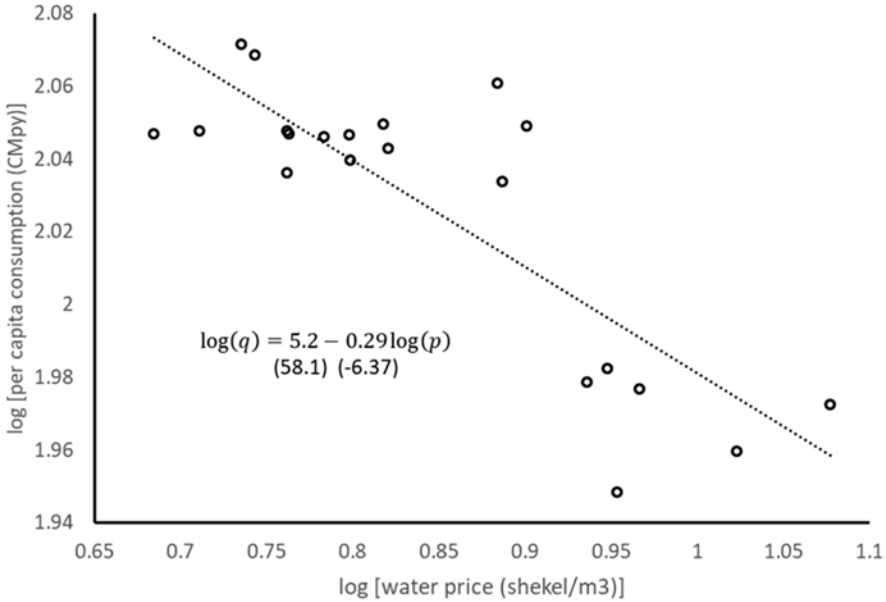

Fig. 8 Log of per capita domestic water consumption vs. log of domestic water prices with least squares estimates (*t*-values in parenthesis), using the domestic per capita consumption and domestic water price data of Fig. 7

(dividing the domestic consumption of Fig. 6 by Israel's population of Fig. 2) together with average annual domestic water prices. The per capita water consumption dropped from 112 CMpy in 2007 to 88.8 CMpy in 2011—a decline of more than 20%. The effect of water prices on domestic demand is obvious. Another way to see the effect of water prices on domestic water demand is to plot the per capita consumptions (CMpy) against the water prices, as done in Fig. 8. The figure also shows the least squares estimates of the derived demand equation in log-log form, revealing a price elasticity of 0.29 (i.e., a one percent increase in the price of water reduces domestic water demand by 0.29 percent).[4]

Turning to water demand in agriculture, Fig. 9 presents real price indices (adjusted for CPI) of natural water in agriculture and agricultural output (crops) over the period 1952–2011. It is seen that while water prices rose almost five-fold during this period, the crop prices were mostly stable and even declined toward the end of the period. As a result, Israel's farmers substituted natural water for recycled water and other types of marginal water (flood and brackish), as shown in Fig. 10. Figure 10 shows that during 1966–2016, the total allocation of water to agriculture has remained more or less stable (with some fluctuations due to rainfall variability) but farmers have shifted away from freshwater toward marginal (mostly recycled) water.

[4]As domestic water prices are determined administratively (as of 2007 by the Water Authority), there is no risk of simultaneity bias by using water price as explanatory variable.

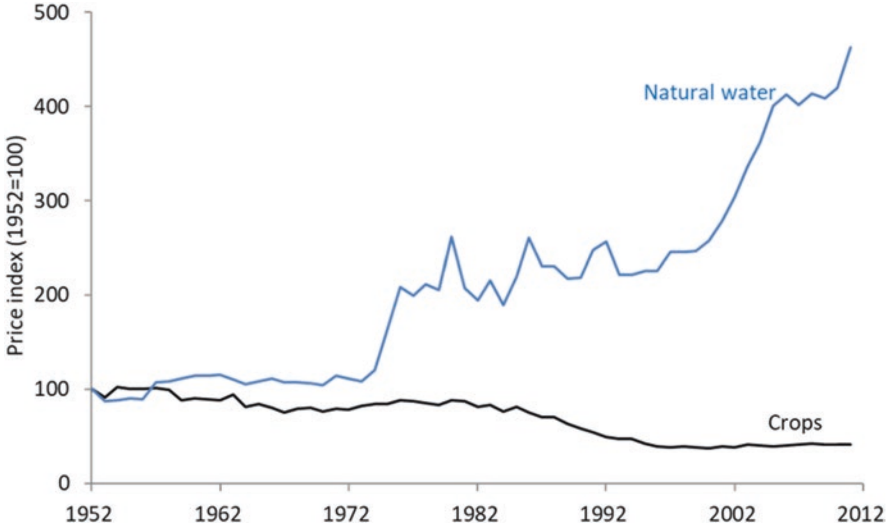

Fig. 9 Price indices (adjusted for inflation, 1952 = 100) of natural water allocated to irrigation and agricultural output (crops) over the period 1952–2011. (Source: Kislev and Tzaban (2013))

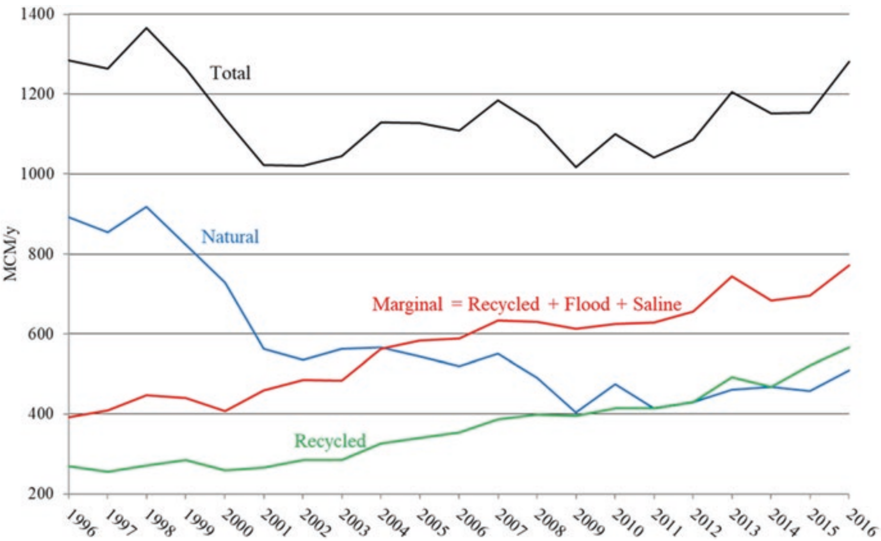

Fig. 10 Water allocations to agricultural from various sources in Israel during 1996–2016. (Source: Israel's Water Authority (http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/20164/thrich%20lfie%20matarot%201998-2016.pdf))

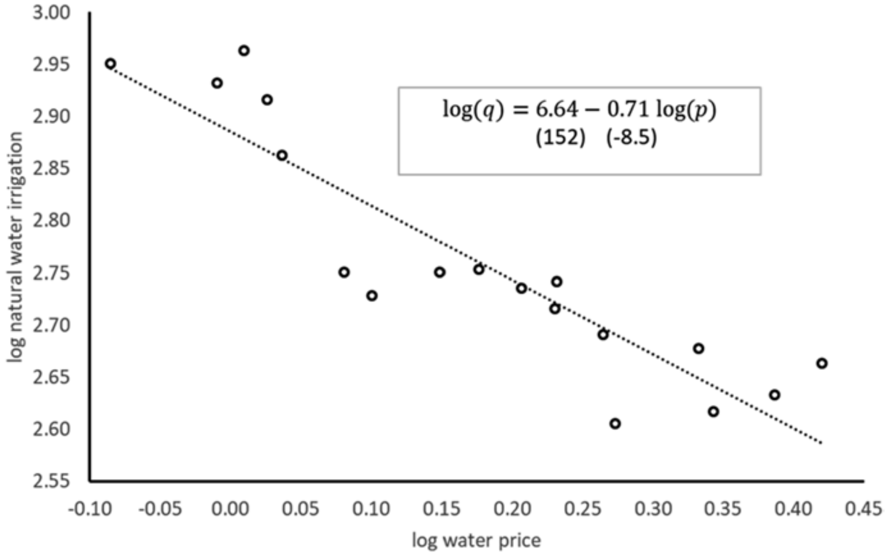

Fig. 11 Quantity and price of natural water for irrigation in log-log form, with least squares estimates (t-values in parenthesis), based on 1996–2013 data. The quantity data (million cubic meter per year—MCM/y) are the natural water data in Fig. 10. The price data (shekel per cubic meter) were obtained from Israel's Water Authority via personal communication (with Amir Shakarov)

Figure 11 shows log of natural water use in agriculture vs. log of prices of this water. The figure also depicts the estimated demand equation (in log-log form).[5] The price elasticity of (minus) 0.71 implies that 1% increase in the water price reduces the natural water demand for irrigation by 0.71 percent. This price effect is larger than the 0.29 price elasticity of households' demand (see Fig. 8), implying that farmers are more sensitive than households to water prices. This is partly because farmers can substitute natural water for recycled water with little or no effect on their overall use of water (see Fig. 10) whereas households must reduce their water consumption. All and all, Figs. 8 and 11 reveal that water prices are effective means in regulating water allocation.

In addition to water pricing, demand management entails the use of market mechanisms in various forms and shapes, on which there is a large (and growing) literature (see Adams et al., 1996, Easter et al., 1999, Zilberman, 2003, Saleth & Dinar, 2004, Rausser et al., 2011, Hansen, 2015, and references they cite).

[5]The water prices are determined by Israel's Water Authority and farmers respond by choosing their demand for irrigation with natural water, justifying the use of water prices as explanatory variable without risking the introduction of simultaneity bias.

4 Supply Management

Supply management policies deal with increasing natural recharge and developing additional (produced) sources. The former entails collecting and storing surface water (including floodwater) for direct use later on or for enhancing replenishment of aquifers, reservoirs and lakes (see Burt, 1964; Tsur, 1990; Tsur & Graham-Tomasi, 1991; Knapp & Olson, 1995). Produced sources include recycled water (obtained by treating domestic and industrial sewage) and desalinated water. We discuss recycling and desalination in turn.

4.1 Recycling

Figure 10 shows water allocation in Israel's agriculture during the 1996–2016. It reveals that the allocation of natural water to agriculture has reduced from 892.3 MCM/y in 1996 to 413.7 MCM/y in 2011—a decline of 54%—and increased slightly afterward. At the same time, the supply of recycled water to agriculture has more than doubled, increasing from 270 MCM/y in 1996 to 566.7 MCM/y in 2016. Israeli growers now use more recycled water than natural water and this trend (of replacing natural water by recycled and brackish water) is ongoing.

The direct effect of reallocating natural water from agriculture to households is to increase the allocation of (potable quality) domestic water. In addition, each cubic meter reallocated to households allows for 0.6–0.65 cubic meter of recycled water that can be allocated to agriculture (irrigation) or environmental purposes.[6] Thus, the overall effect of reallocating freshwater from agriculture to households is to increase total water allocation by 60–65% of the reallocation amount. Almost all domestic and industrial water in Israel are now recycled and made available to irrigation (pending conveyance facilities) and environmental uses. Moreover, all recycling facilities are expected (required by law) to be upgraded to tertiary level, allowing the use of recycled water for irrigating most crops.

4.2 Desalination

The cost of desalination has declined substantially during the last two decades due mainly to learning by doing associated with the increased scale of installed desalination capacity.[7] Figure 12 presents the desalination costs (in dollar per cubic meter

[6] The conversion rates in Israel's water economy master plan range from 0.592 in 2010 to 0.64 in 2030 (see Israel Water Authority, 2012, p. 14).

[7] See Rausser et al. (1972), Willis and Rausser (1973), and Rausser and Willis (1976) on learning by doing in desalination technologies. Rausser (1974) provides a more general account of Arrow's

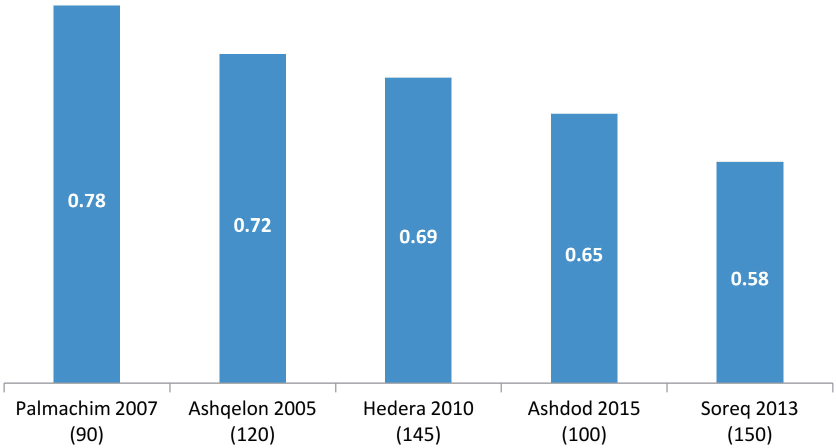

Fig. 12 Desalination costs in dollar per cubic meter at the plant's gate (under the exchange rate $1 = 3.7 NIS) of Israel's five major desalination plants. The numbers at the bottom give the year operation began and production capacity (MCM/y) in parenthesis. (Source: Israel's Water Authority (The desalination prices are based on the original prices at the time the contracts were signed. Over time, these prices have been adjusted for inflation and changed with the capacity expansions. The prices listed in the figure, thus, should be taken as estimates.))

at the plant's gate) and production capacity (million cubic meter per year—MCM/y) of the five major desalination plants in Israel. The overall desalination capacity now exceeds 600 MCM/y, which is about 64% of the domestic water consumption in 2016. The desalination capacity reduces reliance on fluctuating natural water sources and allows a sustainable management of the natural water sources, by reducing average extractions in order to increase stock levels, thereby eliminating risks such as seawater intrusion into the coastal aquifer (see Fig. 4). Moreover, it allows increasing water allocation for environmental purposes.[8]

5 Extending Israel's Experience to the JRB

The water pricing practices implemented in Israel reduced per capital domestic water consumption (Fig. 7) and motivated farmers to shift away from natural water toward recycled water (Fig. 10). A cubic meter of natural water reallocated from farmers to households can generate 0.6–0.65 cubic meters of recycled water suitable for irrigation or environmental restoration. Such a reallocated cubic meter, therefore, while fully contributing to domestic water supply, reduces irrigation water supply only partially, as a share of this reallocation (about 60%) can potentially be

(1962) learning by doing concept. Reducing the cost of desalination via R&D activities is studied in Tsur and Zemel (2000).

[8] See the planned fivefold increase in freshwater allocated to nature and landscape in Israel's long-term masterplan of the water sector (Israel Water Authority, 2012, p. 14).

returned to famers in the form of recycled water. Such a policy requires massive infrastructure investments in treatment and conveyance facility that should be carried out at the regional or state levels.

Learning by doing associated with increased desalination capacity has substantially reduced the cost of desalination. The substantial desalination capacity released Israel from the harmful effects of rainfall fluctuations and allowed closing the gap between water needs and natural water supply, while avoiding depletion of the natural sources. Future increase in domestic water needs, associated with the growing population, will be met by increasing the desalination capacity, thereby increasing the supply of recycled water. This, in turn, will augment the supply of water available for irrigation and environmental restoration.

The water situation of the Palestinian Authority (PA) is similar to that of Israel and the two water economies are highly interlinked. The PA's "water gap", therefore, can be closed in a similar fashion (as long as the two parties agree to collaborate).

Jordan's water situation differs in two main respects. First, the natural water sources of Jordan are smaller (both in absolute and per capita terms) than those of Israel and the PA, implying that its "water gap" is larger. In the coming two to three decades, Jordan will need to increase its water supply by about 500 MCM/y (Allan et al., 2014). Second, the bulk of Jordan's population resides in Amman's area—at about 1000 m above sea level and more than 300 km away from Jordan's only sea access (the Gulf of Aqaba). Desalinating in Aqaba and conveying to Amman is an expensive operation: the cost in Amman of water desalinated in Aqaba (before distribution to households and treating sewage) is estimated above $\$2/m^3$ (Allan et al., 2014), which is about three to four times the cost of desalinated water in Israel and the PA (see Fig. 12).[9] Moreover, discharging large quantities of brine (1 m^3 of desalinated water generates about 1.22 m^3 of brine) in the Gulf of Aqaba could have detrimental effects on the sensitive coral reef ecology and is likely to be objected by the other Gulf of Aqaba's riparian states (Egypt, Saudi Arabia and Israel). For these reasons, desalination in Aqaba (with brine discharge in the Red Sea) and conveyance to Amman is nonviable as a comprehensive solution to Jordan's water scarcity problems. I briefly discuss a blueprint of how to close the "water gap" in Jordan, which requires adding about 500 MCM/y to its supply of potable water, based on the Israeli experience and in collaboration of the three parties.

5.1 Water Pricing, Conservation (Reducing Water Loss) and Recycling

Water losses from Jordan's municipal supply networks were estimated in 2009 at 43%, which amounted to 137 MCM/y of the total municipal water allocation of 320 MCM/y (Yorke, 2013, p. 100). A reduction of water loss, through improved

[9] Most of the population of Israel and the PA resides near the Mediterranean and at low elevation.

management and pricing practices, to internationally conventional levels would increase the supply of potable water by about 100 MCM/y.[10]

Tariffs of freshwater for irrigation do not cover the operational costs of conveyance, let alone the fix cost of the infrastructure (Yorke, 2013, p. 46). Appropriate pricing of this water together with the development of recycling plants and conveyance infrastructure will allow reallocating about 300 MCM/y of good quality natural water from irrigation to domestic users, while fully compensating famers with recycled water. This compensation consists of about 180 MCM/y of recycled water generated by the 300 MCM/y reallocated to households (60%) and additional recycled water generated by the added potable water from other sources outlined below. Overall, appropriate pricing, development of recycled infrastructure and reallocation of natural water from irrigation to domestic users could increase the total supply of water by about 200 MCM/y.

5.2 Additional Freshwater Sources

According to the 1994 Israel-Jordan Peace agreement, Israel is obliged to supply Jordan 50 million cubic meter a year (MCM/y) from the Sea of Galilee (Lake Tiberias in Fig. 1).[11] The existing and planned desalination capacity in Israel allow Israel to reduce (or even terminate) conveyance of water from the Sea of Galilee southward, via the national water conveyor, allowing increasing the amount allocated to Jordan to 100 MCM/y.[12] The net addition of this option is therefore 50 MCM/y. The cost of this water in Amman is about \$1–1.2/m^3.[13] The potential of this option is limited by the annual inflow into the Sea of Galilee (Weinberger et al., 2012).

Allan et al. (2014) examined the cost in Amman of water desalinated along the Mediterranean Sea. The cheapest options considered (the northern alignment) entails desalination around the Haifa – Atlit area and conveyance to Amman via Naharayim-Bakura (at the confluence of the Jordan and Yarmouk rivers, just south of the Sea of Galilee—see Fig. 1). The cost in Amman (desalination and conveyance) was calculated to be in the range of \$1/m^3 to \$1.2/m^3 (about half the \$2/m^3

[10] An immediate effect of the increased domestic water rates in Israel after 2007 (see Fig. 7) was a sharp decline in the municipal water losses (from about 20–24% to about 10–12%).

[11] Jordan already installed the infrastructure needed to convey this water to consumers in the Amman's area.

[12] Actually, Israel has plans to reverse the direction of the National Conveyor by conveying excess desalinated water during the winter from plants along the cost to the Sea of Galilee in order to raise its average water level.

[13] This cost consists of \$0.3–0.4 per m^3 purchasing price plus \$0.7–0.8 per m^3 treatment and conveyance (see Allan et al., 2014).

cost in Amman of water desalinated in Aqaba).[14] The scale of this operation can reach 200 MCM/y.[15]

Small-scale desalination of up to 50 MCM/y can be carried out in the Gulf of Aqaba to satisfy the potable water needs in the Aqaba (and Eilat) area.

5.3 Actions Combined

The above four actions combined will increase Jordan's supply of potable water by about 500 MCM/y at a very reasonable cost as follows:

1. 200 MCM/y due to pricing, conservation and recycling;
2. 50 MCM/y from the Sea of Galilee (increasing the Peace Treaty allocation of 50 MCM/y to 100 MCM/y);
3. 200 MCM/y by desalinating along the Mediterranean (near Atile-Haifa) and conveying to Amman (via Naharayim-Bakura);
4. 50 MCM/y by desalinating in Aqaba.

All alternatives involve water in Amman at a reasonable and affordable cost and can be implemented within a short period. The additional 500 MCM/y will close Jordan's "water gap" for a few decades to come.

6 Concluding Comments

The Jordan River Basin (JRB), comprising Israel, Jordan and the Palestinian Authority, suffers from acute water scarcity: the average natural water supplies available on a sustainable fashion (without drawing down stocks) in this region will soon drop below 100 cubic meter per person per year (Fig. 5). This is far below the supplies needed for human activities (including food and fiber production) and the preservation of ecosystems, and gives rise to substantial "water gaps". The number of regions (worldwide) with similar situations increases over time with population growth, rising living standards and exacerbating climate change processes.

After discussing the water scarcity situation worldwide, I draw on recent experience in Israel's water economy to propose various actions that can be used to close

[14] The cost advantage is due to the shorter distances. The distance from Aqaba to the (southern) Dead Sea is 180 km, while the distance from Atlit to Naharayim-Bakura is about 70 km. The conveyance cost from Atilt to Naharayim-Bkura is fully paid by utilizing a pumped energy facility along the way in Kaukab-al-Awua (see discussion in Allan et al., 2014). As a result, the cost in Amman of this water is the same as the cost in Amman of water from the Sea of Galilee.

[15] Jordan has been explicit about not being dependent on a third party (Israel or the PA) for a large share of its water supply, but may not object to a fraction of the total water supply (say 200 MCM/y to 300 MCM/y) at a substantial lower cost than that of water desalinated in Aqaba.

the gap between available supplies of natural water and water needs (for human and environmental purposes). I then demonstrate how such interventions can rectify Jordan's water shortage, which is the most severe in the JRB. With appropriate modifications, to accommodate various idiosyncrasies, such interventions can be applied anywhere (there is nothing peculiar about the JRB that makes it more or less susceptible to such policies).

A water policy consists of demand management and supply management measures. The purpose of demand management is to increase the efficiency of water use, i.e., to do more with the same quantity of water. It includes measures such as water pricing and water quotas as well as institutional arrangements such as the delegation of municipal water to special corporations designed for that purpose, which can improved collection of water fees and reduced water loss (leakage) and theft. The purpose of supply management policies is to increase the available supply of water mainly from recycling and desalination plants. The two policy types are highly intertwined and must be implemented together, e.g., appropriate pricing scheme (demand management) that induces reallocation of natural water from irrigators to domestic users can reach its full potential only with the development of recycling infrastructure (supply management).

Far from being anecdotal, the case of the JRB involves elements common in many water scarce basins, including transboundary water resources shared by multiple parties, the need to balance environmental and human water consumptions, and the combination of demand and supply management policies in an erratically fluctuating environment. As the JRB case reveals, water does not respect political boundaries and collaboration is often crucial in dealing with water scarcity.

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Remote Sensing Technologies: Implications for Agricultural and Resource Economics

Richard Howitt, Larry Karp, and Gordon Rausser

1 Introduction

All natural resource and agricultural problems are dynamic stochastic control problems by their nature, but as several economists have remarked, not always usefully modelled as such. The dependence of natural resource industries and agriculture on fixed natural stocks of resources whose productivity is buffeted by stochastic events makes their study and management dependent on rapidly realized and precise information. Until recently, this information has not been available leading economists to usually approximate dynamic systems as a series of equilibria in comparative static models. The central theme of this chapter is that a major constraint on the implementation and use of dynamic stochastic analysis to manage natural resources is rooted in the problem of observing, monitoring, and measuring impacts in a dynamic context. For the past 50 years empirical natural resource economics has largely been reliant on data from surveys or government collection systems which are invariably restricted to annual measurement, which itself is probably delivered with a second annual lag. It is our hypothesis that we are in the initial stages of a

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revolution in data generation from natural resources and agriculture that will completely change the precision, cost, frequency, and type of measurement available to both farmers, resource managers, and analysts. As this tsunami of information promised by the developing Remote Sensing Technology (RST) arrives, it will change resource management. Given this wealth of information, decision-makers and analysts can realize the potential of the optimal control of resource policy and the simultaneous valuation and collection of information. In short, this revolution in resource information will realize the significant potential for formally modelling and managing natural resources as they truly are, namely stochastic dynamic systems.

It is ironic that the empirical data and measurement needed to implement stochastic dynamic control of natural resources is arriving 50 years after the basic concepts and theorems were developed. This paper opens with a survey of the conceptual basis of optimal control for agriculture and natural resources and the concepts of the joint solution of active and passive information collection. In Sect. 2, we provide a brief survey of past methods of remote sensing focusing on the current dominant systems using satellites. In Sect. 3, we investigate a new technology that is being advanced by Thorian, outlining its distinguishing intellectual properties and potential competitive advantages. In Sect. 4, we address the possible learning mechanisms that might emerge in the context of Thorium's data measurements, focusing on agricultural systems. Section 5 investigates the role of Thorium measurements more generally on natural resources regulations and management. Better remote sensing measurements can also improve the monitoring and enforcement of land and water property rights. The paper concludes with a cautionary section on the potential adverse consequences for natural resource management of this enhanced information potential that awaits us. Finally, Sect. 8 provides a number of concluding remarks.

In the late 1960s and early 1970s, Rausser, with a number of fellow PhD students at UC Davis, began a journey to conquer and determine the policy relevance of control theory in its richest versions, including dual control, open-loop feedback control, closed-loop control, and M-measurement feedback control formulations. With this common interest, many of his fellow students selected him as their PhD director after Rausser had become a faculty member following only 2 years of coursework towards his own PhD degree.[1] As a group, they recognized early that many agricultural and natural resource systems require stochastic and dynamic models. A host of publications emerged from their collaboration, including the first application of adaptive control to trade policy (Rausser & Freebairn, 1974), and the first application of M-measurement feedback control to environmental externalities (Rausser & Howitt, 1975). The former publication was based on an Outstanding AAEA Dissertation Award and the latter received the Outstanding 1975 AAEA Research Discovery Award. Rausser's book with Eithan Hochman, Dynamic

[1] Three of these PhD students have had sterling careers: John Freebairn, Richard Howitt and Cleve Willis.

Agricultural Systems: Economic Prediction and Control, won the AAEA Enduring Quality Award.

Along the way, a stream of publications focused on agricultural and natural resource systems (Rausser & Lapan, 1979; Pekelman & Rausser, 1978; Rausser, 1978; Freebairn & Rausser, 1975; Rausser, 1974, 1975; Rausser & Pekelman, 1980; Rausser & Willis, 1976; Rausser et al., 1972). All of these publications embedded learning, sometimes passively and other times actively. Two later publications included the critical role of information, measurement, and learning (Yassour et al., 1981; Rausser & Small, 2000).

All of these contributions advanced a policy or optimal control dimension that required taking a stand on the treatment of evolving measurements and information. Among the various approaches, the two most common are open-loop-with-revision and open-loop feedback. The former sets as a benchmark a deterministic problem under the fiction that there will no new information but with an understanding that when new information emerges, it will be incorporated into a decision or policy revision. The latter formulations create a stochastic problem with "anticipated but passive learning;" the decision maker chooses the current policy recognizing that subsequent policy will be adapted to information or data not currently available. In contrast to a deterministic formulation, the state of the system is stochastic, but the moments of the stochastic and dynamic process are generally presumed to be known.

Both the open loop (with revision) and the feedback approaches incorporate new measurements or information as it becomes available but neither selects actions or decisions with the objective of acquiring better measurements of the causal impacts of implemented decisions. A third approach "dual control" or "active learning" recognizes that choices not only have direct effects on outcomes or payoffs but also have indirect effects on improved measurements of causal impacts, sometimes referred to as response impact curves (Judge et al., 1977; Rausser & Johnson, 1975; Rausser et al., 1979). Pekelman & Rausser, 1978 and Rausser & Pekelman, 1980 recognized that firms can learn about an unknown demand function by varying the prices that they charge. A particular pricing choice not only affects current revenues or profits but also provides information about the price elasticity of demand. More accurate measurements increase future profitability. The optimal pricing policy balances the effects on current profits and on the acquisition of information. Active learning recognizes the tradeoff between expected losses in the short run and the future gain arising from more accurate measurements of the uncertain demand function.

The various policy control formulations attained here were originally introduced and applied by electrical engineers. The NBER in the 1970s attempted to integrate the work of electrical engineers with the economic profession. In several NBER conferences, Rausser presented his applications to agricultural and resource economics. Macroeconomists became intrigued with the methods' applicability to monetary and fiscal policy. Following an NBER conference at the University of Chicago, Business Week wrote:

Control theory has swept into the economics profession so rapidly in the past two or three years that most economists are only dimly aware that it is around. But for econometricians and mathematical economists, and for the companies and government agencies that use their skills, it promises an improved ability to manage short-run economic stabilization, long-run economic growth, investment portfolios, and corporate cash positions" (Business Week May 19, 1973; quoted in Athans and Kendrick, 1974).

This quote shows the significant early interest in using active learning formulations to obtain more accurate measurements of economic agents' behavioral responses. However, the electrical engineering formulations generally dealt with physical responses, not agents' behavioral responses. Moreover, macroeconomic applications are perhaps one of the least likely fields for which useful designs could be advanced of active learning models. Designing fiscal and monetary policies to actively acquire information is potentially valuable but the high cost of manipulating the system is typically unacceptable.[2] Solving, implementing and managing active learning to more accurately estimate behavioral responses can present technically insurmountable problems.

The "Lucas critique" (1976) and the subsequent work by Kydland and Prescott (1977), which followed the development of rational expectations modeling, presented a conceptual rather than technical challenge to policy applications of control theory. This critique recognizes that a standard optimal control formulation leads to time inconsistency in a setting where a decision-maker would like to announce a sequence of future policies (e.g. taxes) in order to influence other agents' current decisions (e.g. investment), and moreover the "future self" of this decision-maker would want to deviate from the announced sequence. Absent the ability to commit to this future policy sequence, agents with rational expectations would have no reason to believe that it will be carried out, so the announcement will not have its intended effect in influencing agents' current decisions. The Lucas critique means that policy cannot be effective when it relies on repeatedly surprising people, e.g. by using inflationary shocks to increase effective demand, or by promising low future capital taxes to encourage investment. This critique, sometimes construed to imply that public policy is powerless (Mundalk, 1990), made optimal control methods appear less important or even irrelevant in macroeconomics.

A different response that has gained widespread currency in both micro- and macroeconomics starts with the assumption that the policymaker understands that agents have rational expectation (Klein et al., 2008). These agents make decisions (e.g. about investment) based on their rational expectations about future government policy (e.g. taxes). The individual agents are too small to influence future

[2] The curse of dimensionality is particularly important in active learning formulations. These formulations require at least one state variable for each unknown parameter, potentially leading to an unmanageable number of state variables. The use of conjugate priors leads to tractable equations of motions for these state variables. However, even for specifications where conjugate priors make sense, the curse of dimensionality of the resulting system often makes dynamic programming impractical. Improved algorithms (e.g. a judicious choice of grid points for approximating functions) and computing capacity have dramatically relaxed constraints imposed by the curse of dimensionality.

government policy by manipulating the aggregate stock of endogenously changing capital; they therefore behave non-strategically despite having rational expectations. However, the agents' aggregate decisions do change the stock of capital—or some other payoff-relevant state variable. Moreover, the policymaker in the current period is unable to commit successors to a particular policy sequence. Commitment in this setting is implausible, and it would vacuously "solve" the time consistency problem by assumption.

The resulting model is formally a Stackelberg dynamic game, in which both the strategic policymaker and a large number of nonstrategic agents have rational expectations (Karp & Havenner, 1984). There are many types of equilibria in such a model, although a standard refinement uses Markov Perfection, where all agents condition their current decision on a payoff-relevant state variable such as aggregate capital; the non-strategic agents also condition their decision on their private stock of capital. The solution to a standard optimal control problem requires finding the planner's optimal decision rule. The type of game described here is more complicated, because it requires finding a pair of equilibrium decision rules, one for the policymaker and one that represents the behavior of the nonstrategic representative agent. The Nash condition requires that each decision rule is the best response to the other agent's decision rule. Moreover, each rule is a best response to the equilibrium decision rules that agents' "future selves" use. The last requirement guarantees time consistency. The Lucas critique vitiates the applicability, to public policy, of a *particular naïve* optimal control model, but not dynamic modeling in general.

This chapter discusses the new measurements that have, and will, result from remote sensing for agricultural and natural resources. These improved measurements increase the scope for active and/or passive learning formulations in improving the integration of measurements and choices made by individual agents. We propose that the data improvements engendered by remote sensing, especially, the low cost and high temporal and spatial resolution of data, will make active or well-structured passive learning a more effective means of improving the performance of agricultural and natural resource systems.

2 A Brief History in Remote Sensing Technologies (RSTs)

Remote sensing in agricultural and natural resource systems has become the latest technology to assist agents in enhancing productivity and efficiency. Image information collected through multispectral and hyperspectral sensors can be developed into actionable prescriptions backed by data analytics. Current RST largely relies on aerial remote sensing using drones and aircraft, but is gradually evolving into satellite remote sensing. This section describes leading companies engaged in aerial and satellite remote sensing.

2.1 Aerial Remote Sensing

Aerial sensors have become the go-to option due to their affordability and ability to capture high-resolution images at low-altitude flights, allowing meticulous analysis. Applications include yield estimates, evaluation of soil salinity, crop population count, and capturing differences in leaf chlorophyll content.

Ceres Imaging is a market-leader in the aerial remote sensing industry serving farmers and agribusiness using aerial spectral imagery and analytics. Ceres specializes in irrigation management, nutrient management, pest and disease management, and labor management, using multispectral cameras on fixed wing aircraft to generate crop specific data models to evaluate plant health. Their flagship analytics tool, the Chlorophyll Index, is able to incorporate four narrow bands that can distinguish differences in the nitrogen content of the leaves and relative health of crop canopy. The analysis reveals uniformity issues, tissue sampling, plant stress, and nutrient deficiencies. Recently, Ceres partnered with The Climate Corporation, a subsidiary of Bayer, to integrate the Ceres aerial imaging system with the Climate FieldView platform.

Gamaya is a company that focuses on drone and satellite imagery. Its technology stems from a sequence of international environmental research projects carried out between 2011 and 2015. These include the Leman-Baikal project, a multi-year Swiss-Russian initiative to study and preserve water resources using ultralight aircraft and cutting-edge hyperspectral remote sensing technology. Gamaya's hyperspectral camera is able to detect nematodes, plant nutrient content, weed classification, planting gaps and plant trampling, soil erosion, and is able to predict crop yields and monitor growth. Another company that initially provided services to wine grape growers is PrecisionHawk using autonomous, hand-launched, fixed-wing unmanned aerial vehicles to dispel predatory birds over vineyards. The company soon shifted direction with the addition of cameras to the aircraft that could provide clients with an aerial view of their fields. PrecisionHawk pivoted into a commercial drone company focused on agricultural and natural resource aerial data. Over the last 10 years it has combined with four other companies. The most recent Lancaster 5 drone features a swappable payload bay for various camera sensors. Available sensors include visual, thermal infrared, multispectral, lidar and hyperspectral.

2.2 Satellite Remote Sensing

While analysis using aerial and drone collected data has advantages both in cost flexibility and local applications there has been a significant trend towards data based on satellite remote sensing systems. These systems differ significantly in terms of the size of the satellites with many systems utilizing small cheap microsatellites whereas others are much more sophisticated but expensive conventional sized satellites. Satellite remote sensing allows the coverage of vast landscapes and crops and eventually observing the whole Earth continuously, leading to a multivariate approach that allows accurate analysis of geophysical and biophysical parameters, including tracking weather systems (i.e. natural disaster and weather forecasts).

Planet Labs was one of the first companies to both build and implement visual data networks using mini satellites. Planet Labs is focused on building inexpensive and compact satellites called CubeSats, that can be manufactured in bulk. Over 200 CubeSats satellites known as "Doves" were launched in secondary payloads on other rockets (Antares 110, Soyuz, and Rocket Lab Electron rockets) and are orbiting in sun-synchronous orbits. As of January 2020, Planet Labs controls 45 ground station antennas and boasts 25 successful launches making 363 satellite deployments using ten types of rocket.

In July 2015, Planet Labs acquired BlackBridge and its RapidEye constellation system (officially retired in April 2020). In April 2017, Planet Labs acquired TerraBella and its SkySat constellation system from Google in an equity stake and multi-year data purchasing contract. The SkySat satellite system consists of 150 Earth-observing satellites with a spatial resolution of 0.9 m in its 400–900 nm panchromatic band, making it the smallest satellite to be put in orbit capable of such high-resolution imagery. Planet Labs is in partnership with the Food and Agricultural Organization (FAO) to help track deforestation. A partnership with the California Forest Observatory (CFO) allows Planet Labs to dynamically map forest structure and fuel loads down to the tree level and to provide a clearer picture of wildfire risk.

Maxar was founded in 1969 and has developed the Worldview Network that has evolved through five generations from WorldView-1 to WorldView-4. WorldView-4 was launched on November 2016 can provide panchromatic images at a highest resolution of 0.31 meters per pixel and multispectral images at 1.24 meters per pixel. It has the capability of 14 revisits of Earth per day, 29 cm in resolution, accuracy of <5 m CE90, and 5M sq. km collected each day. It will also be able to create 3D skins of the Earth and regenerate that skin automatically when changes in the crust occurs. The WorldView system provides high-resolution imagery to Google Earth and Google Maps, as well as the Amazon Conservation Team, NSA, the USDD's NGA.

The Argentinian company Satellogic was founded in 2010 to provide spatial information services without major investments in infrastructure. Satellogic specializes in nanosatellites, with its flagship product CubeBugs being the first Argentinian satellites launched into space. Satellogic's NuSat satellite network of inexpensive nanosatellites are produced in scale with each satellite capable of multispectral imaging and hyperspectral camera. This means that Satellogic offers both 1-m resolution multispectral imaging and 30-m resolution hyperspectral satellite imaging. Satellogic has successfully launched ten satellites from China and Russia. (2 CubeBug satellites, 1 BugSat satellite, 7 NewSat satellites) that provide uninterrupted coverage of the Earth, rapid capability recovery and transparent hardware and software satellite updates.

Agricultural and natural resource applications from Satellogic include crop supply chain management, irrigation/water management, precision farming and vegetation index estimation. Forestry applications include asset and capital allocation management, prediction of biophysical variables, planet species/crop detection, automated tree count, and wildfire impact assessments. As part of a project that includes Tencent's "WeEarth" initiative, Satellogic, Tencent Cloud, and Luokung Technology and China Aerospace Science and Industry Crop Haiying Co Ltd. are structured to deliver 300 remote-sensing satellites capable of offering Earth observation services. Each company will play a different role in the project. Satellogic will provide on-orbit satellite constellation services enabling users to get specific images of the Earth; Luokung and Haiying will be responsible for spatial-temporal big data processing; and Tencent Cloud will leverage its expertise to build a cloud platform and a ground station for data analysis, storage and sharing.

Descartes Labs was founded in 2014 by scientists from Los Alamos National Laboratory to initially develop an agricultural and natural resource model to analyze corn and soy production in the US. Using imagery from various satellite constellations, weather data, and other datasets, the model accurately predicted yield 6 months prior to harvest. Realizing the global potential for the technology, Descartes Labs turned its focus to developing a cloud-based supercomputing platform for the application of machine intelligence to massive data sets. With an initial focus on satellite imagery, Descartes Labs processes a pipeline of data flows from all the major satellite constellations, at scale, to provide instant access to analysis-ready images of the entire world via a massive, searchable, on-demand interface. For example, petabytes of imagery can be searched and retrieved, and all features from various constellations accessed in under 100 ms.

The Defense Advanced Research Projects Agency (DARPA) will use the Descartes Labs Platform to build global-scale applications and offer them in the marketplace as a commercial service for data scientists. The platform features a cloud-native infrastructure designed to provide the storage, computing, access, and tools needed to analyze massive, complex geospatial datasets, making it an ideal foundation for this DARPA program. This modeling tool enables forecasting capabilities across industries, including agriculture and natural resource, energy, sustainability, mining, shipping, financial services, and insurance, to facilitate a range of data products from agricultural monitoring to mineral exploration. This is especially critical for commodity-focused companies facing sustainability and efficiency challenges, saving them millions of dollars by transforming the business quickly and cost-effectively.

3 Distinguishing Intellectual Properties and Potential Competitive Advantages

Despite the achievements of the four satellite systems reviewed in the prior section there is another system under development that promises to provide a quantum improvement in terms of precision, speed and spectral coverage called the Thorium

Satellite Network (TSN). TSN has a singular focus on changing mankind's relationship to the physical world. Thorium's business is providing decision-grade analytic products that transform the core efficiency of major physical industries and also has the potential of revolutionizing nation-state security. Thorium, along with its aerospace partners, are building a remote sensing satellite constellation designed specifically to capture a massive data source for core-impact analytics for the major physical industries that underpin nation-state economies. The TSN can continuously capture the world in visible and wideband IR, 752-wavelength hyperspectral imagery, x-band radar and p- and L-band radar. Visible and wideband IR can capture the entire Earth 10x per second, meaning cameras record every half square meter of Earth every day continuously. Hyperspectral cameras can capture entire land mass up to two times per day, meaning it can capture sub-surface stocks (i.e. oil and water) using its spectroscopy of 752 wavelengths. X-band radar cameras can capture entire land masses up to ten times a minute, while p- and l-band radar cameras can capture entire land masses up to four times per day. In contrast to the other remote sensing satellite services (Sect. 2.2), TSN satellites have the capability to continuously capture the whole wavelength spectrum, capturing both visible and invisible spectrums. In 3 days, TSN satellites capture the whole planet two times in ultra-high resolution hyperspectral, nine times in imaging & ground penetrating radar, and 518,400 times in visible and wideband infrared (0.5 M GSD). Thorium goes beyond all visual spectrum wavelengths; Thorium's Heptagon captures visible wavelengths and infrared wavelengths, HST captures hyperspectral wavelengths over the entire Earth twice daily, Radar-X captures large wavelengths through the atmospheric opaque, and Radar-L sees through haze, clouds, foliage, night and day to the surface and subsurface.

In comparison, Planet Labs' visible-only panchromatic sensor along with its multispectral imagery sensors are susceptible to spatial gaps in image information, and lack depth in agricultural and natural resource measurements. Multispectral sensors are mainly used for military purposes as they measure mid-wave IR and long-wave IR. Hyperspectral sensors like those found in TSN satellites are considered superior. Another competitor, Satellogic has developed a hyperspectral sensor that is only capable of 30-m GSD and 150 km Swath, while Thorium's < 1-meter GSD allows the best spatial resolution in the industry.

Thorium's revolutionary technology provides decision-grade feedback analytics for physical industry, exceeding the decision-grade data requirements. Decision-grade data requirements consist of four metrics: spatial resolution, spectral resolution, temporal resolution, and signal-to-noise ratio. In terms of spatial resolution, Thorium satellites can capture 0.18-m ground resolution images, 0.5-m ground resolution continuous video, and boast a hyperspectral camera capable of capturing <1.0-m ground resolution images. Thorium satellites' spectral resolution has 752 non-visible wavelengths measured from visible to long wave infrared waves, doubling the 350-wavelength requirement. In terms of temporal resolution, Thorium satellites can capture the Earth in 0.1 s using Visible/IR/SAR cameras, 0.3 days using ground penetrating radar cameras, and 1.2 days using hyperspectral cameras. Lastly, Thorium satellites' boast 5000:1 signal-to-noise ratio 2.5 times the decision-grade requirement.

TSN satellites are designed to spend 99% of their lives capturing primary revenue-generating data in comparison to tasking satellites that can spend under 5% of their time capturing client-requested data; 13,700 terabytes of useful data are delivered to ground per day. Thorium satellites are expected to have a lifespan of 15 years, and Thorium's constellation/satellite refresh program is globally supported. Due to its vast capabilities, TSN satellites can impact the commercial physical industry as well as increase a country's GDP growth. In particular, TSN satellites show great potential to enhance the underground resource industry, the agricultural and livestock industry, and the articulation of property rights.

Within the underground resource industry, TSN can map the world's sub-surface oil, gas, fish, water and 40 major minerals with precision, meaning that governments can obtain 80–90% exploration success rate for underground resource industry (oil, minerals, water). The satellites measure phenomena associated with underground hydrocarbons and other underground natural resource targets via remote sensing. Thorium processing then combines the phenomena with an artificial intelligence methodology and produces maps of concentration probability. Thorium can then deliver probability maps of underground natural resources which are typically on a 10-m × 10-m surface grid. As a result, the TSN system changes the exploration risk profile.

For the agricultural and livestock industry, TSN can supply precision farm directives to every farmer in every country, every week, meaning farmers may obtain more yield with lower costs on the same land base. TSN satellites remotely measure 72 different characteristics affecting the yield of a crop or plantation and can produce precision prescriptions for 21 crops. Thorium has also developed the specialized ability to measure characteristics of the soil at-surface and beneath-surface, including soil moisture and root density, as well as other related metrics that no other available technology can measure remotely, even with local drone methods. Thorium proposes to provide a simple weekly plan of action to best nurture crops given all factors, including accounting for weather predictions and other climate effects on a 2 × 5 m, 4 × 10 m, 8 × 20 m or tree-by-tree basis depending on the crop. Specifically, the weekly plan includes the precise time and placement of fertilizer (including type), herbicides, pesticides, water (in farms that have irrigation), aeration, and harvest, as well as 24/7/365 surveillance of farm to factory supply chain for fraud/adulteration monitoring.

Within the Infrastructure and Basic Manufacturing Industries, TSN can survey daily every factory and infrastructure in every country for activity and anomalies, leading to reduced downtime, giving more capacity with less risk of liability or service loss. Within the Trading and Physical Goods Movement Industry, TSN can see the entire Earth 2× per second, meaning that logistics and transportation companies can move perhaps 30% more goods via the same roads with real-time maps, alleviating traffic and reducing waste of time. Within the Insurance, Lending and Risk Industry: TSN can enable expansion of insurance and credit in multiple sectors of the global economy and perhaps reduce real risk in underwriting by 20–40% and decrease fraud in some sectors. For continuous tracking and alerts of boats, aircraft, and missiles, TSN can see and track every boat larger than a jet ski, every vehicle, all aircrafts larger than a Cessna 172 and energetic events as small as a grenade, allowing Thorium to locate and track external threats hours ahead of other traditional systems. Within the continuous monitoring and record of exclusive economic zones and border regions, TSN's persistent visible, infrared and radar forms a continuous electronic fence, that observe all crossings of economic zones or borders without the government's knowledge. Thorium can detect and alert authorities of an illegal border entry or exit in 23 s.

TSN enables Thorium to impact most physical industry sectors by potentially improving efficiency by 10%, leading to long-term growth in the GDP of a country. TSN can also dramatically undercut the cost of alternative or existing methods by drones or aircraft-based pipeline surveys, and also provide better results. The cost of adding incremental customers to TSN and applications is de minimus. As to impacts to the security of a nation-state, TSN enables Thorium to virtually eliminate economic smuggling of goods into subscriber countries. TSN also enables Thorium to dramatically reduce organized terrorism and insurgency, as well as direct interdiction of physical criminal activity (i.e. drug smuggling). Lastly, TSN completely upends physical border security paradigms.

Because of the increased frequency of the measurements Thorium enables rapid real-time feedback analytics characterized as "measure-analyze-adjust." This rapidly updated measurement system allows sequential adjustment of resource policy, thus ushering in the potential for rapid active control policy-making. For example, with regard to measurements of plants and the determination of plant health and projecting yields meter-by-meter, Thorium takes this information and determines the optimal inputs meter-by-meter with regard to fertilizers, pesticides, and moisture. Thorium then provides actions that should be optimal for individual agents or farmers. However, if this initial optimization is not implemented or proves difficult in practice, the rapid feedback allows the optimal policy to be adjusted using either a passive or active information analysis. In other words, Thorium's technology allows substantial certainty with regard to the underlying phenomenon but does not directly control the actions of individual agents who have access to their measurements. It is possible to reverse-engineer from future measurements whether individual agents have in fact implemented Thorium's advice. Discrepancies between the Thorium prescriptions and individual actions taken by agents can be monitored to determine the incremental value of additional advice and counsel that might be provided by extension personnel.

4 Agricultural Systems Applications

Remote sensing will not reduce the factors that limit the applicability of active learning arising from technical and computing constraints. However, the data improvements engendered by remote sensing, in particular the low cost and high temporal and spatial resolution of data, may make active learning useful in areas where it has languished. Decades ago, these methods were applied in agricultural and resource economics (Sect. 1). Remote sensing data will potentially lead to a resurgence of this type of research. For example, once high temporal and spatial resolution data of soil characteristics and plant health become available, it will be possible to massively scale up our ability to provide sound advice to farmers. Real-time micro-level data on soil and plants will make it possible to tailor advice to specific plots and also perhaps determine whether the advice is being followed. The variation in the implementation of remotely sensed advice by farmers and managers due to differences in personality and human capital will result in a range of measured reactions to the same advice that will make it possible to conduct massive randomized control trials (RCTs) to improve our knowledge base, while simultaneously improve outcomes (e.g. agricultural yields).

RCTs are the gold standard in empirical research within economics, across other social sciences, and of course in the biosciences. In this chapter we will not venture into the details of RCT design and estimation. All RCTs have been influential within economics, but practical constraints arising from the cost of performing the tests and also of collecting the test results limit their reach. RST can relax both types of constraints. In the case of agriculture, RST enables us to evaluate (e.g. soil) conditions over a vast area, at a high spatial resolution. That information makes it possible to know what types and levels of intervention (e.g. applications of fertilizer and water) are most likely to balance the twin goals of improving our understanding of the consequence of interventions and learning while also achieving high yields. RST also makes it feasible to collect the enormous amount of information that these trials generate. Therefore, RST makes it possible to scale up RCTs while maintaining or even improving both their experimental design and the accurate collection of the result they generate. This potential can increase the scope, the quality, and the external validity of RCTs, thereby magnifying their importance. Agricultural applications of RSTs can increase our ability to learn about and to control the physical relation between inputs such as water and fertilizer and yields. The human responses are likely at least as important as the physical measurements and are more central to economics. The careful design of RCTs and the subsequent accurate measurement of their results enable us to learn about and also influence ("control") these human responses. It will be possible to learn, at a heretofore impossible level of spatial and temporal resolution, how farmers respond to incentives. This question is central to the external validity of RCTs. When, for example, do farmers alter their input choice in response to advice? What level of direct incentive, such as an input subsidy, is needed to elicit a change in behavior? The answers to these and similar questions likely depend on the farmer's experience. Farmers are probably more responsive to advice or a policy change if they have benefitted from the advice or policy change in the past. This type of hypothesis is difficult to test using natural experiments; however, see Cai et al. (2020) for a successful exception. The panel data arising from RCT's creation of data with high spatial and temporal resolution will make it more practical to test such hypotheses.

The agricultural application fits within the framework of active learning because the advice given to farmers will attempt to satisfy two objectives. The first of these will typically dominate: improving farm outcomes, measured by yields, profits, and sustainability (e.g. protection of the soil and water resources). The second objective is to learn about both physical and behavioral responses. Among the many types of questions we will want to answer are: How does the response of plant growth to fertilizer and water applications depend on exogenous (e.g. climate-related) factors? How do farming methods, including the level of inputs, affect the medium to long term quality of the soil? What types of recommendations will farmers follow, which will they ignore, and why?

The few formal economic applications of active learning use small models. This choice arises both from data limitations and the computational burden of solving large problems. The greater availability of data arising from remote sensing will not relax the computational constraints. Thus, at least in the foreseeable future we expect that the type of agricultural application described above will use active learning more as a guiding principle than as a toolbox that can be directly applied. However, we do not know what levels of ingenuity future researchers will achieve. Problems that seem intractable to an older generation trained in classical optimal control might come to be pedestrian. An influx of data could spur the development of new methods of combining measurement and optimization.

Precision agriculture has been practiced for the past 20 years starting with field level ground-based measurements then later utilizing aerial photography and more recently drone based analysis as discussed in Sect. 2.1. The effect of the much greater precision frequency and range of information available from modern satellite systems such as TSN will not change the fundamental technologies used on the ground for precision agriculture, but should significantly lower the costs of implementing it which will lead hopefully to a much greater level of adoption of precision agricultural methods. In addition, the greater precision of information would enable the application of precision agricultural methods to really small fields and plots on semi-subsistence farms in developing countries.

The possibility of active learning offers one of the most exciting applications of RST, but passive learning will probably be more useful in the short run. We therefore discuss the Ensemble Kalman Filter (EnKF), an important and tractable means of incorporating passive learning from large data sets. This method, developed for the geophysics literature in 1994 by Evensen and adapted by Evensen and van Leeuwen (2000) to nonlinear dynamics, relies on sequential approximations that use a linear Gaussian specification on systems that are probably neither linear nor Gaussian. The key innovation in this method is the use of ensembles with smaller dimensions drawn as subsamples from a very large data set. The original foundational use of EnKF was in climatological models for weather prediction. More recently the approach is being applied to other physical and economic processes including land and water use in agriculture. EnKF is part of the universe of machine learning processes, although it has a formal statistical basis within a dynamic linear Gaussian specification. Katzfuss et al. (2016) review the statistical foundations of EnKF, noting that it embodies Tukey's (1962) principle that an approximate solution to the right problem is worth more than a precise solution to the wrong problem. EnKF can be thought of as combining sequentially approximated learning with the formal structural observations and equations of motion in the Kalman filter.

Given the need for sequential inversion of the covariance matrices to solve the filtering problem, a reduction in the covariance dimension is imperative for numerical tractability. There is therefore a significant advantage of operating with small dimensional ensembles drawn from the whole data set or generated by a Monte Carlo process.

Maneta and Howitt (2014) provide the first application of EnKF to the modeling of land and water use. This study estimates and updates parameters for the production function using noisy aggregate observations of agricultural activity and input costs. The analysis produced probability distributions of production and input predictions; those distributions reflect the precision of the observations used calibrate the model parameters and thus provide a basis for analyzing the uncertainty and the nonstationary of the model. This study illustrates what can be accomplished with current data. As such, it gives an indication of what we achieve using the more accurate, disaggregated, and finer temporal resolution made possible by RST. The EnKF method provides only one of many alternative approaches. Among its chief advantages include its ability to use the very large data sets arising from RST, while also incorporating structure, stochasticity, and learning into a formal model.

Maneta and Howitt (2014) use EnKF for the sequential stochastic calibration of the nonstationary hydro-economic model of California's irrigated crop sector. The fundamental model contains a CES production function and quadratic cost functions that are sequentially calibrated over a range of different regions and sequential stochastic draws of the ensembles. The elasticity of substitution parameter in the production function was stabilized in the filtering process using Tikhonov regularization, equivalent to a ridge regression approach. In some applications the ensembles are drawn from different models to derive a consensus forecast. In Maneta and Howitt's crop production and cost function application, the ensembles are generated by a Monte Carlo process that represents the degree of uncertainty of the parameters. Each ensemble is taken through the standard Kalman filter process of forecast, data observation, calculation of the Kalman gain matrix, and updating both the expected state and the covariance. The resulting estimates for the main parameters and their covariance conform to the standard filter interpretation. The posterior mean is a weighted average of the prior mean and the observation factor, where the weights are proportional to the prior precision covariance. The posterior covariance matrix is the sum of the prior covariance and the precision of the observations.

The stochastic calibration took place over 25 cycles; for each of four crops there were three share parameters, a scale parameter, and the elasticity of supply parameter. The results showed that the model converged rapidly; after five assimilation cycles all the 12 share parameters except the labor parameter on tomatoes converged. The tomato labor share parameter took 18 cycles to converge. The scale parameters for alfalfa, wheat, and corn also converge rapidly. Estimates for the elasticity of supply parameter were significantly noisier compared to other estimates; however, the variance was stable across all crops. Given the stochastic nature of the cycles, the baseline condition produced a distribution for each crop and input. The land allocation across the four crops varied from 0.4 to 5.1%; water was the most stable with its use varying from −2.7 to −5.9%, and labor from −0.2 to −6%. Model perturbation produced experiments to show the supply response and input substitution under two scenarios of a 30% and 50% reduction in total water available. Simulations using the calibrated model produce different distributions of input use by crop. Counterintuitively, the change in inputs driven by the 50% cut in the water supply had a tighter distribution than that driven by the 30% cut in supply. As expected, the distributions under the 50% supply cut scenario showed a significant downward shift with the greatest effect on water; land and labor also responded to the cuts in water, with smaller shifts due to a greater degree of substitution. Subsequent research has generalized the CES production model specification, making the returns to scale an endogenous variable to be estimated.

5 Natural Resource Regulation and Management Applications

The data provided by RST offers the possibility of putting natural resource management on a firmer scientific footing. We describe the kinds of controversies that are endemic to the natural resource economics, and then explain how RST can move the field forward. The controversies in the field arise because people have different values and they operate using different mental models about the physical and behavioral constraints that limit opportunities. The better data provided by RST can improve our knowledge regarding these constraints. To the extent that people are willing to change their thinking in light of new scientific information, RST can reduce the second of the two reasons for disagreement.

The management of natural resources in most cases involves decisions that have long run consequences because the decisions affect stock variables that change slowly. In some cases, disagreements about best-practices turn on value judgements, e.g. the importance of protecting current jobs and profits versus the importance of protecting the long-term viability of a particular natural resource. That viability depends on the future stocks of the resource. Often decisions are made in ignorance, guided by intuition that purports to be scientific, but without a strong scientific basis. For example, driftnet herring fishermen in the mid-1800s, demanded restrictions on longlines, a then-new technology. The driftnet fishermen claimed that the long-lines damaged fish stocks and endangered their industry. Many scientists, believing that the self-correcting power of nature would take care of any temporary problems, resisted those requests. Thomas Henry Huxley, a scientist and philosopher, was appointed to a British fishing commission charged with investigating the complaints. This commission concluded in 1883 that the requests were unscientific, and merely designed to impede technological progress. The commission wrote: “Any tendency to over-fishing will meet with its natural check in the diminution of the supply… this check will always come into operation long before anything like permanent exhaustion has occurred” (Kurlansky, 1998). This example illustrates a tendency to reach a conclusion because it is logically consistent with a purportedly scientific worldview; never mind whether the worldview is correct. Around the same time, Maine's fishery commissioner Edwin Gould wrote "It's the same old story. The buffalo is gone; the whale is disappearing; the seal fishery is threatened with destruction. Fish need protection" (Bolster, 2015).

Huxley's faith in the self-correcting properties of nature finds an echo in some schools of economics, and sometimes that belief turns out to be correct. The mid-nineteenth century British government was concerned that high consumption of coal would lead to future scarcity. William Jevons, a prominent economist, advised the government not to use policies that would lead to coal conservation, on the ground that the market would resolve any future problem: if the price of coal did rise, businesses would reduce their demand, and innovators would develop substitutes for coal. Based on this kind of reasoning, Harold Hotelling (1931) produced one of the cornerstones of the field of resource economics. Responding to the pessimists of his time, he wrote "Contemplation of the world's disappearing supplies of ... exhaustible assets has led to demands for regulation of their exploitation. The feeling that these products are now too cheap for the good of future generations, that they are being selfishly exploited at too rapid a rate, and that in consequence of their excessive cheapness they are being produced and consumed wastefully has given rise to the conservation movement." Hotelling's theory recognized that the fact that resources are scarce does not imply that extractive industries need to be regulated.

Non-economists often fail to recognize the role that markets can play in overcoming resource scarcity. However, people interested primarily in short run profits or job opportunities often misrepresent the insights produced by economic theory, using it as an ideology that imbues market economies with qualities that markets do not possess. In doing so, they ignore important caveats that are well understood by economists. Market failures such as imperfect property rights may cause market outcomes to be inefficient. Even when efficient, the market outcome may be inequitable, and may undermine social cohesion. Better science will not, of course, alter the human tendency to cherry-pick the information that accords with their prior beliefs and/or self-interest. But at some point, better science increases the costs of maintaining positions that are inconsistent with evidence. Climate science provides a leading example. As this science has improved, a smaller segment of the political power structure remains comfortable denying the dangers arising from our use of fossil fuels.[3] RST is important because it can improve science and potentially help clarify tradeoffs.

Disagreement between resource optimists and pessimists recurs throughout the history of resource economics. These disagreements often stem from differences in worldview having little to do with science. Barnett and Morse (1963) produced an early empirical study, examining trends in resource prices as a means of gauging the likelihood of impending environmental doom. They found no evidence of increased scarcity. A decade later Paul Ehrlich and Julian Simon made a famous bet that turned on the change in the price of a basket of commodities over the next 10 years,

[3] There are many examples where science wanders down blind alleys, often perpetuating harmful beliefs (e.g. racism and false theories of mental illness). These harmful effects are resolved by better science, not by rejecting science.

with Ehrlich wagering that resource scarcity would lead to price rises. Ehrlich lost the bet and paid up but contended that he had been wrong merely in the timing of the catastrophe. Ironically, had Ehrlich and Simon made the same bet in almost any other decade in the twentieth century, Ehrlich would have won (Sabin, 2013). Price trends are informative, and if they last long enough, they become impossible to ignore: who now thinks that there is a scarcity of coal? In contrast, short run trends may be misleading: remember peak oil? However, in the context of resource markets, where market failures are rife, even many decades of price trends might provide a poor signal of scarcity. Market prices for externalities are clearly unavailable.

5.1 Fishery Management

Poor resource management arises for at least three types of closely related reasons: we lack the knowledge basis for determining the "optimal" regulations; we have difficulty enforcing regulations that are imposed; we disagree on the objective of regulation (e.g. short term versus long term health of the industry). The discussion on fishery economics below explains how remote sensing data can help to overcome the first impediment to good regulation. RST is also likely to be important in overcoming the second impediment. Better data can help indirectly with the third impediment to good management, by providing greater clarity about what is happening to resource stocks and by enlarging the set of policy options.

Fishery economics relies heavily on optimal control methods and has constructed a rich theory that includes both behavioral and biological features. Theory can help frame questions and explore the implications of assumptions and policies, but it almost certainly cannot resolve the deep issues of resource economics. That requires data. For example, very simple models can rationalize the opposing views of Huxley and Gould quoted above. Even under open access, the market-driven behavioral responses induced by changes in fish stocks and the resulting change in the cost of catching fish can make fishery regulation relatively unimportant. A slightly different model predicts that fishery regulation is essential to avoid extinction of stocks. These two scenarios turn on the relation between stock and harvest costs and/or on the elasticity of demand. Without reliable measurements of these factors, superficially similar models can produce completely different policy recommendations. Models without data cannot provide a good foundation for policy. RST opens the possibility of much superior data.

Good quality data is essential, but so is its acceptance by those affected by policy. Fishers may oppose regulations that limit their access to stocks if their objectives differ from the regulators' (e.g. a different evaluation of short and long run costs), and also if they distrust the data underlying the regulation. Better data can resolve the second but, of course, not the first reason for disagreement. Attempting to preserve stocks, the U.S. government closed three areas of the US Northwest scallop fishery in 1994. Scallopers, who opposed the closures, shifted location and exhausted stocks in other areas. An industry group then funded research by University of

Massachusetts biologists who concluded that the population in the closed areas had rebounded. Subsequently, the industry began to commit a fraction of its profits to conduct stock surveys, which the National Marine Fisheries Service (NMFS) relied on to identify areas that should be closed. A closure of 3–5 years often enabled the scallop populations to recover, a system similar to field rotation in agriculture (Wittenberg, 2014). The success of the program depended on good data and cooperation between fishers and NMFS. The regulated have to trust the data used by regulators; in this case, the trust arose because the regulated supplied the data.

The improved data provided by RST will make it easier and cheaper to reliably estimate stock levels for fish and other natural resources. There are currently two main approaches to estimating fish stocks. One method posits a specific functional form relating fish stocks, fishing effort (e.g. inputs such as boats, workers and equipment), and catch. Regressions of catch on effort make it possible to estimate stocks (Zhang & Smith, 2011). A more direct method drags nets across fishing areas to collect samples. Scientists estimate the age of individuals in the sample by counting rings in the ear canal or the jaw (just as we can determine a tree's age by counting rings in the trunk). This data is then used within a dynamic and measurement framework, in a manner analogous to the Kalman filter. The procedure produces estimates of both the unobserved stock and of parameters of the growth equations, e.g. growth rate and carrying capacity (The International Scientific Committee for Tuna 2011). The cost of data collection constrains the quality of these estimates. If RST produces accurate time series on fish stocks, fishery economists will be able to provide a strong empirical foundation for their half-century of modeling effort. This new data could hugely improve the importance of fishery economics in managing fisheries. The same type of transformation can occur in other areas of resource economics.

5.2 Fisheries and Vessel Monitoring Systems

The difficulty of monitoring and measuring fish stocks and the equally important difficulty of monitoring fishers limits the success of fishery management. Many countries have established regional fisheries management organizations (RFMOs), but scarce information reduces their ability to achieve efficient fishery management. For many years, observers placed on boats provided the RFMOs' primary source of information about fishers' behavior. These observers are expensive and are subject to significant pressure, and sometimes outright threats, to modify the information they report. They are also ineffective because a single person cannot observe fishing activities during the entire day.

The Pew Charitable Trust organization has published a comprehensive summary of methods of electronic surveillance of fishing effort, documenting their cost advantages over in-person monitoring (https://pewtrusts.org/internationalfisheries) Pew Charitable Trusts (2019). Different fisheries, boats, and gear types require different types of electronic monitoring. The Pew report classifies the electronic monitors into those that record the location, the drum speed, and depth of troll gear, and two types of camera that record gear setting and gear hauling. The system feeds these sources of information into a central controller that beams the results back to the RFMO for analysis. The type of fishing gear a vessel used often influences an electronic monitoring (EM) system's effectiveness. On longline vessels static cameras can capture data on fish that are brought onboard one at a time. A comparative study across both longline and gillnet boats showed that electronic measures were more consistent with logbook measures for longline boats than for gillnet boats. Electronic methods save between 15 and 50% of the cost associated with individual observers. The electronic monitors, unlike the individual observers, are alert during the entire day. Electronic monitoring is an effective method to measure catch over a range of gears, including trawlers and seiners. However, the Pew report notes several areas in which electronic monitoring may deficient. The electronic systems are unlikely to capture compliance with mitigation measures that do not happen on deck, such as steps to reduce bycatch and discards. The technology also requires basic maintenance by the crew, including making sure that cameras are powered and their lenses are clean. Although well-managed EM systems are a significant improvement over individual boat observers, a more precise RST system could take over the observation activity currently performed by cameras that have to be placed on the boat and maintained, often reluctantly, by the crew.

Resource extractors and users have different objectives, often exhibiting risk aversion. However, many models of management response assume that resource extractors face a common objective such as profit maximization or quota fulfillment. Surveys show that resource extractors may have a broad range of characteristics, leading to significantly different responses to a policy. These behavioral differences have rarely been incorporated into management systems, primarily because it is difficult to classify, estimate, and identify resource extractors according to their type. O'Farrell et al. (2019) use remotely sensed spatial data, logbook information, and gear type, together with statistical clustering, to classify fishers in the Gulf of Mexico Grouper-Tilefish fishery into three main behavioral types that remained relatively constant over time. The three categories differ in terms of mobility, risk bearing, expected revenue, the standard deviation of revenue, days at sea, and the likelihood of exploring new fisheries. The authors measured the different groups' response to significant shocks such as the major oil spill. Estimates of the population and characteristics of different behavioral types are also useful for correctly estimating the impact of alternative policy actions such as spatial closures, temporal closures, quotas, time limits, or gear restrictions. The authors noted that the introduction of individual quotas that eliminated the race to fish and spread fishing over a longer season may have had greater impacts on risk-tolerant fishers. Area-based management actions might have a different impact on the more mobile and exploratory vessels in two of the groups.

This research shows that the potential for spatially and temporally improved RST information will have significant impacts and cost reductions on the ability to manage fisheries using traditional methods of gear restrictions and fishing closures. In addition, the improved RST capacity will facilitate further research that broadens the range of policy response to consider the differences in behavioral aspects amongst the agents. Combining both behavioral and bio-physical responses will lead to more nuanced and effective fishery policy management.

5.3 Extractive Resources: The Unique Case of Sand

Natural resource stocks are defined in terms of their location, quantity, and extraction technology. As the spatial and temporal ability of RST increases the quantity and raises the precision of information on natural resources, the value and use of natural resource stocks will likely grow. Most natural resource economics has focused on the well-known and well-developed stocks such as mining, fishing, agricultural land, forestry, and water. This emphasis has led to the definition of stocks and also rules of extraction. For example, Riparian water rights in the Western US are based on a Roman law that was enacted by the Senate (the original one) to ensure that there was sufficient water in the river Tiber to enable cargo boats to reach Rome. Other long-established natural resource extraction rules such as grazing rights on common land or the way in which dead timber can be taken from forests have stabilized natural resources while allowing uses that have acceptable externalities. Here we discuss sand, a relatively little-studied extractive resource, but one that illustrates the problems arising from weak regulations that result from poor measurements.

Sand is rarely considered a resource with either a high stock value or high extraction-related externalities. Stocks of sand appear plentiful and it might seem that there is high substitutability from one source to another. However, sand's economic use depends on which of the three natural processes, marine, river, or deserts generated it. Sand generated by deserts is spherical and therefore cannot serve as a component for sand's dominant uses in construction materials, concrete and land reclamation. Sand from rivers and marine sources is angular, adding to its strength and rigidity in producing concrete. However, marine sand has to be washed to remove the salt before using it to make concrete. Sand is also used in growing quantities in fracking for oil extraction. This process requires that the fracking sand is small-diameter and round in order to be pumped into fractured rock and effectively hold open the fractures while the oil and gas permeate through them. The location of stocks of sand relative to their use is a key factor affecting the stocks' value. Like water, sand is heavy and difficult to move over distance; thus, the proximity of sand near large city construction regions adds greatly to sand's value and to the incentives for illegal extraction.

For many years sand was mined from riverbeds and land quarries, but with the increased pressure for infrastructure building in developing countries, extraction methods using dredges or high-powered jets have damaged the environment, harming the local economy. Countries have responded with regulations and restrictions, causing a shift in sources of sand to the more plentiful marine sites. These are more expensive to develop due to the need wash the salt out of the sand before it can be used for land reclamation or construction. In several developing countries, particularly India, there is a thriving business in black-market construction sand. Profits are high enough to induce entry of a sand mafia with associated violence and intimidation. The growing demand for sand will increase as urban areas continue to expand, and sea levels rise.

Major international agreements such as the 2030 Agenda for Sustainable Development and the Convention on Biological Diversity promote responsible allocation of natural resources, but there are no international conventions to regulate sand extraction, use and trade. As long as national regulations on sand extraction are lightly enforced, harmful effects will continue to occur. Regulations on sand mining are ineffectual largely because illegal mining is hard to detect. In India, most illegal sand mining takes place at night with trucks removing sand from the riverbanks in rural areas. A sophisticated and multispectral remote sensing system could detect trucks operating in suspicious circumstances and track them back to their sources by day or night. In addition, more precise measurement of changes in the riverbank would reveal where illegal sand mining was taking place and would then alert regulators to monitor the trucks.

Sand mining has resulted in several environmental and health problems in different parts of the developing world. These include habitat destruction for species that rely on sand bars for temperature control or breeding, and the reduction of beaches and wetlands, making coastal communities more susceptible to high water events and storm surges. Sand mining in the Mekong Delta is creating stagnant pools of water, increasing mosquito infestations and the resulting health problems. This litany of impacts from illegal sand mining will not be reduced without significant reductions in the costs of obtaining the information required for identification and enforcement of the regulations against illegal sand mining.

The rapid rise in the use of fracking for oil and natural gas extraction in the last 20 years has stimulated a parallel rise in the demand for fracking sand. Because most of the fracking has occurred in developed countries, sand mafias have not arisen. However, the increase in sand mining in certain parts of the US has harmed the environment even while aiding economic growth, especially in rural areas. Fracking sand mining is concentrated in Wisconsin, Illinois, Minnesota, and Michigan because the suitability of the sand there and the proximity to several productive fracking regions. Mining sand for fracking has damaged the environment by changing the course of rivers, sandbanks, and sediment. Increased precision and frequency of remote sensing can identify the downstream impact of these mining operations on the environment and on local communities.

6 Monitoring and Enforcement of Land and Property Rights

The lack of information about many natural resource stocks makes it difficult to define and enforce their associated property rights. The inability to measure both the stocks and the response to management actions (e.g. a hunting ban) is a root cause of ill-defined property rights. We cannot manage what we cannot measure. Weak or nonexistent property rights are more likely to be a result than a cause of poor information about the resource. The greatly improved information precision and disaggregation resulting from RST's will make it possible to improve the property rights and the management of natural resources. However, better information about natural resources is a necessary, not a sufficient condition for improved management. There are many examples of new technologies, including improved fishing methods and the substitution of aquaculture for the capture of wild stocks, which create the potential for more efficient and more sustainable resource management. But without improved regulation, these superior technologies create new problems, possibly exacerbating the original situation. Better information in the absence of improved management may simply make it easier for extractive firms to locate the resources, worsening the tragedy of the commons.

As previously discussed in Sect. 4, the type of information produced by improved RST will make it easier for scientists to measure both the stocks of natural resources and also the equations of motion that govern their evolution. Such information will enable managers to estimate resource users' responses to policy controls. It will also become easier to detect when resource uses are violating policy, e.g. by excessive extraction or illegal hunting, as the fishing example in Sect. 5.1 illustrates.

6.1 Groundwater

Property rights to groundwater are generally weak and diffuse; where they exist, they are often unenforced. Although there are a few exceptions to this rule, groundwater property rights are ineffective and ill-defined in the majority of U.S. states. We use California to illustrate this point. Groundwater rights in California are usufructuary, meaning that they are defined in terms of their use rather than their quantity or location. With a few exceptions, where a groundwater basin has been legally adjudicated and allocated amongst overlying users, groundwater is not monitored, measured, or restricted. The only restrictions are the requirements that the water must be beneficially used by the overlying users and that this use does not excessively impinge on the use by others. If a neighboring user feels harmed by adjacent pumping, their only recourse is a formal legal proceeding, which inevitably takes much time and is understandably influenced by the wealth and tenacity of the respective sides.

California passed the Sustainable Groundwater Management Act (SGMA) in September 2019, requiring state agencies to oversee local plans to achieve a steady-state sustainable groundwater extraction regime within 20 years. The law mandates local regional agencies to submit plans to manage and measure groundwater for approval within that time horizon. Given the current uncertainty about, and aggregation of, groundwater movement and use, this law has stimulated a jump in the demand for groundwater modeling, measurement, and monitoring. Remote sensing methods have a substantial role to play in this new regime, transitioning from vague and ill-defined property rights to precise managed extraction rights over the next 20 years.

Current empirical groundwater modeling is based on relatively large cells that are spatially and vertically connected and modeled by finite difference equations. Although the models are sophisticated, their empirical precision is limited by information on groundwater use obtained from a network of monitoring wells, operated by the California Statewide Groundwater Elevation Monitoring system (CASGEM). In many places these monitoring wells are sparsely located, requiring significant aggregation to calibrate the models. In addition, the cost of measuring groundwater elevations at different times of year over the large number of locations is substantial.

The potential for measuring groundwater elevation using remote sensing is already being used, but would greatly benefit from improved precision and frequency. Currently there are two dominant methods of groundwater measurement using remote sensing: the Gravity Recovery and Climate Experiment (GRACE) and satellite-based Interferometric Synthetic Aperture Radar (InSAR) approaches (Motagh et al., 2017; Ziwen et al., 2019). InSAR techniques measure ground deformation, providing a suite of observations that can be used to track water volume changes at intermediate scales between GRACE and well data. InSAR has been used to image surface deformation associated with groundwater withdrawal and replenishment. Such measurements improve on the spatial resolution of GRACE's satellite-based gravity observations. However, because ground deformation is an indirect measure of the changes within an aquifer, additional analysis is required to extract the stock measures that water managers require for insightful analysis.

An alternative approach to estimating water use relies on an energy balance measured by reflection from the field coupled with local climatic information to translate changes in energy to the net evapotranspiration (ET) of water from the crop or soil surface. These relationships can be estimated on a 40 m × 40 m pixel and generate estimates not only on the field level but of variations in ET and management within the field. Bastiaanssen et al. (2005) developed the original approach in an energy balance model called Sebal, applied to The Netherlands. Its key innovation is that the energy balance modeling uses a near-surface temperature gradient, which eliminates the need for absolute surface temperature calibration, a major stumbling block in operational satellite ET. Allen et al. (2011) has developed an extension to Sebal called Metric, departing from the Sebal model in its use of weather-based reference ET to establish energy balance conditions at a "cold" pixel. This innovation makes the best use of existing technology in agricultural areas and serves as a reality check on actual ET estimates.

The Sustainable Groundwater Management Act (SGMA) requires filing a groundwater sustainability plan (GSP) by 2020. Given the absence of meters on groundwater pumps in California and the variation in crop water use coefficients across soil types and micro regions, implementation of the plan will need an alternative monitoring system. One water district, Rosedale Rio Bravo in Kern County, has already implemented a remotely sensed water budget plan on the farm scale in its GSP filed in December 2019. The GSP will track net demand using a satellite ET estimation model. The district is developing a web-based water supply accounting database system on an assessor's parcel number (APN) that will provide parcel-level water balance on a monthly time step. This information will enable landowners to track water supply and usage to meet demand-reduction objectives. The important feature is that the water district has managed the process of introducing the potential demand reduction program based on remotely sensed measures of water use. This example shows that if correctly presented with sufficient information, farmers and other resource users will accept data estimated from remote sensing methods not only as the cheapest but also the most reliable way of micro-measuring resource use. Groundwater rights in California are “correlative” and thus proportional to the overlying ground area. Given the substantial cuts in water use that SGMA will engender in many areas and the wide range of value of marginal product from water, efficient implementation of these cuts suggests establishing a comprehensive market for pumping rights. In the absence of meters on most groundwater wells, a low cost, precise groundwater measurement technology such as provided by the TSN system will be very valuable.

6.2 Land Property Rights and Informal Economics

Twenty years ago the Peruvian economist Hernando de Soto published his second book titled The Mystery of Capital (2000). The book had a significant impact on policies and theory of property ownership in developing countries. De Soto proposed that the reason that market economies did not develop in many non-Western countries was rooted in the lack of institutions that enabled clear and consistent property rights that could then be extended by systems of finance, borrowing, and securitization which are necessary to generate capital for more productive activities. De Soto refers to this type of national resource both in terms of real estate, agriculture, extractive resources that is not formally securitized as “dead capital”. De Soto argues that the lack of the ability to move from an informal to a formal capitalist economy is not one of costs, culture, lack of entrepreneurial zeal, or lack of incentives but rather the overwhelming difficulty in registering and defining the units of capital in terms of land, buildings and extractive resources. de Soto points out that since the nineteenth century, developing nations have been copying the laws of the West to try and establish the institutions necessary to generate wealth. Despite this, current property laws have taken a form in which is extremely difficult for individuals to turn their savings into capital. He goes on to argue that is a problem of missing information and malfunctioning institutions. He bolsters his case with a series of convincing accounts of the difficulties of establishing small businesses and of property transfers in several different countries focusing on Peru, Egypt, and Indonesia. This sweeping and somewhat simplistic solution to a persistent and fundamental problem of economic development has stimulated both critics and adherents. In the intervening 20 years there have been some significant successes but also a series of documented failures (Fernandes, 2002). One of the principal criticisms of the de Soto’s conclusions is that they ignore the role of collective capital, and do not account for widely differing socioeconomic attitudes to commerce, profits, and wealth. However the improvement of institutions establishing codifying property rights will certainly be aided by lowering the transaction costs of measurement, specification, verification using RSTs.

An example of this is that property rights and revival of collateral for external bank debt for agricultural and forestry lands can be greatly enhanced by TSN's Thorium Property Rights and Registry System (TPRR). This system is capable of remotely mapping thousands of square kilometers per day to under 10 cm accuracy through trees, foliage, and ground clutter, sufficient for property right registry and most government legal systems worldwide. Thorium can verify occupancy and use/function in most situations using remote sensing methods with minimal interaction with owners/occupants. Thorium has world-class and UN/NGO-compliant systems for verifying the integrity of the registry and assuring that key elements are verified on-ground. As a registry, it is being designed to accommodate international lending standards, and thus enable affiliated lender and insurance companies to begin deploying credit and cash into the local economy. Clients receive a continuously (typically daily) updated database that integrates, supplements or suppliants any existing system, which is compliant with local laws and contains all relevant ownership and physical documentation necessary for lending and securitization to international standards. In overall impact, and using de Soto's method of calculating the quantity of dead capital, TPRR surveying and verification may enable as much as $170 T+ to enter global emerging market economies.

7 Potential Adverse Consequences of Remote Sensing

Given all the data that can be continuously captured and downlinked over the whole planet, both nations and interest groups may object to the implementation of the technology that Thorium and other remote sensing firms are developing. What happens when a country objects to commercial entities collecting data inside their national jurisdiction? Are there currently any international rules or norms that govern this type of information and data collection? Unfortunately, there is currently no well-designed comprehensive governance structure for satellite services and the data they generate. However, there are a number of international agreements and proposals that have been advanced in public discourse that might one day lead to the formation of such a governance structure. We briefly outline existing agreements and then discuss the concerns raised by interest groups.

International governance relies mainly on guidance from the United Nations Office for Outer Space Affairs and on the UN Committee on the Peaceful Uses of Outer Space (COPUOS), the primary UN body for coordinating and facilitating international cooperation in space activities. There are five main United Nations treaties on outer space: The Outer Space Treaty, The Rescue Agreement, The Liability Convention, The Registration Convention, and The Moon Agreement. The Outer Space Treaty of 1967 (Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial

Bodies) serves as the basis for international space law. As of June 2020, 110 countries have ratified this treaty while 23 others have signed the treaty but have not completed ratification. The Principles Relating to Remote Sensing of the Earth from Outer Space, adopted by consensus in 1986, provides non-binding principles to guide activities of remote sensing of UN member states.

United States governance on remote sensing in outer space dates back to the ratification of the Land Remote-Sensing Commercialization Act in 1984 that establishes a system to further the utilization of satellite imagery data obtained from Earth observation satellites located in a geocentric orbit above the atmosphere of Earth. It was later repealed by the Land Remote Sensing Policy Act. The Land Remote Sensing Policy Act of 1992 affected Landsat 7 procurement, Landsat 4 to 7 data policy, transfer of Landsat 6 program responsibilities, regulatory authority and administration of public and private remote sensing systems, federal research and development, advanced technology demonstration. It also influenced Landsat 7 successor systems, data availability and archiving, and the continued prohibition of weather satellite commercialization. As a whole, the new legislation has four primary features: a focus on the value of remote sensing in conducting global change research and other public sector applications; a retreat from the attempted commercialization of remote sensing as practiced since 1984; a more formal merger of national security and environmental remote sensing activities; and provisions for the future evolution of remote sensing policy.

The U.S. Commercial Remote Sensing Space Policy (CRSSP) of 2003 remains in effect. The policy directs the U.S. government to rely on commercial remote sensing space capabilities to the maximum practical extent, and to develop a long-term, sustainable relationship with the U.S. commercial remote sensing space industry. The policy also directs the government to enable U.S. industry to compete successfully as a provider of remote sensing space capabilities for foreign governments and foreign commercial users, while ensuring that appropriate measures are implemented to protect national security and foreign policy objectives. The policy directs the government to provide a timely and responsive regulatory environment for licensing the operations and exports of commercial remote sensing space systems. The Secretary of Commerce is authorized by statute to license commercial remote sensing satellite operations, and this authority has been delegated to NOAA's Commercial Remote Sensing Regulatory Affairs (CRSRA) office.

As with any new technology, particularly within any conditions for entry or well-designed global governance structure or individual country, RSTs carries a potential for unintended consequences and a corresponding need for vigilance, and perhaps for new regulation. While acknowledging this possibility, we think that RST will likely provide overwhelming benefits to agriculture and natural resource management. The effect of RST in the social sphere is more ambiguous. The same capacity that makes it possible to learn about resources and to manage their use also makes it easier to surveil and manipulate people. Increased surveillance creates potential benefits from improved security, and also lower costs associated with political control. Democracies have a greater likelihood, compared to authoritarian regimes, of striking a balance that will lead RSTs to benefit society. Developed countries' experience with currently available surveillance technologies, particularly in comparison with the applications in an authoritarian setting, may foreshadow that issues likely to arise when the much more sophisticated RST becomes widely available. In Thorium's case, the video's half-meter resolution is high enough resolution to distinguish people, but not so high as to see faces, read license plates or invade privacy. After discussing concerns about privacy, we briefly consider more subtle but likely more alarming concerns related to surveillance.

The UK provides a good case study for the social benefit and the public acceptance of remote surveillance. The UK has a long-established street surveillance system, and both public attitudes to surveillance and its impact on crime have been extensively studied. The UK's systems of street-level cameras and recording, Closed Circuit TV (CCTV), were installed sporadically in the 1960s in response to random bombings by the IRA, but comprehensive systems were first installed in 1985. The UK therefore has over 30 years of experience with both the positive and negative aspects of the technology. Many other developed economies have adopted CCTV systems in urban centers to deter property crime, personal crime, and antisocial behavior. In most developed countries, formal rules and regulations accompany the introduction of CCTV. These rules determine how intrusive the technology is and how the information it provides can be used in criminal prosecutions. A growing literature documents the benefits and costs of surveillance as it affects the incidence and severity of crime in urban areas.

Two key issues, displacement and confounding factors, make it difficult to establish a causal link running from surveillance systems to changes in crime. Those skeptical of, or opposed to, surveillance systems point out that intensive surveillance in one area possibly merely moves crime to another area that has a less extensive surveillance system. Limited data, due to the cost of building these systems, and in some cases also to opposition to their introduction, make it hard establish a causal link. Confounding factors complicate the statistical problem. The introduction of surveillance cameras often comes with an increase in lighting and police patrols, making it difficult to determine whether those changes or the surveillance system led to a reduction in crime. By encouraging visitors to parts of the city they previously avoided, the existence of CCTV cameras might even increase crime due to the increase in targets of opportunity.

Disentangling the influence of surveillance systems from these other factors requires a large sample, and ideally a meta-study across several different urban areas. Due to its long history of surveillance systems, most formal analyses come from the UK; however, an increasing number of studies use data from US cities. A key study published by the UK home office used pre-intervention public attitude surveys, conducted by the University of Leicester, carried out in areas implementing CCTV (Spriggs et al., 2005). The report used surveys in nine residential areas and one town and two city centers from January to August 2002, interviewing over 4000 people. The level of fear of crime was similar across and city areas; 25% of the respondents avoided certain areas during the day and 48% avoided these areas at night. Respondents said their main fear was of physical attack, but they also commented on the type of people who gathered in those areas. Thirty percent of those who avoided daytime visits said that they would be willing to make these visits after the installation of CCTV; 25% of those who avoided nighttime visits said that they would increase their business at night following the introduction of CCTVs. Over 80% were happy to accept the installation of CCTVs, although they were not clear how the surveillance would reduce crime; 17% of the respondents felt the CCTV would infringe on the privacy, and this trend was understandably higher amongst those who felt the systems were not likely to be effective.

The University of Leicester research team also carried out an evaluation of 89 sites with 14 CCTV projects set up across England in a range of settings. The research involved a combination of methodologies using a mixture of experimental design based on ‘before and after’ public attitude surveys, and realistic evaluation over a range of contexts to measure confounding factors and their impact on the effectiveness of CCTV systems. Here, researchers found that 22% of the population said that they would use the city center more in the dark if CCTVs were installed, compared with 8% more likely to visit the city center during the day. Support for CCTV differs across demographic groups: women were more supportive than men, and older people were more supportive than younger. The survey found that overall levels of support for CCTV are high, although it was not clear that respondents were well informed about how it functioned. Support for CCTV systems seemed to be based on the perception that their installation would improve safety, rather than actual changes in crime. This reduced fear about crime is, in itself, a social good and a positive contribution of CCTV surveillance systems.

The Urban Institute and the Department of Justice published a study of the effect of CCTV in four American cities, Cincinnati, Chula Vista, Hyattsville, and Tucson (La Vigne et al., 2012). These cities were part of a program called Safe City that combined the introduction of CCTV systems with meetings and information-sharing specifically focused on property crime in the retail sector. The main goal was to analyze the effectiveness and the benefit-cost ratio the program. Implementation varied across cities. Cincinnati and Chula Vista successfully fully implemented the program, Hyattsville only partially implemented it, and Tucson terminated their program within the first year.

As in the UK, implementation increased perceptions of safety in Cincinnati and Chula Vista. Cincinnati observed statistically significant and cost-effective reductions in crime, but the experience in Chula Vista was mixed. In the Cincinnati program the estimated benefits far outweigh the costs of implementing the CCTV program, yielding a benefit cost ratio 3.4:1. This ratio does not include the benefit of reduced vandalism, which the authors were unable to measure. Chula Vista experienced significant reductions in robbery, with an associated benefit-cost ratio of 4.5:1, following the introduction of CCTV. However, increases in vandalism and other property damage more than offset the lower cost of robberies, resulting in an overall benefit-cost ratio less than one. This example illustrates the difficulty of confounding factors mentioned above. It is unlikely that the presence of CCTV cameras would actually increase vandalism. If we cannot ascribe an increase in crime to the presence of CCTV, it is not clear that we should think that a decrease in crime was due to CCTV.

As in the assessments of the effectiveness of CCTV in the UK, the initial results from cities in the USA also suggest that CCTV is a deterrent to certain types of crime in certain circumstances, with mixed results when measured using benefit-cost ratios. Another common theme is that the presence of CCTV cameras is reassuring to most citizens in both countries. The American Civil Liberties Union (ACLU) produced a survey study of the effect of CCTV surveillance in both countries (https://www.aclu.org/sites/default/files/images/asset_upload_file708_35775.pdf). This article concluded that there is little evidence that the increased surveillance from the introduction of CCTV reduced actual crime, as distinct from the perception of crime. Even if the ACLU review might have been colored by its preference for privacy, it seems that increased surveillance arising from CCTV is hard to justify on the basis of a benefit-cost ratio. A policy decision must balance the difficult-to-quantify value of perceived increase in security against the loss of privacy.

While opinions on the effect of increased remote surveillance on crime are mixed, authoritarian regimes' use of remote surveillance identification to solidify control over their population is rejected by nearly everyone except for the authoritarians. China's use of remote sensing systems and facial recognition to monitor dissident populations such as the Uighurs in Xinjiang province in western China (https://www.nytimes.com/2019/05/22/world/asia/china-surveillance-xinjiang.html) is the most widely cited example of authoritarian use of the technology. The system developed by China Electronics and Technology Corporation (CETC), a state-run defense contractor, is all-encompassing, using information from cell phones, checkpoints, and remote surveillance. Treating a city like a battlefield, the platform was designed to "apply the ideas of military cyber systems to civilian public security," Wang Pengda, a CETC engineer, wrote in an official blog post. China's use of surveillance information raises the question of how society can balance improved personal security from surveillance systems against the threat of political control.

China's level of intrusiveness and threat would not be tolerated in most developed countries. However, even developed countries vary significantly in their tolerance for decreased privacy in the interest of public values. For example, reaction in parts of the US to standard public health actions such as wearing masks in the current pandemic differ markedly from responses in Europe, and in other parts of the US. In the UK, with its long history of CCTV, there is still significant unease over extensive monitoring and the possibility that surveillance will be used to undermine individual freedoms and facilitate oppressive forms of social control. This unease persists, although several UK surveys show 80% of the respondents feel more secure with CCTV systems. A report from the House of Lords Science and Technology Committee in 1998 recommended licensing and enforceable codes of practice. The UK Data Protection Commissioner issued a code of practice outlining the obligations of CCTV system operators under the *Data Protection Act 1998*. Australia has adopted some of these recommendations. The introduction of CCTV is usually motivated by the hope that it will create an environment that is more secure, or at least perceived as such, and that this change will attract visitors and the attendant commercial activity to blighted urban retail areas. However, retailers in one British survey did not believe CCTV had increased either their trade or profit. Some UK surveys show reduced crime rates in the immediate proximity of CCTV; other researchers argue that overall crime is not reduced but merely displaced to regions that are not surveilled.

A more immediate example of resistance to surveillance is the use of cameras to detect people running red lights. The use of red-light cameras to issue fines increased in popularity until 2012, when 540 cities were using these cameras. Following prosecutorial losses in several court cases because of camera shortcomings the number of cities using the systems dropped to 503 in 2015. People seem to resist having guilt or innocence decided by a remote surveillance unit. Most of the reversals of fines were based on technical considerations, such as insufficient time allowed before implementing the fine. Studies also suggested that the cameras were not effective at preventing accidents. A recent study in Chicago showed no overall reduction in accidents. However, red light cameras led to a higher rate of conviction and fines for traffic violations. When New Jersey ended a pilot program, Moody's warned of a reduction of municipal credit ratings due to the loss in revenue from fines. This example shows how remote surveillance systems can be used to extract revenues from the public. However, the ostensible purpose of this surveillance is to reduce traffic violations, not to raise revenue. The physical surveillance made possible by CCTV and the methods used in China provide the closest analog to the privacy concerns associated with RST. The example of Google Street View suggests that even if RST's current limitations in facial recognition persist, privacy concerns may remain. In response to privacy issues, Google Street View blurs the faces of people caught by Google's roving cameras. However, it may still be possible to identify these people using their location, posture, clothing, and other marks (Haigney, 2020).

Although physical surveillance creates the most obvious privacy concern, it might turn out not to be the most important. The virtual surveillance carried out by companies such as Google, Facebook, and Amazon likely have much greater effect on society than do any physical surveillance technologies. Virtual surveillance probably creates some benefits, e.g. the more efficient matching of consumers with their desired products. However, the harmful effects include reduced competition and increased ability to price-discriminate, associated with Amazon in particular, and increased political polarization and Balkanization and the spread of disinformation associated with Facebook and Google (Zuboff, 2019). The network effects and resulting increasing returns to scale magnify these harmful effects. Although we do not see a direct link between RST and existing virtual surveillance, it is nevertheless worth mentioning the latter when discussing the former. RST might be at a stage of development similar to that of the internet 20 years ago; at that time, virtual surveillance was not a concern. In addition, both RST and internet technology have strong network externalities and large entry costs. Section 2 provides evidence of strong competition within the RST sector. However, if the efficiency advantages of a particular RST are as great as Sect. 3 claims, it would not be surprising to see the emergence of a dominant firm, along with the attendant monopoly concerns. Those concerns include both the familiar economic-related issues (e.g. consumer harm) and also the much more worrying issues of political influence.

Putting aside these somewhat speculative issues, we conclude this section by noting that RST will likely provide a quantum increase in surveillance capacity over existing methods. The review of current electronic surveillance of natural resources offers three lessons for the introduction of RST. First, although arguments for the increased security made possible by RST will be persuasive to many, others will decide that increased security is not worth the loss in privacy. It would be a mistake to introduce RST-enhanced surveillance under the belief that only Luddites will oppose it, and moreover that they will be easily converted or overwhelmed. Parts of the public have a deep-seated resistance to these methods. The introduction of RST in democracies must be accompanied by the sort of participatory opportunities used in the U.S. Safe Cities program. Where persuasion fails, the democratic decision, however misguided, must be respected. Second, proponents of RST-enhanced surveillance should avoid over-promising results. Although increased security is a plausible outcome from this type of surveillance, decades of experience with CCTV show that this result cannot be taken for granted. Even if it occurs, empirical verification may be hard to establish. The long-term potential benefits of RST-enhanced surveillance will not be realized if either the technology is forced on an unwilling public, or if the public is persuaded to accept it based on promises that do not materialize. Third, it would be foolhardy to think that authoritarian regimes will use the technology differently than they use current technology: as a means of political control and suppression. Democracies have limited sway here, but it is nevertheless important to acknowledge that RST is likely to make authoritarian regimes both more efficient and more oppressive. Conventions to restrict technology-sharing to nations that abide by a code of behavior can be enacted without authoritarian support and provide a modest way to ameliorate increased dangers.

8 Concluding Remarks

We are on the cusp of an explosion of remote sensing technology that will hugely increase our ability to measure natural resource stocks and flows. This increase in data can transform the field of natural resource/agricultural economics, and more importantly lead to major improvement in society's ability to manage natural resource systems. Data improvements will occur across four dimensions: more frequent, more accurate, and more granular measurements, and the ability to identify underground stocks using spectral methods.

Natural resource management requires dynamic methods, because current decisions typically have long-lasting stock-mediated changes. When we catch an additional fish we change the stock of fish, thereby changing the growth in the population, thus changing stocks available for future harvests. Every aspect of this chain is plagued by measurement issues. Monitoring problems limit our ability to accurately measure how many fish are being caught. It is hard to measure fish stocks, because we cannot directly observe them. Without accurate time series of harvest and stock, we cannot reliably estimate the parameters of the equations of motion that determine the fish stocks. Without this information, we can only guess at optimal management practices. Even if we somehow knew optimal levels of harvest, monitoring problems make it impractical to implement those levels. Without frequent and accurate measures of fishers' behavior, we cannot reliably estimate the response of behavior to policy. Thus, our elegant textbook models are only aspirational, not a sound guide to management. These difficulties taken from fishery economics occur for almost every natural resource.

The better data provided by remote sensing technologies offer the possibility of alleviating many of these problems. With accurate, frequent, and spatially disaggregated data on, for example, harvest and stock, we can use the econometric powerhouse to learn about the physical laws that govern stock dynamics. Accurate and inexpensive information on resource users' behavior will make it possible to design randomized control trials to learn about agents' behavioral responses to changes in policy and to changes in their physical environment. The high temporal resolution of data will enable us to learn about these responses rapidly enough to be of practical use. The potential scale of these experiments can allay doubts about the external validity of research findings.

Better data on stocks and flows make it possible to assign property rights and to monitor the exercise of these rights. Creating and sustaining these rights will create two types of advantages. First, they increase our ability to use property rights-based regulation to manage what would otherwise be common pool resources. Property rights-based regulation takes advantage of markets' power of automatic information aggregation. Where feasible, i.e. where property rights are secure, this form of regulation is cheaper and more effective compared to direct regulation. Second, the assignment of property rights creates a claim on future profit flows, thereby creating wealth. If these property rights are assigned to the worlds' poor, it will increase their wealth, possibly by many tens of trillions of dollars. This increase in wealth will be especially important during catastrophes such as pandemics and climate-related disasters.

The economics profession, using results from mathematics and engineering, has developed a rich panoply of tools for solving dynamic decision problems. The better data arising from remote sensing technologies can make these tools vastly more useful, as the fishery example above illustrates. A central theme running through the optimal control literature concerns the manner in which information is acquired, valued, and used. Active learning methods recognize that current policy can serve a dual role, both modifying behavior to increase direct benefits, and modifying behavior to increase variation in order to improve our ability to learn about physical systems and behavioral responses. Active learning methods are computationally intensive, and even for moderate-sized problems require the use of approximations. Hybrid methods have been developed to balance the twin goals of control and information acquisition. The better data and the corresponding increased opportunity to use hybrid active learning methods can spur the development of improved methods: demand creates supply.

Examples abound where better technology or market expansion has harmful effects: we inhabit a second-best world. Better extraction technologies can increase the rapacity of harvest, leading to the demise of resource stocks. Extending credit markets can lead to odious debt. Improvement in information technology can lead to increased political polarization, the dissemination of misinformation, and the exercise of market power. There is no guarantee that the potential benefits accruing from remote sensing technology will be realized. While society develops and implements these technologies in a spirit of adventure and optimism, we should retain the humility needed to think ahead and guard against unintended consequences.

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Part III
Major Developments in Institutional Economics and Political Economy

Special Interests and the Public Interest in Public Policy and Information: Insights from Agricultural and Food Policies

Johan Swinnen

1 Introduction

Economies have been subject to government interventions throughout history and across the globe. Political considerations are crucial to understand these policies. Gordon Rausser has made important contributions in a variety of topics in the political economy literature, several of which are integrated in his 2011 book *Political Power and Economic Policy.*

Much of the political economy literature has studied how policymakers are captured by vested interests by introducing public policies that distort the economy and reduce aggregate welfare, such as import tariffs or export taxes. An important common theme of Gordon Rausser's work has been the focus on the political economy of public policies that include positive welfare contributions of public policy, while at the same time affecting rent distribution and, thus, lobbying of special interests.[1]

He therefore studied the joint decision-making on public investments and redistributive policies. In a policy package, the welfare effects of subsidies and tariffs may be quite different than analyzed in isolation, since what matters is the welfare

[1] Many political economy models specify the objective function of the government as being solely dependent on special interests. Rausser and Zusman (1992) and Grossman and Helpman (1994) explicitly include the public interest, next to special interests' influence or contributions, in the governments objective function (see also Rausser & Freebairn, 1974).

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effects of the policy package, not that of the different policies by themselves (see e.g. Rausser (1982, 1992); de Gorter et al. (1992)).

In this chapter, I review key contributions related to agricultural subsidies and investments in research. I then explain how this mix of public and private interests also applies to government regulations on information. The chapter draws importantly on more elaborate discussions in Swinnen (2018).

2 Political Economy of Public Investments in Research and Subsidies

2.1 Agricultural Subsidies and Taxes

In the second half of the twentieth century, there were major differences in agricultural and food policies between poor countries (where farmers were taxed) and rich countries (where farmers were subsidized and consumers were taxed). This difference was not only huge, it was also counterintuitive (Krueger et al., 1991). In countries where farmers were most of the population, and thus had most of the votes (or more generally since many of these countries were not democracies, the political strength of numbers) they were losing from agricultural policies that taxed them. In contrast, in countries where farmers were a minority, farmers were subsidized, even though their numbers in the political arena had declined. This observation was referred to as "*The Development Paradox*" that triggered a large literature.

Anderson, Rausser and Swinnen (2013) explain how structural differences in agricultural policies between rich and poor countries captured in the development paradox are due to differences in political economy equilibria caused by the combination of structural economic differences, information costs, and changes in governance structures. For example, structural changes during economic development alter the costs and benefits of political activities (see Anderson, 1995; de Gorter et al., 1992; Gardner, 1987; Swinnen, 1994); improvements in rural infrastructure with economic development affect farmers' relative ability to organize for political action (see Olson, 1965); changes in information systems with economic development cause a shift in the political economy equilibrium from supporting consumers to supporting farmers (see Olper & Swinnen, 2013); democratic reforms in poor and middle income countries have reduced taxation of agriculture, and especially those electoral reforms that enhanced the political representation of small farmers and rural workers (Olper et al., 2014; Swinnen et al., 2001).

2.2 Public Agricultural Research Investments

Public investments in agricultural research are an important source of productivity growth (Alston & Pardey, 1996, 2013; Alston, 2017). Studies document high social rates of return to public agricultural research investments, but also that there is significant underinvestment in research in both poor and rich countries (Huffman & Evenson, 1992; Ruttan, 1982; Pardey et al., 2016).

One political economy explanation of the underinvestment by governments is spill-over effects (or externalities) in a policy environment where government research investments in one country affects other countries.[2] Research has both public and private good characteristics, as some of the benefits of research expenditures can be captured by specific groups while other results spill over to other groups or countries. This affects governments' incentives to invest in research. Spill-over effects can thus induce free riding behavior by governments. Governments in one country will invest less than optimal since they pay for all the costs while part of the benefits are reaped by other countries. Or, inversely, governments may think that they can reap (some of) the benefits from other countries, investments without having to bear the (fill) costs of research investments (Huffman & Miranowski, 1981; Khanna et al., 1994; Rose-Ackerman & Evenson, 1985).

A different political economy explanation draws on the distributional effects of public investments (Baland & Kotwal, 1998; de Gorter et al., 1992; de Gorter & Zilberman, 1990; Rausser, 1992). While society may gain from public investments, different groups in society are affected differently, which will create different policy preferences. They will prefer the government to choose their private optimum level of research and will negatively react to the government's choice if this diverges from their (private) optimum. If some groups oppose public investments because of income distribution effects, governments will underinvest in public goods as they balance the political costs and benefits of diverging from the social optimum.

Public agricultural research investments (PARI) has contributed to the dramatic increase in productivity of agriculture during the twentieth century, but it affected different parts of society unevenly (Alston, 2017; Gardner, 2002). Figure 1 illustrates the welfare and distributional impacts of public research in a closed economy.[3] D and S_0 represent the demand and supply curve, respectively. A market clearing price P_0 is paid by consumers and received by producers. Domestic consumption and production are at q on the horizontal axis. Research increases agricultural productivity and shifts the supply curve to S_τ. The market price falls to P_τ. Consumers benefit since they can consume more ($q_\tau > q_0$) and at a lower price ($P_\tau < P_0$). The increase in consumer surplus is area A + B. It is obvious from Fig. 1 that consumers always benefit from PARI in a closed economy. The effect on

[2] Studies have also argued that benefits of public investments in agricultural research are overestimated because of other factors such as e.g., terms of trade effects (Edwards & Freebairn, 1984), the effects on unemployment (Schmitz & Seckler, 1970), and private research (Alston & Pardey, 1996).

[3] For a more complex model, with more inputs on consumer and producer effects, see Alston (2017).

producers is less obvious because they are affected by two (opposing) effects: they benefit from lower costs due to increased productivity but they lose from declining prices. In Fig. 1 the net effect on producer surplus is area D–A (as the pre-research producer surplus was A + B and their post-research surplus is C + D). Whether D–A is positive or negative depends on the elasticity of the supply and demand functions.

Whether consumers (through lower prices) or producers (through higher productivity) benefited depends on the elasticity of supply and demand and the specific productivity effect of the R&D.

Economic development affects the distribution of the benefits from research investment. Rich countries typically have more elastic supply curves for agriculture, because they have less production factor market constraints, better institutions, etc. Rich countries also have less elastic demand for food than poor countries. In developing countries, the effects of public research will be different as supply is typically more inelastic and demand more elastic in developing countries. As consumer incomes grow with economic development and demand become less elastic, benefits shift increasingly to consumers. This implies that one would expect that in rich countries research favors consumers while in developing countries agricultural producers (farmers) benefits relatively more from research. de Gorter and Swinnen (1998) show that in general, with unequal income distributional effects a

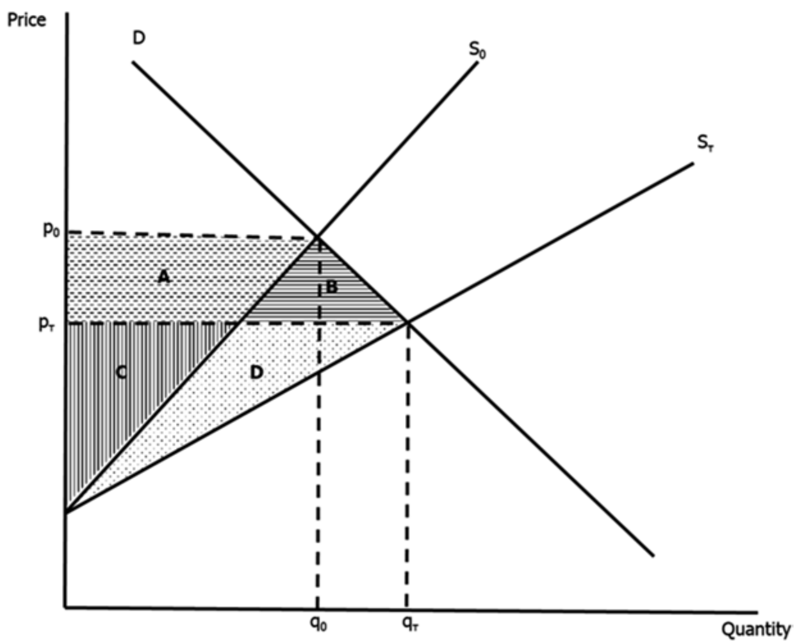


Fig. 1 Welfare and Distributional Effects of Public Research in a Closed Economy (Source: Swinnen, 2018, Chap. 13)

government maximizing political support will underinvest in public research, both in rich countries and in poor countries.[4]

Trade leads to international spillovers and thus to lower incentives to invest in R&D. However, trade also affects the political economy in a different way. Opening the economy to free trade increases the demand elasticity, thereby reducing the price effect of research-induced shifts in the supply function and reducing producer opposition to technological advances. Baland and Kotwal (1998) have used this argument to explain why trade liberalization in developing countries may induce an increase in public investment in agriculture as it makes the terms of trade invariant to public investment.

2.3 Policy Interactions

The analysis above considers the political economy of various policies in isolation, meaning that the analysis is as if there were no other policies. However many policies exist simultaneously. Figure 2 illustrates how during periods of economic development, both subsidies to agriculture and investments in public agricultural R&D increased significantly. In Belgium (Fig. 2a) this occurred gradually over 1880–1980 period and especially during the 1950–1980 period. In China (Fig. 2b), the strong growth of both agricultural R&D and subsidies occurred since 2000.

If these public policies exist simultaneously, they may interact with each other. There are different types of interactions, and one should distinguish between "*economic* interaction effects" which arise if one policy affects the distributional and welfare effects of other policies and "*political* interaction effects" which occur when one policy affects the political incentives of governments to introduce or change other policies.

Combined reforms may reinforce or weaken the impacts of separate policy reforms. For example, in the reform strategies in China and Eastern Europe in the 1990s, land reforms and privatization strategies provided new opportunities and better incentives for farmers, while at the same time distortionary price and market policies were reduced or removed. In these cases, both policy reforms combined to improve efficiency. In some cases policies negatively affect each other. For example agricultural research increases productivity and may thus cause an increase in distortions of existing regulations (Alston et al., 1988; Murphy et al., 1993; Swinnen & de Gorter, 1998).

An example of political interaction effects is the use of agricultural policies for compensation purposes. Compensation is an important element in the political

[4] Note that groups which benefit most from research are politically the weakest. Urban consumers are relatively more politically influential in developing countries and farmers more so in rich countries in terms of agricultural subsidies and taxes. As those who benefit most from research have less politically influence both in rich and poor countries, one would therefore expect to observe underinvestment in both regions (de Gorter & Swinnen, 1998).

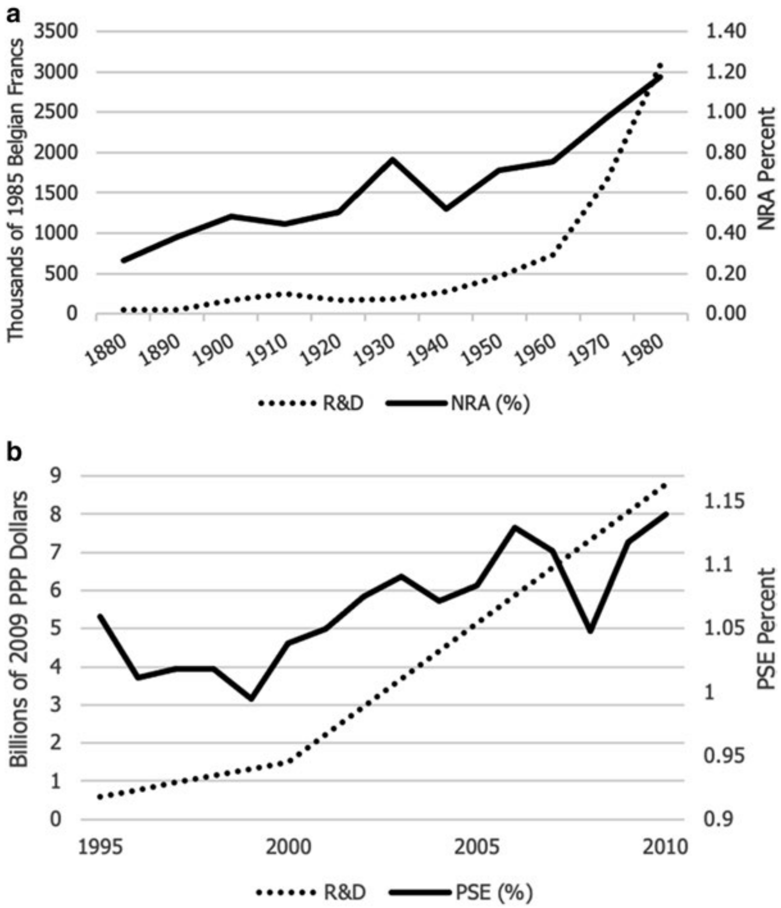


Fig. 2 Agricultural Subsidies (NRA%, PSE%) and Public Agricultural R&D Expenditures with Economic Development. (**a**) Belgium, 1880–1980. (**b**) China, 1960–2010 (Source: Swinnen, 2018, Chap. 4, with original data from OECD (2017), Pardey et al. (2016) and Swinnen (2009, 2017))

economy of policy reform or public investment (Rausser et al., 2011).[5] Reforms to a more efficient policy almost always implies gains for some groups and losses for others. If the gains outweigh the losses, it is socially optimal to implement the reforms or make the investment since the gains of those who win are more than enough to compensate the losers. There are numerous empirical examples of

[5] Trade policy reform and compensation have a long history in the economics literature, going back to the early analyses of Adam Smith and David Ricardo. A crucial element in the arguments on the optimality of free trade are that the gains of the winners of trade liberalization are more than sufficient to compensate the losers of reform, an issue which has clearly become highly relevant again in recent years with discussions on the gainers and losers from globalization.

"policy packages" which include compensation for certain groups. They are a traditional part of multi-annual agricultural policy decision-making both in the EU and the US.

An important problem with compensation, however, is the credible implementation of such schemes. Those who lose from reform may oppose the reforms if they expect that (full) compensation will not take place. The latter may be the case when governments lack the credibility to effectively provide compensation when the reform effects emerge (Acemoglu & Robinson, 2006; Swinnen & de Gorter, 2002), when governments only offer partial compensation to mitigate political opposition sufficient to get the reforms through (Foster & Rausser, 1993), when local institutions prevent the creation of effective compensation schemes (Swinnen, 1997), or when there is uncertainty on the effect of the reforms—and thus on who will be the losers and gainers of the reforms (Fernandez & Rodrik, 1991).

The inability of governments to credibly commit to compensate groups that are adversely affected is a prime cause of underinvestment in public goods or of failures to implement aggregate welfare improving policies more generally. An important question is therefore how to design mechanisms that constraint policy-makers, to bring the discretionary political equilibrium closer to the social optimum. The creation of institutions which make policy reversal more difficult enhance the credibility of policy-makers to commit to future compensation.

Compensation also depends on the choice of the instrument. There is an extensive literature comparing the transfer efficiency and the distortions of various policy instruments in trade and agricultural policies (Alston & James, 2002; Gardner, 1983). The standard argument in the literature is to use lump-sum payments (which are non-distortionary) for compensation, Foster and Rausser (1993) however argue that distortionary policies could be optimal choices in a compensation framework. The total transfers induced through distortionary policies (such as tariffs)—even with deadweight costs—may be lower than would be the case with direct (lump-sum) transfers when governments need to secure a minimum amount of political support.

Related, Mitchell and Moro (2006) explain that governments may prefer distortionary policies, such as tariffs, when they have imperfect information on their target group, or the amount of transfer needed.

Another factor is obfuscation, Magee et al. (1989) argue that politicians have an incentive to use policies that hide their costs or use policies that obfuscate the transfer itself. This obfuscation perspective suggests another reason why methods such as tariffs, may be politically preferable to direct subsidies.[6]

[6] Other political economy arguments why distortionary policies are used are that (a) import-competing sectors have lower comparative advantage than exporting sectors, thus returns to investment in lobbying activities dominate returns from market activities (Swinnen & de Gorter, 1993); (b) the so-called "revenue motive" of public policy—tariff revenues and export taxes increase government revenues and improve their terms of trade; (c) deadweight costs and budgetary costs are higher in sectors with higher supply elasticities (typically exports) which will be subsidized less because it is more costly to do so (Becker, 1983; de Gorter et al., 1992; Gardner, 1983, 1987);

3 Special and Public Interests in Public Information

In his path breaking book *An Economic Theory of Democracy*, Anthony Downs (1957) explains the concept of the "*rationally ignorant voter*." According to Downs, it is rational for voters to be ignorant about certain policy issues, if the costs of information are higher than the expected benefit from being informed. This information mechanism has major implications for agricultural and food policies, one of them being that policies will be introduced that create concentrated benefits and dispersed costs (Anderson et al., 2013). This rational ignorance not only applies to voters' choices in political markets but also to consumers' choices (McCluskey and Swinnen 2004).

Asymmetric information is inherent in many economic markets and especially in agriculture and food. Governments have often intervened through regulations, such as the introduction of public standards, to reduce such problems. In fact, standards to prevent adulterations and frauds have existed as long as products have been exchanged and traded. The addition of water in wine or in milk to increase the volume has been documented throughout history and across the globe. However, in recent years, standards have increased rapidly, both geographically and in addressing new concerns. Production and trade are increasingly regulated through stringent public (and private) standards on quality, safety, nutritional, environmental, and ethical and social aspects. As an illustration of the growth of standards in agriculture and food markets, Fig. 3 shows the rapid growth of SPS notifications to the WTO since the mid-1990s.

As with public research discussed in the previous section, standards can enhance aggregate welfare, but they can also be set at suboptimal levels, causing welfare losses. The introduction of a standard may create winners and losers as its effects will differ between e.g. consumers and producers, and even between consumers and producers in their respective groups.

3.1 Efficiency and Equity Effects

Figure 4 illustrates the equity and efficiency effect of standard,[7] which generate efficiency gains by solving (or reducing) asymmetric information problems, but also involve implementation costs.[8] Such standards can create welfare gains but also involve rent redistribution between different interest groups. The standard yields

(d) trade taxes (either import tariffs or export taxes) are easiest and least costly to implement in countries with weakly developed tax collection institutions (Dixit, 1996; Rodrik, 1995).

[7] The literature has adopted different modeling assumptions depending on which product or production process characteristic (safety, quality, social and environmental effects, …) is regulated by the standard. See Swinnen et al. (2015) for a review of model approaches.

[8] In general, a standard can be interpreted as a prohibition to use a cheaper technology (Swinnen & Vandemoortele, 2011). Examples are the prohibition of an existing technology (e.g. child labor) or of a technology that has not yet been used but that could potentially lower costs (e.g. genetic modification (GM) technology). Most studies therefore assume that standards raise domestic production costs. In an open economy, the production costs of foreign producers (interested in) exporting to the stan-

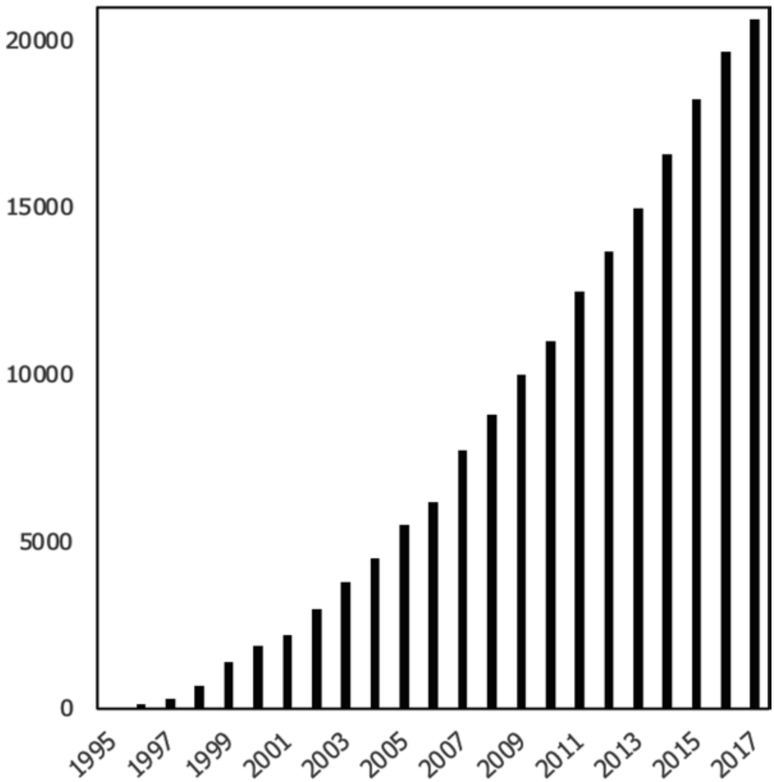


Fig. 3 The Growth of Food Standards: SPS Notifications to WTO (Total Number) (Source: Own calculations based on data from WTO)

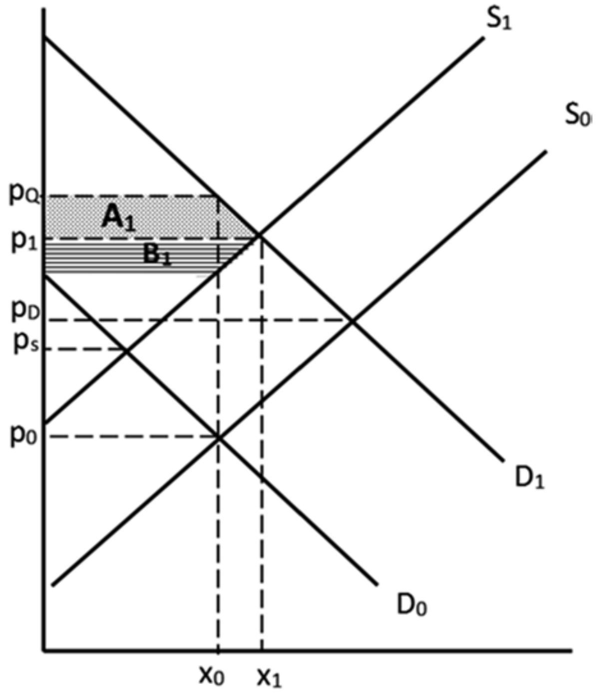
(positive) efficiency gains, i.e. the value that consumers attach to the reduced informational asymmetries; and an increase in the equilibrium price due to increased demand and the cost of implementing the standard. The impact on producer profits is a combination of a (positive) increase in revenue, due to increased consumption, and a second (negative) producer's *cost* of *implementing* the standard. The net impact depends on the relative size of the increase in revenue and the implementation cost.

S_0 and D_0 represent the pre-standard supply and demand functions[9] and p_0 and x_0 the equilibrium price and consumption (which equals production in this closed economy). The introduction of a standard *s* shifts supply and demand functions to S_1 and D_1. The new equilibrium price and quantity are p_1 and x_1. The total price

dard-imposing country may also rise if the standard is also imposed and enforced on imported goods. The effect on prices depends on various factors such as demand and supply elasticities and trade.

[9] The figure can also be interpreted as a shift from a lower to a higher standard.

Fig. 4 Impact of Standards in a Closed Economy



effect ($p_1 - p_0$) is the result of rising prices due to the growth in demand ($p_D - p_0$) and a cost increase ($p_S - p_0 = p_1 - p_D$).

In the case illustrated by Fig. 4 the effect of the growth in demand (represented by the vertical shift in the demand curve) is stronger than the increasing cost effect (represented by the vertical shift in the supply curve). Consequently, consumption and production increase ($x_1 > x_0$) and both producers and consumers gain. Consumer surplus increases by area A_1 and producer surplus increases by area B_1. Total welfare increases by area $A_1 + B_1$.

It is easy to illustrate that with different elasticities of supply and demand the size of the effects would be different. With different shifts in (or rotations of) the supply and demand curves the sign of the effects could be different—in particular if the cost effect is larger than the demand growth effect, the impact on welfare would be negative.

Producers gain (lose) if the price increase (due to higher demand with the standard) is higher than the cost increase. Consumers gain if the gain in utility (from reduced uncertainty) is larger than the price effect from the standard, and vice versa. This simplified model may apply to various stages of the supply chain since the general terms ‘producers’ and ‘consumers’ depend on the stage of the supply chain. For example, at the processing stage, ‘consumers’ are retailers who source products from processors (the ‘producers’). At the retail stage, the retailers are ‘producers’ who sell products to the final consumer.

3.2 Standard and Development

Standards can thus enhance aggregate welfare by reducing asymmetric information or negative externalities but can also create rents for specific interest groups. Because of the distributional effects of standards, interest groups have a vested interest in influencing governments' decisions on standards. When interest groups have differing lobbying strengths, the political equilibrium will generally differ from the social optimum.

The political equilibrium standard may be either too high or too low compared to the social welfare optimum. Influential lobby groups may push for either more stringent or less stringent standards depending on the relative magnitude of the price (demand) effect compared to the implementation cost (for producers) or the efficiency gain (for consumers) (Beghin et al., 2015; Swinnen, 2016). For example, if producers are more influential than consumers, over-standardization results when producers' profits increase with a higher standard and in under-standardization otherwise. Higher profits for producers are more likely when the standard's price (demand) effect is large and when the implementation cost is small.

This political economy can explain the empirically-observed positive relationship between standards and economic development. First, higher income levels are typically associated with higher consumer preferences for quality and safety standards as reflected in higher efficiency gains. Second, the quality of institutions for enforcement of contracts and public regulations are positively correlated with development. Better institutions imply better enforcement and control of standards. Poor countries may have a cost advantage in the production of raw materials while better institutions in rich countries lower the marginal increase in production costs caused by standards. Third, higher education and skills of producers, better public infrastructure, easier access to finance and the like also lower implementation costs. Fourth, differences in the organization and structure of the media in rich and poor countries can affect the outcome. The cost of media information and government control is higher in poor countries. Therefore, the media structure and information provision is likely to induce a more pro-standard attitude in rich than in poor countries, as increased access to media increases attention to risks and negative implications of low standards (Curtis et al., 2008).

In combination, these factors are likely to induce a shift of the political equilibrium from low standards to high standards with development. A pro-standard coalition of consumers and producers in rich countries results if consumers derive large efficiency gains from a standard, while producers incur only moderate increases in costs. In contrast, an anti-standard coalition may be present in poor countries if consumers are more concerned with low prices than with high quality (leading to small efficiency gains form a higher standard) while the implementation costs for producers may be large. Structural differences in information and media may reinforce the positive relationship between standards and development.

3.3 Information, Standards and Trade

An important critique is that standards are (non-tariff) trade barriers. As trade agreements such as WTO have reduced tariffs, countries may use standards to shield their domestic markets from foreign competition (Anderson et al., 2004; Brenton & Manchin, 2002; Fischer & Serra, 2000). Convergence (or not) of standards is at the heart of recent trade negotiations such as CEFTA, TTIP, etc.

Standards affect trade.[10] However, the implicit comparison with tariffs in the trade debate is not entirely valid. In a small open economy, the socially optimal tariff level is zero. A positive tariff level constrains trade, is harmful to social welfare, and is protectionist. However, this is not necessarily the case for standards since this ignores the potential benefits of standards. Standards may both stimulate trade ("catalysts") or reduce trade ("barriers"). If the standard reduces asymmetric information or externalities there is no simple relationship between the trade effects of a standard and the social optimum (Beghin, 2013; Marette, 2014; Marette & Beghin, 2010; Sheldon, 2012; Van Tongeren et al., 2009). This result, however, does not imply that there are no protectionist elements in standards setting.

3.4 Persistence of Standards

Once adopted, countries will tend to stick to the status quo in standards because implementation costs depend on existing standards because of past investments. Differences in standards between countries may persist because of this and trade may reinforce this. The reason is that producer or consumer preferences may change in a dynamic way once the standard is introduced.[11] The standard will affect comparative advantages and will thus induce producers to support maintaining the standard in order to protect them from (cheaper) imports without standards. Hence, although standards may have been introduced because of consumer demands, their persistence in the long run results from (a coalition of consumer and) producer demands. Hence, hysteresis in standards can be driven by protectionist motives even if the initial standards were not introduced for protectionist reasons.

With these forces in play, standards and regulations often persist over long periods of time and their protectionist effects and inefficiencies may increase over time.

[10] Only in very special circumstances do standards not affect trade: this is when the effect on domestic production exactly offsets the effect on consumption (Swinnen & Vandemoortele, 2011).

[11] The case that producers have different preferences and consumers have the same is analogous. For example, Paarlberg (2008) and Graff et al. (2009) argue that consumers on both sides of the Atlantic tend to dislike GM technology, but agribusiness lobbying has been much more pro-GM in the US. In the longer run it may be that as consumers live in different GM-food environments in the US and the EU, they develop different preferences. Hence, consumer attitudes with respect to biotechnology are likely to be endogenous. In countries where GM products are available consumer preferences may shift in favor of this technology, while consumers may distrust GM technology more in countries where GM products have been banned.

Regulatory differences among countries may cause major conflicts over time as vested interests and industries which have invested in adhering to these standards, will lobby governments and international organizations to impose their own standards on foreign producers.

Several empirical case studies documents that there can be strong persistence of standards over time, and that the protectionist or welfare reducing effects of standards may increase over time. For example, Meloni and Swinnen (2013) show how stringent standards in the wine industry which were first set in France in response to pressure on wine growers in the early twentieth century further tightened over time in response to more "crises" in the wine sectors and later spread to the rest of Europe with integration of other wine producing countries in the EU. Meloni and Swinnen (2015) also document how the introduction of food standards in the mid-nineteenth century in response to the discovery by new scientific means of massive fraud and adulterations in food production led to different regulatory approaches in different countries. These regulations and standards persisted for a long time and influenced production processes and consumer preferences in the domestic industries.

3.5 Shocks and Reforms

Does the persistence that reversals in standards are not possible? Not necessarily. Standards and regulations can change over time when their use—or their vested interests—weakened. For example, Vogel (2003, p. 557) documents important historical shifts in the difference between consumer and environmental protection policies in the EU and US.

However, significant "shocks" to the political economy system may be required for such changes, i.e. to move the political economy equilibrium given the dynamic political and institutional constraints to overcome (Rausser et al., 2011). Shocks may come from both internal and external sources.

An internal source is when domestic "crises" affect food standards. The first wave of modern public food safety and quality regulations were induced in the late nineteenth century by public outrages of consumers over the use of cheap and sometimes poisonous ingredients in food production (Meloni & Swinnen, 2015, 2017). In the early twenty-first century, major changes in public food standards in the EU followed food safety scandals in the late 1990s with consumers demanding better protection and triggering new policies such as traceability through value chains, etc. (McCluskey & Swinnen, 2011). Also, the introduction of various public regulations in China in the late 2000s followed the "milk scandal" where people died from consuming milk products with poisonous ingredients (Mo et al., 2012).

Another source of shocks is external. One example is the integration of countries with different standards through international agreements. This may either cause the removal of "inefficient standards" or the opposite: that inefficient standards are extended to other countries with international integration. Both have been observed, often reflecting the bargaining power of the industries and countries where the (in) efficient regulations were in place before integration.

In summary, theory and historical evidence suggests that there is an important dynamic political economy component to the political economy of standards. Countries have introduced different standards to address consumer, producer or environmental concerns. However, once these standards have been introduced vested interests change after they made the investments. What was a cost for producers initially now becomes a potential instrument for market protection. International integration can both lead to the mitigation of inefficient standards or to a spread of such regulations, depending on the political equilibria.

Cases of public standards where efficiency enhancement and rent distribution are mixed and that have attracted wide attention in recent years and continue to do so are the cases of GIs and "food definitions." These cases represent interesting mixes of private and public interests and of changing political coalitions. I discuss each in turn.

3.6 Geographical Indications (GI)

GIs are increasingly important instruments of agricultural and food regulations and growing as contentious issues in trade negotiations and disputes. What makes the discussion complex is that GIs can have both equity and efficiency effects. GIs can reduce information asymmetries and improve efficiency but GIs can also be used as a protectionist instrument to protect vested interests.

Globalization and economic integration have increased the linkages between consumers and producers globally, but at the same time stimulated farmers to lobby for their "local products," seeking a coalition with consumers interested in local foods. The issue has created significant tensions in trade negotiations as the number of GIs has grown rapidly over the past 20 years, initially especially in the EU but now growing worldwide, and are an increasingly important item in trade negotiations (Josling, 2006; Huysmans & Swinnen, 2019; Raimondi et al., 2020).

The EU has the most GIs in the world, but there is a remarkable geographic concentration of GIs in the south of the EU (see Table 1). One obvious reason for this is that wine GIs take up a significant share of the EU's GIs. However, excluding wine there are seven times more food GIs per capita in the southern EU member states than in other EU member states. Huysmans and Swinnen (2019) discusses several factors which may explain the geographic concentration of GIs in the south of the EU.

Economic explanations for these differences are (a) that southern countries have more differentiated and higher quality food products, which would thus benefit more from reductions in asymmetric information, and (b) that there is "learning by doing" in GI applications and in understanding the impacts. The latter is consistent

Table 1 Regional distribution of GIs (in absolute numbers, percentages, and per capita)

	1996			2017		
	Food	Wine	Total	Food	Wine	Total
Number of GIs						
Old MS (EU 15)	**329**	**736**	**1065**	**1196**	**1510**	**2706**
North	23	0	23	103	22	125
Middle	11	40	51	123	80	203
South	295	696	991	970	1408	2378
EU28 Total	**329**	**736**	**1065**	**1337**	**1760**	**3097**
% of EU Total						
Old MS (EU 15)	**100.0%**	**100.0%**	**100.0%**	**89.5%**	**85.8%**	**87.4%**
North	7.0%	0.0%	2.2%	7.7%	1.3%	4.0%
Middle	3.3%	5.4%	4.8%	9.2%	4.5%	6.6%
South	89.7%	94.6%	93.1%	72.6%	80.0%	76.8%
EU28 Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
Per capita						
Old MS (EU 15)	**1.41**	**1.51**	**2.92**	**3.52**	**3.14**	**6.65**
North	0.15	0.00	0.15	1.03	0.26	1.29
Middle	1.42	1.15	2.57	2.73	1.59	4.32
South	2.92	3.60	6.52	7.14	7.83	14.97
EU28 Total	**0.76**	**0.81**	**1.56**	**2.97**	**3.66**	**6.62**

OMS North: Denmark, Finland, Ireland, Netherlands, Sweden, United Kingdom, OMS Middle: Austria, Belgium, Germany, Luxembourg, OMS South: France, Greece, Italy, Portugal, Spain, NMS North: Estonia, Latvia, Lithuania, Poland, NMS Middle: Czech Republic, Hungary, Slovakia, NMS South: Bulgaria, Croatia, Cyprus, Malta, Romania, Slovenia
Source: Huysmans and Swinnen (2019)

with the strong correlation between the GIs in wine, which were introduced first and concentrated for climatic reasons in the south, and food GIs at the regional level.

Political explanations include (a) agriculture and the food industry in the southern EU countries is less productive and is therefore more inclined to use GIs as an instrument to protect their agriculture and food industry from intra-EU and global competition; (b) "learning by doing" also applies to the politics of GI applications and in lobbying, creating political institutional spillovers.

In summary, economic and political factors may be behind more GIs in the south—a conclusion which is consistent with historical studies pointing at a mix of economic and political determinants of food regulations (e.g. Meloni & Swinnen, 2018). This also means that GIs are likely to remain a hotly disputed issue in trade negotiations. An interesting related issue is how organizations representing environmental interests will reinforce the "local products" coalition by pointing at the environmental costs of trade and global sourcing.

3.7 The Definition of Foods

Another case of how standards may reduce information asymmetries and transaction costs but also protect vested interests is regulations which define specific foods.

One of the oldest cases is the *definition of beer* in Germany—the so-called *Reinheitsgebot*—which lasted as a public regulation for exactly 500 years: from 1497, when it was first introduced in the region around Munich, to 1997, when the European Court of Justice ordered its removal as a barrier to trade in the EU's single market. van Tongeren (2011) finds that these centuries-old regulations (definition of beer) still today have a major impact on the different evolution of the German beer market. He shows how the 500-year-old German Purity Law was the reason for trade disputes in the late twentieth century.

The *definition of wine* was first introduced in France in the late nineteenth century to protect French wine growers against the production of cheap wine from imported raisins. This definition later became the official definition in the EU (Meloni & Swinnen, 2017).

The *definition of chocolate* also has its roots in the late nineteenth and early twentieth centuries which had major implications for international trade in these food products a century ago and continues to affect trade and consumption patterns today (Meloni & Swinnen, 2015, 2017). In the case of the chocolate industry, differences in definitions caused major trade conflicts later as the chocolate industries lobbied their governments to impose their own definitions on foreign producers.

An interesting recent case is "*the definition of meat*" with technological advances and changing consumer preferences. As plant-based "meat" products have grown rapidly in recent years, US livestock farms have lobbied for regulation to prohibit companies from using words such as meat, burger, sausage, etc. unless the product came from an animal. However, they face opposition from a coalition of new plant-based "meat" companies and large food companies that have invested in them.

4 Special and Public Interests in Private Information

If we want to understand how public information and regulations on information affect welfare, we should also take into account private sources of information which may have a significant impact on people's behavior.

Information costs and communication technologies have changed dramatically over the past decades. Consumers and voters have constant and convenient access to information. One example is enhanced (rural) infrastructure, including communication infrastructure, that occurs either through public investments (as in many high-income countries earlier in the twentieth century) or through technological innovations and commercial distributions (as in the recent dramatic increase in mobile-phone use in developing countries). More recently, a key factor is the spread of commercial mass media and social media.

However, rational ignorance, as Downs (1957) identified, may still play a role today despite the overwhelming presence of mass and social media in many countries for several reasons. The major one is the opportunity costs for people of processing information. The opportunity costs of time make it necessary to limit both the size, the choice set and consumption of information. Another reason is ideological, which may influence consumer and voter decisions (not) to follow/subscribe and process information provided by certain individuals and/or media sources.

Most voters and consumers today receive much of their information from commercial or social media. This contrasts with past generations, especially outside the United States, who got the bulk of their information from state-controlled media, which, of course, had their own biases. Commercial and social media have their own objectives and constraints.

4.1 Mass Media and Consumer Perceptions

There is often a divergence in risk perceptions between the scientific community and the general public (Huffman & McCluskey, 2014). The effectiveness and use of new technologies in agriculture and food production is dependent on consumers' risk perceptions. McCluskey and Swinnen (2010, 2011) argue that it is not cost effective for consumers to research the details about many food risks. Consumers must decide how much information to "consume" or process. While consumers constantly update and adjust their risk perceptions in the face of new information, studies suggest that consumers are willing to pay only modest amounts to reduce currently perceived food risks. One possible explanation is that the cost of risk avoidance is quite low because close substitutes are often available.

The nature of information matters as well. The "bad news hypothesis" argues that media consumers in general tend to be more interested in negative news items than in positive news items, ceteris paribus (McCluskey & Swinnen, 2004). This demand effect of the media market drives mass media to pay more attention to "bad news." (McCluskey et al., 2016)[12] Another concern is that the media is "dumbing down" news, and that this trend is leading to decreased quality and quantity of coverage of complex topics, such as science and technology, which need in-depth

[12] For example, Heinz and Swinnen et al. (2015) find that job market losses are reported much more likely than job market gains in the media. Other empirical studies find that there is a bias towards "negative coverage" in mass media in a variety of policy and public interest areas, such as trade policy, globalization and food safety (Swinnen et al., 2005). Marks et al. (2006) find that reporting on globalization was positive early on but switched to more negative in recent years. As a result, the potential risks (real or imagined) are reported much more often than the benefits.

explanations. This is caused by competitive pressures are associated with cutbacks in reporting and editorial quality (Alterman, 2008).

Consumers (and citizens in general) may anticipate that information from media may be biased. Then they can take that into account in evaluating the information. The conclusion from several behavioral studies is that even when viewers know that the media sources are biased, they insufficiently discount the information to fully consider the bias. Exposure to media can thus systematically alter beliefs and consumer behavior.

Hence, the impact of bias in mass media reporting on consumer attitudes is substantial, but also bi-directional and complex. Consumer bias in personal preferences and beliefs affect the media's reporting strategies to convince these consumers to buy their media products. Similar complex interactions occur between media and politicians and between media and business.

Social media also plays a role in food choice, but the impact is subtler than often suggested (Grebitus et al., 2014; Matin & Goddard, 2014). With so many social media choices available, consumers must limit who they follow. The choice of whom to follow results in a customized information flow. Thus, in their use of social media, consumers often follow like-minded people and companies (Moe & Schweidel, 2014). This leads to reinforced opinions and the lack of diversity of perspectives.

4.2 Mass Media and Public Policies

Studies have found that media bias can have important impacts on agricultural and food policy (Marks et al., 2003). Mass media affect public policymaking through several mechanisms (McCluskey & Swinnen, 2010). Access to mass media empowers people politically, and a more informed and politically active electorate increases the incentives for a government to be responsive (Besley & Burgess, 2001; Strömberg, 2004). This influence has been found for various types of government programs, such as unemployment programs and disaster relief (Eisensee & Strömberg, 2007; Francken et al., 2012), better governance and less corruption in public food provision (Besley & Burgess, 2002), and rural educational spending (Reinikka & Svensson, 2005; Francken et al., 2009).

Mass media tends to target large audiences because of scale economies. In this way, mass media can play an important role in agricultural policy by altering the political-economy mechanisms through which small special-interest groups influence policy. Group size (e.g., the number of farmers versus the number of food consumers in the economy) helps determine lobbying effectiveness because it affects collective-action costs as well as per capita costs and benefits of agricultural policy (Olson, 1965; Swinnen, 1994). Mass and social media can alter these political-economic mechanisms (Strömberg, 2001; Kuzyk & McCluskey, 2006).

Competition leads mass media outlets to provide more news and information to large groups such as taxpayers and dispersed consumer interests, thus reducing the influence of special interest. Olper and Swinnen (2013) find that in developing countries, agricultural taxation is reduced when mass media grow in importance, while in rich countries, agricultural support is reduced, and thus that mass-media reduce distortions to agricultural and food prices.

4.3 Mass Media, Fundraising and Policy Communication

Not only media but also organizations such as the FAO, the World Bank, Oxfam, Greenpeace etc. provide information. Policy communication of these development and aid organizations tries to influence policies but also to capture media attention and fundraising. Bias in their policy communication may draw in larger revenues through fundraising, but it may have negative welfare effects if it induces suboptimal behavior by decision-makers who use this advice for their decision-making. Swinnen et al. (2011) develop a model of "the market for policy communication" in which donors and development organizations interact. NGOs and development organizations need to invest in fundraising activities in an environment where they compete for attention and funding of donors (e.g. Andreoni & Payne, 2003; Rose-Ackerman, 1982). Communication on issues may fit in such strategy to secure and raise funds. A key result is that that "slanting" (communication bias) will almost always occur. When donors prefer donating to policy organizations that (claim to) address more severe problems, policy organizations will depict situations as being more negative than they are, even when donors' beliefs are unbiased. Furthermore, when donors update their beliefs with the policy communications of the organizations, both donors' beliefs and the policy organizations' slanting converge to a biased equilibrium.

There are two distinct social mechanisms at work. The first mechanism is the impact of stories that appear in the media on the communications of the organizations. Media may influence donors' initial beliefs, and thus the policy organizations' communication. Emotionally charged media coverage, typically concentrated around "events" or "shocks", invokes public responses, which induce politicians and governments to act (Hawkins, 2002).[13] The second mechanism is the desire of the organizations to appear in mass media in order to achieve their objectives (Cottle & Nolan, 2007). Sudden changes with dramatic effects, such as the 2008 food crisis, not only present important challenges to the international organizations in addressing these, but also important opportunities for development organizations to capture

[13] A higher level of media attention to developing countries problems leads to more aid (Eisensee & Strömberg, 2007).

media attention and signal their relevance and importance to their donors and the public.[14]

In combination, these factors create a set of incentives for international organizations to emphasize the negative welfare implications in their analysis and policy communications, and to put less emphasis on the positive effects. This attracts media coverage and, is thus, more likely to reach a wide audience and to influence policy-makers.

4.4 Fake News and Social Media

In the past decade, there is a major shift in the supply and consumption of information from mass media to social media. By 2016, 62% of US adults get their news from social media and 40% from Facebook alone. In the final 3 months of the 2016 US presidential campaign, the top performing fake election news stories on Facebook attracted more views than top stories from major news outlets as the NY Times, the Washington Post, NBC News, etc. More specifically, the 20 top-performing false election stories from fake news sites generated 8.7 million shares, reactions and comments on Facebook compared to 7.3 million from 19 major news websites (Allcott and Gentzkow (2017) and Kshetri and Voas (2017)).

How do social media differ from mass media? According to the studies of Allcott and Gentzkow (2017) and Kshetri and Voas (2017), there are similarities and differences compared to mass media. From a conceptual perspective, social media entrepreneurs also have both profits and ideology as objectives. Both studies identified fake news providers on social media who did it for profits and others because of ideological reasons. Key differences are that investment and operating costs are considerably lower for social media and that the costs of biased (fake) reporting are lower, both in terms of economic costs (reputation) and political/legal costs.

This implies that access to information on social media is cheaper and is supplied by a wider variety of sources. This enhances information consumption but at the same time makes it more difficult for the consumer to evaluate the quality of the media source, and thus of the story. On the supply side, there are less incentives to limit bias and fake news, for either ideological or profit reasons.

With the expansion of news sources and the supply of information and opportunity costs of processing info (leading to rational ignorance) the demand for "guides" and "leaders" has risen. Most major social media platforms have therefore accumulated editors or "curators" who choose, tone down, and fill in gaps in the content produced by users and media companies.

[14] A related factor is that the public at large is more interested in media reports concentrating on negative (development) effects—according to the so-called "bad news hypothesis" (see above).

This creates opportunities for "activists/influencers" to step in and "lead" their readers in a certain direction. For example, in Canada, "mommy bloggers" and in the USA, "mothers of America" have become influential voices, often taking a "naturalist perspective" (Rausser et al., 2019) and using social media to influence their readers. A key issue is who readers chose as their "guide"—and more generally who they follow on social media. In their use of social media, consumers often follow like-minded people and information suppliers. This leads to reinforced opinions, in other words, to *an echo chamber* (Moe & Schweidel, 2014). This in turn leads to *polarization of minds* (Allcott & Gentzkow, 2017).

This has major implications for politics and economics. For example, in a representative study of US adults, Fernbach et al. (2019) find that as opposition to and concern about GM foods increases, perceived understanding of GM increases, but objective knowledge about science and genetics decreases. Extreme opponents know the least but think they know the most.

5 Conclusions

Political considerations are crucial to understand economic policies. Gordon Rausser has made important contributions in a variety of topics in the political economy literature. An important theme of Gordon Rausser's work on political economy has been the political economy of public policies that have positive welfare effects, while at the same time affecting rent distribution. A key focus is on public funding of agricultural research and how a mix of public and private interests determines government investments.

A similar framework can also be applied to understand government regulations on information: the political economy of information, with important implications for economics and politics. In economics, asymmetric information is a characteristic of many economic activities, especially in agriculture and food. To reduce such problems governments have intervened through regulations, such as the introduction of public standards. Such public regulations can enhance aggregate welfare (by reducing asymmetric information), but the introduction of a standard may create winners and losers. This mix of effects will trigger lobbying by special interests and may lead to suboptimal regulations.

In politics, it is rational for voters to be ignorant about certain policy issues, if the costs of information are higher than the expected benefit from being informed. This rational ignorance is still relevant in today's world where information supplies have multiplied. Mass media and, increasingly, social media play a very important role in providing information about food, agriculture, health, technologies and environmental issues to consumers, producers and other interest groups. The interactions between mass and social media, risk perceptions and consumer behavior are complex. Long-term effects of biased media reporting come directly from imperfect discounting of bias by consumers and voters and indirectly via its influence on changes in public policy.

The past decade has witnessed a dramatic increase in information supply from social media. Social media entrepreneurs, like mass media, have both profits and ideology as objectives. However, investment and operating costs are lower for social media as are the costs of biased (fake) reporting. The quantity of information has increased (and is cheaper) but the quality is more difficult to evaluate. This creates opportunities for activists to influence information consumers and can lead to a polarization of minds and societies.

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The Evolution of Political Hyperbole and Polarization: Echo Chambers and Voter-Elite Feedback Loops

Leo Simon and Jinhua Zhao

1 Introduction

As in many other countries, the political landscape in the US has witnessed increased polarization, hyperbolic messages, and efforts to control narratives by political elites (Bénabou, 2012; Bénabou et al., 2018; Eliaz & Spiegler, 2020; Jones & McBeth, 2010; Crow & Jones, 2018). Polarization and hyperbole have permeated a wide range of issues, from climate change (Prasad, 2019; Meyer, 2019) to genetically modified organisms (Bar-Ilan & Halevi, 2020), from abortion (Mouw & Sobel, 2001) to affirmative action, from tax policies to facemasks during the Covid 19 pandemic (Hartley & Vu, 2020). Partly due to the proliferation of social media, voters are increasingly embedded in echo chambers, turning to media sources that provide comforting rather than objective news, and then passively absorbing social media posts and news feeds provided by artificial intelligence algorithms designed to generate clicks and views rather than provide truthful and balanced information (King et al., 2017; Levy, 2020; Törnberg, 2018; Qureshi et al., n.d.; Bouvier, 2020). Possibly because of these echo chamber effects and the prevailing tolerance of fake news, politicians are increasingly resorting to extremely hyperbolized messages to fire up their bases, further exacerbating voter misinformation (Levy & Razin, 2019; Allen et al., 2014; Nai, 2020). Despite the prevalence of these important and coalescing developments, the economics literature has focused little attention on studying the structural relationships among the political features of polarization, hyperbole,

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and narrative control, how these factors evolve or co-evolve, and how their evolution is related to the proliferation of echo chambers and social media. Previous research has for the most part focused on some of these factors in isolation. For example, McCarty et al. (2006) and Böttcher and Gersbach (2020) study the drivers of polarization. Shiller (2017) and Shiller (2019) study hyperbole while Barberá et al. (2015) and Allcott and Gentzkow (2017) study echo chambers. However, without a conceptual framework that integrates the parallel developments in polarization, hyperbole, echo chambers and social media, it is difficult to tease out the causal relations between these factors and to identify ways to reduce or avoid their undesirable consequences.

In a recent paper, Rausser et al. (2020) (RSZ hereafter) advances a theoretical framework to investigate the causal relationship among elite polarization, hyperbole and narrative control. Building on the literature on information aggregation (Gruner & Kiel, 2004; Morgan & Stocken, 2008; Kawamura, 2011; Rosar, 2015; Rausser et al., 2015), RSZ shows that polarization can lead to increased hyperbole in political discourse, that hyperbole can lead to information losses but can offer asymmetric advantages to opposing political parties, and that the winner of a narrative battle can use hyperbole to greater effect than the loser, thus steering public policies in his preferred direction. RSZ also highlights an important distinction between *IS* and *IB* polarizations: *IS* polarizations drive members from opposing factions further apart, while *IB* polarizations bring members within each faction closer together. RSZ shows that an *IS* polarization among elites intensifies narrative battles and lowers welfare, while these impacts are reversed for an *IB* polarization.

In this paper, we build on the political economic themes explored by Gordon Rausser (Rausser & Zusman, 1992; Rausser et al., 2011) and extend RSZ to study how polarization and hyperbole evolve over time as voters influence the political preferences of elites or representatives, while in turn being influenced by elite messages. RSZ is static in nature: it takes a snapshot of the level of elite polarization and studies the nature of the associated hyperbole and narrative battles. This paper extends the RSZ model to a dynamic setting, in which elites and their constituents participate in a feedback loop: elite polarization and hyperbolized messages affect voter preferences and voices; these changes at the voter level are then transmitted back to elites, affecting the latter's preferences and polarization in subsequent periods. Key to this dynamic process is the way in which voters, whom the elites represent, choose, absorb, and respond to elites' hyperbolized political messages. Our model of the feedback loop generates insight into the critical roles of a number of facets of the polarization phenomenon: echo chambers, the relative influence of extreme versus moderate members within elites' constituencies, voter sophistication in distinguishing hyperbole from valid information, and the permissive stances taken by social media in relation to fake news.

We show that echo chambers play a critical role in driving the vicious cycle of increasing polarization and hyperbole that evolves over time. Elites send hyperbolized messages in order to influence policies. The more messages are hyperbolized, and insufficiently "fact checked" to cleanse hyperbole from the stream of transmitted messages, the more important it is for voters to receive "balanced" messages, i.e., messages from both sides of the story, so that hyperbole and counter-hyperbole from each of the opposing factions mitigate the contamination by the other side. When voters are encapsulated in echo chambers, however, they weigh more heavily, and are primarily influenced by the messages from elites representing their own factions. When hyperbole is unbridled, these messages will be distorted relative to the information to which elites are privy, and will not be balanced by contrary messages from the opposing side. In response, voters' preferences will become more extreme as well, and this will, in subsequent periods, feed back into the stances taken by the elites that represent them.

We model voters within a constituency as having different *"voices;"* this is our shorthand for different levels of activism, engagement, political contributions, etc. In our setup, a voter's voice will become louder as her preferences become more aligned with the (possibly weighted) average of the elite messages that she receives. That is, a voter will become more engaged with her representative, for example, by contributing more to political campaigns, as what she hears matches more closely her prior preferences. When voters are confined to echo chambers, they will be exposed to hyperbolized and unbalanced elite messages. In this case, the voices of more extreme voters will come to drown out those of more moderate voters. In response, elite preferences will become more responsive to the preferences of more extreme voters. That is, echo chambers lead to increasing polarization of elite preferences over time, as the voices of more extreme voters come to dominate those of more moderate voters. We show in addition that the echo chamber effect will also aggravate the social costs of other factors, such as the proliferation of fake news.

Social media is increasingly coming under scrutiny for its tepid response to fake news and to extremist messages more generally. The original model in RSZ was unable to capture the deleterious impact of these trends: in RSZ, more stringent discounting of extreme elite messages have no real consequences on information aggregation and welfare. In the dynamic model developed here, by contrast, more severe discounting does lead to a welfare improvement, at least when echo chambers are a prominent feature of the landscape. Extreme message discounting becomes even more important when voters lack sufficient sophistication to be able to "reverse-engineer" elite messages, and thus extract the relevant information content from its hyperbolized context. Similar to RSZ, we consider a special form of discounting, where messages more extreme than certain credibility boundaries are "censored" to the boundaries. It is important to distinguish our usage of the term "censorship" from its conventional usage, i.e., the suppression or prohibition of communications deemed by a central authority to be politically unacceptable. In our context, censorship is shorthand for the idea that society discounts hyperbolic messages.

The paper is organized as follows. In Sect. 2, we review the main, static results of RSZ to lay the foundation for the dynamic analysis in this paper. We set up the dynamic model in Sect. 3. In Sect. 4, we report on a series of comparative static experiments that demonstrate the interactions between echo chambers, voter sophistication and censorship, as well as the feedback effects between voters' preferences and voices on the one hand and elites' preferences on the other. Section 5 examines the implications of our model in the context of two examples, climate change and personal protective responses to Covid-19. In both cases, elite messages and voter preferences have co-evolved in directions strikingly consistent with the predictions of our model. Section 6 concludes and relates our paper to the contributions of Gordon Rausser to the political economy literature. Technical details of our dynamic model are contained in the appendix.

2 Polarization and Hyperbole in Elite Competition

We first review the main results and intuition in RSZ, which provide the foundation for the dynamic models developed in this paper. RSZ studies strategic interactions among two opposing groups of political elites or representatives, and shows how polarization and hyperbole interact under different narratives. For concreteness, consider an example of climate change in which the government decides on the amount of greenhouse gas (GHG) emissions. We model the government's decision as balancing two dimensions of the issue, a *pro* dimension, e.g., cost of abatement that is "for" GHG emissions, and a *con* dimension, e.g., damages from climate change that is "against" GHG emissions. Voters have their own preferences or biases regarding the emission level, which can be different from the level that would maximize the aggregate social welfare. We consider a representative political system, where voter preferences or biases in each district are aggregated to that of a representative, also called an *elite*. There are two factions of $n = 2m$ elites, with the left faction consisting of elites $1, \ldots, m$, and the right faction consisting of $m + 1, \ldots, n$. Aggregating the biases of voters in their respective districts, the representatives are also biased relative to a social welfare maximizing emission level, with those on the *Right* preferring more GHG emissions and those in the *Left* preferring less. Let k_r denote elite r's bias about the emission level. We order the elite biases so that $k_1 < k_2 < \ldots < k_n$, with $k_r < 0$ for $r \leq m$ (i. e., those in the *Left*) and $k_r > 0$ for $r \geq m + 1$ (i.e., those in the *Right*).

Each elite member receives a pair of signals about the two dimensions of the issue; in the case of climate change, a representative has an information advantage relating to the abatement costs and climate change damages in his local district. The elites send *messages* about their private information to a "center," representing the "court of public opinion," who then aggregates the information by summing up all received messages. The center then decides on an emission level that equals the average of all messages; in the context of climate change, the average message is simply the average net benefit of GHG emissions.

An elite's payoff is represented by a penalty function that is quadratic in the difference between his preferred decision and the center's decision, with his preferred decision being a perturbation of the first best decision (obtained if every elite reports his true information) in the direction of his bias k_r. Thus, an elite in the *Right* faction, with $k_r > 0$, has an incentive to over-report along the *pro* dimension (i.e., to overstate the abatement costs) and to under-report along the *con* dimension (i.e., to under-state the damages), so as to steer the center's decision to the right. Those in the *Left* faction, with $k_r < 0$, have mirror-image incentives to hyperbolize their messages, only in the opposite directions, where we say a message is *hyperbolized* when it over- or under-reports the true signal. The opposing incentives of elites in opposite factions and the fact that the center averages their messages imply that the elites will engage in a tug-of-war when they send their messages. If elite r^+ in the *Right* faction over-states his net message, his opponent r^- in the *Left* will under-state, not only to steer the center's decision to the left but also to counter the over-report of r^+. Because of this tug-of-war of hyperbole and counter-hyperbole, the messages or platforms are much more polarized than the elites' preferences, and hence the voters' preferences; as RSZ puts it, platform polarization far exceeds preference polarization.

A key feature of the RSZ model is that the transmission of elite messages is subject to asymmetric natural bounds along the two dimensions. Specifically, zero is the natural lower (or upper) bound for the *pro* (or *con*) dimension: the abatement costs and climate change damages are all nonnegative. To capture the fact that some messages are too extreme and hence less credible, there are also two credibility bounds, a large positive (or negative) number along the *pro* (or *con*) dimension; messages that exceed these bounds are censored. For example, if a message along the *pro* dimension says that the abatement cost is higher than the credibility bound, it will be censored back to the bound. To capture the phenomenon of extremely tolerant media and the proliferation of extreme messages, the credibility bounds are assumed to be much less restrictive than the natural bounds.

Given the censoring rule, no elite has incentive to hyperbolize beyond the credibility bounds, so that in equilibrium all messages along any dimension will lie within the interval between the natural (i.e., zero) and the credibility bounds. Whereas uncensored messages would have varied with the underlying true signals, messages that are censored to the bounds remain at the bounds even when the underlying signals vary. Thus, when messages outside of these credibility intervals are censored, information about the elites' true signals is lost, leading to losses in social welfare and elite payoffs. In equilibrium, all but at most one elite has his message constrained by the bounds with strictly positive probability.

In this setting, RSZ shows that the *Right* faction prefers to hyperbolize along the *pro* dimension, while the *Left* faction prefers to hyperbolize along the *con* dimension. The intuition is illustrated in Fig. 1. The horizontal axis represents the two dimensions of the (climate change) issue, with the *pro* dimension pointing to the right and the *con* dimension to the left. The natural bound of zero and the two credibility bounds are represented by three vertical lines. Figure 1 depicts two members, one belonging to each of the two factions, who receive private signals along the two dimensions. The red dots represent the signals of the *Right* faction member and the blue dots those of the *Left* faction member. Consider these members' incentives when they report their private information along the *pro* dimension. Purely for heuristic purposes, think of the members as engaging in three "rounds" of mis-reporting. In the first round, in order to steer the center's decision, the *Right* faction member over-reports his private signal, while the *Left* member under-reports his; these misreporting incentives are represented by the two arrows in Panel (a). In Panel (b), the

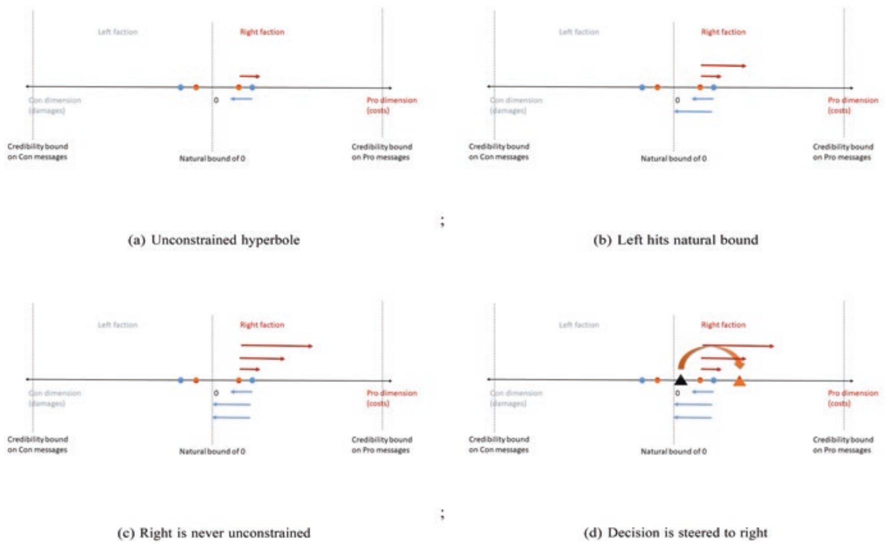

Fig. 1 Tug of war in hyperbole. (**a**) Unconstrained hyperbole, (**b**) Left hits natural bound, (**c**) Right is never unconstrained, (**d**) Decision is steered to right

two members mis-report even more (the outermost two arrows): this time the mis-reporting serves not only to steer the center's decision but also to counter the mis-reporting of the other side in the previous round. Significantly, *Left*'s mis-reporting hits the natural bound of zero, while *Right*'s is unconstrained. Panel (c) illustrates the third round of mis-reporting: while *Left*'s mis-report is again constrained by zero, *Right* can over-report more to the right, without any constraint, to offset the under-reporting by *Left*. The result is shown in Panel (d): the center's ultimate decision, represented by the orange triangle, coincides with *Right*'s ideal location, and is skewed to the right relative to the first best choice indicated by the black triangle.

Figure 1 shows that each faction has a "preferred dimension" along which to engage in hyperbole: *Right* prefers the *pro* dimension, while *Left* prefers the *con* dimension. RSZ models a two-stage game: the outcome of the first stage determines whether or not hyperbole is allowed along each dimension. The first stage is played by political operatives, representing the two factions: each chooses whether to "politicize" one or both dimensions, and hyperbole is allowed only along a dimension that has been politicized by at least one operative. We refer to this choice—which dimension(s) to hyperbolize—as *narrative selection*. Thus there are four possible narratives, depending on whether none, one or both dimensions is politicized. We say that a faction *wins the narrative battle* if its preferred dimension is the only politicized dimension. Figure 1 represents the case where the *Right* faction wins the narrative battle. An operative gains a political prize by winning the narrative battle, but information is lost along any dimension that admits hyperbolic messages. The equilibrium narrative outcome of the first stage game is determined by balancing these political prizes against the incurred information losses.

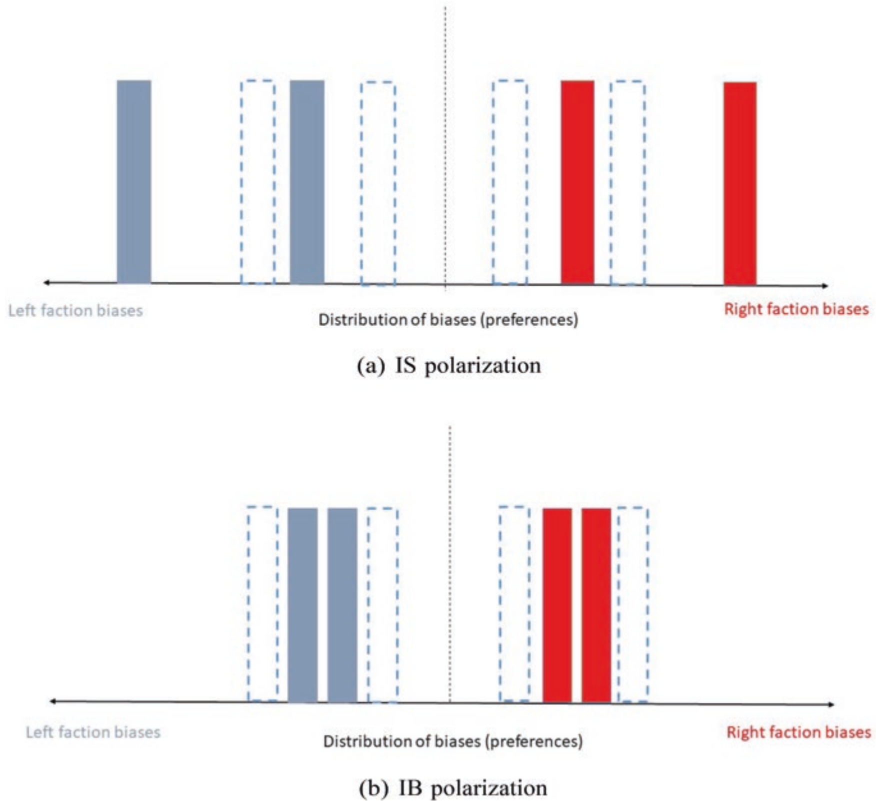

Fig. 2 Preference polarizations. (**a**) IS polarization, (**b**) IB polarization

RSZ shows that an important factor that influences the narrative outcomes is the preference polarization of the elites. They distinguish between two kinds of polarizations. In an increasing spread (*IS*) polarization, the biases of the two opposing factions move further apart with k_r^+ moving to the right for r^+ in the *Right* faction and k_r^- moving to the left for r^- in the *Left*. In an increasing bipolarity (*IB*) polarization, the biases within each faction become more homogeneous: the moderate members become more extreme while the more extreme members become more moderate. Figure 2 illustrates the two cases. The dashed bars represent the starting locations of the elite biases (i.e., the k's), while the solid bars represent the ending locations after *IS* or *IB* polarizations. A typical polarization can consist of combinations of multiple *IS* and *IB* polarizations.

RSZ shows that in general an *IS* polarization of elite preferences leads to more intense narrative battles and thus lower welfare: it is more likely that both dimensions are politicized in the equilibrium. In contrast, an *IB* polarization of elite preferences tends to lessen the narrative battles and thus raise the welfare: it is more likely that only one or neither dimension is politicized. Underlying both results is the fact that extreme elite members play critical roles: they will gain the most when their preferred dimension is politicized since they can then hyperbolize with less constraint. After an *IS* polarization, the elites become more extreme, while after an *IB* polarization, the most extreme members become less extreme. The movement of the biases of the extreme elites in opposite directions then lead to opposite impacts on narrative battles.

3 A Dynamic Model of Voter and Representative Interaction

We next take the core model of RSZ and extend it to study how voters and their representatives interact, and how their interaction affects the evolution of elite preferences and polarization. Specifically, recognizing the fact that the elites are representatives of voters and face election pressures, we explicitly model elite preferences as partly determined by voter preferences weighted by voter voices, which in turn are affected by elite messages. The mutual influences of elites and voters through their messages, voices and preferences are the core drivers of the dynamic evolution of polarization and hyperbole. Thus, in the dynamic model there are two types of players: $n = 2m$ elites or representatives with m of them in each of the two opposing factions, and a non-atomic uniformly distributed mass of voters, D_r, in elite or representative r's district. To focus on the evolution of polarization and hyperbole, we assume that the narrative, either *pro* or *con*, is exogenously given and fixed.

The timeline of the game is divided into *phases*, indexed by $t = 1, \ldots, T$, with each phase consisting of two periods. A phase starts, in period one, with a given profile of voter preferences or biases on the issue, e.g., climate change, as well as their voices in conveying their preferences to the elites or representatives. Each elite's preference or bias then equals the weighted average of the preferences of the voters in his district, with a voter's weight being increasing in his voice level. Given these elite preferences and the particular narrative of the game, elites strategically determine their messages as in RSZ, resulting in equilibrium levels of hyperbole and polarization of their messages. At the end of the phase, i.e., in period two, voters respond to the elite messages that they receive by updating their preferences and voices - the specific process of updating depends on important factors such as echo chambers and voter sophistication. The updated voter preferences and voices then form the starting values for the subsequent phase, leading to new levels of elite preferences and thus new equilibrium messages and hyperbole. The dynamic evolution of polarization and hyperbole is characterized by this process of elite messages being determined by the current phase voter preferences and voices and then affecting next phase voter preferences and voices.

Let $h_{t,r}(j)$ and $w_{t,r}(j)$ be the preference and voice over a policy issue of voter j in the district of elite r at the beginning of phase t, and let $\boldsymbol{h}_t \equiv (h_{t,r}(j), j \in D_r, r = 1, \ldots, n)$ and $\boldsymbol{w}_t \equiv (w_{t,r}(j), j \in D_r, r = 1, \ldots, n)$, be, respectively, the voter *preference profile* and *voice profile*. The variable $w_t(j)$ represents the importance of voter j, or the loudness of j's "voice," in shaping the representative's preferences.

The profile $\boldsymbol{w}_t$ might, for example, be a measure of the various constituents' contributions to the political campaign of their representative. We assume that in the first phase of our model, $\boldsymbol{w}_1$ is constant, meaning that all voters in the same district start out with the same voice level. For the remainder of this subsection we will fix a representative r, and examine how r's preferences, as well as those of a typical member of his consistency, $j \in D_r$, evolve over time. To reduce notational clutter, we suppress subscript r in time-dependent functions such as $h_t(j)$ and $w_t(j)$, with the understanding that all these variables are defined relative to the constituency D_r.

Each elite starts with his own preference or bias, $k_{0,r}$, which could represent r's intrinsic belief about the issue. Given the preferences and voices in his district, r updates his preference as a convex combination of his own intrinsic preference $k_{0,r}$ and the weighted mean of the current preferences of the voters in his district. Specifically, at the start of phase t, r's preference is given by

$$k_{t,r} = (1-\varphi)k_{0,r} + \varphi \int_{Dr} w_t(j)h_t(j)dj, \quad \text{with}\, \varphi \in [0,1], \int_{Dr} w_t(j)dj = 1. \tag{1}$$

The scalar φ is a measure of the representative's responsiveness to voter concerns. When $\varphi = 0$, the elite sticks to his own intrinsic preference and is not influenced by voter preferences at all, while $\varphi = 1$ represents the other extreme. We use $\boldsymbol{k}_t \equiv (k_{t,r}, r = 1, \ldots, n)$ to denote the profile of elite preferences in phase t.

As described in RSZ, given $\boldsymbol{k}_t$, the elites simultaneously choose their messages about their private signals on the *pro* and *con* dimensions of the issue (of climate change), resulting in a vector of equilibrium messages $\hat{\boldsymbol{a}}_t = (\hat{\boldsymbol{a}}_t, \textit{Left}, \hat{\boldsymbol{a}}_t, \textit{Right})$, where subscript *Left* represents the *Left* faction and *Right* represents the *Right* faction. These messages, representing the platforms of the elites about the issue, will in turn affect voters' preferences and voices. To represent possible *echo chamber effects*, we allow voters in different factions to be exposed to different messages; and to reflect the fact that voters tend to focus on the kind of messages they prefer to hear, we allow a voter to assign (weakly) more weight to messages from representatives of his own faction. Let $\tilde{a}_t(j)$ be the "average message" that voter j is exposed to, then

$$\tilde{a}_t(j) = \begin{cases} \gamma \sum_{i=1}^{m} \hat{\boldsymbol{a}}_{t,Left} + (1-\gamma) \sum_{i=1}^{m} \hat{\boldsymbol{a}}_{t,Right} & \text{if } j < 0 \\ \gamma \sum_{i=1}^{m} \hat{\boldsymbol{a}}_{t,Right} + (1-\gamma) \sum_{i=1}^{m} \hat{\boldsymbol{a}}_{t,Left} & \text{if } j > 0 \end{cases} \tag{2}$$

where scalar $\gamma \in [0.5, 1]$ represents the echo chamber effect. When $\gamma = 1$, the voter updates her preference based only on messages from elites in her own faction. This polar case captures the idea of a voter living in an hermetically sealed echo chamber, e.g., a liberal who reads only the Washington Post, or a conservative who watches only Fox News. When $\gamma = 0.5$, voters have a perfectly balanced media diet, and assign equal weights to messages from both factions.As shown in RSZ, elite messages tend to be highly hyperbolized, so that the messages can depart significantly from the true signals that the elites receive. Voters do not have to take the messages at their face value; it is not uncommon for hyperbolized messages to be "fact checked" and for voters to "see through" what is behind the messages. In the present model, we allow sophisticated voters to discount these hyperbolic messages, "reverse engineering" them to recover the senders' actual information. Specifically, when updating his preferences, j will use the discounted average message $\ddot{a}_t(j)$, defined by

$$\ddot{a}_t(j) = \left((1-\mu) + \mu \frac{\nu_k}{\nu_a} \right) \tilde{a}_t(j), \quad \mu \in [0, 1] \tag{3}$$

where ν_k and ν_a are, respectively, the mean absolute deviations of the $\mathbf{k}_t$ vector and the equilibrium message vector $\hat{\boldsymbol{a}}_t$. In a hyperbolized environment, ν_a will be much larger than ν_a. The ratio ν_k/ν_a scales down the elite messages to bring them back to the scale of elite preferences, For example, if elite messages were all three times as extreme as their preferences, then $\nu_k/\nu_a = 1/3$. In this case, if $\mu = 1$, then $\ddot{a}_t(j)$ would be a third the size of $\tilde{a}_t(j)$ and thus of the same order of magnitude as elites' preferences, so that hyperbole is effectively eliminated. In contrast, if $\mu = 0$, the messages are taken at their face value by the voters. Thus, μ indicates how much a voter discounts the hyperbolized messages, and can be interpreted as a kind of voter sophistication, reflecting the degree to which she anticipates that her representative will engage in hyperbole.Having observed elite messages transmitted in the first period of phase t, voter j, in the second period, updates her preference over the policy outcome by taking a convex combination of her own current preference $h_t(j)$ and an "echo-chamber-filtered" discounted average elite message $\ddot{a}_t(j)$:

$$h_{t+1}(j) = \rho\, \ddot{a}_t(j) + (1-\rho) h_t(j), \quad \rho \in [0,1], \tag{4}$$

where parameter ρ captures voters' sensitivity in responding to observed messages from elites.In the second period of phase t, voter j also updates her voice level $w(j)$, again by comparing her current preference to the discounted average message $\ddot{a}_t(j)$. Exhibiting a kind of confirmation bias effect, a voter will become more engaged in the political process when the messages transmitted from elites are more congruent with her personal political preference. That is, voters who "hear what they want to hear" become more engaged than those that do not.[1] Specifically, given the starting voice level $w_t(j)$, voter j updates her voice level after observing $\ddot{a}_t(j)$ as

$$w_{t+1}(j) = \frac{\zeta_{t+1}(j)}{\int_{Dr} \zeta_{t+1}(j)\, dj}, \tag{5}$$

where $\zeta_{t+1}(j)$ is an unnormalized voice level given by

[1] This specification is similar to biased consumers more willing to purchase news that conforms to their biases (?; ?). While we believe that this largely reflects the political reality, it is possible that voters are more motivated to participate in the political process, i.e., their voices become louder, when candidates' policies were further from their ideals. This possibility represents an interesting extension of our model.

$$\zeta_{t+1}(j) = w_t(j)\Big((1-\eta)+\eta g(\ddot{a}_t(j)-h_t(j),\sigma)\Big), \quad \eta \in [0, 1]. \tag{6}$$

The normalization in (5) is to ensure that updated voter voice weights $w_{t+1}(j)$ integrate to one, as required in (1). In (6), η is a "reactiveness term," measuring the sensitivity of voters' voices to the elite messages. For example, if $\eta = 0$, voters' voice levels would be completely immune to political messaging. The function $g(\cdot, \sigma)$ denotes the standard normal density,[2] rescaled so that *on average* for the representative's constituency, $g(\cdot, \sigma)$ is equal to one. When η is close to 1, j's unweighted voice level will be stronger (resp. weaker) tomorrow than today, if today's discounted average message $\ddot{a}_t(j)$ is relatively close to (resp. far away from) j's preference. Between two voters, the one whose preference is closer to the discounted average messages will have a larger voice. Finally, parameter σ measures the dispersion of the voices or heterogeneity of voter engagement.

Representatives are "shortsighted" in the sense that in each phase, they play the RSZ game without taking into consideration the evolution of voter preferences and voices and the implications for future phases. That is, they are concerned only with their payoffs within the current phase. This assumption is natural if a phase is sufficiently long that it encompasses a representative's political life, and future phases do not matter for the current generation of representatives.[3] Given the voter preferences and voices and thus elite preferences, we derive the equilibrium strategies of the representatives in Appendix 1. The strategies are similar to but extend the equilibrium identified in RSZ: while RSZ focuses on symmetric elite preferences $\boldsymbol{k}$, we allow $\boldsymbol{k}$ to be asymmetric.

4 Dynamic Evolution of Polarization and Hyperbole

In this section, we study the evolution of elite preference polarization and hyperbole, as well as voter preferences and voices, building on the feedback loop between elites and voters outlined in the previous section. To begin, we fix the narrative (either *sym* or *pro*), together with the starting distributions of voter preferences and voices (and thus elite preferences). In phase 1, we assume that all voters have the same voice level. In each phase, the equilibrium strategies of the elites together with the private signals they observe, determine their messages, which in turn determine voters' preferences and voices at the start of the next phase. These voter attributes, in turn, determine elite preferences and equilibrium hyperbole in subsequent phases.

[2] Precisely, $g(xj, \sigma) = N(xj, 0, \sigma)/\xi \in Dr\ N(\chi, 0, \sigma)d\chi$, where $N(x, 0, \sigma)$ is the density of a normal distribution with mean zero and variance σ. of a Gaussian distribution with mean zero and standard deviation σ.

[3] This setup is in a sense similar to that in evolutionary games, where in each replication, the players are wired to play certain strategies without considering the dynamic implications of their strategies.

Our comparative statics analysis of the evolution of elite preference and hyperbole, along with voter preferences and voices, provide interesting insights into several important recent developments in the political landscape, relating to the roles of echo chambers, censoring rules, voter sophistication and elites' preoccupation with firing up their bases.

Since our model is rather complex, we use numerical simulations with $n = 8$ elites to illustrate the insights that emerge from our model. We analyze four *treatments*, representing a 2×2 combination of the two narratives, *sym* and *pro*, and whether or not there are echo chamber effects when voters process elite messages. In the *balanced messages treatment*, voters assign equal weight to all messages they receive; in the *echo chamber treatment*, which might be more realistic, voters pay less attention to messages of elites in the opposite faction. For concreteness, think of liberals who pay more attention to NPR and the Washington Post than Fox News, and conservatives who do the reverse. The two echo chamber treatments are distinguished by the values of parameter γ: if $\gamma = 0.5$, voters assign equal weight to messages from both sides of the political spectrum; when $\gamma > 0.5$, they pay more attention to politically sympathetic news sources.

Table 1 lists the parameters we use in our simulations, together with summary interpretations of each parameter and the equations in which they are defined. For each of the listed parameters except γ, we run a comparative statics exercise for each of our four treatments, varying only that parameter. For the top four listed parameters, the baseline values and their comparative statics perturbations are the same for each treatment. For variable μ, we use different values for each treatment. The labels in column (IV) of the table indicate the treatments, with (a) representing *balanced messages* treatment and (b) representing *echo chamber* treatment. For example, *sym* a) refers to *balanced messages* treatment for the *sym* narrative.

4.1 Baseline: The Critical Role of Echo Chambers (γ)

We first show how elite preferences and hyperbole evolve for the baseline parameters values listed in column (V) of Table 1. We begin with the *balanced messages* treatment for the *sym* narrative (i.e., treatment *sym* a)). Fig. 3 shows the evolution of equilibrium in each phase for this case. The top left panel shows how voter and elite preferences evolve over time from phase 1 (top row) to phase 3 (bottom row). Each thick bar depicts the distribution of voter preferences, $h_{t,r}(j)$, in district r (of a total of 8 districts), while the vertical thin lines represent the preferences of the elite for this district $k_{t,r}$. Fig. 3 shows that, all preferences move to the center over time, while, within each faction, they become more homogeneous. In the language of RSZ, as time progresses, there is a *reverse IS* polarization (the k's move towards 0) as well as a (regular) *IB* polarization (the k's moving closer to each other within each faction). One driver of these movements is that all voters are exposed to the same set of messages, the average of which is rather moderate (in fact, zero in expectation). Thus, voter preferences become increasingly homogeneous, driving

Table 1 Parameters for comparative dynamic simulations

(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Parameter	Parameter name	Interpretation	Treatments	Baseline values	New values under *sym*	New values under *pro*	Equation reference
$\varphi \in [0, 1]$	Elite attunement	Elite responsiveness to voter pref	All	1	0.7	0.7	(1)
$\rho \in [0, 1]$	Preference reactivity	Voter preference reactivity to elite mesgs	All	0.2	0.3	0.3	(3)
$\eta \in [0, 1]$	Voice reactivity	Voter voice reactivity to elite mesgs	All	0.5	0.99	0.99	(6)
$\bar{b} \geq 2n$	Censor bound	Credibility threshold	All	6	6.6	6.6	
$\mu \in [0, 1]$	Hyperbole discounting	Voter discounting of elite hyperbole	*sym* a) *sym* b)	0.98 0.97	0.97 0.96		(4)
			pro a) *pro* b)	0.98 0.98		0.90 0.965	
$\gamma \in [0.5, 1]$	Echo chamber	Voters discounting of dissonant information	*sym* a) *sym* b)	0.5 0.53			(2)
			pro a) *pro* b)	0.5 0.9			

elite preferences towards the center (reverse *IS*) as well as closer to the other faction members (*IB*).

A second driver for the patterns in the top left panel is the evolution of voter voice levels, which is graphed in the top right panel. The horizontal axis represents the location of voter *j*'s preference $h_{t,r}(j)$, while the vertical axis depicts the associated voice $w_{t,r}(j)$. In phase 1, all voters start with the same voice level (the voice lines are flat) within each district. As time progresses, the voices of more moderate voters within each district become louder, relative to those of more extreme members. The reason is that in the *balanced messages* treatment, voters are exposed to a rather moderate average elite message, which is more consonant with the preferences of moderate voters than elite ones, leading the former to lend relatively more political support to their respective representatives. Responding to their constituents, elites' preferences become more moderate, leading to the reverse *IS* polarization.

The bottom right panel shows the evolution of elite hyperbole, $\lambda_{t,r}$ for the 8 elites over the three phases, with the horizontal axis being the three phases and the vertical axis representing the level of hyperbole. Left faction member r^- under-reports his signal (i.e., $\lambda_{t,r^-} < 0$) while right faction member r^+ over-report his (i.e., $\lambda_{t,r^+} > 0$). More extreme elites engage in higher degrees of hyperbole (i.e., under- or over-reporting more), but as time progresses, all elites become less extreme and under- or

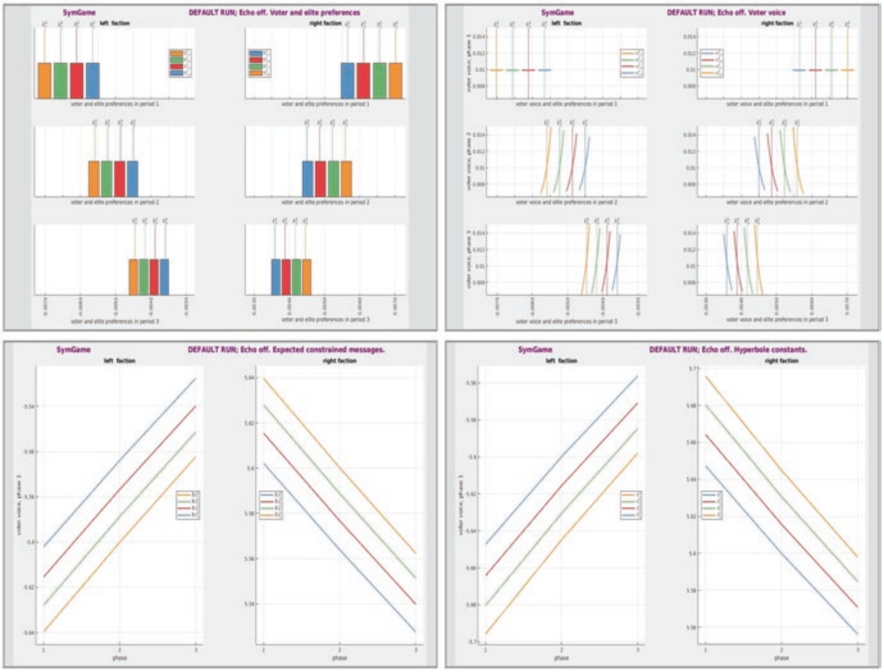

Fig. 3 Baseline run: *sym* a), *balanced messages* treatment under the *sym* narrative

over-report less. That is, in the *balanced messages* treatment, elites will gradually engage in less hyperbole as their preferences become less extreme. As a result, the messages they send are less likely to be constrained by the credibility bounds. The lower left panel shows the evolution over the three phases of the severity of elite messages being constrained by the (credibility) bounds, with the vertical axis measuring the difference of otherwise-uncensored messages and the censored messages. Again, as time progresses, the difference decreases in absolute value, so that the severity of elite messages being censored decreases. As shown in RSZ, this implies that the welfare of all players increase over time.

Figure 4 depicts our baseline run for the *echo chamber* treatment under *sym* (i.e., treatment *sym* b)). Relative to Fig. 3, the directions in which polarization and hyperbole evolve over time are reversed. Over time there are increasing (regular) *IS* and *IB* polarizations (top left panel), while extreme voter voices start to drown out those of moderate voters (top right panel). As a result, elite messages exhibit increasing hyperbole (bottom right panel) and increasing degrees of messages being censored (bottom left panel), raising the level of welfare loss over time. What drives these differences is the echo chamber effect: voters in each of the *Left* and *Right* factions pay more attention to messages sent by the elites from their own factions, whose messages become hyperbolized and thus more extreme relative than their preferences. As time passes, voters' preferences (the $h_{t,\,r}(j)'s$) become more extreme, and the voices of more extreme voters become louder, dominating their more moderate

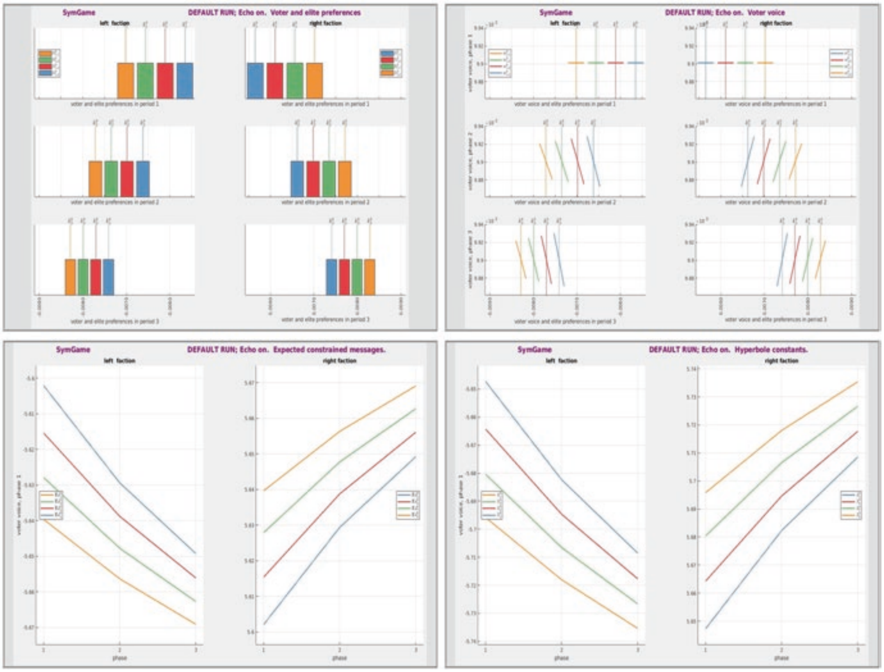

Fig. 4 Baseline run: *sym* b), *echo chamber* treatment under the *sym* narrative

neighbors. The two factors combine to induce both *IS* and *IB* polarizations of elite preferences.

Under the *pro* narrative, the evolutionary patterns are similar to *sym* in some respects, but quite different in others, due to the prominent role played by the most extreme member of the *Right* faction ($n = 8$). Figure 5 depicts the patterns for the *balanced messages* treatment (i.e., treatment *pro* a)). As in Fig. 3, there are reverse *IS* polarization and regular *IB* polarization as time progresses. As shown in RSZ, player 8's degree of hyperbole (over-reporting) is the most dramatic, while other players under-report in response. Because the voters in our baseline run are sufficiently sophisticated—their hyperbole discounting parameter μ is very high—the average of the reverse-engineered elite messages become less polarized over time, despite the elite hyperbole. As a result, voter preferences move towards the center and the voices of more moderate voters become relatively louder, inducing a reverse *IS* polarization of elite preferences. In turn, the level of hyperbole decreases over time: the messages of all elite members except $n = 8$ shift to the right (they under-report less) while the 8th player's message becomes less extreme. RSZ shows that the over-reported messages of the largest player $n = 8$ are never constrained; on the other hand, the messages of all players than 8 are constrained with positive probability. As a result, the *Left* faction's preferences converge to the center more rapidly than those of the *Right* faction.

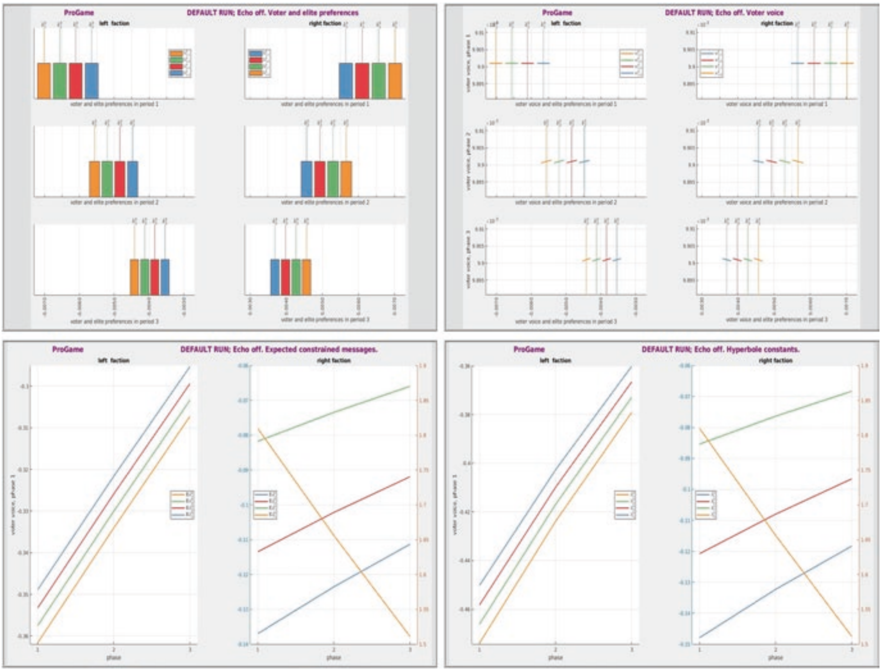

Fig. 5 Baseline run: *pro* a), *balanced messages* treatment under the *pro* narrative

Figure 6 illustrates the *echo chamber* treatment for the *pro* narrative (i.e., treatment *pro* b)). In this case, voter and elite preferences in the two factions move further apart as time progresses (*IS* polarization), and the voices of more extreme voters begin to drown out those of more moderate voters. Again, due to the dominance of player 8's messages, the *Right* faction's elite preferences shift to the right at a faster rater than the *Left* faction's shift to the left.

Below we summarize the major findings from our baseline analysis.

Summary 1

1. *Since voters in the same faction are exposed to the same elite messages, their preferences will become more homogeneous over time, inducing in all treatments an IB polarization of elite preferences as time progresses.*
2. *The echo chamber effect plays a major role in driving IS polarization.*

   (a) *When voters listen more attentively to messages from elites in their own factions, their preferences diverge from the center and the voices of more extreme voters come to drown out those of more moderate voters, inducing an IS polarization of elite preferences over time. Consequently, elite messages become increasingly more hyperbolized.*

   (b) *Without echo chambers, voter preferences converge towards to the center and voices of more moderate voters come to dominate those of more extreme*

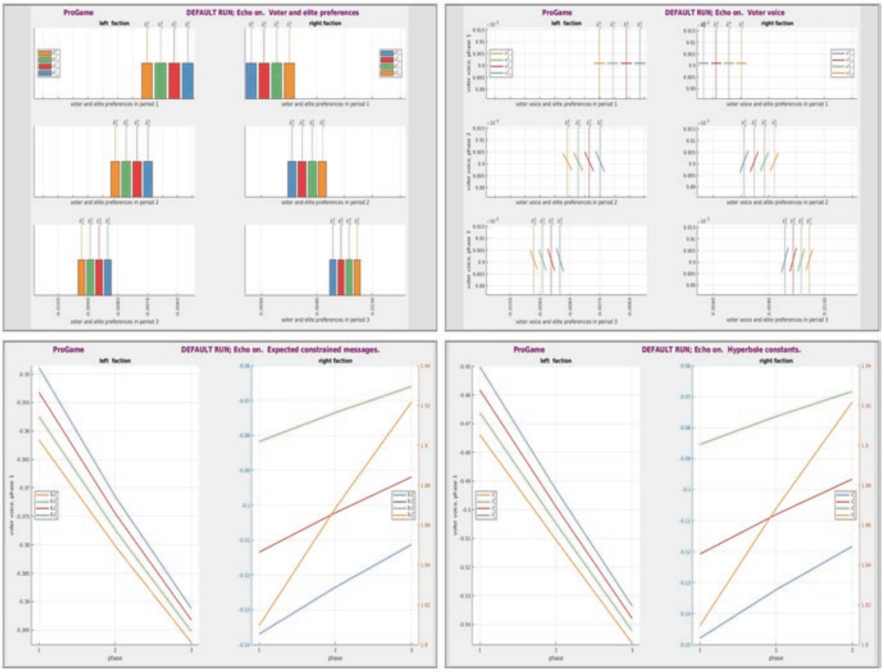

Fig. 6 Baseline run: *pro* b), *echo chamber* treatment under the *pro* narrative

voters, inducing a reverse IS polarization of elite preferences and less hyperbolized elite messages over time.

3. *While the shifts in elite preferences in the two factions are symmetric under the sym narrative, in the pro narrative, there is an overall drift to the right, i.e., Left faction elite preferences come to be less extreme than those of the Right faction.*

4.2 Elite Responses to Voter Preferences (φ)

In the baseline analysis, the elite attunement parameter, φ, is set equal to its maximum value of 1, meaning that elite preferences are fully responsive to voice-weighted voter preferences, and move in step with them as time progresses. In reality, of course, elites have some autonomy from their constituents; in fact, a politician may deem it a virtue to make decisions based on principles rather than polling numbers. Figures 7–10[4] demonstrate how preferences evolve when the elite attunement parameter, φ, decreases from 1 to 0.7, and contrasts these trends with the

[4] Figures 7–10 are available on https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3809413.

corresponding ones in our baseline runs (Figs. 3, 4, 5, and 6). In each of these new figures, the upper left panel shows the evolution of voter and elite preferences when $\varphi = 0.7$; the lower left panel provides a basis for comparison, showing what happens under the baseline scenario with $\varphi = 1$. In the upper- and lower-right panels, solid lines represent the voter voices and elite hyperbole when $\varphi = 0.7$, while dashed lines represent those in the baseline case of $\varphi = 1$.

In all four treatments, the movements of elite preferences across time lag behind those of their constituents. As voter preferences exhibit regular *IS* or reverse *IS* polarizations (in the *balanced messages* and *echo chamber* treatments respectively), elite preferences move in the same direction, but at a slower rate, because they remain faithful, to some extent, to their "underlying principles" (i.e., the starting elite preferences $\mathbf{k}_0$). Consequently, relative to the baseline scenario, the degree of hyperbole in elite messages is either reduced—when elites are less *IS* polarized than their constituents—or increased—when they are more *IS* polarized. Further, the "echo chamber effect" is less pronounced when φ is lower, because elites, maintaining some attachment to their initial biases, do not fully track the evolutionary trends of their constituents. In fact, in the polar case of $\varphi = 0$, elite preferences would have remained fixed across time, while voter preferences and voices still demonstrate the trends illustrated in With this extreme parameterization, the echo chamber effect would have no impact on either elite preferences or the extent of their hyperbole. Summarizing:

Summary 2
As elites become less attuned to voter preferences, the echo chamber impact is less influential on both elite preferences and hyperbole. Specifically,

1. *In the balanced messages treatment, elite preferences still exhibit a reverse IS polarization as time progresses, but to a lesser extent.*
2. *In the echo chamber treatment, elite preferences still exhibit an IS polarization as time progresses, but to a lesser extent.*

4.3 Voter Reactivity to Elite Messages (ρ and η)

In our model, voters' preferences and their voices are both influenced by elite messages. Parameter ρ measures the weight that voters assign to elite messages when they updating their *preferences* (cf. (4)), while parameter η plays the corresponding role when they update their *voices* (cf. (6)). Since the effects of the two parameters on elite preferences and hyperbole are quite similar, we focus our discussion on ρ, noting that the qualitative results described here can be extrapolated to the other parameter, η. In this exercise, we increase ρ from its baseline value of 0.2 to a higher value of 0.3, so that voters become more responsive to elite messages when they update their preferences over time. Figures 11–14[5] show how our game evolves as ρ is increased.

From Figs. 11 and 13, we see that in the *balanced messages* treatment, the rate of reverse *IS* polarization as time progresses is accelerated relative to the baseline case. Since voters are more reactive to elite messages, and the unweighted average messages are rather moderate, voter preferences respond, relative to the baseline, by becoming more moderate as well, as time progresses. In response, elite preferences also become more moderate, exhibiting increased degrees of reverse *IS* polarization relative to the baseline. In contrast, Figs. 12 and 14 show that in the *echo chamber* treatment, *IS* polarization is exacerbated relative to the baseline as time goes on. Since voters are more reactive to elite messages, and average messages are more hyperbolized due to the echo chamber effect, voters' preferences also become more extreme, in turn driving elite preferences to become progressively more *IS* polarized. In all four treatments there is a greater degree of *IB* polarization over time: all voters within each faction are exposed to the same filtered average message, so that as they become more attuned to these messages, voters' within-faction preferences become more homogeneous as time progresses, again relative to the baseline. Summarizing:

Summary 3
As voters' preferences and/or voices become more attuned to elite messages,

1. *the rate of elite preference IB polarization increases over time relative to the baseline.*
2. *the echo chamber effect plays a more significant role in determining elite preferences and hyperbole. Specifically,*
   - *in the balanced messages treatment, elites' preferences reverse-IS-polarize to a greater extent than in the baseline, as time progresses;*
   - *in the echo chamber treatment, elites' preferences* regular-*IS-polarize to a greater extent than in the baseline, as time progresses.*

4.4 Voter Discounting of Hyperbole in Elite Messages (μ)

Our next comparative statics exercise reduces the value of parameter μ, which measures the degree to which voters reverse-engineer the hyperbolic nature of elite messages (cf. (3)). We interpret a reduction in μ as a decline in voter sophistication: they become less discerning, and more inclined to take at face value the hyperbolized messages that elites transmit. These changes are illustrated in Figs. 15–18[6]. Figures 15 and 17 show that in the *balanced messages* treatment, the evolution of

[5] Figures 11–14 are available on https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3809413.
[6] Figures 15–18 are available on https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3809413.

elite polarization is largely unaffected by a decrease in voter sophistication. The reason is that in this case, even though individual elites are engaging in hyperbole, the unfiltered *average* messages are quite balanced, because hyperbole and counter-hyperbole tend to cancel each other out. Self-evidently, if average messages are not hyperbolized, the extent to which voters discount hyperbole is immaterial. Things are quite different in the *echo chamber* treatment; in this case voter sophistication plays a prominent role. Figures 16 and 18 show that in this treatment, elite preferences exhibit more *IS* polarization, and their messages become more hyperbolic, as voters become less sophisticated. In this sense, the echo chamber effect becomes more socially costly, as voters are less sophisticated in reverse engineering the hyperbole of elite messages. In sum,

Summary 4
When voters discount less the hyperbole in elite messages, echo chambers exacerbate IS polarization of elite preferences and increase the hyperbolic component of their messages. Thus, echo chamber effects are more pernicious when voters are less sophisticated.

4.5 Censoring of Extreme Messages ($\bar{b}$)

Our final comparative statics exercise relaxes, relative to the baseline case, the credibility threshold $\bar{b}$ beyond which messages are censored. Since this threshold is never binding in the *pro* narrative (see RSZ and Appendix 1), changing $\bar{b}$ will not make a difference in this case. Accordingly, we focus here on the *sym* narrative. As shown in RSZ, while relaxing $\bar{b}$ in *sym* leads to more extreme messages, it has no bearing in that static setting on the degree to which messages are constrained, and hence the level of welfare. The reason is that as censoring rules are relaxed, elite messages become more hyperbolic in lockstep: that is, the endogenous shift exactly offsets the exogenous one, so that in the end, the degree to which messages are constrained, as well as the extent of information loss, remain unchanged. In the dynamic model developed in this paper, by contrast, when voter preferences are influenced by elite messages, the censoring bound plays a more substantial role, although only when echo chambers are present.

Figures 19 and 20[7] illustrate the impact of increasing the credibility bound on the evolution of the equilibrium under the *sym* narrative. In the *balanced messages* treatment, while elite messages become more hyperbolized as $\bar{b}$ increase, the evolution of voter and elite preferences remains unchanged. The reason is that when the average message is unfiltered, the increases in hyperbole on both sides cancel each other out, leaving the average message unchanged. In the *echo chamber* treatment, on the other hand, the increased hyperbole that accompanies censor relaxation does

[7] Figures 19 and 20 are available on https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3809413.

lead both voter and elite preferences to become more *IS* polarized: because of the echo chamber effect, the average message that each faction receives skewed more in the direction that the faction favors. Except when voters fully reverse-engineer the hyperbole embedded in these messages (i.e., when the hyperbole discounting parameter $\mu = 1$), their preferences will become more extreme and the voices of more extreme voters will drown out those of more moderate ones. These shifts in turn induce elite preferences to become more extreme. Thus, the polarizing impacts of echo chambers, and the resulting welfare loss, become more significant as the credibility bounds are relaxed. In sum,

Summary 5
When credibility bounds are relaxed in the sym narrative, reflecting increased tolerance of hyperbole, the echo chamber effect has a more pronounced impact on IS polarization of elite preferences, leading to increasingly hyperbolic messages, and greater welfare losses. Thus, as echo chambers play more prominent roles in our societies, a more aggressive approach to censoring of extreme messages can be justified on welfare grounds.

5 Two Applications

In this section, we examine the implications of our model in the context of two US examples. The first is global climate change; the second is personal safety responses to Covid-19. We show how our model can shed light on the evolution of public opinions (i.e., voter preferences) and elite messaging.

There has been significant ideological and partisan polarization in the US about climate change, especially about whether climate change is anthropogenic and whether urgent actions are needed to reduce GHG emissions (McCright & Dunlap, 2011; Kennedy & Hefferon, 2019) While the majority of Democrats believe that climate change is real, is caused mainly by human activities, and requires significant reductions in GHG emissions, many, if not most, Republicans hold opposite views (Leiserowitz et al., 2020). This polarization of voter opinions along the party lines is accompanied by the polarizing platforms or messages of politicians (Antonio & Brulle, 2011); climate change and renewable energy are major parts of Biden's platform, in contrast to Trump's withdrawal from the Paris Agreement and his push for more coal. The platform polarization is also due to hyperbole and counter-hyperbole; the anti-climate change messages of Republicans are often driven by their distrust of Democrats' climate policies rather than by their true preferences (Van Boven & Sherman, 2018). Further, hyperbolized elite messages have significant impacts on public opinions about climate change (Baron, 2005). Brulle et al. (2012) analyzes 74 separate surveys conducted during 2002 and 2010 and finds that elite cues have the largest impact on public opinions on climate change, dominating the effects of scientific information and activist movements. The elite cues are often conveyed through media coverage; in fact, news media has played a major role in affecting public opinion on climate change. King et al. (2017) randomly increased the coverage on issues including climate change in 48 media outlets, and found that this treatment significantly raised public discussions on these issues (e.g., on Twitter).

There are striking parallels between the trends described above and the range of personal responses to the Covid-19 crisis of 2020. As with climate change, public views on measures like social distancing and mask-wearing have polarized along party lines (Yeung et al., 2020; de Bruin et al., 2020; Gollwitzer et al., 2020; Boxell et al., 2020). These papers compile a great deal of evidence that democrats have been much more concerned than Republicans about the risks of being infected by Covid, being hospitalized and dying and/or experiencing severe financial hardship. They are also much more supportive of government interventions in response to the crisis and are significantly more inclined to adopt protective measures, especially wearing masks and social distancing. Many papers attribute these differences to selective news consumption (our echo chamber effect) and to the hyperbolized positions taken by conservative public figures, ranging from Donald Trump (Sanders et al., 2020; Gollwitzer et al., 2020) to media celebrities such as Rush Limbaugh (Torres-Spelliscy, 2020) and, especially, Sean Hannity (Ash et al., 2020; Bursztyn et al., 2020; Simonov et al., 2020). Indeed, the last three cited papers "find that people social distance less if quasi-randomly exposed to news sources that argue that Covid-19 is less risky, suggesting that media exposure is one possible driver for…" the extreme polarization of willingness to take pandemic-related protective measures (Boxell et al., 2020, p. 4). Moreover, consistent with our model, these differences have increased significantly over time: for example, Gollwitzer et al. (2020, Fig. 5) shows that from March to May 2020, the gap between Republicans' and Democrats' willingness to visit non-essential services increased from 2 to 6%.

6 Conclusion

In this paper, we build on RSZ to analyze how elite and voter preferences, as well as voter engagement, evolve and interact with a number of widely discussed intersections between the media and politics. These include: echo chambers; the feedback loop between political actors' preferences and the messages elites send; voter sophistication in reverse-engineering the hyperbole in elite messages; and the willingness of traditional and social media outlets to censor extreme content. To highlight the role that echo chambers play, we present simulation results for two treatments: a benchmark in which voters receive balanced messages vs one in which they pay more attention to messages from like-minded elites. The differences are striking: in our *balanced messages* treatment, *IS* polarization decreases over time, while increasing in our *echo chamber* treatment. Moreover, in the *echo chamber* treatment, polarization is exacerbated, and the information transmission process degraded, the more reactive are elites and voters to each other, the less sophisticated are voters at discounting hyperbole, and the more permissive are media sources with respect to censoring extreme messages.

These findings offer important insights relating to the increase in polarization within the US and many other countries. With the proliferation of social media, echo chambers have become more entrenched and media censoring rules more permissive. The magnitudes of ex-President Trump's twitter following, and of his rallies during the 2016 and 2020 elections, demonstrate the extent to which (at least some) voters are attuned to elite messages. As voters become more responsive to extreme messages, politicians are more motivated to send hyperbolized messages, in order to "fire up their bases." Meanwhile, responsiveness is a two-way street: it seems that each year, politicians become more reactive as well, being driven more by polling numbers and voter sentiments than by any underlying principles they may once have had. Our model demonstrates how all of these developments coalesce into increased polarization and hyperbole.

Our results complement the themes emphasized by Gordon Rausser in his work on political economy over the past several decades. Rausser (1982) underlines the importance of nurturing political economic systems promoting welfare-improving policies that correct market failures (PERTs) and impede self-serving policies (PESTs). Our work highlights aspects of the information transmission process that may either facilitate or hinder the preeminence of PERTs over PESTs. Political developments within the last few years have illustrated dramatically how easy it is for echo chambers to legitimize PESTs at the expense of PERTs, a problem exacerbated when media fails to clamp down on hype and voters are not sufficiently sophisticated to disentangle self-serving hype from messages accurately reflecting the available data. Rausser's major contribution to the political economy literature, Rausser et al. (2011), emphasizes the critical role that governance structures play in preserving "the rules of the game that constrain political operators." Our paper sheds some light on the difficulties of maintaining good governance, since narrative battles, hyperbole and polarization all contribute to undermining these rules. These difficulties are particularly pernicious when the underlying narrative is *pro*. In our benchmark *balanced messages* treatment of this narrative, the distribution of political power among political elites becomes more balanced as time progresses, while our *echo chamber* treatment portrays the evolution of a political environment in which the balance of power becomes increasingly skewed in one direction, resulting in outcomes that increasingly diverge from the public interest, so that overall welfare declines over time.

Our comparative statics results offer some lessons about how polarization and hyperbole may be reduced. Echo chambers play a critical role in the evolutionary process we have modeled: in our benchmark simulations, in which the echo chamber flag is turned off, the other factors we have mentioned have only minimal impacts on the level of polarization and hyperbole. This suggests that the best policy levers to pull in order to reduce polarization are ones which dilute or eliminate echo chambers. News organizations must renew their commitments to providing both sides of arguments, while social media services should avoid the practice of suggesting contents based on the number of "clicks," since, by definition, this magnifies the echo chamber effect. Other things can be done to mitigate the damages caused by echo chambers. For example, more aggressive media debunking of fake news and extreme claims, and flagging such messages in social media, may help voters to become more sophisticated in decoding hyperbolized messages.

Our paper can be extended in several directions. First, we have largely relied on numerical simulations to illustrate the relationships of interest in this paper. A fully fledged analytical model would allow us to test the generality of our findings. Second, while the choice of narrative was endogenous in RSZ, in the present model it is exogenous, and held constant across phases. Thus a central topic of RSZ—the battle for narrative control—makes no appearance in this paper. Further research is required in order to integrate the evolutionary phenomena we have studied here into a framework in which narrative battles can be won or lost, and the associated social welfare impacts studied.

Appendix 1: The Phase-Level Equilibrium

APPENDICES

A The phase-level equilibrium

In phase t, given the current distributions of voter preferences $\boldsymbol{h}$ and voices $\boldsymbol{w}$, and thus $\boldsymbol{k}$, and given the private signals elites receive about the two dimensions of the issue, the elites simultaneously choose their messages. As shown in RSZ, when the vector $\boldsymbol{k}$ is symmetric around zero, i.e., when the elites in the *Left* and *Right* factions are symmetrically opposed to each other, in equilibrium each elite's strategy is unit affine: r's message equals his private signal plus a hyperbole factor λ_r. In our dynamic game, when the narrative is *pro* instead of *sym*, even when we start with a symmetric $\boldsymbol{k}$, the resulting $\boldsymbol{k}$ can be asymmetric as voters update their preferences and voices. In this section, we show that the elites' equilibrium strategies are still unit affine, and further derive the equilibrium levels of the hyperbole profile $\boldsymbol{\lambda} = (\lambda_1, \ldots, \lambda_n)$. For simplicity, we ignore the time subscript t in this subsection. We make the following technical assumptions:

Assumption 1: *$\boldsymbol{k}$ is such that (i) $k_n \geq 0$, and (ii) there exists $k_u \in [k_m, k_{m+1}]$ that satisfies*

$$nk_u + \sum_{r=1}^{n} \left(n(k_r - k_u) - \sqrt[3]{6n(k_r - k_u)} \right) = 0. \tag{7}$$

The first assumption ensures that not all elite biases k_i are negative; they are polarized in the sense that there are still differences in the direction of the biases among the elites. In (7), if $\boldsymbol{k}$ is symmetric with the negative left faction and the positive right faction, then k_u=0 is a solution. Small deviations of $\boldsymbol{k}$ from symmetry would imply that k_u will deviate slightly from 0 in compensation. In a sense, k_u represents a certain kind of nonlinear geometric mean of the vector $\boldsymbol{k}$: it would equal $(\sum_i k_i)/(n-1)$ without the $\sqrt[3]{\cdot}$ terms, akin to a degree-of-freedom adjusted linear mean, and would be a $\sqrt[3]{\cdot}$-geometric mean without the linear terms. Assumption 1(ii) ensures that this mean can serve as a median of $\boldsymbol{k}$, dividing the entire vector to two halves with equal number of elements. This assumption ensures that as elite biases $\boldsymbol{k}$ evolves over the different phases, it does not become too lopsided. Both assumptions are satisfied in our numerical examples.

The following Proposition states the optimal hyperbole $\boldsymbol{\lambda}$ and the associated optimal reports $\boldsymbol{a}$.

Proposition 1 (Equilibrium Strategies):† *If Assumption 1 is satisfied, then the optimal unconstrained strategy of player r is given by*

$$a_r^* = \begin{cases} \theta_r + \lambda_r & \text{in sym} \\ \max\left(0, \theta_r + \lambda_r\right) & \text{in pro} \\ \min\left(0, \theta_r + \lambda_r\right) & \text{in con} \end{cases}, \tag{8}$$

where the equilibrium values of λ are given by

$$\lambda_r = \begin{cases} \begin{cases} \bar{b} - 1 + \sqrt[3]{6n(k_r - k_u)} & \text{in the sym narrative, if } r \geq m+1 \\ \underline{b} + 1 - \sqrt[3]{6n(k_u - k_r)} & \text{in the sym narrative, if } r \leq m \end{cases} & (9) \\ \begin{cases} -\sqrt{2n(k_n - k_r)} & \text{in the pro narrative, if } r < n \\ n(1-n)k_n - \sum_{i=1}^{n-1} \lambda_i + n\sum_{i=1}^{n} k_i & \text{in the pro narrative, if } r = n \end{cases} & (10) \\ \begin{cases} \sqrt{2n(k_r - k_1)} & \text{in the con narrative, if } r > 1 \\ n(1-n)k_1 - \sum_{i=2}^{n} \lambda_i + n\sum_{i=1}^{n} k_i & \text{in the con narrative, if } r = 1 \end{cases} & (11) \end{cases}$$

In the pro narrative, the only departure from RSZ is the additional term $n\sum_{i=1}^{n} k_i$ for player n; the strategies of player $r < n$ are not changed. Intuitively, for players other than n, their strategies are determined entirely by (13) and $E\xi_n=0$, as in the case of symmetric $\boldsymbol{k}$. The additional term for player n is to take care of the case when the k's are not symmetric, in which case $\sum_i k_i$ does not necessarily equal zero.

The formula for sym narrative is more complicated than those in RSZ. The intuition is best understood if we consider a fictitious anchor player with $k=k_u$ so that $\lambda_u=0$ and the player is never constrained. Then the formula in Eq (12a) of RSZ has been simply rewritten by replacing k_r with $(k_r - k_u)$. The complication arises from the fact that k_u is determined by the entire vector of $\boldsymbol{k}$, and the equation characterizing k_u is of order 3. It is thus difficult to characterize k_u analytically.

B Proofs

Proof of Proposition 1. The strategy in (8) can be established by repeating the same steps as in the proof of Proposition 1 of RSZ. That proof also shows that the equilibrium values of $\boldsymbol{\lambda}$ in

Appendix 2: Proofs

(8) can be rewritten using $\xi(\theta_r|\lambda_r) \equiv \hat{s}(\theta_r|\lambda_r) - s(\theta_r|\lambda_r)$:

$$\begin{aligned}\lambda_r &= nk_r - \sum_{i\neq r} E_{\boldsymbol{\theta}_{-r}}(\theta_i - \xi(\theta_i|\lambda_i) - s(\theta_i)) = nk_r - \sum_{i\neq r} E_{\boldsymbol{\theta}_{-r}}(\theta_i - \xi(\theta_i|\lambda_i) - \theta_i - \lambda_i) \\ &= nk_r - \sum_{i\neq r}\lambda_i - \sum_{i\neq r} E\xi(\cdot,\lambda_i).\end{aligned} \tag{12}$$

We next verify that the expressions in Proposition 1 are closed-form versions of (12) for the sym and pro (and thus con) narratives. Before proceeding, we note (12) implies $\sum_j \lambda_j = nk_r - \sum_{i\neq r} E\xi(\lambda_i)$, which, upon substracting $r=i$ and $r=j$ in this equation, yields

$$n(k_i - k_j) = E\xi(\lambda_j) - E\xi(\lambda_i), \quad \forall i, j. \tag{13}$$

The sym narrative. Consider $r \geq m+1$ - the case of $r \leq m$ is similar. The player's strategy is $s_r = \lambda_r + \theta_r$, where from (9), $\lambda_r = \bar{b} - 1 + \sqrt[3]{6n(k_r - k_u)}$. Because $k_r, k_u < 1/12n$ and $\bar{b} > 2n$, we have that $0 < \lambda_r < \bar{b}$. Thus, $s_r(\theta_r)$ will be censored from above if and only if $\theta_r > \bar{b} - \lambda_r > 0$; r is never censored from below (since $\underline{b} < 0$). Since the density $h(\theta_r)$ when $\theta_r > 0$ is $1 - \theta_r$. we have:

$$\begin{aligned} E\xi(\lambda_r) &= \int_{\bar{b}-\lambda_r}^{1} (\bar{b} - (\theta_r + \lambda_r))(1-\theta_r)d\theta_r \\ &\underbrace{=}_{\text{substituting in (9)}} \int_{\bar{b}-(\bar{b}-1+\sqrt[3]{6n(k_r-k_u)})}^{1} (\bar{b} - \theta_r - \bar{b} + 1 - \sqrt[3]{6n(k_r - k_u)})(1-\theta_r)d\theta_r \\ &= -n(k_r - k_u) \end{aligned} \tag{14}$$

Thus, the right hand side of (12) becomes

$$\begin{aligned} nk_r - \sum_{i\neq r}\lambda_i - \sum_{i\neq r} E\xi(\lambda_i) &\underbrace{=}_{\text{from (14)}} \left(n\sum_i (k_i - n(n-1)k_u - \sum_i \lambda_i\right) + \lambda_r \\ &\underbrace{=}_{\text{from (9)}} \left(nk_u + n\sum_i (k_i - k_u) - \sum_i \sqrt[3]{6n(k_i - k_u)}\right) + \lambda_r \underbrace{=}_{\text{from (7)}} \lambda_r \end{aligned}$$

establishing that the solution in (9) satisfies (12) for the sym narrative.

The pro narrative. We first show that member n, whose bias parameter k_n is the largest, is never constrained, i.e., given n's strategy specified in (10), $E\xi(\lambda_n) = 0$. Since $\theta_n \in \Theta^+ = [0,1]$, it suffices to check that $0 < \lambda_n < \bar{b} - 1$: if $\lambda_n < \bar{b} - 1$, then since $\theta_n < 1$ she will never be censored by $\bar{b}$; if $\lambda_n > 0$, then since $\theta_n > 0$, she will never be constrained by the natural bound of 0. To verify that $\lambda_n < \bar{b} - 1$, note from (10) that

$$\begin{aligned}\lambda_n &= n(1-n)k_n - \sum_{i=1}^{n-1}\lambda_i + n\sum_i k_i = -\sum_{i=1}^{n-1} nk_n + \sum_{i=1}^{n-1}\sqrt{2n(k_n - k_i)} + n\sum_i k_i \\ &= \sum_{i=1}^{n-1}\left[\sqrt{2n(k_n - k_i)} - nk_n\right] + n\sum_i k_i.\end{aligned} \tag{15}$$

Moreover, since $k_1 < k_j$ for all $j > 1$,

$$\text{RHS of (15)} < \sum_{i=1}^{n-1}(\sqrt{2n(k_n - k_1)} - nk_n) + n\sum_i k_i = (n-1)(\sqrt{2n(k_n + k_n)} - nk_n) + n\sum_i k_i$$
$$\underbrace{<}_{\text{since } nk_n < 1/12} n - 1 + n\sum_i k_i \underbrace{<}_{\text{since } \sum_i k_i < 1} 2n - 1 \underbrace{<}_{\text{since } \bar{b} > 2n} \bar{b} - 1$$

To verify that $\lambda_n > 0$, note that

$$\lambda_n \underbrace{=}_{\text{from (15)}} \sum_{i=1}^{n}\left(\sqrt{2n(k_n - k_i)} - n(k_n - k_i)\right) + nk_n$$
$$= \sum_{i=1}^{n}\left(\frac{1}{2} - \left(\frac{1}{\sqrt{2}} - \sqrt{n(k_n - k_i)}\right)^2\right) + nk_n = \frac{n}{2} - \sum_i\left(\frac{1}{\sqrt{2}} - \sqrt{n(k_n - k_i)}\right)^2 + nk_n$$
$$> \frac{n}{2} - \sum_i\left(\frac{1}{\sqrt{2}}\right)^2 + nk_n = nk_n \underbrace{\geq}_{\text{from Assumption 1(i)}} 0.$$

Since n is never constrained, we know $E\xi_n = 0$, so that $E\xi_i = n(k_n - k_i)$ from (13).

Now consider $r < n$. Since $\lambda_r < 0$ in (10), $s_r(\theta_r)$ will be constrained by the natural bound of 0 if and only if $\theta_r < -\lambda_r$. Since $\theta_r \leq 1 \leq \bar{b}$, $s_r(\cdot)$ will never be censored by $\bar{b}$. Therefore

$$E\xi(\lambda_r) = \int_0^{-\lambda_r}(0 - (\theta_r + \lambda_r))d\theta_r = \lambda_r^2/2 \underbrace{=}_{\text{from (10)}} n(k_n - k_r) \tag{16}$$

From (16) and the fact that $E\xi_n = 0$, we have

$$E\xi(\lambda_r) = n(k_n - k_r) \quad \forall r \tag{17}$$

Using (17), we know the right hand side of (12) equals

$$nk_r - \sum_{i \neq r}\lambda_i - \sum_{i \neq r}E\xi(\lambda_i) = nk_r - \sum_i \lambda_i + \lambda_r - \sum_{i \neq r} n(k_n - k_i)$$
$$= \underbrace{n(1-n)k_n - \sum_i \lambda_i + n\sum_i k_i}_{=0 \text{ from (10)}} + \lambda_r = \lambda_r$$

establishing that (10) satisfies (12) for players $r < n$.

For player n, the right hand side of (12) equals

$$nk_n - \sum_{i \neq r}\lambda_i - \sum_{i \neq r}E\xi_i \underbrace{=}_{\text{from (17)}} nk_n - \sum_{i \neq r}\lambda_i - \sum_{i \neq r} n(k_n - k_i)$$
$$= nk_n - \sum_{i \neq r}\lambda_i - \sum_i n(k_n - k_i) \underbrace{=}_{\text{from (10)}} \lambda_n,$$

establishing that (10) satisfies (12) for player n.

The proof for the *con* narrative is analogous to that of the *pro* narrative. ■

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The Puzzle of Lagging Sub-Saharan Africa Agriculture: Toward a Theory of Connectedness

Alain de Janvry and Elisabeth Sadoulet

1 A Puzzle: Opportunities and Lags in Agriculture-Based Development

Agriculture can have a major role to play for development in "agriculture-based countries," that is countries having a high contribution of agriculture to GDP growth and a high share of their poor in the rural sector (World Bank, 2007). With a few exceptions in Central America and the Caribbean, these countries are mainly low income in Sub-Saharan Africa (SSA) and South Asia. An agriculture-based development strategy has been effective for many countries that have now reached middle-income status such as China, Vietnam, Indonesia, Chile, Brazil, Guatemala, and Morocco. In the emerging context of weakening labor-intensive industrialization (Rodrik, 2015) and urban-based structural transformations (Rodrik et al., 2016), the current potential role of agriculture for growth in SSA has been confirmed by major development organizations such as the FAO (2016), IFAD (2016), IFPRI (Jayne et al., 2019), the World Bank (Goyal & Nash, 2017), the Brookings Foundation (Page, 2018), and UNU-WIDER (Stiglitz, 2018). While peaking in 2008 and again in 2010–2014, world food prices have remained high relative to the long pre-2008 period, particularly for high income consumption goods such as meats and dairy products (FAO, 2020). Agriculture has been highlighted as an attractive investment sector at a world scale due to the combination of population growth, rising incomes, rapid urbanization, changing consumer tastes and diets, and

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the negative pressure of climate change (New York Times, 2019). Success with agriculture-based growth is currently observable in several SSA countries, most notably Ethiopia, Rwanda, Ghana, Senegal, Kenya, and Cameroon that have all averaged more than 4% annual growth in agriculture value added over the 2015–2019 period. They provide role models for other countries as to how this can be done. Yet, there is striking under-investment in agriculture in most SSA countries, for example relative to the CAADP (Comprehensive Africa Agriculture Development Program) standard of 10% of public expenditures allocated to agriculture. In a recent review of public expenditures by SSA countries, Goyal and Nash (2017) observed that only 3 of 25 countries currently meet this target.

Not surprisingly, with low adoption of fertilizers, improved seeds, and high value crops, SSA agriculture increasingly lags behind in land and labor productivity relative to other regions of the world. Besides the permanence of extensive rural poverty, the consequence has been increasing dependency on food imports and declining export market shares at a world scale.

In this paper, we ask the fundamental question as to why this is the case? How can the puzzle of continued under-investment in using agriculture for development be explained and addressed? And why are urban consumers increasingly relying on food imports rather than being supplied by domestic production? Finding answers to these questions could help transform the lives and livelihoods of millions of present and future inhabitants of SSA.

Our thesis is that we need to alter course in our conceptualization of how to make agriculture effective for development in SSA which was largely derived from Western and Asian experiences that occurred in markedly different contexts. We will identify three successive phases in how the puzzle of a lagging agriculture has been addressed.

The first phase consisted in analyzing surplus extraction from agriculture via the price mechanism. Ample empirical evidence of underpricing at the farm level was provided by writers such as Krueger et al. (1988), Anderson (2009), and Anderson et al. (2013). A political economy rationalization was provided by Bates (2014) who showed that the income effects of distorted markets can be selectively compensated by targeted transfers that are more effective in mobilizing political support than the operation of efficient free markets. While domestic price distortions against agriculture have largely disappeared after 1993 (Anderson & Martin, 2020), other distortions remain under the form of OECD farm subsidies and import restrictions that have serious negative effects on SSA agriculture.

The second phase consisted in focusing on the barriers to adoption of presumed available technologies, basically chemical fertilizers and improved seeds, the ingredients of the Green Revolution. Barriers were found in access to credit, availability of insurance and other risk-reducing mechanisms, lack of information available to farmers about how to use and what to expect from the new technologies, and high transaction costs on markets due to such factors as poor infrastructure and lack of competitiveness. Major institutional innovations were proposed to remove these constraints. This approach has been importantly pursued by the ATAI project (Bridle et al., 2018). However, impact turned out to be modest, with many missing complementary factors limiting adoption of technological innovations and productivity gains in staple crops basically insufficient to take smallholder farmers out of poverty.

The third phase, which we explore in this paper, is based on observing a growing disconnection between what cities consume and what the countryside produces. With this disconnection, cities are increasingly fed by imports of both raw products and processed foods. Quality is a major hurdle for domestic farmers in competing with imports. Connecting farmers and domestic consumers requires a major transformation of agriculture, with the construction of demand-driven value chains that meet consumer demand in both quantity and quality and functionalize domestic producers in servicing domestic consumers. We diagnose how this disconnection has emerged and explore what has been done to address it and what more could be done to effectively use agriculture for development in SSA.

2 A Conceptual Framework for the Puzzle of Lagging Agriculture

2.1 Specific Structural Features of SSA Agriculture

There are good reasons why effectively using agriculture for development in SSA has been a difficult challenge. Specifically, there are eight structural features of SSA agriculture that together create unique hurdles to modernization:

Property rights. The first is a product of colonial history, where property rights over land are notably incomplete for users. Property rights are most often vested with the national state, rarely with the community, and even less frequently with individuals. The result is insecurity of continued access to land that places severe limits to investments that have more than one-crop duration. This can include fertilizers that have residual soil fertility effects beyond one season. It certainly is a major hurdle to irrigation, the big absent in SSA agriculture and a major constraint to intensification of farming systems and extended land calendars. A few countries such as Ethiopia and Benin have started to emit individual land ownership certificates, but they remain an exception (Goldstein et al., 2018).

Smallholder farmers. The second is also a product of the history of land settlement and demographic pressure. Smallholder farmers and extensive rural poverty are the norm among producers. This makes adoption of technology and achieving economies of scale in production and marketing particularly challenging. It also closely links any agriculture-for-development initiative with the Sustainable Development Goals on poverty and malnutrition. Growth and development are thus inextricably linked to the performance of agriculture.

Irrigation. The third is due to natural conditions and lack of water control. With only some 6% of cultivated land irrigated, most agriculture is under rainfed conditions, with as a consequence strong seasonality in labor calendars and most often only one crop per year. As we will see, prolonged idleness of land and agricultural labor associated with seasonality is a major cause of low annual labor productivity and extensive rural poverty. Extending labor calendars to achieve an agricultural transformation with diversified farming systems does importantly require water control beyond the rainy season.

Climate change. The fourth is extensive exposure to climate change with a large share of SSA agriculture under tropical and semi-arid conditions. Both mitigation through carbon capture by agriculture and adaptation to achieve better resilience of yields and livelihoods to climate shocks are priority issues as rapid climate change is putting at risk the livelihoods of millions of smallholder farmers and herders whose main alternative option will be migration.

Heterogeneity. The fifth is that rainfed farming makes agriculture highly dependent on local conditions related to climate, soil, and culture, as opposed to a situation where irrigation homogenizes production conditions over vast geographical areas, as it does in Asia. Strong local heterogeneity requires customization of agricultural practices, making it difficult to achieve economies of scale in the development of improved farming systems. The resulting trade-off between precision and cost is a major challenge, with potential solutions through the greater use of IT in diagnosing conditions (sensors) and in recommending alternatives (precision farming).

Urban bias. The sixth is the typical dominance of urban elites over the making of agricultural policy, particularly regarding seeking cheap food to lower the nominal cost of urban labor. Urban bias in price formation and in the allocation of public budgets and public goods has been the norm in African policy-making and rapid urbanization reinforces this bias (Lipton, 1977; Bates, 2014).

State interventions. The seventh is that the history of state-market relations has historically been characterized by strong state dominance over market forces. This took the form of parastatals monopolizing markets, setting prices for major commodities. Following debt crises in the 1980s and structural adjustment policies in the subsequent period, markets have been extensively liberalized, but transitions remain most often incomplete with presence of rent-seeking policy interventions in markets, such as temporary import bans and subsidies to key inputs like chemical fertilizers. Erratic and politically motivated market interventions thus remain pervasive, often compromising private investment in agriculture, particularly those with a long maturation period.

Disconnection. Finally, and importantly for the interpretative thesis we develop in this paper, there has been creeping disconnectedness between what domestic agriculture produces and what domestic urban consumers demand, mainly due to lack of quality standards (such as phyto-sanitary) in meeting urban consumer demand, lack of delivery of high value crops, and lack of supply of processed foods by an agro-industry linked to domestic agriculture. The result has been rising food imports for the cities, while domestic agriculture feeds the rural populations (maize, millet, cassava) and delivers eventual booms driven by export demand (coffee, cocoa, cut flowers, tropical fruits, vegetables). As a consequence, agricultural growth does not strongly drive industrialization through cheap labor and forward linkages, and urban income growth does not strongly drive an agricultural response (Jedwab & Vollrath, 2015).

2.2 How to Use Agriculture for Development? A Cumulative Strategy

The theory of the role of agriculture in support of industrialization has been dominated by the idea of surplus extraction from agriculture to the benefit of an urban-based industry (Mellor, 1995; Basu, 2003). Surplus extraction would take the form of cheap food, labor relocation, financial transfers, and foreign exchange earnings. This perspective has been at the core of the influential dual economy models explaining the generation and transfer of an agricultural surplus to the benefit of industry such as those of Lewis (1954), Jorgenson (1961), and Lele and Mellor (1981). This theory of structural transformation (Timmer, 2012) has been importantly revised in recent years, due to difficulties with both labor-intensive industrialization in the context of robotization and reshoring (Rodrik, 2015) and with labor transfers inducing the growth of urban slums rather than industrial growth (World Bank, 2007). The emerging cumulative strategy replacing the surplus extraction-structural transformation model covers the following dimensions:

- **Asset transfers**: Smallholder farming cannot be productive without improved land security (Deininger, 2003), minimum asset endowments (Eswaran & Kotwal, 1986), and eventually comprehensive graduation models for inclusiveness of the ultra-poor (Banerjee et al., 2015). Asset transfers have included human capital (health and education, managerial capacity), access to microfinance credit in particular to rent land (Das et al., 2019), and livestock.
- **Green Revolution (GR)**: Productivity growth in agriculture starts with yield growth in staple crops based on high-yielding seeds and chemical fertilizer adoption (Sanchez et al., 2009). The Green Revolution is the foundation of national food security for the rural populations as well as for the urban populations for as long as consumption patterns are similar. This Green Revolution is still to reach most rainfed areas of the world, and for that reason most of SSA. Promoting a GR for Africa (AGRA) is the centerpiece of efforts by the Rockefeller and Gates Foundations in using agriculture for development in SSA.
- **Agricultural Transformation (AT)**: This consists in the introduction of diversified farming systems with high value crops, use of the land over more than one growing season per year, more complete labor calendars, and value chain development to link high value crops to markets (Barrett et al., 2019). It is epitomized by success in switching to high value crops linked to markets by value chains in such places as Morocco (tomatoes), Guatemala (temperate vegetables), Chile (fruits), Mexico (tomatoes, avocados), and Kenya (green beans) (IFAD, 2016).
- **Rural Transformation (RT)**: This is driven by employment and incomes in a local Rural Non-Farm Economy pulled by productivity growth in agriculture

through forward, backward, and final demand linkages (Adelman (1984)'s Agriculture Demand-Led Industrialization). This calls on territorial development driven by local governance (Schejtman & Berdegué, 2004), the promotion of economic clusters specialized in particular commodities (Porter, 1998), and place-based policies for the development of labor markets and the provision of public goods (Kline & Moretti, 2013). Recent empirical evidence has shown how labor-saving in Brazilian agriculture due to adoption of GMO soybeans leads to labor transfers and local non-agricultural growth (Bustos et al., 2016), and how productivity growth associated with positive rainfall shocks in India increases the demand for local non-tradable goods and the growth of non-agriculture (Emerick, 2018).

- **Structural Transformation (ST)**: Ultimately, populations become increasingly urbanized and industry and services locate in large urban agglomerations where they benefit from economies of scale. The strategy of successful Assets/GR/AT/RT becomes a novel pathway toward ST that could be particularly effective for SSA where initial conditions for a ST need to be established.

The AT/RT strategy thus opens new perspectives in using agriculture for development, helping overcome neglect and motivating investment toward the CAADP target. It goes beyond the traditional Jorgenson/Lele-Mellor TFP growth in agriculture in support of urban-based industrialization and a ST through labor transfers and cheap food for urban workers. It looks at local, place-based development rather than necessary accelerated urbanization in large cities, putting instead the emphasis on the growth of secondary cities closely linked to agriculture (Christiaensen & Todo, 2014).

2.3 Three Interpretations of the Under-Investment Puzzle

Why has this not occurred more extensively in SSA? There have been three successive interpretations of the puzzle of under-investment in SSA agriculture. The first was that predatory taxation on agriculture, implemented through price distortions and extractive policies such as forced deliveries, reduced the profitability of agriculture and hence the drive to invest. The second was that constraints to adoption of new technologies originating in a variety of market and government failures, as well as in civil society weaknesses, make adoption unprofitable or impossible. And the third is that there exists a growing disconnection between domestic agriculture production and urban consumer demand that prevents productivity growth in agriculture from serving as a source of dynamics for domestic industry. Exploring this third interpretation is the main contribution of this paper.

3 Explanations for Lagging Investment in SSA Agriculture

3.1 Explanation 1: Price Distortions as Predatory Policies

The price distortion interpretation of underinvestment in agriculture dominated the policy discourse in the 1960s and 1970s, before emergence of sovereign debt crises in the mid-1980s. Rausser (1982 and 1992) provided an important theoretical framework for this interpretation using in a combined fashion the concepts of PERT (growth-promoting) and PEST (rent-seeking) policies. In industrialized countries, agricultural PEST policies take the form of redistributive protection and subsidies interventions. These policies are compensatory to PERT policies that promote productivity growth in agriculture through research and development. These policies are thus part of a political equilibrium with endogenous PEST transfers buying the political feasibility of yield-increasing and growth-promoting PERT policies which have strong redistributive effects favoring consumers over producers given inelastic demand for food. In developing countries, PEST policies under the form of agricultural taxation via price are used to obtain cheap urban food for urban constituencies, with neglect of investment in agriculture. Extractive policies (PEST) are pursued without PERT legitimation, in support of an agricultural transformation (Rausser & Foster, 1990). Ample empirical evidence in support of this interpretation was made available by Krueger et al. (1988), and Anderson (2009). For tradable goods, both exportables and import-competing, overvalued exchange rates had an important role to play in underpricing. For non-tradable goods, consumer subsidies and forced procurement were instruments for low farm prices.

Following extensive policies of trade and market liberalization after the mid-1980s debt crises and comprehensive responses by the Washington Consensus (Williamson, 1993), price distortions on tradable goods have largely disappeared (Anderson & Martin, 2020). Transitions to market economies are however incomplete with continued erratic PEST-type government interventions in markets creating uncertainties about future market conditions and discouraging investment (Economist, 2019). Urban political elites and urban populist agendas continue to dominate the politics of agri-food policy, with low rural political engagement (Beegle & Christiaensen, 2019). And important trade distortions also remain for developing country agriculture under the form of OECD farm subsidies and restrictions to imports of food products. What remains of trade distortions and urban bias contributes to the low adoption of technological and institutional innovations resulting in large and continuously growing total factor productivity deficits for SSA (Fuglie et al., 2019).

3.2 Explanation 2. Constraints to Adoption: A Supply-Driven Approach

In this perspective, adoption of productivity enhancing technologies is constrained by market failures and state deficiencies. Extensive experimental research using randomized controlled trials was directed at identifying the major constraints to adoption and experimenting with ways of overcoming them. They addressed principally liquidity constraints, uninsured risks, information deficits, and transaction costs in access to markets (Magruder, 2018; Bridle et al., 2018). This research led to the exploration of institutional innovations with the potential of overcoming each of these constraints. The policy objective is not to pursue an import substitution policy toward food self-sufficiency, but to modernize smallholder agriculture to achieve competitiveness in a comparative advantage perspective.

On the issue of credit, access to liquidity is clearly important to farmers due to seasonality of agricultural production and potential benefits from holding harvests until market prices peak. Yet, credit services are typically inaccessible to a majority of smallholder farmers, too expensive to obtain through microfinance, too risky to expose collateral to loss, or ill-adapted to farmers' seasonal liquidity cycles. While much progress has been made in customizing financial services to smallholder farmers liquidity needs, recent experiments have shown that a liquidity constraint is most often not the main reason for under-investment in fertilizers. The main constraint tends to be low profitability in using fertilizers for a majority of farmers due in particular to lack of complementary inputs to secure high returns and high transaction costs faced in accessing markets.

Exposure to uninsured risks is another major constraint to technology adoption. It forces farmers to engage in costly shock-coping and risk-management strategies that contribute to the reproduction of low growth and poverty. To respond to this, progress has been made with index-based insurance that could be well adapted to the conditions of smallholder farmers, with payouts triggered by a verifiable local rainfall index or a satellite-based small area yield estimate. Use of index insurance has been shown to make a difference in inducing higher risk-higher yield investments in agriculture. Yet adoption rates have been notably low. Initiatives to promote adoption include improved design of the insurance product to reduce basis risk, better data to calculate fair premiums, group insurance such as coffee cooperatives, and combining index insurance with other risk-reducing instruments such as resilient technology and pre-approved emergency loans (Carter et al., 2017).

Information is key to adoption for farmers to not only know of the existence of a new technology, but also how to use it and adapt it to their own circumstances. Availability of extension agents is notably low and services typically of poor quality in SSA. Learning-from-others is made difficult by heterogeneity of circumstances (Tjernström, 2017). Important progress has been made in identifying the most effective contact farmers in spreading information in social networks (Beaman et al., 2018) and in motivating these farmers to act as proactive diffusion agents (BenYishay & Mobarak, 2019). Private sector agents such as agro-dealers can also be trained to the new technologies and used to diffuse information and provide advice to their clientèles. And extension services can be made more effective through the use of IT services (Aker, 2011). Finally, the diffusion of information can be reversed from a push approach initiated by well selected contact farmers to a pull approach where community members are induced by signals to seek information from informed individuals in the community (Dar et al., 2019). In the push approach, contact farmers are expected to diffuse in their social networks the information received from extension agents. Difficulty has been in identifying and motivating these agents. In the pull approach, the signal induces community members to engage in conversations with informed farmers to gain information. Experimental results in India show that the pull approach can be quite effective in diffusing information to farmers not well connected in social networks, with aggregate effects of a similar magnitude. Such new approaches are promising, but additional experimentation with new designs and new tools is needed.

Finally, profitable adoption requires well performing markets, with low transaction costs, competitive traders, and relatively elastic demand to sustain prices with shifting supplies following technology adoption. Important interventions thus include improved infrastructure and market facilities (Aggarwal et al., 2018), better information on prices (Fafchamps & Minten, 2012), more competitive traders facilitated by entry (Bergquist & Dinerstein, 2017), and perhaps most importantly improved quality to be competitive with imports and meet urban consumer demand (Bernard et al., 2017). Lack of market quality recognition prevents farmers from responding to incentives to improve quality. Difficulty is with both quality recognition up the value chain before produce gets aggregated and also subsequent traceability down the long value chain to where quality meets willingness to pay.

The constraints removal approach has been effective in identifying institutional innovations that can overcome constraints and induce adoption. Yet, adoption has typically been capped at some 30% of the farm population. This is due to three factors (Laajaj et al., 2018): (1) heterogeneity of circumstances implies that complementary factors securing profitability are often missing. Examples are soil fertility provided by organic matter (Marenya & Barrett, 2009) and soil acidity requiring complementary inputs (Burke et al., 2017); (2) farmer objectives are different from breeders, with major concerns to utilize family labor throughout the year and to achieve food security for the household; and (3) farmers capacity to adopt may be limited by the need to acquire new knowledge. Ideal are new technologies that do not require modifications in agronomic practices, such as the flood resistant feature in rice that leaves cultivation methods unaltered. The limited success of the constraint removal approach suggests that another strategy is needed to complement a supply-driven constraint-removing approach. This suggests focusing on the development of value chains that originate with the specificity of urban consumer demand.

3.3 Explanation 3. Market Disconnections: A Demand-Driven Approach

3.3.1 Rising Disconnectedness

A disturbing fact in most of SSA is that food imports have been increasing rapidly in response to urbanization, rising incomes, and changing tastes. Because of quality and price issues, domestic production has often not been competitive with imports. We specifically investigated this phenomenon with two case studies. The first is the case of onions in Senegal, a key ingredient in local diets (Bernard et al., 2017). An increasing share of domestic consumption is imported, now reaching 40%, and domestic production needs protection under the form of a seven-month import ban to be competitive. Domestic production cannot compete with imports without a quality upgrade. The second is the case of wheat in Ethiopia (Abate & Bernard, 2017). Millers prefer imported wheat as it is of greater homogeneity and higher quality than domestic procurement due to aggregation of smallholder deliveries on local markets before any grading takes place. In these two cases, markets fail to recognize quality, creating a disconnect between domestic production and procurement for urban consumption. The big policy gamble to which we still do not have proof is that quality response by domestic producers can establish competitiveness with imports.

How did this disconnection happen? With growth driven by primary commodities exports (typically of cocoa, coffee, palm oil, cotton, mining products, and petroleum), cities emerge as consumption places rather than industrialization places (Jedwab & Vollrath, 2015; Tomich et al., 2019). Urban income dynamics creates demand for food imports (rice, wheat, processed foods) rather than for domestic production (corn, millet, sorghum, cassava which still dominate rural consumption) (Staatz & Hollinger, 2016). The import share of consumption is 50% for rice and 70% for wheat, with both rising. Only a few countries like Ethiopia produce a majority (80%) of their wheat consumption, and even there, as we have seen, domestic production is struggling over quality issues to remain competitive with imports.

The analysis of consumption in six countries from East and South Africa shows very different patterns between urban and rural households in terms of the share of processed food (Tschirley et al., 2015). For rural households, 57% of consumption is self-produced, with the remaining purchased food including 13% in un-processed (e.g., pulses, whole grains, and fresh fruit and vegetables), 16% in low value-added processed (e.g., flour, sugar, meat, and dried fish), and 14% in high value-added processed (e.g., vegetable oil, bread, biscuits, food away from home, and dairy products) food. Patterns for urban households are 9% in own production, and 27% in unprocessed, 26% in low processed, and 38% in high-processed food. Another important dimension of rural-urban differences in food purchases is the distinction between perishable (that requires cold chain) and non-perishable goods. Purchased perishable products make 18.8% of rural and 43.2% of urban household consumption. In a detailed study of the change in consumption patterns of rural-urban migrants in Tanzania, Cockx et al. (2018) show that while rural diets are dominated by maize, cassava, and starchy foods, urban diets are much more diversified and include rice, bread, pasta, poultry, sugar, sweets, pastries, snack foods, beverages, tobacco, and dairy products that rely heavily on imported raw materials (Staatz & Hollinger, 2016). In Mozambique, compared to rural consumers, urban consumers shift away from cassava to rice and they consume more chicken and fish, all of which have high import shares (Romanik, 2008).

With domestic agriculture and agroindustry currently under-supplying these foods and at the desired quality levels, agriculture growth does not meet rising urban consumer demand, and imports fulfill these needs. The growth of commercial imports is often simply due to the very large advantages in scale, infrastructure, and technology that non-SSA countries have that imply lower production costs. For example rice has by far the largest share of cereals consumed in urban markets in SSA, estimated at 92% in Côte d'Ivoire, 76% in Burkina Faso, 72% in Nigeria, and 60% in Ghana and Senegal (Vorley & Lançon, 2016). Rice increasingly also reaches rural consumers. More than 50% of rice consumed is imported commercially, mainly from Asia, where it is produced at much lower cost.

In the case of milk, domestic production is competing with cheap imported powder milk. SSA processors find it easier to reconstitute powder milk rather than establish a cold value-chain linking domestic producers to consumers (Vorley & Lançon, 2016). An interesting case of displacement of local production by imports arises in the case of poultry. Total broiler meat imports accounted for 44% of SSA domestic consumption in 2014. These imports are largely due to a strategy by transnational corporations that supply the best cuts to their premium markets and send the remaining cuts to developing country markets, at a low opportunity cost and hence a very low price (Vorley & Lançon, 2016).

3.3.2 Modeling Market Disconnectedness

We worked in the past on a model of market disconnectedness and its consequences for growth and the distribution of benefits (de Janvry & Sadoulet, 1983). In this case (Fig. 1), the demand for industrial goods originates in exports, in profits and rents (luxury goods), and in public expenditures (infrastructure).

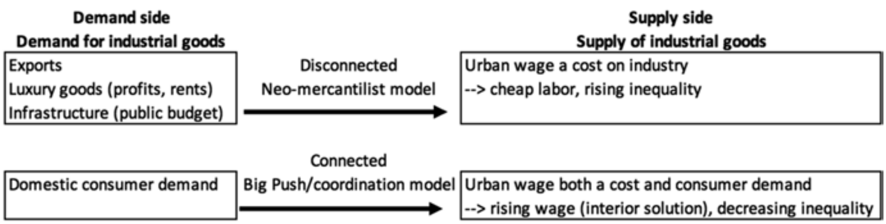

Fig. 1 Disconnected vs. connected growth model

In this disconnected growth model, the urban wage is a cost on competitiveness and is unrelated to effective demand creation. Accelerated growth benefits from cheap labor and leads to rising inequality. The model applies well to Chinese export-led growth that sustained accelerated growth for some 25 years, until the financial crisis of 2008 reduced the demand for imports in OECD countries. To respond to the crisis, China shifted to public expenditure-led growth with construction of highways, bullet trains, and housing, all three with extensive excess capacity and use of public debt as a source of financing. The next, and current step, is to place domestic consumer demand at the center of effective demand for industry. In the history of thought in development economics, this corresponds to the Big Push approach of Rosenstein-Rodan (1961) and the coordinated multiple-equilibria investment models of Hirschman (1981) and Sachs and Warner (1999). In this connected model, the urban wage is both a cost and a source of effective demand for industry, implying an interior solution for rising wages and potentially decreasing inequality as workers capture part of the productivity gains in industry. The political economy of the transition from disconnected to connected growth is the struggle to relocate market for industry in domestic consumer demand via rising wages. Connectedness thus opens the door to a potentially virtuous pattern of growth where the benefits of productivity growth are at least partially passed-on to workers in order for wages to create effective demand and sustain corporate profits.

We can think by analogy of a disconnected growth model for Sub-Saharan Africa where disconnection is not between wage income and effective demand for industry as above, but between domestic agricultural production and urban food consumption (Fig. 2).

In this case, the demand for agricultural goods originates in exports of either traditional cash crops such as cocoa, coffee, and cotton or of high value agricultural crops such as fruits and vegetables, animal feed, cut flowers, and meat and fish. Urban demand for food, driven by changing life styles, the rising opportunity cost of women's time, limited space for cooking, and rising incomes, is for high quality raw materials and for processed and prepared goods (Gollin, 2019).

In the connected version of the model, the urban wage drives consumer demand for agriculture. The supply side of the model consists in value chain development

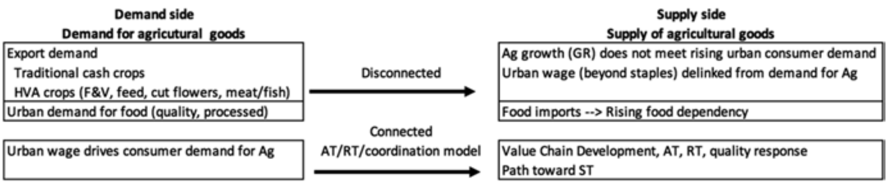

Fig. 2 Disconnected vs. connected transformation model

and potentially agricultural transformation, rural transformation, and importantly quality response. The political economy of the transition from disconnected to connected growth is the struggle to relocate the market for agriculture in domestic consumer demand driven by rising wage and changing diets. The change is not trivial as an agricultural transformation requires large investments in infrastructure and likely mechanization and land consolidation. A rural transformation requires medium size enterprises with wage labor that can deliver processed and prepared foods. Empirical evidence of connectedness is provided by the experiment with quality recognition in the onion market in Senegal and in the wheat market in Ethiopia which both induced production of higher quality domestic products.

3.3.3 Policy Implications of Disconnectedness

Essentially, the use of agriculture for development has to be quite different in SSA than it was in Asia. In Asia, particularly India and Indonesia, smallholder farmers could produce foods, principally wheat and rice, that were the staples of urban diets. The Green Revolution could help lower the real price of food, reduce the nominal urban wage without lowering the real wage, and deliver low cost labor for industrialization. Industry emerged in the urban environment, supporting the theory of the structural transformation as the way of using agriculture for development (Timmer, 2012). Trying to achieve the same outcome through a Green Revolution for SSA is insufficient as the structural context is markedly different.

In SSA, smallholder farmers need to deliver diversified quality foods and raw materials for the current urban consumer diets and agro-industrial processing that are competitive with imports. Agriculture must also focus on the export of cash crops for foreign exchange earnings. The agricultural transformation thus corresponds to farming systems with diversified food crops and cash crops. This is a model of agriculture supporting industrialization and services, but quite different from the one that made the success of Asia. A Green Revolution for Africa is thus necessary, but far from sufficient for an ultimate structural transformation.

4 Ingredients to Value Chain Development for Transformation and Connectedness

The normative program to achieve modernization of SSA agriculture beyond attacking remaining trade distortions and removing constraints on adoption consists in developing value chains to connect agriculture with urban demand and to achieve agricultural and rural transformations. Much the same as the protracted Chinese shift from disconnected to connected growth, this is a long process that requires a comprehensive program with roles for the state/governance, the market/private sector, and civil society/producer organizations. There have been extensive efforts at developing these value chains and achieving smallholder inclusiveness. Among the many contributions, this includes diagnostic work by Minten et al. (2013) and

Barrett et al. (2019), experimental work under ATAI, and support to investment by the World Bank (2016) and the IFC (Molenaar et al., 2015). These efforts leave us with an incomplete task but much can be learned from what has been done. Briefly stated, key elements of the approach include the following:

4.1 Role of the State

Planning connectedness requires broad coordination across branches of government using the like of an Agricultural Transformation Agency to inform, propose, and monitor implementation of the necessary investments, responding to the highest levels of political leadership. This was effectively done in Ethiopia, Rwanda, and the State of Orissa in India where we see agriculture effectively progressing toward transformation (Boettiger et al., 2017).

Security of property rights is essential to investment, hence land certification programs must be implemented where rights to manage and exclude others are assigned to individuals or to communities (Ostrom, 2001). Ethiopia, Togo, and Sierra Leone have introduced certification programs. Security of property rights over land is still lagging in most SSA countries. It is likely to be a major contributor to the low development and poor maintenance of irrigation systems, one of the greatest hurdles to an agricultural transformation.

Infrastructure is essential, requiring public investment, particularly in the trilogy of roads, irrigation, and storage. As we have seen, public investment in SSA agriculture has been lagging relative to international norms. The major multilateral lending institutions should likely return to prioritizing such large investment programs rather than direct engagement in especially transfer programs.

A pro-active state is necessary to target nudges on the winners, build on the best opportunities across regions and enterprises, and compensate through "smart PESTs" the losers (regions and individuals) to achieve political feasibility and meet the Sustainable Development Goals. Smart PESTs are policy interventions such as cash transfers that achieve their purpose in a self-sustaining fashion and can thus be removed after a one-time or short-term intervention. For many foreign aid donors motivated by poverty and inclusiveness of the poor into income-earning opportunities, building on the best as an entry point is a major departure from the way they look at the role of agriculture for development. Once success has been secured in the best areas and with the best entrepreneurs, spread of the transformations to less well-endowed regions and entrepreneurs can be actively pursued, including with the necessary smart-PEST transfers and public assistance (Rausser et al., 2011).

4.2 Role of the Market

Markets urgently need to be fixed to achieve quality recognition and to pass-through to farmers the quality premiums paid by consumers to create incentives to produce higher quality. Quality recognition can be achieved as part of contracts, or through third-party certification. State regulatory interventions are necessary to secure the accuracy, fairness, and sustainability of the quality recognition mechanisms. Hence, a proactive state is also necessary to fix markets failures, sustain market performance, and secure the investment climate.

Coordination in value chains is important to achieve shared norms among agents, to guide complementary private investments, and to invest in value chain club goods that will otherwise not be delivered, neither publicly nor privately. There are several institutional options for organizing coordination, including a multi-stakeholder platform (Devaux et al., 2016), a lead agent typically with monopoly or oligopoly power—either high in the value chain such as a producer cooperative or low in the value chain such as the lead buyer or lead procurement agent in an agroindustry or a supermarket chain, or a state or donor-sponsored institutions such as a social development fund, at least as a transitory solution (de Janvry et al., 2019).

Contracting enables security of transactions among participating agents and can if properly designed help overcome market failures and government deficiencies. Contracts can be resource-providing (also called interlinked, Bardhan, 1989), giving smallholder farmers access to information, technology, credit, and potentially insurance that would not be available to them through the state or the market.

4.3 Role of Civil Society

Producer organizations can be effective for contracting with smallholder farmers. World Bank experiments with Productive Alliances have shown that they can build discipline among farmers in avoiding side-selling and oversight over commercial partners in constraining hold-up practices (World Bank, 2016; Collion, 2018). Yet, sustainability of the approach beyond the donor-supported grant period has been an issue, calling on the role of higher-order organizations such as second-degree cooperatives, or on continued public support typically implemented through social development funds.

5 Conclusion: Toward a Political Economy of Connectedness

Using agriculture is essential for growth and poverty reduction in agriculture-based countries such as the SSA nations. For these countries, conditions are markedly different relative to how agriculture has been used for development in the Asian countries. SSA has witnessed an increasing disconnection between what agriculture produces and what urban consumers demand. As a consequence, urban markets are increasingly served by foreign imports of convenience food grains (rice and wheat), high quality foods, processed foods, and prepared meals. The dynamic sectors of agriculture cater to international cash crops markets, especially tropical commodities and specialty crops. Achieving greater connection between domestic agriculture and urban markets is an important policy objective to dynamize domestic agriculture and have it serve urban industry and services. This suggests moving beyond a Green Revolution in staple foods as the main policy instrument in using agriculture for development, the way it was effectively pursued in Asia. What is needed instead is an Agricultural Transformation to meet urban demand for diversified diets and quality foods, and for more complete rural labor calendars contributing to reduce rural poverty. It also requires a Rural Transformation for the production of processed and prepared foods and for the expansion of rural non-farm sources of income to help take households located in rural clusters out of poverty.

The main policy implication is consequently to move beyond a supply-driven technology-adoption model to a demand-driven value chain development approach. This requires exploring alternative business models to promote entrepreneurship in these value chains and functionalize smallholder production to construct the supply side of the value chains. Addressing the political feasibility of re-connectedness requires using compensations (smart PESTs) as the strategy initially favors the best locations and entrepreneurs, and striving to achieve the SDGs through complementary policies until the transformations become more inclusive of the rural poor, especially through the labor market.

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Control of the Research Agenda in University-Industry Partnerships

Jill J. McCluskey

Public universities funding comes from many different sources, including federal, state, and private entities. At a time when the University of California, Berkeley was facing major budget deficits and improper funding for research, Gordon Rausser, then the Dean of the College of Natural Resources, negotiated and signed an agreement with Novartis that provided \$25 million over 5 years to fund plant and microbial biology research. This is no small accomplishment to obtain additional private funding in a competitive environment.

Under the terms of this agreement, Novartis gained the right-of-first refusal on commercialization of the department's discoveries. In a much-discussed *Atlantic* magazine article, Rausser is quoted that the university's value is "enhanced, not diminished, when we work creatively in collaboration with other institutions, including private companies." (Press & Washburn, 2000) Rausser was able to leverage his public resources with private money. Rausser pointed out, "Without modern laboratory facilities and access to commercially developed proprietary databases…we can neither provide first-rate graduation education nor perform the fundamental research that is part the University's mission." (Press & Washburn, 2000)

Research and development (R&D) provide both public and private goods. Public land grant universities are a special case of government funding of research. The land grant mission of research and extension faculty is to deliver and apply research and new knowledge to positively impact communities. As such, public universities in the United States have been key players in generating new research and innovations. In particular, U.S. academic institutions conducted 56% of all basic research (Lach & Schankerman, 2008) and received 34.6% of all U.S. spending on

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agricultural R&D (Alston et al., 2010), with the number of U.S. academic patents rising from 500 to 3225 between 1982 and 2006 (Lach & Schankerman, 2008).

University researchers may be attractive assets for private companies to access. Private companies can leverage their research dollars without the overhead of maintaining their own workforce. Many innovations in industries ranging from agriculture to pharmaceuticals to computer technology have their origins in publicly funded research conducted at universities and other non-profit institutions. Due to the risk of knowledge spillovers and imperfect intellectual property rights (IPR) protection, as well as the schism in economic value association, basic research funding has seen an underinvestment from the private sector.

1 Changing Funding Landscape

Both federal and state support for agricultural R&D at public universities has been declining since the 1960s (Alston et al., 2010; Cahoon, 2007; Alston & Pardey, 2008). With dwindling U.S. government support for public agricultural R&D, the need for alternative arrangements to sustain R&D activities has grown over time (Huffman & Just, 1999; Just & Huffman, 2009). At most universities, researchers are encouraged to replace public funding with external grants, many of which originate from private commercial interests (Rausser et al., 2016). However, the group who funds the research has an impact on what type of research is accomplished. Rausser et al. (2008) find with their theoretical model that a decline in government funding increases the ratio of mousetraps (applied research) to theorems (basic research.)

Prior to 1980, the government was assigned property rights for discoveries resulting from publicly funded research conducted at U.S. universities. The Bayh-Dole Act of 1980 granted universities the right to patent the IPRs from university-conducted research projects that are financed with federal funds, which provided universities with additional sources of revenue (Henderson et al., 1998; Jensen & Thursby, 2001; Thursby & Thursby, 2003; Jensen, 2016). Further, the Bayh-Dole Act requires that universities share any licensing revenues that come from the federally funded innovation with the inventor, which creates incentives for individuals to pursue commercially profitable research topics. The revenue flows from the patents can be used to support the universities' R&D efforts.

The precedent set in *Diamond v. Chakrabarty* (1980) changed intellectual property law. It gave researchers the right to patent the living things that they engineer/modify, including genetically modified organisms. This ruling created the opportunity for biotechnology firms to be profitable, resulting in the formation of numerous biotechnology firms; many of which were started by university faculty (Rausser et al., 2016). Establishing intellectual property rights for genetic material opened the floodgates for private investment in R&D, including at publicly funded universities.

2 A Continuum of Control of the Research Agenda

In this chapter, I consider public-private research partnerships broadly construed and the implications for control of the research agenda. Rausser's Berkeley-Novartis partnership maintained more control of the research agenda than Washington University in St. Louis' partnership with Monsanto (Gillam, 2017). The Washington University-Monsanto relationship can be characterized by Monsanto offering requests for proposals (RFPs) on a topic. In turn, Washington University researchers could respond to an RFP by submitting a proposal. Funding decisions for the submitted proposals were made by a joint review committee from both Monsanto and Washington University. Washington University had the right to exclusive licenses to the innovations that resulted from the research (Culliton, 1990), but Monsanto chose the topics to be funded.

The issue of control of the research agenda is key to public-private partnership. There is a continuum of control, as depicted in Fig. 1 below. At one extreme, the individual researcher has complete control over her own research agenda, which is curiosity-driven and likely to include public good research. At the other extreme is pure-industry-driven research or consulting. The Berkeley-Novartis Agreement is located to the left of the Washington University-Monsanto Agreement on this continuum.

Topics of research inquiry vary widely, even within fields of study. One common way of categorizing research is basic research versus applied research. Private businesses must receive a timely return on its research investments. Previous research (e.g. Just & Huffman, 2009) consider welfare in terms of linear flows of basic and applied research. However, in reality, there is no clean separation. In a dynamic sense, basic research is often driven by applied research, and applied research depends on basic research. There are complementarities or feedback loops between the two types of research. In a famous quote, Pasteur (1871) states, "There does not exist a category of science to which one can give the name applied science. There are science and the applications of science, bound together as the fruit of the tree which bears it."

However, it is useful to consider a second way of differentiating research. For simplicity, let us add a second dimension to represent the variety of topics. This is depicted in Fig. 2 with the example of biofuels research. This is similar to the idea of differentiation in product attribute space. Rather than attributes, the horizontal axis represents areas of research. This approach to thinking about research is useful to understand the implications of control of the research agenda.

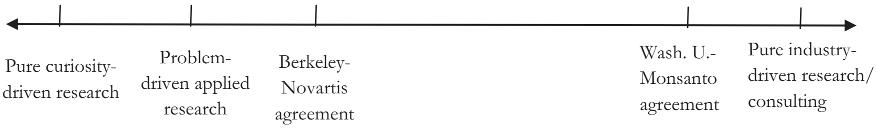

Fig. 1 Control of the Research Agenda

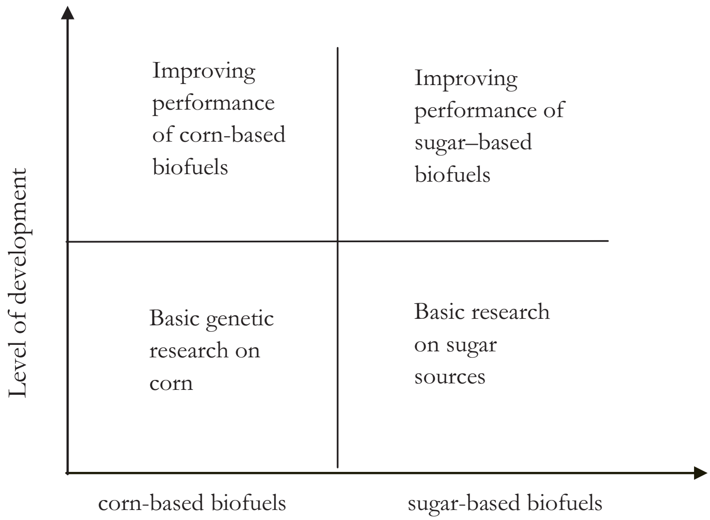

Fig. 2 Double Differentiation of Research Biofuel Example

One can think about double-differentiation of biofuels research, for example. In Fig. 2, the vertical axis represents the level of development towards a final product. A low value on the vertical axis could represent research in basic chemistry or basic biology. In contrast, a high value could represent how a specific biofuel performs with a specific engine. Continuing with the biofuel example, the horizontal axis could represent different types of materials which lead to final the biofuel products. The materials could range from algae to corn to sugar stocks. All of which could be used to develop biofuels.

I now make the argument that it is important for society to conduct research broadly on this horizontal dimension. We do not know where the next discovery will come from. If there are diminishing returns to research areas, all researchers should not focus on a few limited areas. This, of course, is too simplistic, but a diverse research portfolio is important for discovery. Often when researchers first embark on a new topic, they can obtain breakthroughs with "low-hanging fruit." When a field is saturated, it becomes more difficult to make paradigm-changing breakthroughs.

Aghion et al. (2008) (hereinafter ADS) model the development of an economically valuable product, which starts with an initial idea. This idea can be improved by subsequent scientists over *k* stages. Researchers must be successful in each stage to obtain the value that comes from the final product value *V*. They argue that scientists value creative control and must be paid a wage premium in order to give it up. Thus, an advantage of academia is that scientists can be hired more cheaply than in the private sector. The disadvantage is that they may end up working on projects that they find interesting, but that may have little immediate economic value. In contrast, a firm can, by virtue of their control rights, direct scientists to work on those projects that have the highest economic payoffs *to the firm*. A concern with private funding is that the objective function of the private firm is not necessarily aligned with the public good. Consider a line of research, the probability of success in a given stage is function of the number of scientists working on the problem $\phi(n)$, given the previous stages were successful. For research to be more valuable in the private sector, it must be the case that the expected payoff must be greater than the disutility of being directed.

This framework implies many results, which are derived by ADS, including that it cannot be value-maximizing to have academia operate at later stages of R&D than the private sector. There is a socially optimal time at which research should transition from the public to the private sector. Because of the higher wages in the private sector, if the transfer is made too early, the private firm may have too few researchers working on problem relative to what would happen in academia. As the number of stages becomes large, it will not be viable for research to be exclusively conducted in the private sector.

In contrast to ADS, I consider the horizontal axis of a generalized version of Fig. 2. ADS do not consider researchers working on different topics/materials/ideas. Thus, departing from ADS, consider researchers who can work on different varieties of research problems. Researchers can create innovations in different research areas. We assume diminishing marginal returns to researchers working on a specific problem. We do this by assuming that the increase in the probability of successfully reaching the next stage decreases with each additional researcher.

A key question is then: What is the distribution of scientists' interests? For simplicity of discussion, we can assume a uniform distribution of scientists' research interests, which would result in researchers being interested in a given topic to be equal across topics. Equal numbers of researchers across topics would be optimal if the final value to society of topics is the same (note the value to society could differ from monetary values). If the final value of specific products to society is different across topics, then the social planner will want to redirect some researchers to from products that are lower value to society to those that are higher valued. The social planner could do this through a public university with differential funding across departments. A concern is that, in practice, political economy forces may prevent the optimal levels of university research funding.

Private funding is governed by the market. A concern is that the social value of an innovation will differ from the private market (monetary) value. If this is the case, in the private sector, too many researchers will be working on topics with high private values and too few will be working on topics with social values that are higher than their private values.

2.1 Theoretical Framework

Applying a simple location model, I assume that research topics are distributed in one-dimension along a horizonal space of unit length, similar to the horizontal axis in Fig. 2. I assume that the university has N scientists who work in one of two science departments (A and B), with different exogenous research areas (thus, with locations on different points on the horizontal axis). I also assume that there is a private firm with scientists. The wage in the private company is exogenous (scientists are wage takers in the private market). If a scientist works in the private market, she must be compensated for her disutility, z, from being directed by a supervisor. Thus, scientists obtain utility from their wages. They obtain disutility from working on topics in which they have less interest and being directed by a supervisor. A university scientist i's research decision depends on her research preference location x_i, which is exogenous, wage w_i, and research group location of each department x_j, $j = \{A, B\}$. Thus, scientist i's preferences can be defined as follows:

$$u_i\left(w_i, x_i, x_j\right) = R + w_i - \left(x_i - x_j\right)^2 \tag{1}$$

where R denotes the reservation wage.

To find the labor share for each department within the university, I find the location $\tilde{x}$ of the indifferent scientist at the university. Setting the utility of working in department A equal to working in department B and solving for x, I obtain the location of the indifferent scientist:

$$\tilde{x} = \frac{w_B - w_A + x_A^2 - x_B^2}{2\left(x_A - x_B\right)} \tag{2}$$

The indifferent scientist is depicted in Fig. 3 below. The number of scientists working in Department A is then $N\tilde{x}$ and the number of scientists working in Department B is $N\left(1-\tilde{x}\right)$. There are m scientists working at the private firm, where m is exogenous. There is a barrier to entry for industry scientists to join the university faculty. That is, that is only a one-way movement of university faculty to industry. I assume the private firm is exogenously located at $x_P > x_B$. I assume that all locations are fixed.

The *social value* of the final product of discoveries made by university scientists is V_j, $j = \{A, B\}$, and the private value of the final product to the private firm is V_p. Note that the social value is the sum of public and private values. The probability of a successful discovery is a function of the number of scientists working on the

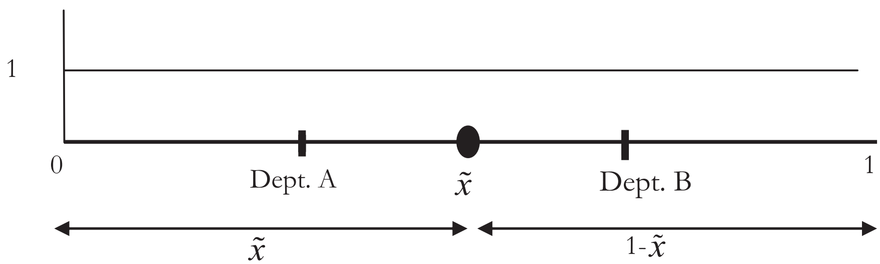

Fig. 3 Location of Research Group and Distribution of Scientists

project, $\phi(n) > 0$ for $n > 0$, $\phi(0) = 0$, $\frac{\partial \phi(n)}{\partial n} > 0$, and $\frac{\partial^2 \phi(n)}{\partial n^2} < 0$. For simplicity, we assume that the discovery takes a single period. There is a discount factor of δ.

I assume that the wages are set by the university administrator such that the scientists are distributed across areas in a socially optimal way, given the expected value of the final products produced by each research group and the wage at the private firm. The university administrator's problem is then to maximize the discounted expected social value of final products less wages subject to the constraints that the university scientists' utility must be at least as high they would obtain from working in private industry and a budget constraint, where B is the university's total budget.

$$\max_{w_A, w_B} \delta\phi\left(N\tilde{x}\right)V_A - w_A + \delta\phi\left(N\left(1-\tilde{x}\right)+m\right)V_B - w_B \tag{3}$$

s.t

$$u_i\left(w_A, w_B, x_i, x_j\right) \geq R + w_p - \left(x_i - x_P\right)^2 - z, for \ \ j \in \{A, B\}$$

$$N\tilde{x}w_A + N\left(1-\tilde{x}\right)w_B \leq B$$

Substituting the expression for $\tilde{x}$, the Lagrangian can be expressed as the following:

$$\begin{aligned} \mathcal{L} = {} & \delta\phi\left(N\left(\frac{w_B - w_A + x_A^2 - x_B^2}{2\left(x_A - x_B\right)}\right)\right)V_A - w_A + \delta\phi\left(N\left(1-\left(\frac{w_B - w_A + x_A^2 - x_B^2}{2\left(x_A - x_B\right)}\right)\right)\right)V_B - w_B \\ & + \lambda_1\left(w_A - \left(x_i - x_A\right)^2 - w_p + \left(x_i - x_P\right)^2 - z\right) + \lambda_2\left(w_B - \left(x_i - x_B\right)^2 - w_p + \left(x_i - x_P\right)^2 - z\right) \\ & + \lambda_3\left(B - N\left(\frac{w_B - w_A + x_A^2 - x_B^2}{2\left(x_A - x_B\right)}\right)w_A - N\left(1-\left(\frac{w_B - w_A + x_A^2 - x_B^2}{2\left(x_A - x_B\right)}\right)\right)w_B\right). \end{aligned} \tag{4}$$

The first-order conditions are:

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial w_A} = {} & \frac{\delta N}{2\left(x_B - x_A\right)}\phi'\left(N\frac{w_B - w_A + x_A^2 - x_B^2}{-2\left(x_B - x_A\right)}\right)V_A - 1 \\ & + \frac{-\delta N}{2\left(x_B - x_A\right)}\phi'\left(1-\left(N\frac{w_B - w_A + x_A^2 - x_B^2}{-2\left(x_B - x_A\right)}\right)\right)V_B + \lambda_1 + \\ & \lambda_3\left(-N\left(\left(\frac{w_B - w_A + x_A^2 - x_B^2}{2\left(x_A - x_B\right)}\right) + \frac{-w_A}{2\left(x_A - x_B\right)} + \frac{w_B}{2\left(x_A - x_B\right)}\right)\right) = 0 \end{aligned} \tag{5a}$$

$$\frac{\partial \mathcal{L}}{\partial w_B} = \frac{-\delta N}{2\left(x_B - x_A\right)}\phi'\left(\frac{w_B - w_A + x_A^2 - x_B^2}{-2\left(x_B - x_A\right)}\right)V_A$$

$$+\frac{\delta N}{2\left(x_B - x_A\right)}\phi'\left(1-\left(\frac{w_B - w_A + x_A^2 - x_B^2}{-2\left(x_B - x_A\right)}\right)\right)V_B - 1 + \lambda_2 \tag{5b}$$

$$\lambda_3\left(-N\left(\left(1-\frac{w_B - w_A + x_A^2 - x_B^2}{2\left(x_A - x_B\right)}\right)+\frac{-w_B}{2\left(x_A - x_B\right)}+\frac{w_A}{2\left(x_A - x_B\right)}\right)\right)=0$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_1} = w_A - \left(x_i - x_A\right)^2 - w_p + \left(x_i - x_B\right)^2 - z = 0 \tag{5c}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_2} = w_B - \left(x_i - x_B\right)^2 - w_p + \left(x_i - x_P\right)^2 - z \text{ or } \lambda_2 = 0 \tag{5d}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_3} = B - N\left(\frac{w_B - w_A + x_A^2 - x_B^2}{2\left(x_A - x_B\right)}\right)w_A - N\left(1-\left(\frac{w_B - w_A + x_A^2 - x_B^2}{2\left(x_A - x_B\right)}\right)\right)w_B = 0 \tag{5e}$$

There are several conclusions that can be drawn from this model. Wages within university departments depend on the distribution of scientists' preferences, the outside option (the private firm), and the expected potential value of the final products. As the expected social value of the final product associated with a specific department increases, so does the wage for that department. Since the private firm is closer in location (specialty/interest) to Department B, the expected wages in Department B will be greater than in Department A, *ceteris paribus*.

2.2 *Implications for Public-Private Partnerships*

Given this background, I will discuss the two approaches that were used in Berkeley-Novartis and Washington University-Monsanto agreements: RFPs and the Right of First Refusals. Please see Rausser et al. (2016) for a detailed case-study comparison of these specific agreements.

2.2.1 Requests for Proposals (RFPs)

With an RFP, the private company asks the University to respond with proposals to conduct research on a specific topic. Rausser et al. (2016) write, "As the request for research proposals becomes more limited in scope and perhaps skewed to the interests of the private partner, the choice set for the public institution becomes more restricted," (p. 178). Monsanto's agreement with Washington University was to issue RFPs. In the context of the theoretical framework discussed above, a specialized company issuing RFPs will likely result in more researchers than is socially optimal working on their specific topic. Grant funding can result in additional salary (e.g. summer salary) that can compensate researchers to deviate from their research interests. Within the model express above, an RFP is equivalent to an increase in the wage (through summer salary), w_B, for Department B and a simultaneous increase to the university's budget. From the model, we know that $\frac{\partial \tilde{x}}{\partial w_B} < 0$, which means that scientists will shift their work from Department A to Department B.

Thus, the with an RFP approach, the private company is influencing the research agenda at the public university. With the RFP approach, more university researchers will conduct research of the topic that is specified by the private company. Since they only care about private values, the private company's objectives are unlikely to be aligned with societal objectives. Thus, the RFP approach to public private partnerships can cause more scientists to work on topics which are closer to Department B, since by assumption, the private firm is located to the right of Department B.

2.2.2 Right-of-First Refusal

A private firm may be able to increase its profits with a contract that gives a university money in exchange for the right-of-first refusal of the patents it generates. This right-of-first refusal is an option value to the firm. It allows the firm to buy the final product of the research but it does not directly influence the research agenda, except when the ratio of public and private values of final goods differ across departments. The common practice is for scientists to receive one third of the private value of their discoveries.

2.3 Directions for Future Research

There are many aspects of this model that can be explored. First, I can allow the probability of success to vary across the university and the private firm. It might be the case that the private firm has access to propriety data, which increases the industry scientists' probability of success. If the industry scientists partner with the academic scientists, they may share data and make the academic scientists more productive. It may be that more talented scientists are attracted to academia (or industry), which affects the probability of success. Heterogenous ability of scientists will affect the results. It might also be the case that one academic department has a greater probability of success than another, *ceteris paribus*.

I could also evaluate how an increase (or decrease) in the university's budget affects social welfare. I could allow for the location of departments to become endogenous. It could be the case that unsuccessful scientists are denied tenure and scientists are risk averse, which could be similar to a tax. Finally, the model could include multiple stages, as with ADS.

3 Conclusions

Innovation is key to a sustainable future. The research, conducted both at public universities and by private companies, fuels innovation and will help to solve the important problems of our times. Thus, the decline of government funding for public research is a great concern. Many university researchers are looking to private sources to fill the gap. Universities must be mindful that the contractual relationship with private firms will determine who controls the research agenda.

This chapter proposes a theoretical model to consider how innovation occurs in the academic setting with an outside option. Different types of public-private partnerships will affect the allocation of scientists across areas. This, in turn, will affect social welfare because the probability of successful innovation depends on the number of scientists working on each area, on the expected value to the society and the wage and area of the outside firm. There are several extensions to consider.

Based on this discussion and issues in this chapter, we circle back to the contribution of Gordon Rausser. Dr. Rausser was a pioneer in building a university-industry partnership that thought carefully about control of the research agenda. He negotiated the public-private research partnership with Novartis, which enabled the College of Natural Resources of the University of California at Berkeley to grow during challenging budget times. Many were critical of forming a strategic partnership with a private company. Rausser wrote, "The question is not whether universities must deal with the outside world but how effectively they do so," (Rausser, 1999, p. 1014.) His legacy and ideas influence many in both the public and the private sector as the importance of strategic alliances in public-private partnerships and the research agenda increases with each passing year.

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Econometrics in Litigation: Challenges at Class Certification

Gareth Macartney

1 Introduction

When I was asked to write this chapter, it was suggested that I should attempt to summarize Gordon Rausser's expert testimony and scholarship in the field of law and economics. I consider this a near impossible task. Dr. Rausser has filed hundreds of expert reports in complex, high-stakes commercial litigations, covering such topics as merger evaluations, antitrust analysis, measurement of monopoly power, predatory pricing, predatory bidding, environmental damages, pollution damages, groundwater contamination, superfund remediation, the dynamics of pharmaceutical markets, infringement on intellectual property, chemical damages, false labelling and marketing representation, endangered species, allegations of fraud, class certification, fisheries and many more. His scholarly publications span a similarly wide gamut: monopoly power (Perloff & Rausser, 1983; Rausser et al., 1987; Rausser & Foote, 2013); merger analysis and intellectual property (Marco & Rausser, 2002, 2008, 2011; Graff et al., 2003); environmental damages (McCluskey & Rausser, 2001, 2003a, b; McCluskey et al., 2002; Rausser & Fargeix, 1994; Arnott et al., 2008; Berkman & Rausser, 2006); endangered species (Rausser & Small, 2000); predatory pricing and bidding (Just & Rausser, 2007); pollution damages (Fishelson et al., 1976; Hyde et al., 2000); groundwater contamination (Rausser et al., 2011a, b; Rausser et al., 2004); superfund remediation (Rausser et al., 2008); fisheries (Rausser et al., 2009); and class certification (Macartney & Rausser, 2016; Rausser & Macartney, 2016; Hausfeld et al., 2014).

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So, instead I decided to focus on Dr. Rausser's extensive work concerning the use of econometrics in class action litigation. There has always been a tension between economists and lawyers concerning what econometric modelling can and should be able to do. Economists are accustomed to the idea that models cannot be expected to explain, and do not need to explain, all the random variation in a market.[1] While there will always be unexplained variation, if it is random with respect to the systematic variables in the model, such variation will not undermine the reliability of the model's estimates. In the mid-1980s, Franklin Fisher wrote: "Lawyers may understand this in principle, but they do not like it."[2] Indeed, economists who do not work in litigation would be surprised by how much emphasis lawyers place on models having high explanatory power. This tension has recently come to a head in antitrust class actions, with a much stronger emphasis on individual prediction, which is often belied by unexplained variation. This chapter documents how we got here. It also looks to where this tension might lead us in the future, including to techniques, such as machine learning, that focus on fit over all else. Such methods, if used in antitrust class actions, will face their own challenges.

2 The Questions at Class Cert

A *class* action, as opposed to a *direct* action, is a lawsuit in which one or several plaintiffs (called the "class representatives" or "class reps") sue on behalf of themselves and a similarly situated group of others.[3] Whether the case can proceed as a class action is decided by the judge in a preliminary, but critically important, procedural phase called class certification (or, simply "class cert"). In federal court, that decision is governed by Federal Rule of Civil Procedure No. 23. This rule has several parts, ranging from the relatively simple such as *numerosity* ("the class is so numerous that joinder of all members is impracticable"[4]) to the much more nuanced, such as *predominance*. Indeed, most of the fighting in the battle of the experts at

[1] "No model could hope to encompass the myriad essentially random aspects of economic life," Greene (2012).

[2] Fisher (1986), p. 278.

[3] The context of this discussion is the U.S. legal system, which has supported "opt out" class actions for many decades. In an opt out class action a group of plaintiffs bring the case on behalf of themselves and others similarly situated, whether those others know about the case or not. Those other plaintiffs can elect to opt out of the class action and pursue their own direct actions if they wish. If they do not, the value of their claims will be assigned to the overall class action award (or settlement), and they can make a claim on that award if they wish. In recent years, European countries such as the U.K. have initiated similar proceedings, having previously required all plaintiffs to knowingly opt in, which limited class action activity.

[4] Fed. R. Civ. P. 23(a)(1). Rule 23(a) has four parts, all of which must be certified for the case to proceed as a class action. They are colloquially referred to as numerosity, commonality, typicality, and adequacy, and need not be discussed further for the purposes of this chapter.

class cert centers on the predominance requirement of 23(b)(3): the court must find "that the ***questions of law or fact common to class members predominate*** over any questions affecting only individual members, and that a class action is ***superior*** to other available methods for fairly and ***efficiently*** adjudicating the controversy."[5] To the legal layman, Rule 23(b)(3) provides a window into the court's calculus. Simply, the court must be satisfied that, when the time comes, the trial can be conducted efficiently for the class as a whole, without it disintegrating into a set of "mini-trials" and "side-bar fights" specific to individual class members.

What this means for an economist retained by plaintiffs' counsel, is that the court needs to be satisfied economic questions can be answered using economic theories, evidence and models that are *common* to the class (hereinafter, "common evidence"). For an antitrust case, there are three questions for the economist (throughout we will have in mind a monopolistic, cartel price-fixing case, for simplicity). At class cert, plaintiffs' economist does not technically have to answer these questions, but rather has to prove to the court that the economist will be *able* to answer them using common evidence when it comes to trial. The three questions are:

1. ***Is the economic evidence consistent with the allegations against the defendants?*** In many cases, this will require analyses showing that the benefits of a cartel (higher prices) outweigh the costs (lost sales to possible substitute products, for example) and that the communications between defendants (exchange of price lists, discussion of agreements on prices or supply, for example) are consistent with how economists understand anticompetitive behavior. Although hotly contested, this analysis generally focuses on the economic circumstances and behavior of the defendants. It is therefore evidence common to the class by its nature and it will not be the focus of this chapter.
2. ***Did all or virtually all class members suffer antitrust injury?*** The term antitrust injury can be defined as "injury of the type the antitrust laws were intended to prevent and that flows from that which makes defendants' acts unlawful."[6] The more day-to-day term is simply "impact." In the experience of this author, there is little guidance on what "all or virtually all" means and there are often thousands, or even millions, of putative class members. If an economist shows that common evidence proves 95% of class members suffered impact, defendants will almost certainly argue nonetheless that this is inadequate. Answering the question about whether all or virtually all class members were injured is colloquially referred to as proving "common impact" and can be a challenging task. Although the threshold question is whether class members were each injured, the quantum of their injury (*i.e.*, the percentage price increase suffered) need not

[5] Fed. R. Civ. P. 23(b)(3). Plaintiffs can apply for class certification under any one of the three clauses of Rule 23(b). The court will decide if the specified clause is satisfied, so that the case can proceed as a class action. The most common clause specified by plaintiffs in antitrust cases is Rule 23(b)(3) and is the focus of this chapter.

[6] *Brunswick* (1977), p. 697.

be the same for all class members. Rather, it appears that the "common" in common impact refers to a similar type or mechanism of injury.

3. ***What is the quantum of class-wide damages?*** Once common impact is proven, the economist must estimate the amount of the *aggregate* economic damages suffered by the class. The very purpose of the class action format is to create efficiency through common proof, an objective inconsistent with individually proving each class member's damages. In practice, only after a favorable trial verdict or settlement must a method of apportionment be devised to distribute those funds among individual class members. At class cert, plaintiffs' economist seeks to establish that aggregate class-wide damages can be calculated using a methodology common to the class that does not require individual inquiry (usually a regression model). The model would calculate an average overcharge or, perhaps, a set of average overcharges that vary by year or product group or some other dimension, depending on the economics and facts of the case. The resulting overcharge(s) are then typically applied to aggregate class-wide purchases to calculate class-wide damages.

   So, for common *impact*, an economist must prove that all or virtually all class members suffered impact from the allegedly unlawful conduct. But, strictly speaking, for class-wide *damages*, the economist must only quantify (usually through a regression model) the *aggregate* harm for all class members together. This distinction, and how it has recently become blurred, is at the heart of this chapter. The justification for examining *individual,* as opposed to aggregate damages, ties back to the common impact requirement. Increasingly, defendants argue that if they can use plaintiffs' class-wide damage model to identify sufficient class members who suffered no damage, then there is a lack of common impact, and/or that the damage model being proposed is itself flawed and not "workable." To understand what has changed and the implications for econometrics in this area, requires a discussion of the traditional approaches to the analysis of common impact and class-wide damages and a whistle-stop tour of court rulings, old and new.

3 The Old Standard

The topic of rising standards for class cert has been documented by several authors, including myself in work co-authored with Gordon Rausser.[7] It is described here in brief, with a focus on the economic and econometric issues that are the subject of this chapter.

[7] Macartney and Rausser (2016), Rausser and Macartney (2016), Hausfeld et al. (2014).

3.1 The Eisen Rule and the Bogosian Shortcut

For some time, class cert was governed by two standards: one derived from a 1974 Supreme Court ruling (*Eisen v. Carlisle & Jacquelin*) and the other from a 1977 Third Circuit Court of Appeals ruling (*Bogosian v. Gulf Oil Corp.*). *The Eisen Rule* was interpreted by many courts as holding that, during class cert, the court should not seek to resolve factual disputes inherent in the merits of the case.[8] Instead, plaintiffs' economist was allowed to presume the allegations of the complaint to be true. The intuition of this is simple: it is up to the jury to decide the merits of the case and a court determination at class cert would deprive the jury of that opportunity. *The Bogosian Shortcut* created an implementing standard if an industry exhibited a "price structure" (meaning that prices across different products and customers generally moved up and down together) then one could infer common impact.[9] The basic economics behind this inference was that demand and supply-side substitution kept prices across the industry in lockstep, so that collusive action by sellers with market power would cause some price increase for all (or virtually all) of the buyers.

These two standards provided a short cut to class cert. If plaintiffs' economist could provide evidence of a price structure through an analysis of price movements, then that would satisfy common impact. If defendants' expert provided contradictory evidence, the court might apply *the Eisen Rule*, decide not to resolve a factual dispute that should be determined by a jury, grant class cert and press on to trial. Ironically, there is slim chance of a jury ever hearing the case once class cert is granted because defendants seek to avoid the risk of treble damages by settling.[10] Table 1 reproduces the results of a 2005 report from the Federal Judicial Center regarding case outcomes after 486 class cert decisions.

For the 119 cases where the class was certified, 106 (89%) proceeded to settlement and only 5 (4%) went to the trial. In stark contrast, cases where class cert is denied tend to be dismissed or resolved for defendants on the merits. The Federal Judicial Center concludes[11]:

> *The dichotomy between certified and noncertified cases could hardly be clearer. A certification decision appears to mark a turning point, separating cases and pointing them toward divergent outcomes. A profile of certified cases suggests that they have shown class-wide merit, at least in the sense of surviving or avoiding motions to dismiss or motions for summary judgment. Certified cases concluded with a court-approved, class-wide settlement 89% of the time; a few were tried and a few were dismissed involuntarily. Noncertified cases did not show evidence of having class-wide merit; they were dismissed by a court, settled on an individual basis, or voluntarily dismissed 97% of the time; a few had individual trials.*

[8] *Eisen* (1974).

[9] *Bogosian* (1977).

[10] Antitrust damage awards may in some cases be trebled.

[11] Willging and Wheatman (2005), at p. 50.

Table 1 Case outcomes after class cert (Willging and Wheatman (2005), Table 19, at p. 50. "Note: The categories do not add up to 100% because respondents could select more than one category and because 'other' responses have been omitted")

Outcomes of cases	Certified ($N = 119$)	Not certified ($N = 367$)
Proposed class settlement approved	101 (85%)	Not applicable
Revised class settlement approved	5 (4%)	Not applicable
Class settlement proposed and rejected	1 (1%)	3 (1%)
Case dismissed for lack of jurisdiction	Not applicable	26 (7%)
Case dismissed on merits	5 (4%)	90 (24%)
Case dismissed on other grounds	2 (2%)	Not applicable
Summary judgement granted	None	29 (8%)
Class representatives settle individually	1 (1%)	107 (29%)
Case dismissed voluntarily	Not applicable	103 (28%)
Individual trials held	Not applicable	8 (2%)
Class trial held	5 (4%)	Not applicable

3.2 Economic Analysis Under the Old Standard

To an economist, there is nothing particularly wrong with the spirit behind *the Bogosian Shortcut*, even if its very name implies a lack of rigor. Basic economic theory establishes that if one can define a market of goods where demand and/or supply-side substitution link prices together, then one *would* expect that a reduction in supply orchestrated by suppliers with market power would increase prices for all buyers. That said, in the past, some of the analysis to prove a so-called price structure and some of the analysis to refute it, was at times somewhat cursory. Examples are given in Figs. 1 and 2, taken in redacted form from expert reports in a cartel price-fixing case. Figure 1, a chart of average prices for different strengths of a product, was offered by plaintiffs' expert as evidence of a price structure that would lead one to infer a common impact. Visual inspection was offered by that expert as demonstration that the wavy lines exhibited such a structure.

Figure 2, a scatter plot of individual transaction prices eschewing all forms of averaging, was defendants' expert's response that there was no such price structure.

Class cert was often a horse race between the wavy line chart and the scatter plot, with the *Eisen Rule* constraining the court from resolving such factual disputes and instead favoring certification and possible trial. Importantly, under the old standard, plaintiffs' expert did not generally have to run a class-wide damages model to pass the class cert test. Instead, the economist could simply explain that there were feasible methods for estimating class-wide damages. There were often three such promised methods: (1) a simple comparison of the cartel's prices to a competitive benchmark of prices from a different time, geography or product unaffected by the cartel; (2) a reduced form regression model, similar to the benchmark approach, but controlling for systematic differences between the cartel transactions and the benchmark transactions; and (3) a full structural model. At class cert, courts were often satisfied with assurances that such models were feasible, without having to see them work.

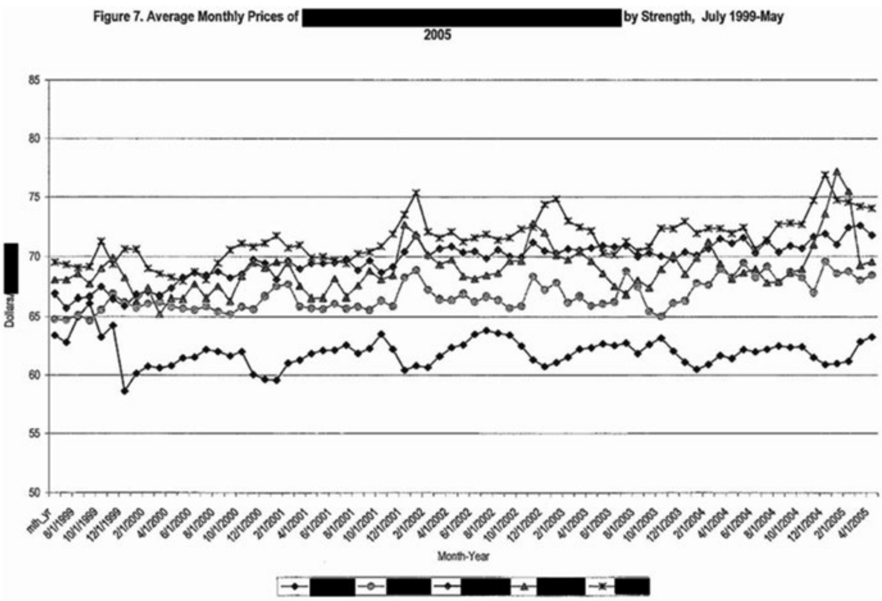

Fig. 1 Plaintiffs' common impact analysis under the old standard

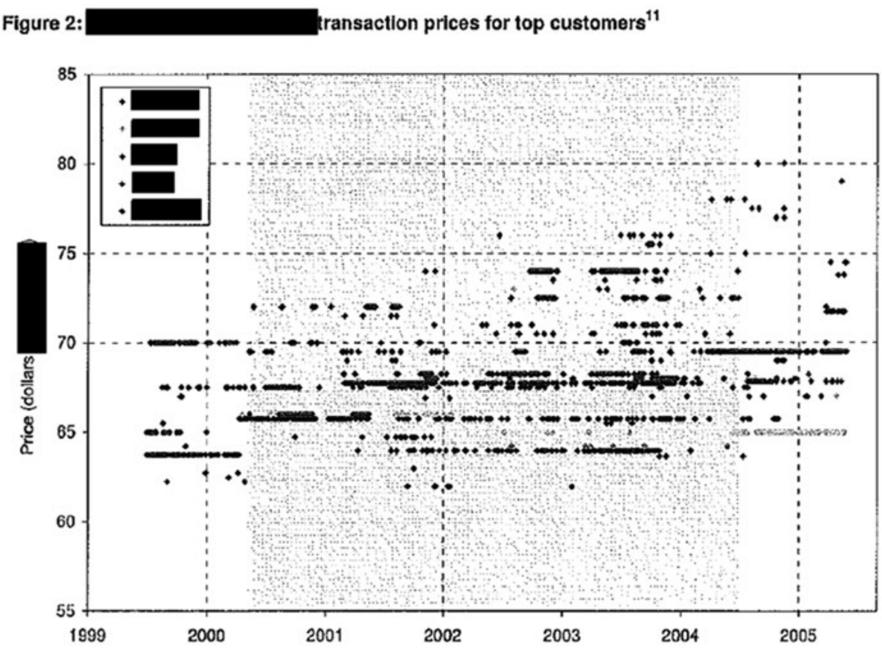

Fig. 2 Defendants' common impact analysis under the old standard

4 The New "Rigorous Analysis" Standard

Given the importance of class cert to case outcomes, it was perhaps not surprising that the standards would come under closer scrutiny, particularly given the cursory nature of some of the analysis under the old standard.

4.1 What's in a Word or Three?

Although written in 1937, the modern version of Rule 23 was the result of substantial amendments in 1966.[12] That version required the court to make the class cert decision "***as soon as*** practicable after the commencement of the action."[13] Rule 23 was amended in 2003 to require that the class cert decision be made "***at an early*** practicable time."[14] Surprising as it may seem, this subtle change gave courts more time to make the class cert decision and was responsible for a significant increase in the scrutiny with which courts examined economic analysis at class cert.

4.2 Rulings Developing the Higher Standard

In the 10 years following the 2003 amendments, there were three rulings most reflective of the rising standards: *Hydrogen Peroxide*, *Wal-Mart*, and *Comcast*. Economists working in antitrust class actions are more likely to be asked by their clients about their approach to "the *Comcast* question," but in many ways *Hydrogen Peroxide* is the most important of the three.

4.2.1 Hydrogen Peroxide

This case was a cartel price-fixing case concerning the compound used primarily as bleach in the pulp and paper industry, but also in chemicals and laundry products, textiles and electronics.[15] Plaintiffs' expert had found a pricing structure in that "prices across producers, grades and concentrations of hydrogen peroxide, and end uses moved similarly over time," suggesting that the conspiracy would have had a common impact.[16] In contrast, defendants' expert argued that pricing varied substantially, with "'no tendency for prices charged to individual customers to move

[12] Fed. R. Civ. P. 23 (1966).

[13] Fed. R. Civ. P. 23 (1966) (emphasis added).

[14] Fed. R. Civ. P. 23 (2003) (emphasis added).

[15] *Hydrogen Peroxide* (2008), p. 307.

[16] *Id.,* 313.

together,'" cutting against common impact and "necessitating individualized inquiries."[17] Concerning class-wide damages, plaintiffs' expert had described two of the usual three approaches (a simple benchmark comparison and a reduced-form regression model), but had implemented neither of them.[18] The district court applied the *Bogosian Shortcut* and the *Eisen Rule*, deciding not to resolve a factual dispute between experts.[19] Class cert was granted.

In 2008, that decision was overturned by the Third Circuit Court of Appeals in a detailed opinion that set the phones ringing in economic consultancies across the country. This opinion proved to be the death knell for the *Eisen Rule*, holding that courts should resolve factual disputes with bearing on class cert and fully consider expert opinions from both sides (opinions described in *Hydrogen Peroxide* as "irreconcilable.")[20] The appellate court focused on the criticism of plaintiffs' expert's pricing structure analysis, and was persuaded by defendants' argument that its use of *average* prices may have "glossed over differences in actual prices."[21] The district court had "held that it was sufficient that [plaintiffs' expert] proposed reliable methods for proving impact and damages…and…would not require plaintiffs to show at the certification stage that either method would work."[22] In light of testimony from defendants' expert that the proposed methods were not feasible "[g]iven the record of individualized factors on pricing"[23] the Third Circuit found the lower court had failed to conduct a "rigorous assessment of…the method or methods…which plaintiffs propose to use…"[24] On this basis, the Third Circuit vacated the order granting class cert and the phrase "rigorous assessment" became engrained in the law of class certification.

4.2.2 Wal-Mart

The *Wal-Mart* case involved allegations of gender wage discrimination and a putative class of 1.5 million female employees of the well-known retailer.[25] In 2011, the United States Supreme Court overturned a District Court's grant of class cert which had been upheld by the Ninth Circuit Court of Appeals.[26] The case alleged that "Wal-Mart engages in a *pattern or practice* of discrimination."[27] The Supreme Court

[17] *Id.*, 314.
[18] *Id.,* 313, 315.
[19] *Hydrogen Peroxide* (2007), p. 163.
[20] *Hydrogen Peroxide* (2008), p. 320.
[21] *Id.*, 314.
[22] *Id.*, 315.
[23] *Id.*, 314.
[24] *Id.*, 312.
[25] *Wal-Mart* (2011)), p. 2544.
[26] *Id.*, 2544–46.
[27] *Id.,* 2545 (emphasis in original).

noted that without any explicit policy of discrimination alleged, plaintiffs required “significant proof” of a “general policy of discrimination.” ” in order to proceed as a class action.[28] The Supreme Court found such proof to be absent.[29]

Plaintiffs’ sociological expert had found “that Wal-Mart has a ‘strong corporate culture,’ that makes it ‘vulnerable’ to ‘gender bias,’” but “could not calculate whether 0.5 percent or 95 percent of the employment decisions at Wal-Mart might be determined by stereotyped thinking.”[30] Plaintiffs’ statistical expert had performed regression analysis region by region, investigating the number of women promoted into management positions relative to the percentage of women in the available pool of hourly workers, and finding statistically significant disparities between men and women that could only be explained by gender discrimination.[31] Plaintiffs’ labor economist used regression analysis to compare workforce data from Wal-Mart with that from competitive retailers, concluding that Wal-Mart “‘promotes a lower percentage of women than its competitors.’”[32] But the Supreme Court found that both of these regression analyses suffered a “failure of inference,” in that regional disparities do not establish disparities at individual stores or a company-wide policy of discrimination.[33] For instance, an average regional pay disparity may be attributable to a small set of stores, rather than each of the stores in that region.[34] The Supreme Court found that the 120 affidavits reporting experiences of discrimination submitted by the plaintiffs were “too weak to raise any inference that all the individual, discretionary personnel decisions are discriminatory,” partly because they were few in number relative to the size of the putative class.[35] Finally, the Supreme Court disapproved of the proposed “Trial by Formula” method for damages. This method involved selection of a sample of class members for whom the fact of discrimination and the amount of lost backpay as a result of that discrimination would be determined in deposition. The percentage of valid discrimination claims and the average lost backpay found for this sample would then be extrapolated to the entire class to arrive at class-wide damages.[36]

For our purposes, the Supreme Court’s ruling further heightened scrutiny of averages, extrapolation, and inference in evaluating a motion for class certification. The Supreme Court also clarified that class cert should require a “rigorous analysis” which frequently “will entail some overlap with the merits of the plaintiff’s underlying claim,” noting that its decision in *Eisen v. Carlisle & Jacquelin* “is sometimes mistakenly cited to the contrary.”[37]

[28] *Id.,* 2553.

[29] *Ibid*.

[30] *Ibid*.

[31] *Id.,* 2555.

[32] *Ibid*.

[33] *Ibid*.

[34] *Ibid*.

[35] *Id.,* 2556.

[36] *Id.,* 2561.

[37] *Id.,* 2551–2552.

4.2.3 Comcast

Comcast was an antitrust case against the telecommunications conglomerate. In 2013, the Supreme Court overturned a District Court's grant of class cert which had been affirmed by the Third Circuit Court of Appeals. The problem this time went directly to plaintiffs' expert's proposed damage model. Initially, plaintiffs had proposed four theories of antitrust impact, based on four alleged behaviors by Comcast. Plaintiffs' economist designed and implemented a regression model that estimated the overcharge caused by all four behaviors combined.[38] The District Court certified the class, but accepted only one of the four theories.[39] The Third Circuit Court of Appeals refused to consider the argument that plaintiffs' expert's model could not isolate damages from the one remaining theory because this would require delving into the merits at class cert.[40] The Supreme Court in its ruling started with the "unremarkable premise" that a workable damage model must measure only the damages attributable to the one theory that the District Court accepted for class-action treatment and nothing else.[41] This is simple causality and may indeed appear unremarkable to economists. But the practical implication is that plaintiffs' experts may in some cases need to offer models capable of being decomposed to isolate the effects of particular acts.

5 Repercussions

To recap, under the old standard, plaintiffs' expert could prevail at class cert by showing a price structure to prove common impact and by describing some method for estimating class-wide damages without necessarily implementing it. Following the 2003 amendments to Rule 23 and the rulings in *Hydrogen Peroxide*, *Wal-Mart*, and *Comcast*,[42] courts began engaging in a much more rigorous assessment of plaintiffs' experts' common impact opinions and began requiring them to demonstrate that their proposed class-wide damage models actually work at class cert. Moreover, the use of averages, extrapolation, and inference, are now increasingly viewed by courts with suspicion. And there is a renewed emphasis on causality, specifically ensuring that any proposed damage model can isolate the effect of whatever specific act(s) the court ultimately finds to be illegal. These developments have led to several repercussions, some predictable, some less so.

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[38] *Comcast* (2013), 1428, 1433–34.

[39] *Id.,* 1428.

[40] *Id.,* 1428.

[41] *Id.,* 1433.

[42] As well as other rulings which we do not have space to discuss here.

5.1 Less Class Actions

One obvious repercussion of the rising standards for class cert is that it makes bringing a class action a much riskier proposition for plaintiffs' lawyers, who frequently work on a contingency basis. Data on antitrust class action filings in Federal Courts suggests an increased reluctance to file class action complaints following the *Hydrogen Peroxide* decision. Indeed, as shown in Fig. 3, the data suggests that class action filings (grey line) were increasing substantially in the run up to 2008, before decreasing substantially thereafter. Relating class action filings to direct actions (blue line), whereas both decreased somewhat after 2008, class action filings decreased much more so and, unlike direct actions, have not yet recovered to their previous high levels.

Further, based on this author's personal experience, there appears to be a greater tendency for individual plaintiffs to opt-out of class actions and bring their own direct actions. Nevertheless, class actions continue, but now with a much more intensive examination of economic evidence at class cert.

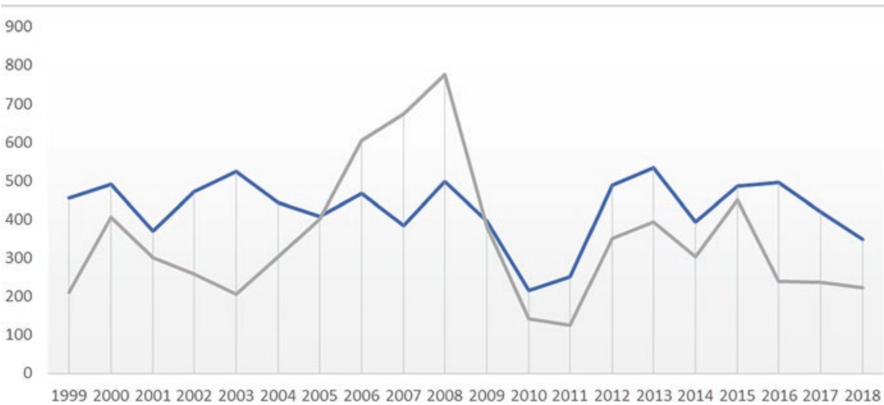

Fig. 3 Waning Class Actions (Grey Line) Relative to Direct Actions (Blue Line) (Search conducted on Lexis Courtlink. To find antitrust class actions, the search was restricted to cases filed within United States District Courts every year from 1999 through 2018, and the following filters were applied: "Class Action" and "Antitrust" (in the "Litigation Area" field). To find individual antitrust actions, the "Class Action" filter was removed. The number of class actions found in the first search was then deducted from the number of actions found in this second search. There are limitations to this search, as some antitrust class actions are not classified as such by Lexis Courtlink and are, thus, counted as an "individual" action in the graph.)

5.2 A New Burden Placed on Regression Models

Perhaps a less predictable repercussion of the rising standards is the exact nature of the new burden it has placed on regression models. This comes from the confluence of two factors. The first factor is the greater rigor with which common impact analysis is scrutinized, including greater skepticism concerning opinions on pricing structure, the use of averages, extrapolation, inference, and so on. The second factor is the greater tendency to implement a class-wide damage model at class cert to demonstrate that it works. The first factor created a vacuum. The second factor filled it. Courts now often ask: what does plaintiffs' expert's *class-wide* damage model say about *individual* class members? Does it undermine or support common impact? And, defendants' experts have urged them to do so.

To understand why requiring a class-wide damage model to prove common impact can be a problem requires a brief exposition of the models routinely used to calculate class-wide damages. As Baker and Rubinfeld have noted, "[r]educed-form price equations are the workhorse empirical methods for antitrust litigation."[43] Such a model might take the following form, for customer i, buying product j, at time t:

$$P_{ijt} = c + \alpha D_t + \beta Supply_t + \gamma Demand_t + \delta X_{ij} + \varepsilon_{ijt} \qquad (1)$$

where c is a constant, D_t is the "cartel indicator variable," a dummy variable distinguishing the class period when a cartel was in operation, from a competitive benchmark period when it was not. $Supply_t$ contains supply factors such as input costs, $Demand_t$ is some demand driver, X_{ij} is a set of product characteristics (*e.g.*, flavor, strength) and customer characteristics (*e.g.*, size, location), and ε_{ijt} is an error term.[44] The coefficient of interest is α, which represents a reliable estimate of the average price elevation (*i.e.*, the overcharge) suffered by the class, if (1) is well specified, the control variables are exogenous, and so on. Equation (1) is, for obvious reasons, known as the "dummy variable approach" to estimating overcharges. A slightly different approach, known as the "forecasting approach," is to estimate the regression model on the benchmark period and then predict (or "forecast") prices into the cartel period. The average difference between those predicted prices and the actual prices in the cartel period will give an estimate of the average overcharge across the cartel period.[45]

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[43] Baker and Rubinfeld (1999); *see also* Brander and Ross (2006), p. 351: "… estimation of reduced-form price equations is the preferred and most commonly applied method for damage estimation by economists in price-fixing cases."

[44] There are many variations to this, of course, including the use of customer fixed effects, product fixed effects, and the variation of the cartel indicator variable across time, product, geography, or some other dimension. Interactive effects between variables are also routinely estimated and variables may be in logs or levels. Dynamic models are also sometimes used, as are instrumental variable techniques on, say, endogenous cost measures. For our purposes we will stick to this simple form.

[45] For discussion of these two approaches, *see* Finkelstein and Levenbach (1983), p. 156; Brander and Ross (2006), p. 352; Nieberding (2006), at 367–371.

One important thing to note is that in antitrust cases, unlike in most academic research, the experts typically have detailed proprietary transaction data at their disposal. Thus, models may be run on many thousands and even millions of observations. In *Rail Freight*, plaintiffs' expert was able to run his model on almost every rail cargo shipment made in the United States over a nine-year period, a total of 90 million transactions (although there is some aggregation used in the model resulting in 15 million observations).[46] In *Eggs*, plaintiffs' expert ran his model on almost every egg sold in the United States in a 17-year period, a total of 32.7 million transactions.[47] One of the reasons that these models are run on so many observations is a desire to include as many class member transactions as available and avoid any possible critique of extrapolation. As a practical matter, aggregation necessarily involves using "averages," a term that has raised suspicions in the wake of *Hydrogen Peroxide*, although often some form of aggregation to the level of the right-hand side variables is used. Because proprietary transaction data is often detailed with many product and customer attributes recorded, relatively high explanatory power can often be achieved. The *Rail Freight* model explained 86% of price variation and the *Eggs* model explained 65% of price variation.[48]

Models of the type described above are designed to estimate aggregate class-wide damages, after a reliable analysis of common impact has been performed. That analysis of common impact can be reliable if it is performed in a rigorous fashion, using tools such as careful evaluation of the economics of the industry in question, the market power of the defendants, the lack of non-defendant substitutes available to class members, the nature of price co-movement and variation, correct use of averages when needed and correlation and cointegration testing if appropriate, as well as visual inspection. Common impact analysis may sometimes include preliminary regression analysis to determine that common factors predominantly determine the variation in the prices paid by class members.[49] In his work, Dr. Rausser has described how a rigorous common impact analysis creates a "maintained hypothesis" that serves as the foundation for the class-wide damages model described in Eq. (1).[50] Based on that foundation, Eq. (1) can then test the hypothesis concerning the quantum of the overcharge. If that overcharge is positive and statistically significant, it can be applied to class-wide sales to calculate class-wide damages. As Dr. Rausser has described, there is a scientific order from common impact analysis to class-wide damage analysis, that should not be reversed.[51]

The trend away from traditional common impact analysis (regardless of how rigorously performed) and towards examining what damage models may say about common impact *in isolation*, has opened the door to two techniques that produce misleading results.

[46] *Rail Freight* (2017), p. 57.

[47] *Eggs* (2015), p. 188.

[48] *Rail Freight* (2012), p. 68; *Eggs* (2015), p. 188.

[49] *Rail Freight* (2012), p. 62.

[50] Macartney and Rausser (2016), pp. 62–63.

[51] *Ibid*.

5.2.1 Sub-Regressions

Defendants' experts' often take Eq. (1) and run it separately for each customer *i*. Although to a layperson this may seem like a natural thing to do if one wants to know what the model says about common impact—*i.e.*, whether each customer suffered an overcharge—economists will immediately recognize that this method is fraught with difficulties.[52] While experts tend to have very many transactions available to them, there can also be very many class members. Some of those class members will be small and will have made relatively few purchases, such that Eq. (1) cannot be run reliably on their transactions alone. Also, if a customer has few transactions in the benchmark relative to the class period, or *vice versa*, estimating a reliable overcharge can be difficult. A variation on running Eq. (1) for each customer is to run it on all customer transactions but allow the cartel indicator variable D_t to be different for each customer. This method generally stands a slightly better chance of estimating the coefficients on the control variables, but suffers from mis-estimated overcharges for customers with few transactions in the cartel period, in the benchmark period, or in both.[53] Nevertheless, the sub-regression method is advocated by several experts who tend to work on the defense side of class actions.[54]

Some courts have rejected the use of sub-regressions, but others have been willing to embrace them. In *Air Cargo* (a cartel price-fixing case) the court was "not persuaded that [defendants' expert's] sub-regressions are particularly compelling…because they are fundamentally mis-specified…"[55] However, in *Plastic Additives* (another cartel price-fixing case), the court was persuaded. In that case, defendants' expert's sub-regressions (using plaintiffs' expert's model) produced coefficients of different sign and magnitude on what should be systematic price determinants, such as costs. Defendants' expert argued that such differences might be expected because "one customer may be a 'very aggressive negotiator,' and so even as costs go up, that customer is able to 'extract lower prices.'"[56] Such arguments eschew traditional market economics and what it means to have systematic, exogenous price determinants in a reduced-form model run on purchases occurring in a well-defined market. Yet, they can be convincing. The court in *Plastic Additives* concluded that "Plaintiffs jump to an unsupported conclusion when they argue that

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[52] In direct actions (*i.e.*, cases on behalf of just one plaintiff) it can be reliable and desirable to first run Eq. (1) for the entire market and then run it for the one plaintiff in question to provide a specific measure of damages for that plaintiff. Whether it is reliable or not will depend on the amount of data available for that one plaintiff and the nature of its variation. In such cases, damages may be presented using the estimated overcharge from Eq. (1) for the full market and the estimated overcharge from Eq. (1) for the one plaintiff in question.

[53] Brander and Ross (2006), pp. 353–354: "The investigator will need data from both inside and outside the cartel period …. In addition to needing data of high enough quality, we need it to be of sufficient quantity. Precise estimates require a large number of observations."

[54] Johnson (2011); Cremieux et al. (2009-2010); Johnson and Leonard (2007, 2011).

[55] *Air Cargo* (2014).

[56] *Plastics Additives* (2010).

the individual regressions are therefore misspecified. We find that the inconsistency is explained by market realities."[57]

5.2.2 Predicting Individual But-for Prices

Another method currently popular with defense experts is to use Eq. (1) to predict *but-for* prices for the individual transactions in the data. That is, the prices *but-for* the cartel, meaning the prices each customer would have paid on each transaction in the counterfactual world where there was no cartel in operation. Defense experts would then calculate the so-called individual "overcharge" for each transaction as the difference between the actual price paid and this estimated but-for price. Defendants' expert will argue that if there truly is a common impact, this individual "overcharge" should be positive for every transaction in the cartel period or for at least one transaction for each class member in the cartel period. In theory, Eq. (1) would be used to calculate but-for prices by "setting other variables at their value in the period of interest [*i.e.*, the cartel period] and setting the indicator variable for price-fixing [*i.e.*, D_t] at zero to reflect what would happen if price-fixing were not present."[58] Similarly, the forecasting approach described above would be used by defense experts to estimate a set of predicted (or forecasted) but-for prices for the transactions in the cartel period. These would then be compared to the actual prices for those same transactions to estimate the individual "overcharge" for each transaction.

But, although such an exercise can mechanically be performed, this is not the purpose of the model described in Eq. (1). Also, obviously, there will be prediction error which, although not a problem for estimating the average overcharge because those prediction errors cancel out, will be a serious obstacle to estimating individual, transaction-level overcharges. In most regression models—perhaps all—there will be instances when some individual overcharges are found negative; there are likely to be more such instances when the model has lower explanatory power and overcharges are low. In a sense, smaller overcharges can be swamped by high prediction errors.

5.3 *Four Recent Rulings*

In recent years, some courts have been convinced by plaintiffs' expert's careful common impact analysis and their class-wide damages models, rejecting defendants' experts' attempts to turn the damage models against common impact. Other courts have gone in the opposite direction. The first two cases described here (*Eggs*

[57] *Id.,* 39.

[58] Brander and Ross (2006), p. 352.

and *Packaged Seafood*) are examples where plaintiffs' experts have prevailed. The second two cases (*Rail Freight* and *Optical Disk Drives*) are examples where defendants' experts have prevailed.

5.3.1 Eggs

This case involved allegations of collusive supply reduction by the main egg companies in the United States.[59] At class cert, plaintiffs' expert offered a thorough analysis of common impact, based on a detailed industry analysis and detailed pricing analysis including the use of cointegration tests.[60] For class-wide damages, plaintiffs' expert also implemented a regression model estimating an average overcharge for the class.[61] Defendants' experts attacked that analysis and ran the regression model on individual customer data (the so-called "sub-regressions") to show instances of negative overcharges as an attempt to undermine common impact. The court rejected their use of sub-regressions, correctly stating: "[b]y narrowing the amount of data, [defendants' expert] necessarily makes the regression more unstable and unreliable."[62] Concerning plaintiffs' expert's model, the court concluded that[63]:

> *even though the use of a single average overcharge to demonstrate the impact of a conspiracy across the class can be problematic, Plaintiffs have laid a* ***sufficient foundation for the inferential finding that the impact reflected in the single average overcharge was shared by virtually every class member***
>
> …
>
> *As the Court has discussed, Defendants have largely not contested the results of the pricing structure analysis conducted by [plaintiffs expert], which found that class members would not have been able to escape the effects of the conspiracy, because the egg industry is an integrated, nationwide commodity with significant demand- and supply-side substitutability.*

The court granted class cert.[64] The decision is interesting because the court accepted plaintiffs' expert's common impact analysis and its inference regarding all, or virtually all, of the class members being impacted. It also rejected defendants' expert's misuse of plaintiffs' expert's damage model in isolation, in an attempt to disprove common impact.

[59] In this case, Dr. Rausser served as plaintiffs' expert.

[60] *Eggs* (2015).

[61] *Id.,* 183.

[62] *Id.,* 189.

[63] *Id.,* 199 (emphasis added).

[64] *Id.,* 204.

5.3.2 Packaged Seafood

This case centered on allegations that the three major sellers of canned tuna in the United States conspired to artificially raise prices and downsize their cans so that the effective price increased.[65] Plaintiffs' class expert used "several forms of evidence, including findings concerning the canned tuna market in general, documentary evidence from the record, and most importantly—and most in contention—econometric analysis in the form of a regression model which purports to prove that the price-fixing conspiracy harmed all, or nearly all, of the Class members."[66] His determination on common impact was based on "both qualitative nonempirical work and empirical statistical analysis."[67] That non-empirical work included the defendants' guilty pleas concerning certain of the allegations against them, the experts' evaluation of the defendants' business practices which he found consistent with the alleged conspiracy, the dominant market share of the defendants, barriers to entry (capital costs, brand awareness, distribution agreements, *etc.*), defendants' ability to communicate with each other, their standardized products and use of common price lists, and the inelastic demand for tuna, all of which pointed to common impact.[68] Plaintiffs' expert then performed price correlation analysis using the defendants' sales data, the court noting his assertion that "[a]lthough price correlation models cannot prove a conspiracy's existence or common impact on its own…this type of evidence can be helpful in understanding industry behavior and show a likelihood of common impact."[69] Finally, plaintiffs' expert "use[d] a reduced-form regression model to estimate overcharges of canned tuna at the wholesale level."[70] As well as using the model to estimate an average overcharge for the putative class, plaintiffs' expert conducted "robustness checks by estimating overcharges specific to each of the Defendants, as well as separately based on fish type, package type, and for private label products."[71]

Defendants' expert countered by using the sub-regression method described above.[72] Specifically, running plaintiffs' expert's model allowing the overcharge estimate to be different for each of the 604 putative class members, claiming to find that only 72% of them suffered a positive and statistically significant overcharge.[73] The court commented that "[a]t first glance, this seems to be a major flaw with [plaintiffs' expert's] model," because "[a] model unable to show impact to over 28%

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[65] *Packaged Seafood* (2019), 316–317. The author was involved in this case as an expert for one of the opt-out plaintiffs.

[66] *Ibid.*, 320–321.

[67] *Ibid.,* 321.

[68] *Packaged Seafood* (2019), 320, 328.

[69] *Id.,* 322.

[70] *Ibid.*

[71] *Id.*, 323.

[72] *See* Sect. 5.2.1.

[73] *Packaged Seafood* (2019), 323.

of the class members would unquestionably surpass the *de minimis* standard," which states that uninjured class members must only constitute a *de minimis* number for a class to still get certified.[74] Plaintiffs' expert's reply to these sub-regressions was that many class members either: (1) did not make enough purchases for estimation of an individual overcharge to be possible *at all*[75]; or, (2) did not make enough purchases for estimation of an individual overcharge to be *statistically significant*. Considering this, the model showed that "looking at only the statistically significant results, 98% of the [putative class members] showed positive overcharges."[76]

Defendants' attorneys responded with the simple but often successful (as we shall see in the next two rulings I discuss) argument that if the model cannot estimate overcharges for class members with insufficient purchases then "common issues do not predominate" and "the Class members without sufficient data to produce results will have to prove their cases using evidence not common to the Class."[77] The court was unconvinced by this argument and, in granting class cert, found that "these Class members would still be able to point to the same econometric model as it pertains to similarly situated Class members as proof. This, along with the record evidence, guilty pleas, and market characteristics, shows that all Class members will still use common evidence and that common questions will continue to predominate over the case."[78] In sum, despite defendants' best efforts to focus the court's attention solely on what the regression model suggested about common impact when decomposed into sub-regressions, the court considered plaintiffs' expert's common impact analysis as a whole.

5.3.3 Rail Freight

This case involved allegations that the four major Class I railroads in the United States conspired to apply fuel surcharge formulas that over-recovered on fuel costs to their cargo shipping customers.[79] At class cert, plaintiffs' expert implemented a regression model that estimated the average weekly overcharge, which varied with the price of fuel due to the formulaic nature of the fuel surcharge formulas.[80] The expert also performed a detailed analysis of common impact, based on the facts of the industry (such as most shippers lacking options other than rail by which to transport their goods, and so on). In 2012, the District Court granted class cert based on plaintiffs' expert's common impact analysis and class-wide damages model. The

[74] *Id.,* 323–24.

[75] This would occur for class members who made purchases only in the conspiracy period and none in the benchmark period.

[76] *Packaged Seafood* (2019), 324.

[77] *Ibid.*

[78] *Ibid.*

[79] In this case, Dr. Rausser served as plaintiffs' expert.

[80] *Rail Freight* (2012), 66–67.

District Court agreed with plaintiffs' expert that his damage model did not "in isolation attempt[] to prove common injury-in-fact [*i.e.*, common impact]. Rather, the result of the damage model 'must be viewed as the final step in the body of evidence [*e.g.*, market analysis] …presented' to show that injury-in-fact is capable of common proof."[81]

Defendants appealed. In 2013, the D.C. Circuit Court of Appeals overturned the lower court's decision.[82] The appellate court was concerned by defendants' expert's assertion that plaintiffs' expert's damages model suffered from "false positives."[83] Defendants' expert had made this argument to the District Court, but it was not addressed at that time.[84] In contrast, the D.C. Circuit found the argument more compelling in light of *Comcast*.[85] The case was remanded back to the lower court for reconsideration, including further expert reports (defendants using a different expert than first time around). This time, the lower court denied class cert. Of most interest for this chapter, the court was persuaded by defendants' new expert's assertion that plaintiffs' damage model showed some class members were not impacted. Defendants' expert claimed to have taken that model and used it to predict the individual transaction prices that would have occurred absent the conspiracy (so-called "but-for" prices, using one of the methods described in Sect. 5.2.2 above). He argued that comparing these individual predicted but-for prices to actual prices provided a measure of individual "overcharges" and that in doing so he had found negative individual "overcharges" for 2037 of the 16,065 class members.[86] It should be noted that these supposedly uninjured shippers were very small, representing only 0.04% of class revenue.[87] Plaintiffs' expert explained that the result was due to ordinary prediction error, which affects class members with fewer shipments more so (because for large class members such individual transaction errors will average out).[88] But, although the court accepted this in principle, it found that prediction error could not explain all of the uninjured shippers[89] and that plaintiffs had not suggested a method for identifying which of the 2037 were in reality impacted. Also, despite the tiny share of revenue associated with the uninjured shippers, the court found the number was "more than de minimis and insufficient to demonstrate impact on a class-wide basis."[90] Plaintiffs appealed the decision, but it was upheld

[81] *Id.*, 69.

[82] *Rail Freight* (2013).

[83] This issue is not the subject of this chapter and will not be discussed further, other than to say that plaintiffs' expert did not agree with such a characterization.

[84] *Rail Freight* (2013), 253.

[85] "As we see it, [*Comcast*] sharpens the defendants' critique of the damages model as prone to false positives." *Ibid.*

[86] *Rail Freight* (2017), 136, 140–41.

[87] *Rail Freight* (2017), 136, 140–41.

[88] *Id.*, 138.

[89] Its basis for this finding is unclear. *Id.*, 139.

[90] *Id.,* 141.

by the D.C. Circuit solely on the basis of this argument about supposedly uninjured shippers; no other issues were considered.[91]

What is interesting about *Rail Freight* is that it typifies the evolution of the burden being placed on regression models in antitrust class actions. In its initial decision, the district court was persuaded that plaintiffs' expert's damage model did not "in isolation attempt[] to prove common injury-in-fact [*i.e.*, common impact]."[92] But by its second decision (upheld on appeal), it *was* persuaded by defendants' expert's use of the same model to perform a test of common impact in isolation from all other analysis.

5.3.4 Optical Disk Drives

This case involved allegations that the main manufacturers of optical disk drives engaged in a global price-fixing cartel.[93] According to the court, plaintiffs' class expert offered "three basic categories of opinions."[94] The first was that he described market conditions that showed the industry was conducive to collusion. The court noted that "there is no real dispute that the factors identified by [plaintiffs' expert] as being 'conducive' to anticompetitive activity existed in the industry."[95] However, the court said "[a]s defendants correctly argue…while such industry characteristics may be preconditions for any colorable case of class-wide impact, they do not establish such impact."[96] Second, plaintiffs' expert contended that the alleged price-fixing conduct would have had a common impact because defendants' most-favored nation clauses in contracts with key customers would have linked prices together.[97] But, as the court noted, plaintiffs' expert "does not suggest his opinions about market conditions and the most-favored nation clauses suffice to establish class-wide impact."[98] Rather, he relies on his third category of opinion, which employed correlation and regression analysis. The court was unconvinced by the correlation analysis, because plaintiffs' expert "testified, '[w]ith or without a conspiracy I would expect to see high correlation of prices across customers in this industry.'"[99] This appears to miss the point in that the correlation analysis was aiming to show common impact—*i.e.*, that *if* there was a conspiracy, then prices would increase commonly—rather than to

[91] *Rail Freight* (2019), 620.

[92] *Rail Freight* (2012), 69.

[93] The author was involved in this case as an expert for one of the opt-out plaintiffs.

[94] *Optical Disk Drives* (2014), 320.

[95] *Ibid.*

[96] *Ibid.*

[97] *Ibid.*

[98] *Ibid.*

[99] *Id.*, 321.

show that there was, *in fact*, a cartel in operation. Regardless, the court was also unconvinced that the regression analysis showed common impact[100]:

> *[plaintiffs' expert's] regression analysis is, by his own characterization, designed to determine 'how much lower prices would have been but for the alleged conspiracy.' To that end, [he] applies a model in which the alleged conspiratorial overcharge is assumed to be the same for all purchasers across all models of ODDs and throughout the entire class period. Whatever utility such an approach might have in calculating a damages total, it cannot serve to establish that all (or nearly all) members of the class suffered damage as a result of defendants' alleged anti-competitive conduct.*

The court was also persuaded by defendants' expert's use of sub-regressions to undermine plaintiffs' expert's model. Although the court decided it did not need to conclude whether the sub-regressions were reliable, the technique led plaintiffs' expert to admit that the model essentially assumed common impact. The court was not satisfied with this[101]:

> *[Defendants' expert], purporting to show that if [plaintiffs' expert's] regression model is modified to allow estimates of overcharges to be made for different customers, ODD types, and time periods, it establishes a lack of class-wide impact, and proves that many direct purchasers incurred no statistically significant overcharge. Whether [defendants' expert's] modification to the models are analytically sound need not be decided at this juncture. Regardless of what those modifications do or do not show, [plaintiffs' expert's] unmodified model makes no attempt to establish, but instead simply assumes, class-wide impact.*

In sum, the court declined to find market analysis and correlation analysis as being probative to common impact. Looking to plaintiffs' expert's damage regression model for proof that all class members were injured, the court found the model wanting because, by the expert's own admission, its primary function was to calculate the overall overcharge suffered by the putative class, *i.e.*, class-wide damages. The court denied class cert.

Each of the four cases discussed in this section has its own distinct facts and allegations. However, there are also similarities, despite the wide divergence in outcomes. All four involved allegations of horizontal price-fixing by companies that collectively dominated their industries. In all four, plaintiffs' experts offered market analyses, factual analyses of the defendants' anticompetitive behavior, correlation, and regression analysis, to show that liability, impact, and damages could be proven using common evidence. In all four, defendants' expert turned plaintiffs' expert's model against him, using it to offer some form of sub-regression analysis or estimation of individual but-for prices, to show that the model on its own could result in findings that cut against common impact. Yet, in two cases the court was convinced by the plaintiffs' expert and in two cases the court was convinced by the defendants' expert.

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[100] *Ibid.*

[101] *Ibid.*

6 The Future

Economists rely on formal hypothesis testing using regression models and other statistical techniques. But economists also rely on economic theory applied to market realities to formulate opinions and infer market outcomes. As the recent rulings described above show, some courts are comfortable with that approach in antitrust class actions. Others are increasingly looking to statistical tests for common impact, as well as the traditional regression model to prove class-wide damages. It is impossible to tell which approach will prevail and both may persist across different courts for years to come. A number of alternative approaches may be considered going forward.

6.1 Hypothesis Testing of Common Impact

Dr. Rausser and this author have written concerning economic principles for sound analysis at class cert, emphasizing scientific hypothesis formulation and empirical testing.[102] Techniques increasingly employed by defendants' experts at class cert, such as sub-regressions, do not follow those sound principles. Often, there is no formal hypothesis being tested, no theory or facts to suggest which class members would suffer an overcharge and which would not. Simply, a model intended to be run on a market is instead run one customer at a time, even if the data for some customers is severely limited. The assertion by the advocates of such techniques that the hypothesis they are testing is plaintiffs' expert's "assertion that a proposed 'common' regression model provides a reliable determination of injury for all or virtually all class members," is facile.[103]

That said, regression models can be used to test whether effects are common across a class or differ among groups of well-defined class members. As Dr. Rausser and this author have written, those tests can be conducted in a scientific manner and one can ensure that there is sufficient data in each group to perform a reliable test[104]:

> *One can hypothesize, for example, based on theory and factual evidence outside of the transaction data itself, that some group of class members was able to bargain its way out of a price-fix. This could include large customers with strong bargaining power or customers closer to non-conspiratorial suppliers. Support for this hypothesis may come from discovery documents or other evidence that suggest such customers were exempt from the price-fix. Then, to investigate this hypothesis, an expert can include variable(s) into the model that test if the quantum of harm is different for this group compared to the rest of the class, investigating whether any such differences are both statistically and economically significant.*

[102] Macartney and Rausser (2016).

[103] Haider et al. (2016), p. 53.

[104] Macartney and Rausser (2016), p. 64.

Such approaches have been used successfully at class cert. As described above, plaintiffs' expert in *Packaged Seafood* conducted "robustness checks by estimating overcharges specific to each of the Defendants, as well as separately based on fish type, package type, and for private label products," which appeared to help the court find in favor of class cert.[105] However, there is a limit as to how granular such tests can viably become. As the group sample sizes decrease, finding statistically significant results can be difficult. Or worse, with many groups and endless data mining, such as in the class member specific sub-regressions, statistically significant but spurious results can be found. Thus, if courts insist on models that in and of themselves, without reference to other facts, establish that virtually all class members were overcharged, other methods to improve prediction may eventually be considered.

6.2 Better Prediction Through Machine Learning?

At the start of this chapter, we recalled how in the mid-1980s Franklin Fisher wrote that lawyers understand models cannot explain all the variation in real world data, but they "do not like it."[106] His reasoning was prescient, especially with respect to class actions[107]:

> *Statisticians are used to the idea that regression equations do not generally fit the data perfectly… There will always be unexplained deviations from the regression plane. Lawyers may understand this in principle, but they do not like it. Attorneys, presented with a general argument, tend to think in terms of counterexamples, and the fact that not all observations lie in the regression plane may seem to them to provide **ammunition for the opponent**.*

Indeed, the unexplained variation inherent in regression models has provided ammunition for defense lawyers arguing against class cert, to great effect in some cases. Fisher warned that experts "cannot simply mine the data until a satisfactory model is found to fit the sample. To do so…vitiates any claim as to the statistical properties of the model."[108] However, recently economists fueled by the availability of big data and enormous computing power, have turned to techniques such as machine learning that apply data mining methods with a focus on prediction. Economists have recently written: "[p]ut succinctly, machine learning belongs in the part of the toolbox marked $\hat{y}$ rather than in the more familiar $\hat{\beta}$ compartment. This perspective suggests that applying machine learning to economics requires finding relevant $\hat{y}$ tasks."[109] Predicting individual class member but-for prices is

[105] *Packaged Seafood* (2019), 323.

[106] Fisher (1986), p. 278.

[107] *Ibid* (emphasis added).

[108] *Id.*, p. 279.

[109] Mullainathan and Spiess (2017). $\hat{y}$ is used by econometricians to denote a predicted outcome (*e.g.*, a predicted individual transaction price) and $\hat{\beta}$ is used to denote a coefficient estimate (*e.g.*, an estimated overcharge percentage).

one such $\hat{y}$ task and it is natural to explore how machine learning could be applied in this context.

In contrast to traditional econometric modelling, which first uses theory to design a model and then runs that model on data to test which variables are statistically significant, machine learning goes in the opposite direction. It eschews theory and instead uses algorithms to choose both the explanatory variables and their parameter values based on an objective function that minimizes unexplained variation in-sample. Unsurprisingly, left to run amok, machine learning will overfit, explaining well in-sample, but terribly out of sample. To mitigate this, machine learning uses "regularization." Regularization penalizes model complexity and large model parameters that may be driven by idiosyncratic in-sample variation. The strength of regularization is often set by one or more "hyperparameters" that are chosen through "empirical tuning." Empirical tuning chooses the regularization hyperparameter to maximize the accuracy of out-of-sample prediction. In practice, empirical tuning can be implemented using "k-fold cross validation," where the data is split into k subsets (or "folds"), one fold is used to test out-of-sample prediction for a model that is formed (or "trained") on the other k-1 in-sample folds. This is repeated k times, with each of the k-folds taking its turn as the out-of-sample test fold.

The most straightforward method for those of us used to traditional econometric modelling to understand is elastic net, which chooses the coefficients ($b_1,\ldots,b_p$) by minimizing the sum of the squared residuals (*i.e.*, ordinary least squares) plus the following "penalty term;"[110]

$$\lambda \sum_{p=1}^{P} \left[(1-\alpha)|b_p| + \alpha |b_p|^2 \right].$$

This penalizes model complexity (too many coefficients and therefore too many explanatory variables) and, particularly, large coefficients through the quadratic term. The hyperparameters are the weights λ and α, and their values are chosen using empirical tuning often in the form of k-fold cross validation.[111]

There are many other machine learning techniques, such as classification trees, regression trees, random forest and neural networks.[112] But the principles of using an algorithm to choose the explanatory variables that result in the best prediction, with regularization to mitigate overfitting and empirical tuning to maximize out-of-sample prediction are generally common across them. A number of economists have found these methods to be better at prediction than traditional estimation.[113] Naturally, the methods benefit from the availability of large amounts of data. In some class actions, although not all, experts can have at their disposal lots of data,

110 Varian (2014).

111 When $\lambda = 0$ this reduces to ordinary least squares, when $\alpha = 1$ this is known as "ridge regression" and when $\alpha = 0$ it is known as *LASSO*, standing for least absolute shrinkage selection operator.

112 Varian (2014); Athey and Imbens (2019).

113 Mullainathan and Spiess (2017) found that LASSO and random forest were better than ordinary least squares at predicting house values out-of-sample.

with high dimensionality. For instance, in *Eggs* proprietary transaction data was produced covering practically every egg sold in the United States over a 17-year period. In *Rail Freight*, the available data covered practically every rail cargo shipment made in the United States over a 9-year period; hundreds of millions of carloads, with all conceivable shipment characteristics (commodity, route, car type, weight, departure and arrival times, prices, and so on).

The possibility of machine learning being applied in antitrust cases is not inconsistent with techniques used in the past. As we described in Eq. (1) in Sect. 5.2 above, reduced form models are traditionally used to estimate overcharges, comparing a cartel period to a competitive benchmark period, while controlling for systematic differences between the two that affect pricing. Often the model is run on both periods and a dummy variable distinguishing the two captures the overcharge. But, as we described in Sect. 5.2, experts have in the past estimated such models in the benchmark period and then predicted but-for prices in the cartel period, comparing them to actual prices in order to calculate overcharges (known as the forecasting approach). This is very similar to how Hal Varian describes machine learning being used to estimate the effect of an advertising campaign on website visits (Varian, 2014, p. 23). Machine learning can be used to train and test a model on website visits in a period before the advertising campaign (in our case, a competitive benchmark period) and then be used to predict what visits would have been in the campaign period (in our case, a cartel period) absent the campaign; the difference with actual visits in that period giving the effect of the campaign (in our case, an overcharge).

6.2.1 An Illustration

In this section, we provide an illustration of how machine learning techniques might theoretically be used to investigate antitrust overcharges in a dataset of individual transactions. Transaction data produced in litigation is often proprietary and cannot be used in a publication such as this. So, we use publicly available transaction data on household purchases over a two-year period of four product categories: syrup, pancake mix, pasta sauce, and pasta, (Dunnhumby, Carbo-Loading: A relational database (2014)). We focus our analysis on syrup and pasta sauce, modelling each separately. We increase log prices on all of the transactions in the second year by 0.2, roughly a 20% overcharge,[114] assuming that in this year a price-fixing cartel was in operation and was successful. The first year can then be used as a competitive benchmark. Although the data is limited in that it only covers 2 years and the providers do not indicate which years those are, it is sufficient for illustrative purposes. The method we adopt to estimate overcharges is the "forecasting approach," described above in Sect. 5.2. That is, the model is estimated (or "trained" when we use machine learning) in the benchmark period and then used to predict (or

[114] We work in log prices for simplicity. The addition of 0.2 to log prices equates to a 22.1% (*i.e.*, 100*(exp(0.2)−1)) increase in price levels, thus roughly 20%.

Table 2 OLS model results—estimated on the benchmark period

Explanatory variables	Syrup	Pasta sauce
Log package size (oz.)	−0.517***	−0.526***
Month trend	−0.001***	−0.002***
Brand fixed effects	Yes	Yes
Display fixed effects	Yes	Yes
Feature fixed effects	Yes	Yes
County fixed effects	Yes	Yes
Constant	−0.927	−0.009
R-squared	0.81	0.66
Observations	350,278	994,962

Three stars indicate statistical significance at the 99% level of confidence.

"forecast") but-for prices into the cartel period (*i.e.*, the prices that should have occurred absent the cartel). The differences between those predicted but-for prices and the actual prices in the cartel period can be viewed as an estimate of the individual overcharge for each transaction. The average of those individual overcharges may thus represent the class-wide overcharge (the class in this case being the households that purchased in the cartel period) and we can also investigate how well the model does at detecting individual overcharges (which we have, by construction, set equal to an increase in log price of 0.2 for all transactions in the cartel period).

Table 2 presents the results of a simple OLS model estimated in the benchmark period for syrup and pasta sauce. The dependent variable is log price per ounce and the model includes log package size (ounces) as an explanatory variable (its coefficient is negative as one would expect given bulk discounting), a monthly trend, and fixed effects for brand, product display characteristics, featured promotions, and county of store location. Both models explain a reasonable amount of variation and are similar to the types routinely used in class actions.

Tables 3 and 4 present the mean of the individual overcharges, the standard deviation of the individual overcharges, and the percent of transactions in the cartel period that have negative overcharges (*i.e.*, where the predicted but-for price is greater than the actual price, instead of less than), for syrup and pasta sauce, respectively. The first row in each table presents the "reality" given our construction of a 0.2 increase in log prices (*i.e.*, roughly a 20% overcharge in price levels) on all transactions in the cartel period. The second row in each table ("OLS (selected variables)") presents the results when the OLS model estimated in Table 2 is used to predict but-for prices in the cartel period that are then compared to the actual prices in that period to calculate individual transaction overcharges. The OLS model performs reasonably well, but due to prediction error it (erroneously) finds that 12.8% of the syrup transactions and 11.2% of the pasta sauce transactions experienced negative overcharges. As we have discussed, such a finding may result in a denial of class cert (likely after a debate among the attorneys as to what "all or virtually all" means).

Table 3 Syrup model results

Model	Mean of overcharges (changes in log prices)	Standard deviation of overcharges (changes in log prices)	Percent of transactions with negative overcharges
Reality	0.200	0.000	0%
OLS (selected variables)	0.198	0.199	12.8%
LASSO	0.209	0.159	6.7%
Elastic Net	0.244	0.147	3.3%
Regression Tree	0.175	0.127	6.9%
Gradient Boosted Regression Tree	0.174	0.126	6.7%
Random Forest	0.177	0.121	6.2%
Neural Network	0.239	0.143	5.5%
OLS (all variables)	244.290	52.794	0.0%

Table 4 Pasta sauce model results

Model	Mean of overcharges (changes in log prices)	Standard deviation of overcharges (changes in log prices)	Percent of transactions with negative overcharges
Reality	0.200	0.000	0%
OLS (selected variables)	0.213	0.232	11.2%
LASSO	0.257	0.175	5.0%
Elastic Net	0.177	0.175	8.0%
Regression Tree	0.149	0.173	18.0%
Gradient Boosted Regression Tree	0.149	0.168	17.6%
Random Forest	0.161	0.145	8.4%
Neural Network	0.039	0.234	34.5%
OLS (all variables)	491.544	104.084	0.0%

The remaining rows in Tables 3 and 4 (except for the last one in each) run a set of machine learning algorithms, each one training a model in the benchmark period using k-fold cross validation and regularization, that is then used to predict but-for prices in the cartel period used to calculate overcharges, as before. However, for the machine learning models, we offer the algorithms every variable we can construct from the dataset.[115] This makes sense because the comparison we are making is

[115] Which includes all of the variables used in the OLS model (*i.e.*, log package size, month trend, brand, display, feature, and county fixed effects), as well as the log price per ounce of pasta/pancake mix (*i.e.*, obvious complements), coupons, median household income for each county in 2010, store fixed effects, number of stores within the surrounding zip code of each store, package size fixed effects, product fixed effects, and county-month trends. Some of these variables will be

between a simple reduced-form econometric model designed based on economic theory (our OLS model) and machine learning techniques that consider many variables, unconstrained by theory.

As shown in Table 3 for syrup, the machine learning algorithms always perform better than our OLS model in finding fewer transactions with so-called negative overcharges. The best performer in this regard is elastic net which finds only 3.3% of transactions negatively overcharged (compared to 12.8%, for our OLS model).

As shown in Table 4, the results for pasta sauce, the results are more mixed. Half of the machine learning algorithms perform better than OLS in finding fewer transactions with negative overcharges. The best performer in this regard is LASSO, which finds only 5.0% of transactions negatively overcharged (compared to 11.2%, for our OLS model), although this comes at some expense in terms of the accuracy of the mean overcharge estimate.

At this stage, the obvious question is how would OLS do if we used the full set of variables that we are offering the machine learning algorithms? The answer in this case is: not very well. We show this in the final row of Tables 3 and 4. For both syrup and pasta sauce, when we offer all of the potential variables to OLS there is a massive overfitting problem, which results in nonsense overcharge estimates.

Finally, in Figs. 4 and 5 we present the distribution of overcharges for each model, for syrup and pasta sauce respectively, with the vertical pink line indicating the constructed overcharge. In class actions, the distribution of overcharges can also matter, as well as the percentage that are negative. For instance, a finding that all of the overcharges are positive can be undermined if some significant proportion of them are too high to be believable. As we can see from the distributions here (and from the standard deviations in the prior tables), the regression tree algorithms may not produce the lowest number of negative overcharges, but they can produce quite tight distributions with the highest number of transactions having the constructed overcharge (*i.e.*, highest green bar, along the pink line).

The illustrative analysis just presented is based on a dataset that, although useful, is somewhat limited and the models are highly simplified. The analysis is not offered as any demonstration that machine learning algorithms are "better" than traditional econometrics for class action analysis. Nevertheless, we feel it describes well how machine learning could theoretically be used and what advantages it may offer, although likely in combination with traditional modelling.

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collinear and would not appear together in a traditional econometric model, but recall that the machine learning algorithms will choose which ones to include and which to exclude based on predictive performance.

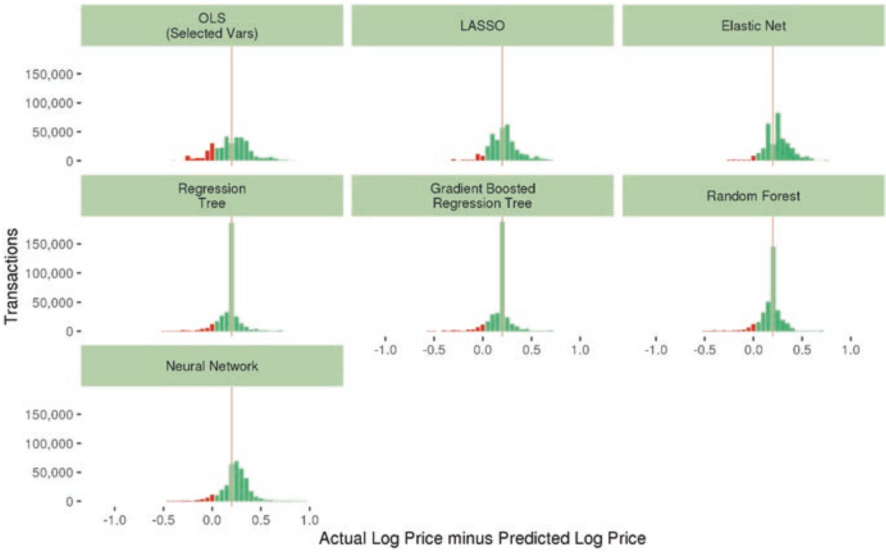

Fig. 4 Distributions of Individual Overcharges, Syrup

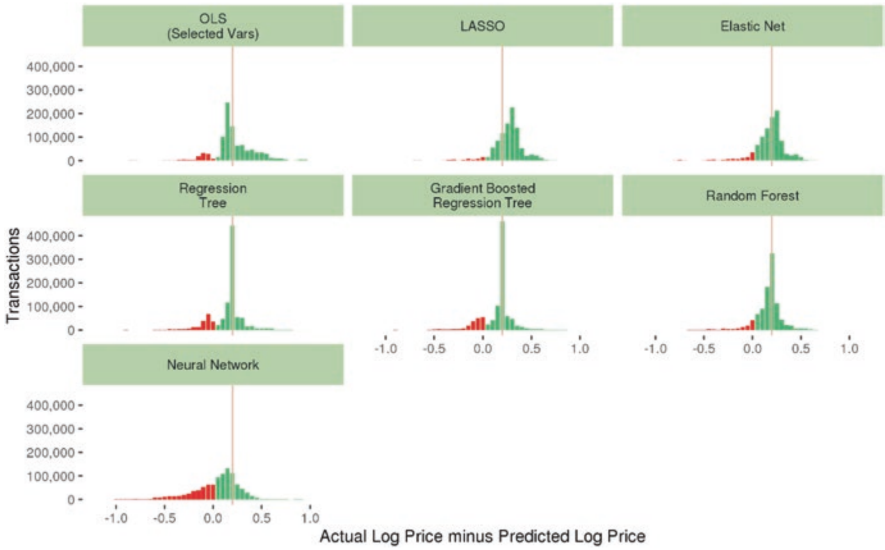

Fig. 5 Distributions of Individual Overcharges, Pasta Sauce

6.2.2 Challenges

So far, so good. But, as is hopefully apparent from our discussion above, the application of economics to litigation in general, and class actions in particular, comes with its own unique set of hang-ups that will prove challenging for machine learning to overcome, at least in the near future. We discuss these issues now.

What Sorcery Is this?! That Is, It's New

Generally, expert work is not the place for new techniques that are not yet fully accepted by the expert's profession. Testimony by expert witnesses is governed by Federal Rule of Evidence 702[116]:

> *A witness who is qualified as an expert by knowledge, skill, experience, training, or education may testify in the form of an opinion or otherwise if: (a) the expert's scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue; (b) the testimony is based on sufficient facts or data; (c)* ***the testimony is the product of reliable principles and methods****; and (d) the expert has reliably applied the principles and methods to the facts of the case.*

This amended version of Rule 702 was motivated by the 1993 United States Supreme Court's ruling in *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, which found, among other things, that the trial judge served a "gatekeeping" function to protect the jury from pseudoscience.[117] *Daubert* also found that, although "general acceptance" of a technique in the relevant scientific community "is not a necessary precondition to the admissibility of scientific evidence under the Federal Rules of Evidence," general acceptance "can yet have a bearing on the inquiry."[118] These days, it is common for lawyers on both sides to file what are known as "*Daubert* motions" to convince the judge to exclude the opposing side's expert from trial, and possibly at the class cert stage as well. Losing such a motion is not only damaging for the case at hand, but can have a lasting impact on the expert's career.

Susan Athey has written, "I believe that machine learning (ML) will have a dramatic impact on the field of economics within a short time frame."[119] That may be so, but it is clear that these techniques are not yet fully accepted by the profession and there has been some pushback, as recorded in the trade press.[120] For economists, machine learning is still relatively new and an economist applying it in litigation may struggle to convince a judge that the profession accepts it as reliable. One of the reasons economics is naturally reluctant to accept machine learning is that it eschews theory in favor of data mining. This leads to another potential problem. In discussing the distinction between science and pseudoscience, the Supreme Court's ruling in *Daubert* quoted a book by Karl Popper on that subject which stated: "The criterion of the scientific status of a theory is its falsifiability, or refutability, or testability."[121] But a model designed by a machine learning algorithm does not come with much theory that is falsifiable. The algorithm chooses the variables (and, possibly, interactions between those variables) that explain the most variation (both in

116 Fed. R. Evid. 702 (2011) (emphasis added).

117 *Daubert* (1993), 2800.

118 *Id.,* 2797, 2799.

119 Athey (2019).

120 Mason (2018).

121 *Daubert* (1993).

and out of sample). So, an economist does not need a theory that, say, corn feed costs increase egg prices and that increases in such costs were not sufficient to explain why prices in a cartel period were so high. In fact, if there was little variation in corn feed costs over the time period investigated, the algorithm might not even choose that variable to be in the model at all. And the algorithm, when run on different samples, may choose it as a variable in some and not others. As texts on machine learning make clear: "we must be careful not to overstate the results obtained, and to make it clear that what we have identified is simply *one of many possible models* for predicting."[122]

Not One Model, But Many

Machine learning works best when it uses an "ensemble" of models. That is, what tends to predict better than elastic net, LASSO, ridge regression, trees, random forests, neural networks, and so on, is some weighted average of all these methods in combination. This appears to be a consistent finding.[123] Hal Varian provides an illustrative anecdote[124]:

> *An important insight from machine learning is that averaging over many small models tends to give better out-of-sample prediction than choosing a single model. In 2006, Netflix offered a million dollar prize to researchers who could provide the largest improvement to their existing movie recommendation system. The winning submission involved a 'complex blending of no fewer than 800 models,' though they also point out that 'predictions of good quality can usually be obtained by combining a small number of judiciously chosen methods' (Feuerverger et al., 2012). It also turned out that a blend of the best- and second-best submissions outperformed either of them.*

So, to get the most out of a machine learning approach—*i.e.*, to predict but-for prices sufficiently accurately for a finding that all class members were harmed—an expert may require an ensemble of many models. Although there is a history in economics of using combinations of models, for instance in composite forecasting,[125] it may prove difficult for courts to accept.

Causality

Causality is important in antitrust expert work (as it is in economics in general), because plaintiffs must show that their injury is "of the type the antitrust laws were intended to prevent and…flows from [*i.e.*, is caused by] that which makes

[122] James et al. (2017), p. 243 (emphasis in the original).

[123] Mullainathan and Spiess (2017).

[124] Varian (2014).

[125] Dr. Rausser pointed this out when this chapter was presented at the *Festschrift* conference. *See*, *e.g.*, Johnson and Rausser (1982) and Park and Tomek (1988).

defendants' acts unlawful."[126] In traditional econometric analysis in antitrust cases, an economist can present a model to the court and say that these are the variables that economic theory suggests, and statistical tests confirm, drive pricing in this industry. Prices increased in the cartel period, compared to a competitive benchmark period, more than these variables suggest they should have done. Therefore, in combination with a detailed analysis of the conspiracy evidence in the cartel period, the expert can claim that the model shows that defendants' cartel *caused* prices to increase. As we have described, machine learning is good at predicting prices, but it does not produce a causal model, and may produce very many models, making such a claim more difficult to justify. This issue is exacerbated by the ruling in *Comcast*, which has put a renewed emphasis on causality: plaintiffs' model must estimate the price increase that is only attributed to the act(s) found by the court to be illegal.

In sum, although machine learning is a natural contender to improve prediction such that models can be used as empirical proof that all (or virtually all) class members suffered impact in an antitrust case, there is likely some way to go before these techniques are tried by experts and accepted by courts. It is possible that the hurdles described here can be overcome by a hybrid approach: a traditional econometric model to prove causality and estimate class-wide damages, coupled with machine learning techniques to improve but-for price prediction and support common impact, all in the context of rigorous analysis of the economics and facts of the market in question and the antitrust violation alleged.

7 Conclusion

Dr. Rausser has spent much of his consulting career working on some of the biggest and most complex antitrust class actions in the United States. He has emphasized in that work, and in publications, the sound scientific approach that should be followed at class cert. Over the last 13 years, I have supported him in much of that work. This chapter documents how in that time, initiated by a change of three words in the federal rule governing class actions, there has been a marked increase in the rigor with which courts approach the class cert decision. Due to a confluence of two factors—a greater tendency for experts to run their class-wide damage regressions at class cert to show that they work and an increased emphasis on rigorous proof of common impact—a new burden has been placed on the reduced-form regression models traditionally used in class actions. Such models can struggle to meet that burden, depending on whether the court in question welcomes a holistic approach (market and factual analysis, combined with correlation and regression analysis) or insists that a regression model on its own proves that all, or virtually all, class members were impacted. The future is uncertain, but plaintiffs' experts may need to consider how their models can be used to investigate common impact (as well as

[126] *Brunswick* (1977), 697.

estimate class-wide damages) and may need to consider new techniques to improve individual prediction, even if such techniques will come with their own challenges.

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Part IV
Major Developments in Macroeconomic Linkages, Futures Markets, and Commodity Systems

Macroeconomic Linkages to the Agricultural Supply Chain

H. Alan Love and John Freebairn

1 Background

While on the faculty of Harvard University, Rausser initiated a hedge fund focusing on commodity market futures investment and trading. His experience of managing this fund actually revealed the overshooting phenomenon among the causal links between commodity futures prices, exchange rates, and interest rates. Shortly after he made this discovery, based on empirical observations of the market links, the famous Dornbusch article (Dornbusch, 1976) on overshooting appeared. This chapter is motivated by the seminal contribution of Gordon Rausser and his colleagues regarding macroeconomic linkages with the U.S. agricultural sector. Many of his publications on this topic began in his analytical work on finance, in particular to the futures market in the 1960s and 1970s.

From his direct observations of the futures market, Rausser was able to publish both before, during and after, a large number of scholarly works on commodity future markets. This stream of publications and real-world experiences led to a series of publications (*the Journal of Finance, Journal of American Statistics Association, Journal of Monetary Economics,* three articles in the *Review of Economics and Statistics, AJAE*, and a host of reprints and chapters in various book publications) on macroeconomic linkages with commodity markets whether spot or future. Based on these publications, he was selected on numerous occasions by the Chicago Board of Trade (CBT), the New York Mercantile Exchange (NYME), and

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the Chicago Mercantile Exchange (CME) to give formal presentations at their various conferences documenting his theoretical and empirical results. From the standpoint of impact, CME was successful based on Rausser's presentations and publications in influencing a large number of institutional money-managers to include commodity futures markets as another asset class in their investment portfolios.

The scholarly work on futures markets and finance all culminated in the award-winning 1986 publication in collaboration with Jim Chalfant, Alan Love, and Kostas Stamoulis, The Macroeconomic Linkages with the U.S. Agriculture Sector (Rausser et al., 1986) This seminal work demonstrated for the first time that U.S. agricultural policy programs that offer subsidization to the agricultural sector can be justified by the external macroeconomic conditions reflected by exchange rates and interest rates. For much of the 1970s-decade, exchange rate, interest rate and inflation rates were all supportive of high commodity prices; those external forces to commodity futures markets actually generated favorable market-based to the U.S. agricultural sector and thus government subsidies were minimal or non-existent. However, in the 1980s, the situation reversed, with the aforementioned interest and exchange rates running in the opposite direction and thus resulted in the taxation of agricultural companies, which, in turn, was offset by the agricultural and food policy interventions by the U.S. government that provided large subsidies to commodity markets. No one had previously established these critically important causal links.

2 Introduction

U.S. government macroeconomic policies primarily are directed at achieving economy-wide objectives of maximum sustainable employment and stable prices. Federal fiscal policy uses direct policy tools such as spending via the federal budget and tax policy. Federal monetary policy uses interest rates and direct market operations aimed at the money supply. These macroeconomic policies have important implications for agriculture prices, commodity production, farm sector incomes, food security, and a broad array of rural outcomes.

At the same time, the agricultural sector can influence the general economy. In 2019, US households spent about 13% of their total budget on food and the agricultural and food sector contributed about \$1.109 trillion or about 5.2% of gross domestic product (GDP) to the economy. This includes value added to GDP by food service, eating, and drinking places; food and beverage stores; textile, apparel, and leather manufacturing; food, beverage, and tobacco manufacturing; forestry, fishing, and related activities; and US farms. US farm sector production directly contributed \$136.1 billion to GDP in 2019, or about 0.6% to GDP. But the total farm sector contribution is higher since the farm sector relies on other agricultural inputs that are not considered part of its valued added measure (USDA ERS, 2021; Bureau of Economic Analysis GDP by Industry, 2020).

Agricultural policies seek to ensure food supply, enhance price stability, ensure food safety, stabilize farm income and rural employment, maintain environmental quality, and increase productivity. Food purchases are an important part of the consumer spending, with roughly 5% of disposable personal income being spent on food prepared at home and another four and one-half percent on food away from home (USDA ERS, 2020). Agricultural exports are a large part of total U.S. exports, about 8% (Bureau of Economic Analysis, 2020) and government programs applicable to the agricultural sector can significantly impact federal expenditures.

This chapter discusses linkages between the macroeconomy and the agricultural sector and rural economies. The discussion is structured as follows. Section 2 provides a general background on monetary and fiscal policy over recent decades in the general economy. Section 3 considers the effects of monetary and fiscal policy on agriculture and the rural economy in the context of agricultural sector and macroeconomic modeling. Section 4 considers how the agricultural sector has changed in the past few decades. Section 5 posits a stylized model and suggests new approaches for future work. Section 6 provides a summary and conclusion.

3 Macroeconomics

Monetary and fiscal policies seek to support sustainable macroeconomic outcomes, growth of output and incomes, full employment, and stable prices. Monetary and fiscal policies should complement each other and interact with sector-specific policies to produce economic outcomes. The target level for one primary economic outcome, growth of Gross Domestic Product (GDP), is usually between 1.5 and 4% per annum. That level of growth is usually sustainable and compatible with a slow growth in producer and consumer prices. Target levels for inflation are usually between 1 and 3% per year. The current U.S. target is 2%.

The Federal Reserve has the main responsibility for monetary policy and is mandated by the 1913 Federal Reserve Act (Board, 2020) to promote maximum employment such that all Americans who want to work are gainfully employed and to promote stable prices for goods and services. The Fed works primarily by controlling the money supply, setting interest rates, regulating financial institutions, and through open market operations of purchasing or selling debt in capital markets. Following the financial crisis of 2008, the Federal Reserve contributed strongly to the recovery of the economy by following a policy of quantitative easing, which involved buying up a lot of problematic debt that was causing distortions in capital markets.

Fiscal policy involves decisions on taxation, other revenues, expenditures and the net government debt to offset fluctuations in private sector aggregate demand over the business cycle. Congress and the executive branch impose taxes or fees on economic activities or assets and use those funds to support public goods and services or to subsidize economic activities. The agricultural sector benefitted from agricultural programs that ensured the food supply by paying farmers for their crops if market prices did not provide sufficient return. In times of deficient (excessive) private sector aggregate demand, fiscal policy via a larger (smaller) debt, and then via automatic stabilizer effects and active changes in expenditures and taxes, seeks to offset the private sector demand shortfall (exuberance).

Most economies experience cyclical movements of growth of output, unemployment, inflation and other indicators. Post-1980, the U.S. experienced recessions, defined as two or more quarters of negative real GDP growth, with output five or more percentage points below potential GDP and sharp increases in unemployment in 1979–1982, 1990–1991, 2001, and 2007–2009 (FRED, 2020). Drivers of economic cycles include aggregate demand shocks, changes to consumer and business investment, household consumption changes, supply shocks, international trade dynamics, and price shocks and bubbles. For each cycle, the duration and magnitudes of the recession and expansion vary widely. The rationale for anti-cyclical monetary and fiscal policy interventions is to reduce the magnitude and duration of cyclical swings of economic growth, employment, and inflation to achieve higher social welfare outcomes.

The nature of these economic swings has varied over time. The 1970s and early 1980s are often referred to as "stagflation" with rising unemployment and high inflation. This situation was in part triggered by exogenous shocks such as the OPEC U.S. oil embargo in 1973 during which the Organization of Petroleum Exporting Countries (OPEC) oil cartel restricted output to substantially raise oil (and energy) prices and the Iranian Revolution in 1979 which significantly disrupted U.S. oil imports (Energy Information Administration (EIA), 2020; Encyclopedia Britannica, 2020). The early 1970s also saw the move from "fixed" exchange rates, to exchange rate flexibility (Odell, 1979). The move to flexible exchange rates in conjunction with increasing internationalization of markets and more market oriented agricultural policies resulted in significant volatility in exported oriented U.S. agricultural production, exports and prices (Rausser, 1985a, b). Conditions were further exacerbated with the Russian Grain Deal, several crop short-falls, significant drawdowns in U.S. and world grain stocks and the Federal Reserve letting short-term interest rise to combat inflation that all had amplifying effects on volatility (Rausser, 1985a, b).

The energy and commodity price shocks caused significant economic problems and increasing unemployment at the same time that prices of goods produced with lots of energy were rising disproportionately. Stagflation provides a challenging situation for macroeconomic policy of low economic growth and high inflation. Stimulating economic growth further raises inflation, while taking anti-inflation measures, the way the Federal Reserve did, can depress economic growth. During these periods, the agricultural support programs were in place for many commodities and protected the farm sector and rural incomes. Recessions of the 1990s and 2000s primarily were periods of low or negative GDP growth, high unemployment, and relatively low inflation (FRED, 2020). In this context, both monetary and fiscal policies sought to stimulate GDP and employment, while tolerating relatively higher inflation.

The 2008–2009 financial crisis resulted in a different macroeconomic situation of high unemployment, low inflation, and low GDP growth. This crisis was precipitated by the housing bubble and resulting financial fallout (Case & Shiller, 2004; Christiano, 2017). Interest rates were very low and went lower as the Federal Reserve sought to increase growth by making more capital available. Tax cuts increased money available for both consumers and businesses. Monetary policy options were limited as interest rates approached the zero lower bound (Christiano, 2017; Krugman, 2018). These very low interest rates provided the opportunities to borrow capital inexpensively, but the economy was slow to respond in terms of GDP growth and employment. Stock and equity markets boomed, however, and provided more capacity for growth. Yet, low growth persisted in the U.S. economy for several years.

During actions to spur recovery from a recession, fiscal deficit spending financed by bond sales to domestic and foreign savers works to push interest rates up and increase net foreign capital inflows. This results in a larger current account deficit and a higher value for the exchange rate (in terms of domestic currency per foreign currency). By contrast, monetary policy promoting lower interest rates to stimulate aggregate demand by making capital more available has the opposite effect on the current account deficit and exchange rate as foreign investors avoid domestic bonds.

International agricultural trade and prices can be strongly affected by fiscal and monetary policy interventions meant to stabilize economic growth. Chen et al. (2010) show that exchange rates continue to have robust power in predicting global commodity prices but that the reverse is much less robust. They hypothesize that while exchange rates are strongly forward-looking, commodity price fluctuations are more responsive to short-term supply-demand imbalances.

By the time of the Great Recession, agricultural support programs had been mostly eliminated in favor of subsidized crop insurance. This insurance pays growers in the event of crop damage from weather or other natural causes (Crop Insurance, 2020). Price risk can be hedged in commodity cash and futures markets (Iowa State Extension, 2015) and/or through forward contracts with buyers or processors.

Most recently, the agricultural sector has experienced hardship due to U.S. international trade policy. The imposition of tariffs on some foreign goods drove those nations to retaliate by imposing their own tariffs on U.S. goods or by switching their supply from the U.S. to other suppliers. This policy has had major negative impacts on the agricultural sector (Congressional Research Service, 2019).

Over time, economic theory and practice of macroeconomic policy have evolved. At one extreme, efficient markets theorists argued against policy interventions, citing the superiority of market solutions over government intervention. These ideas stem from the classical economic model that assumed full information and competitive markets and then incorporated the idea that rational expectations neutered any policy effects as those effects would have been fully anticipated by rational economic agents (Friedman, 1968; Sargent & Wallace, 1975; Lucas & Robert, 1973). In contrast, the Keynesian perspective includes the assumed prevalence of sticky wages and prices and slower adjustments in expectations that supported a key role for government actions that could have real and important positive impacts on the macroeconomy and industry sectors like agriculture (Tobin, 1969; Dornbusch, 1976; Frankel & Hardouvelis, 1985; Rausser, 1985a, b; Rausser et al., 1986).

Fiscal and monetary policy interventions to stabilize economic growth and inflation have important different second-round effects on the exchange rate and agriculture as a traded product. Consider a stimulus for recovery from a recession; with the reverse to slow down a boom. A fiscal stimulus to aggregate demand and a larger budget deficit financed by additional bond sales to domestic and non-residents savers works to push up the interest rate and to increase net foreign capital inflows, with the latter balanced by a larger current account deficit and higher exchange rate. By contrast, a monetary policy stimulus via a lower interest rate reduces the attraction of residents and non-residents placing savings in the US, an increase in net capital outflows balanced by an increase in in the current account and a lower exchange rate.

In observed policy practice, the Federal Reserve has played an active role in adjusting monetary policy to shorten and soften recessions via manipulation of the money supply and interest rates and to stifle inflation through tightening actions. Fiscal policy actions have been imposed to counter recessions and, occasionally to harvest excess economic capacity during booms through increased taxation. These actions include active adjustment of government taxation and expenditures to counter cyclical swings, in addition to the stabilizing effects of continuing government programs such as Social Security payments.

Monetary policy, in the latter part of the twentieth and the first part of the twenty-first century, had the advantages over fiscal policy of easy policy reversibility, flexibility, and timeliness. The combination of very low interest rates and limited capacity for monetary economic stimulus led the US Federal Reserve to use quantitative easing to purchase large chunks of debt from the general economy, particularly mortgage backed debt. Coupled with fiscal policy tax cuts and continued increases in government spending, this quantitative easing was instrumental in pulling the United States out of the Great Recession. How the resultant accumulation of debt will affect the future is as yet undetermined, as addressing these issues has been delayed by COVID-19, perhaps for years.

Macroeconomic policy has extended and differential effects on the many sectors of the economy. A stimulative policy, including increased government spending and a looser monetary policy of lower interest rates, supports higher consumption and business expenditures, higher investments in real property and manufacturing, and, depending on the nature of fiscal policy, potential impacts on imports and exports. Floating exchange rates further enhance these effects while making an economy susceptible to overseas economic activity. The many free-trade agreements executed during recent decades have increasingly made domestic prices subject to international market forces. Finally, there will be feedback effects between the macroeconomy and specific sectors of the overall economy.

The U.S. agricultural economy has evolved from a relatively labor-intensive, low capital industry in the early twentieth century to a highly capitalized sector with mainly seasonal labor requirements in the twenty-first century (USDA NAL, 2020). In addition, government agricultural policy has evolved from a highly complex and intrusive policy that basically set agricultural prices and quantities by commodity for major crops to one with fairly limited intervention. Additionally, free-trade agreements mean that the U.S. imports much higher levels of fresh and processed food than in the past. The U.S. exports large amounts of grain, tree nuts, fruits and fresh produce, so that domestic markets are impacted by world prices for these commodities.

4 Macroeconomic-Agriculture Linkages

The seminal paper Rausser et al. (1986) investigates three interrelated questions. First, is overshooting observed in agricultural markets like that Dornbush studied relating to exchange rates? Second, what are the major linkages between the macroeconomy and the agricultural sector that might give rise to overshooting? Third, what is the likely magnitude of macroeconomic effects on the agriculture sector and agriculture sector effects on the macroeconomy? To answer these questions, Rausser, et al. set up a comprehensive model of the linkages between the macroeconomy and the U.S. agricultural sector.

The authors model an agricultural sector, a macroeconomic sector, and an international sector to evaluate potential overshooting effects relating to macroeconomic and agricultural policies. Rausser, et al. fully integrates the macroeconomy and agricultural sector models so that the entire system, with dynamic linkages, can be simultaneously solved. Previous modeling efforts depended on obtaining forecasts through an iterative approach of solving an aggregate macroeconomic model, feeding that solution into sector models to produce forecasts and simulations, and then possibly passing-back of some elements from the sector models to the macroeconomic model for a second-round solution. This latter approach missed important dynamic feedbacks that are directly incorporated in the work of Rausser et al. (1986).

The Rausser et al. model uses the Hicks and Okun fixed-flex price distinction (Okun, 1975, 1981). The "fix-price" model originates with Hicks and is described by Okun as an economic modeling method that ignores price variations in the short-run for analytic simplicity. For some period of time, prices are taken as given, or fixed (Okun, 1981). Flex prices fluctuate with market conditions, balancing supply and demand in an auction framework (Rausser et al., 1986).

The agricultural sector is modeled as a set of markets cleared by price, while the macroeconomy utilizes gradual adjustment in prices. The macroeconomy is composed of aggregate demand (consumption, domestic investment, government finance), aggregate supply (price and wage equations) and a financial sector (money demand, money supply, interest rate determination). Nonagricultural prices are a productivity-adjusted markup over wages and material costs, potential-actual income gap, and expected money growth rates (proxy for inflationary expectations).

Agricultural markets are modeled as flexible prices for wheat, feed grains, beef, poultry and pork. Separate equations are included for commodity acreage and yields, private storage, government storage, farmer-owned reserve and export demand. Livestock is similarly modeled with price-dependent per capita meat/poultry demand, inventories, breeding stocks, feed costs, and non-farm income.

The international sector includes imports and exports of both nonagricultural and agricultural goods, exchange rates, and exogenous rest-of-world variables. The agricultural model incorporates a number of linkages with the rest of the economy including the general price level as a deflator, interest rates as an opportunity cost of holding all stocks, and rest-of-world income and exchange rates entering agricultural export equations. The agricultural policies of the time were fully included in this model.

An important, and unique, feature of the Rausser, et al. model was incorporation of important policy rules regarding management of government stock programs directly into the model solution algorithm. During the 1970s and 1980s, policy rules governing entry and release of stocks into and out of government control depended upon the exact details of the storage program where the inventory was held. Positioning of stocks had important and varying effects on market prices with privately held, farmer-owned reserve and government-owned stocks having the most depressing to least depressing effects on price. Including stock management rules into the solution algorithm was essential for understanding the short-term transmission of macroeconomic shocks through the agricultural sector and back to the macroeconomic sector. No other models at the time featured this endogenizing of government programs into simulations.

The policy experiments considered two important scenarios at the time. One scenario simulated a "tax period" for the agricultural sector corresponding to policies followed in the 1981–1983 period representing tight monetary policy implemented though a money growth rule aimed at not monetizing any of the federal deficit and ending the stagflation experienced though the 1970s. The other scenario simulated a "subsidy period" for agriculture corresponding to 1972–1974 period featuring an accommodating monetary policy aimed at monetizing debt and expanding economic growth. The major macroeconomic variables linking the agricultural sector and macroeconomy are consistent with those included in the agricultural sector model: income, inflation, interest rate and exchange rate.

Rausser et al. find that the major beneficiaries of the subsidy period are the livestock producers with beef, pork and poultry all rising over the 12-quarter forecast horizon. Likewise, under the tax scenario, livestock producers lose the most. Major drivers of the gains and losses for livestock producers are inflation and interest rates. Inflation directly effects consumer prices and demand for meat while interest rates strongly effect carrying costs of live animals, especially breeding stocks. The effects of taxes and subsidy scenarios on the food and feed grains are mixed with only small price differences between the subsidy and tax scenarios in the first eight quarters and larger differences in quarters 9–12. The major driver for the food and feed grains was exchange rate effects on exports. Exchange rate effects are much less for livestock since trade represents a much lower part of total demand compared to grains.

Rausser et al. find that "analysis of agricultural market dynamics must take into account not only real demand and supply forces directly related to the sector but also the effects of monetary and fiscal policies. To the extent that these policies are able to effect real changes in the short run, the agricultural sector will experience some instability in addition to that caused by the traditionally emphasized sources within the sector." Further, they find that "[b]ecause of the nature of current agricultural policies, which support prices in the face of downward pressure but do little or nothing to prevent increases, there is an asymmetry in the effects of monetary policy. Much, if not all, of the benefits during a subsidy scenario accrue to the private sector. However, the downside risk tends to be borne much more by the public sector, to the point that, in our simulation results, a comparison of incomes shows that the grain sector has a slight preference for a tax period since the entire burden is shifted to government expenditures to support price." (Rausser et al., 1986).

Subsequent work analyzing linkages between the agricultural sector and macroeconomic policies has generally proceeded in three directions. The first follows the Rausser, et al. practice of using a structural model. A second approach uses time series methods such as vector autoregression (VAR) and vector error correction models (VEC). These approaches place more weight on data rather than a priori assumptions about structure to explain the links between exogenous shocks, including macroeconomic policy changes, and macroeconomic and agriculture sector outcomes. Tests for directions of causation, use of impulse response functions, and other tools permit tracing of outcome variable responses to changes in policies. A third approach is computable general equilibrium (CGE) models. These models have the advantages of commodity disaggregation, detailed international trade and policy interventions, and expanded scope for detailed model expansion and enhancement for particular issues of interest. To date, models have generally assumed competitive markets.

Frankel (1986) published an article analyzing commodity prices and monetary policy linkages. He theoretically confirms that monetary policy has effects on real agricultural commodity prices and that those effects include overshooting because prices of other goods are sticky. Dorfman and Lastrapes (1996) use a Bayesian approach in a structural model to confirm that agricultural prices rise with expansionary monetary policy.

Time series models used to analyze macroeconomic-agricultural effects include Orden and Fackler (1989), who apply this modeling to monetary policy impacts on agriculture and find that technical modeling issues can confuse the results. Hua (1998) uses an error-correction model to conclude that monetary policy shocks translated into instantaneous changes in commodity prices. Kwon and Koo (2009) use an error-correction model to confirm overshooting behavior of agricultural prices in response to macroeconomic policy. Algieri (2014) uses an error-correction model and finds that real effective exchange rates, among other factors, have impacts on international wheat price movements. Amatov and Dorfman (2017) confirm earlier findings that commodity prices are sensitive to monetary policy using a vector error correction model. Saghaian et al. (2002) employ an error correction model and find that agricultural prices do overshoot in response to changes in money supply. Scrimgeour (2014) applies a vector autoregression model to find that commodity prices had an outsized response to a monetary shock that remained for as long as a year.

Computable general equilibrium (CGE) models used to analyze agricultural sector-macroeconomic linkages are discussed in a review piece by Hertel (1999). He notes that CGE models are limited by treatment of the agricultural sector as an aggregate unit producing a single good, their failure to treat land differently from other capital inputs, and their tendency to under-specify behavioral parameters in the agricultural farm and food systems. Hertel suggests that these models can be improved by disaggregation in a number of directions that account for household heterogeneity, agricultural producer heterogeneity, and the various kinds of capital in agriculture (specifically to separate land from other capital).[1]

5 Changes in the Agricultural Sector

The agricultural sector in the U.S. has changed greatly from what existed and was modelled in the Rausser et al. (1986) paper. These changes require important modeling adjustments, and will likely impact the empirical effects of macroeconomic policy on the agricultural sector.

In the 1990s, agricultural support programs, with their complex structures of support prices, base acreages, and target prices, were largely eliminated (Bonnen & Schweikhardt, 1998) by Federal Agricultural Improvement Act (FAIR) of 1996. Some few remain, such as tobacco, sugar, and peanuts, but agricultural markets have been largely freed from government intervention. At the same time, insurance and futures markets have become much more highly used as risk neutralizers for farmers.

Perhaps the biggest change in agriculture is the vertical integration of the supply chain that has occurred in the last 30 years. The sector now presents as a set of a few supply chains, with supply linkages tracing from the fields and barns all the way through to retail sales points. For example, poultry is highly vertically integrated. Chicks are raised by growers who provide the capital (houses) and labor. Ownership of the fowl is retained by the integrator, which provides feed, vet care, and pays a price to the grower for average weight gained per bird. When the poultry reaches full weight, the integrator picks up the birds and takes them to the processor for slaughter. After processing, the meat is taken to distribution points for grocery stores, restaurants, etc. These relationships and prices are all predetermined by contracts, some long term and some short, that comprise a supply chain from farm to retail. Essentially, no cash market exists for poultry any longer. Other livestock sectors are similarly, but to a lesser extent, contract driven. Fruit and vegetables are also handled through supply chains from grower to retail. With the possible exception of

[1] Hertel summarizes a large number of publications and the reader is referred to this well-done survey.

farmer's markets, even small farms sell their output through the supply chain. While supply chain contract terms are frequently driven through historic relationships and bilateral negotiations and often have nondisclosure clauses that forbid specific terms to be revealed, some contracts are driven by prices conditional on flexible futures prices, and more closely conform to vertical price relationships prevalent in the 1970s and 1980s. For a full discussion, see MacDonald et al. (2018).

On the input side, supply chains dominate as well. While there may be local farm stores in rural towns, there has been considerable consolidation in the industry that supply farm tools and machinery, chemicals and pesticides, biotechnology derived inputs and seed. In recent years, mergers among some of the largest firms in the agricultural chemical, seed and genetics industry significantly reduced the number of competitors world-wide. There have been consolidations within farm machinery as well. A number of factors have driven mergers including complementarities and spillovers among patent and asset portfolios, research and development (R&D) synergies, and other factors contributing to post-merger R&D incentives and success and internalizing post-merger technological spillovers (Marco & Rausser, 2002, 2008, 2011). In addition to supply chain consolidation, enhanced mechanization of agriculture has reduced the labor required on the farm. As such, farming has become an increasingly capital-intensive industry, with significant labor required only seasonally in fruits and vegetables which have not yet had their harvest fully mechanized. A detailed evaluation of this trend is Astill et al. (2020).

The implication of these changes is that agricultural sector modeling has changed profoundly. Imperfect competition among supply chains needs to replace the vertical series of auction markets that have traditionally been used to characterize the agricultural sector (Park et al., 2011; Raper et al., 2007). As such, it may be difficult to understand how macroeconomic policies affect agricultural prices because: (1) these supply-chain prices are contractually based, (2) since the transfer prices within many supply chain are proprietary, they are no longer reported, and (3) the substantially vertical structure of the industry may mean that the effects cannot be properly discerned.

Another big change from the last century is the rise of environmental awareness in farming, processing, and in society in general. Externalities, such as farm run-off of fertilizer and pesticides and potential impacts of genetically modified seed use, are now of major social importance. Green space provided by farms is regarded an important public good to society. Environmental protection laws and farming standards are now in place to make sure that farms follow clean practices. Water is not just subject to environmental pollution laws, but water rights and the high use of water on farms combined with expanding urban areas and use has led to improved water distribution systems for crops, development of drought-resistant varieties, and other measures to safeguard future water resources. The interaction of wildlife with farms is also the subject of restriction and use changes. All of this means that modeling of the agricultural sector is substantially different to that in 1986.

Food security remains important in society. The 1930s act which set up many of the traditional farm programs did so to safeguard the U.S. food supply. As the structure of the industry has migrated to supply chains and farm programs have been largely eliminated, food expenditures have fallen as a percent of disposable personal income, from 17.0% in 1960 to 9.5% in 2019 (USDA ERS, 2020). Society still considers, both in the U.S. and internationally, that food security in the sense of having sufficient nutrition each day is a basic human right. Government programs aimed at food security in the U.S. have migrated from a farm focus to become anti-poverty programs. At the same time, rural incomes and populations have fallen. Land use is changing from rural to ex-urban or suburban as cities and town sprawl, and those who remain in rural areas are increasingly isolated and aging. Incorporating these fundamental changes into a large agricultural model with links to macroeconomic policy is challenging.

6 Organization of Supply Chains

Modern food delivery results from a series of relationships (supply chain) starting with input suppliers and ending with consumer purchases. The supply chain consists of all parties involved, directly or indirectly, in fulfilling consumer demand and includes retailers, processors, and input suppliers (principally farm level production). While firms at each stage in the supply chain will attempt to maximize profit, these activities require coordination. Vertical relationships in a supply chain may be organized through contracts or coordinated though market exchanges. When participants at a particular point of exchange in a supply chain are concentrated, they have the potential to improve their terms of trade with respect to other supply chain participants. Such efforts would be reflected as market power exertion that can potentially be exercised in both purchases (monopsony power) and sales (monopoly power) at each stage of the supply chain, so that both buyers and sellers in the concentrated retail, processor and farm input supply levels in the chain can potentially exert market power. In intermediate goods markets, downstream firms' profits may be decreased by monopolistic actions taken by upstream firms. Alternatively, upstream firms may suffer losses from monopsonistic actions taken by downstream firms. When concentration exists on both sides of a market, possible industry structures include monopoly, oligopoly, monopsony, oligopsony, and cooperative and noncooperative bilateral monopoly.

Buyer and seller concentrations in a market may not reliably indicate the direction of market power exertion since firms are aware that market power exertion at multiple stages in the supply chain can result in double marginalization that can lower profit. Double marginalization results when, at a particular stage in the supply chain, the upstream firm anticipates the downstream firm's optimizing behavior and sets prices to exploit the downward sloping marginal revenue from that firm's profit maximization. Because of downward sloping demand, double marginalization ultimately results in prices that are overly high and, as a result, under-production and lower profits for the entire supply chain.

7 A Model of Exchange and Price Transmission through Concentrated Supply Chains

To investigate the effects of macroeconomic shocks on an agricultural supply chain, a stylized model is developed that incorporates three levels of exchange, including farm-level production, processor, and retail levels. The model is constructed to admit the possibility of market power exertion by both retailers and processors in both their input procurement and output sales. Market conduct parameters are included in the style of New Empirical Industrial Organization (NEIO) models that allow simulation of alternative market power relations at various stages in the supply chain. Further, since international trade plays key roles in many agricultural supply chains and these exchanges have historically played a key role in agricultural-macroeconomic linkages, the model includes equations representing import and export decisions by participants at each stage in the supply chain.

This model allows demand or supply shifts or potential changes in market conduct to be represented and the consequent effects on prices and quantities to be isolated. Probable market effects from macroeconomic shocks can be obtained using different market conduct assumptions among supply chain participants at each stage in the chain. The stylized supply chain is consistent with those found in poultry, pork, beef, fish, fruits and vegetables, dairy, eggs, and many other food products that are farm grown, assembled, processed, shipped, and then sold through retail groceries.

Model structure, based on new empirical industrial organization (NEIO) econometric methods, can simulate various levels of market power exertion at stages in the supply chain. Numerous studies have estimated market power exertion in various markets using NEIO techniques pioneered by Appelbaum (1979, 1982), Bresnahan (1982) and Lau (1982). In his review of empirical studies of market power, Bresnahan (1989) cites over 60 empirical studies utilizing NEIO models in various forms. Many more NEIO based studies have been published since Bresnahan's review.

The idea behind modeling market power using the NEIO approach is that departures in equilibrium market quantity and price from their competitive levels can be understood using marginal conditions from profit maximization that incorporate a market power parameter into the marginal revenue and\or marginal expenditure first-order conditions. To find competitive market behavior, the profit maximizing condition equates marginal cost with market price. In the case of possible monopoly market power, if there is a departure from competition, the profit maximizing condition will equate marginal cost with apparent or "perceived" marginal revenue. Perceived marginal revenue is the product of a market power parameter that measures (or indexes) firm behavior and the slope of the demand curve. If firms perceive demand is flat, or perfectly elastic, then all firms are price takers and no monopoly market power is expressed. However, if firms perceive that quantity demanded responds to price, then sellers can potentially take advantage of this situation by either charging a higher price or reducing quantity produced so that equilibrium price rises. Such behavior would then be measured as monopoly market power exertion through the market power parameter. Monopsony market power can be measured in an analogous way where buyers adjust offer price or quantity purchased to lower price paid by exploiting input supplier's upward sloping supply.

In this model, both buyers and sellers may be assumed to be concentrated at the retail and processor levels so that both monopoly and monopsony market power exertion is possible at those stages in the supply chain. The model can simulate alternative market structures where both buyers and sellers of an intermediate product can potentially exert market power. The model nests both monopolistic and monopsonistic market power exertion and admits the possibility of cooperative and noncooperative bilateral monopoly.

8 Agricultural Sector Overview and Assumptions

Retailers are assumed to purchase a food product from domestic processors/packers and import food product suppliers. They are assumed to be price takers in the market for imports, with no market power in world markets, but that there is heterogeneity in domestic and imported products so that they are imperfect substitutes. High concentration among food retailers suggests the possibility of market power exertion in both domestic sales and procurement. Retailers are allowed to potentially exert monopoly market power against consumers in sales of domestically produced and importer food product and monopsony market power against processors.

Processors/packers purchase domestically grown raw agricultural inputs and produce food products for sale to domestic retailers and for export. The processing/packing stage may involve significant product transformation as in producing cheese, potato chips and retail meat cuts. Alternatively, processing/packing may involve only minor transformations like sorting, cleaning and packaging as needed for producing retail packages of apples, fresh potatoes or head lettuce. Processors are assumed to be price takers in the export market and products produced for domestic and export sales are assumed to be heterogenous so that market clearing does not enforce equality in domestic and export sales prices. Industry concentration allows processors to potentially exert monopoly market power against retailers and monopsony power against raw agricultural input producers.

Farm level supply equations are included for domestic production of high- and low-quality agricultural product for sale to domestic processors/packers and for export. It is assumed that farm production for domestic and export markets is heterogenous for each of the two-quality levels. Heterogeneity may result from differing hedonic product characteristics for domestic and exported products or may simply result from locational considerations that effect farm gate price for individual producers relating transportation costs. Substitution relations are included in each agricultural supply equation for sale in the domestic and export markets to facilitate investigation of the effect of exchange rate changes on the supply chain. Agricultural producers are assumed to be price takers in both their procurement of inputs for agricultural production and in their sale of agricultural products to domestic processors and as exports.

9 The Equations

This section contains model specifications for consumer demand, cost of production, and profit at each stage in the supply chain. Equilibrium conditions are included that allow for simulation of market power.

9.1 Retail Demand

Retail demand plays a critical role throughout the supply chain. To some extent, each upstream firm's demand is derived from consumer demand. Generally, retail demand can be written as:

$$Q_i^d = f_i\left(p, g, Y, \eta\right) \text{ for } i = 1, 2, \ldots, N, \tag{1}$$

where Q_i^d is retail quantity demanded for domestic product i; p is a vector of prices for products Q_i^d, i = 1, 2, …, N; g is a vector of prices for related goods (substitutes and complements); Y is consumer expenditures for the product category; and η is a vector of parameters. Eq. 1 can be written in price dependent (inverse) form as:

$$p_i = f_i^{-1}\left(Q_i^d, p_{\sim i}, g, Y, \eta\right) \text{ for } i = 1, 2, \ldots, N, \tag{2}$$

where $p_{\sim i}$ is the vector of all prices p except p_i. The relevant market is assumed to be the U.S. and that the equation represents national-level aggregate demand. Further, in the simulations, functional form for f_i (.) is assumed to be linear.

9.2 Retail/Wholesale Cost and Profit

Retail and wholesale costs arise from sales efforts, purchasing costs, warehousing and holding costs, spoilage, and transportation. The three principle cost components for retail/wholesale costs are related to cost-of-goods, labor, and energy. Because joint production is observed in the retail grocery sector, retail and wholesale costs are difficult to measure for specific items. To simplify the analysis, retail and wholesale costs are assumed to result from constant returns-to-scale Leontief, or fixed-proportions, technology. At the retail/wholesale level, a vector of aggregate outputs (retail food products), Q^d, result from employing a quasi-fixed production technology that does not allow substitution between basic inputs y^R (e.g., food items procured from processors and imported), and other retailer/wholesaler provided inputs (labor, refrigeration, etc.). Retail/wholesale technology allows substitution among variable inputs, z, and quasi-fixed inputs k (e.g. refrigeration capacity) and exhibits constant-returns-to-scale. Since retail/wholesale food items are often highly perishable, especially meat, dairy, bakery, and fresh fruits and vegetables, inventories are managed within narrow operational adjustment parameters. To simplify analysis, it is assumed that inventories are held at a constant target level to ensure availability and are exogenous in the short run. Retail/wholesale total cost function for this technology can be written as:

$$TC^R\left(Q^d, y^R, w^R, v, k^R\right) = Q^d\, C^{Ru}\left(v; k^R\right) + w^{R'} y^R + FC^R\left(k^R\right), \tag{3}$$

where w^R is a vector of input (processor and import) prices associated with y^R; v is a vector of variable input prices associated with variable input vector z; and $FC^R(k^R)$ is fixed costs associated with quasi-fixed inputs k^R. Quasi-fixed inputs can be conceptualized as capacity with corresponding fixed cost $FC^R(k^R)$. Retailer/wholesaler variable costs for inputs other than y^R is given by $C^{Ru}(v;\, k^R) = \min_z \{v'\, z : f(z;\, k^R) \geq y^R{}_i\}$, where $f(z;\, k^R)$ is a constant-returns-to-scale technology. The term $w^{R\,\prime}\, y^R$ represents costs of domestic processor supplied and imported food product inputs. Given these assumptions and letting β represent a constant conversion factor of processor and imported food inputs y into retail food product output $Q^d{}_i$ ($Q^d{}_i = y^R{}_i / \beta_i$), retailer/wholesaler cost can be rewritten in terms of output quantity Q^d so that

$$TC^R\left(Q^d, w^R, v, k^R\right) = Q^d\, C^{Ru}\left(v; k^R\right) + w^{R'}\, \beta \cdot Q^d + FC^R\left(k^R\right), \tag{4}$$

where represents element by element multiplication. If retail products and processor outputs are identical, then $\beta_i = 1$ and $Q^d{}_i = y_i$. Further, unit retail cost, C^{Ru} (v; k^R), is the same for all food items sold at retail.

Retail/wholesale profit is given as revenue minus cost:

$$\begin{aligned}\pi^R\left(Q^d, w^R, v, k^R\right) = p'\, Q^d - TC^R\left(Q^d, w^R, v, k^R\right) &= p'\, Q^d - Q^d\, C^{Ru}\left(v; k^R\right)\\ &- w^{R'}\, \beta \cdot Q^d - FC^R\left(k^R\right)\end{aligned} \tag{5}$$

If retailers are competitive in all markets, the first-order conditions of (5) with respect to output and intermediate good quantities give the firms' price-dependent (inverse) output supply and intermediate good demand equations, and Shephard's lemma gives their conditional demand equations for the input vector, z.

9.3 *Processor/Packer Cost and Profit*

Processors utilize a number of variable and fixed inputs to produce outputs for domestic and international markets. Variable costs arise from use of raw agricultural inputs (including both high and low quality raw agricultural products), labor, utilities, power and packaging materials. Fixed costs result from employing plant facilities. For processors, capacity utilization can affect average cost per unit of output since plants are often designed for a targeted production level. However, we assume that plants are operating within their designed capacity and that production and cost are constant returns-to-scale.

Processors are assumed to produce a vector of outputs $y = (y^R, y^X, y^B)$, where y^R is a vector of domestic food products, y^X is a vector of export products, and y^B is a vector of byproducts. Processor prices associated with y are given by the vector $w = (w^R, w^X, w^B)$. Processors' primary input is raw agricultural input x. Given that raw agricultural inputs are often highly perishable and are heavy and expensive to ship, agricultural inputs are assumed to be procured domestically. Hence, agricultural input is represented by the vector $x^F = (x^H, x^L)$, where x^H is domestically procured high quality agricultural input and x^L is domestically procured low quality agricultural input. Agricultural input prices paid by processors are given by vector $r^F = (r^H, r^L)$. Variable inputs, other than agricultural ones, are given by the vector, h, with associated prices, u and processor capacity is given by k^P. Since many food products are highly perishable, to simplify analysis, it is assumed that inventories are held at a constant target level to ensure availability and are exogenous in the short run. Processor's total cost is then given by:

$$TC^P\left(y,u,r^F,x,k^R\right) = C^P\left(y,;,u,;,x,;,k^R\right) + r^{F'} x^F + FC^P\left(k^P\right), \tag{6}$$

where $C^P(y, u; x, k^R)$ represents processors' conditional cost (variable cost excluding the cost of raw agricultural input); $r^{F\prime} x^F$ is agricultural input cost; and fixed cost is given by $FC^P(k^P)$. Conditional cost is defined as $C^P(y, u; x^F, k^P) = \min_h \{u' h : g(y, h; x^F, k^P) = 0\}$, where $g(y, h; x^F, k^R)$ is a multioutput production function.

Expanding y and x^F, processor profit can be written as:

$$\begin{aligned}\pi^P\left(y,w,u,r,k^P\right) &= w' y - TC^P\left(y,u,r,x,k^R\right) = w^{R'} y^R + w^{X'} y^X + w^{B'} y^B \\ &\quad - C^P\left(y^R ,;,,y^X ,;,,y^B ,;,,u,;,,x^H ,;,,x^L ,;,,k^R\right) - r^{H'} x^H - r^{L'} x^L + FC^P\left(k^P\right).\end{aligned} \tag{7}$$

It should be noted that processor cost and profit are related to retail quantities through the parameter β, the conversion factor for processor outputs y^R into retail food output Q^d_i ($Q^d_i = y^R_i/\beta_i$).

If the firm is competitive in all markets, the first-order conditions of (7) with respect to output and intermediate good (food product) quantities give the downstream firm's price-dependent (inverse) output supply and intermediate good demand equations, and Shephard's lemma gives its conditional demand equations for the input vector, h.

9.4 Raw Agricultural Product (Farm Level) Cost and Profit

Raw agricultural input producers are the furthest upstream producers. Farm producers purchase inputs, like young animals and feed for various types of livestock and dairy production, or land services, seed, and fertilizer for crop production and other inputs (e.g., labor and energy) to produce raw agricultural products for sale to processors. These inputs can be represented by the vector l with associated prices s. Capacity is denoted k^F. Production capacity may take extended time to adjust in agriculture. For example, to increase production in animal agriculture breeding inventory size must be increased and this may have the short-run effect of decreasing food output. In the case of animal agriculture, k^F is inventory of live animals and related specialized equipment at various production stages so that, for example, placement of cattle on feed depends on the calf crop realized in previous months. The adjustment dynamics, especially in animal agriculture, can be complex. For example, in beef production, dynamic adjustments in k^F depends on decisions involving choices to maintain or cull breeding cattle, rearing times for calves, background feeding times and placement of cattle on feed. In the case of tree fruit, nuts and other specialty crops, k^F is inventory of trees or other perennials and inventory in supporting infrastructure like trellises, irrigation and other specialized equipment and it may take multiple years to realize production after initial investments are made to expand output. With production lags, today's production depends on capacity observed at each stage in in previous time periods. These dynamics can be introduced with the following substitution: $k_t^F = \sum_i \alpha_i k_{t\text{-}i}^F$. Inventory adjustments can be modeled as $k_{t+1}^F = k_t^F - x_t^F + h(s_t, r_t^F, \sum_i \mu_i k_{t-i}^F)$, where $h(s_t, r_t^F, \sum_i \mu_i k_{t-i}^F)$ results from forward looking profit maximization and represents new additions (investment) in capacity. Specifics of capacity adjustments differ by enterprise but may include decisions like retaining heifer calves to increase breeding herd for cow-calf producers, or, in the case of tree fruit, planting new trees. Farm supply is modeled separately for both high-quality agricultural inputs (contract-type production) and low-quality (commodity-like) agricultural inputs. Given these definitions, raw agricultural product cost is given by:

$$TCF\left(xF,s,kF\right) = CF\left(xF,;s,;kF\right) + FCF\left(kF\right), \tag{8}$$

where F is an index for high and low quality raw farm products, F = H and L, $C^F(x^F, s; k^F)$ represents farmers' variable cost and fixed cost is given by $FC^F(k^F)$. Variable cost is defined as $C^F(x^F, s; k^F) = \min_l \{s' l: o(l; k^F) \geq x^F\}$, where $o(l; k^F) \geq x^F$ is a production function.

Farm profit is given as revenue minus cost:

$$\pi^F\left(x^F,r^F,s,k^F\right) = r^{F'} x^F - TC^F\left(x^F,s,k^F\right) = r^{F'} x^F - C^F\left(x^F,;s,;k^F\right) - FC^F\left(k^F\right). \tag{9}$$

If farm production is competitive in all markets, the first-order conditions of (9) with respect to output gives the firms' price-dependent (inverse) output supply equation, and Shephard's lemma their conditional demand equations for the input vector, l.

Inverse farm supply is:

$$r^F = S\left(x^F,;s,;k^F,;\Omega\right), \tag{10}$$

where S^F (x^F, s, k^F; Ω) is a function representing the inverse supply (marginal cost) of raw farm product production and *Ω* is a vector of parameters. Farm supply is modeled separately for both high-quality agricultural inputs (F = H) and low-quality agricultural inputs (F = L).

9.5 Equilibrium Conditions for Market Power in a Vertical Supply Chain

In this analysis, market power may be exerted by two entities: retailer/wholesalers and processors/packers. Consumers and farm level producers are presumed to be competitive price takers. Both retailer/wholesalers and processors may exert either or both monopoly and monopsony market power. The case where both are exerted is often referred to as the pure middleman solution. Further, if processors and retailer/wholesalers are simultaneously exerting monopoly and monopsony market power, then the possibility of bilateral monopoly exists.

Retailer/wholesaler profit maximization involves consideration of the high concentration in food retailing. It is possible that retailers exert either or both monopoly and monopsony market power. Monopoly market power might be achieved by exploiting the downward sloping consumer demand for branded and unbranded meat through Bertrand price competition among competing retail chains as well as through Cournot competition with retailers restricting sales in an effort to optimize profits. Which form of game play is used depends on whether retailers are able to price food products sold in their stores differently than their competitors. However, Kreps and Scheinkman (1983) show that, even if firms set prices instead of quantities, the industry equilibrium is equivalent to Cournot so long as firms choose capacity (k^R or k^F) before they select price. Similarly, monopsony market power exertion might be achieved by exploiting the upward sloping packer supply of meat products through restricting purchases from processors below the competitive level and might be facilitated through Cournot competition among retailers. It should be noted, however, that this analysis cannot distinguish which form of game play retailers are actually using (if any), only the extent of market power exertion.

9.6 Retail/Wholesale Profit Maximization

To maximize profit, retailers must choose the optimal retail (and wholesale) quantity for each product (Q^d_i). From Eq. 5, this results in the following first-order profit maximizing equation:

$$\partial\pi^{R}\left(Q^{d},w^{R},v,k^{R}\right)/\partial Q^{d}_{i}=\lambda^{R}_{mi}\,\partial p_{i}/\partial Q^{d}_{i}\,Q^{d}_{i}+\left(p_{i}-C^{Ru}\left(v;k^{R}\right)-w^{R}_{i}\,\beta_{i}\right) -\lambda^{R}_{si}\,\partial w^{R}_{i}/\partial y^{R}_{i}\,\beta_{i}\,Q^{d}_{i}=0, \tag{11}$$

where $\lambda^R_{m\,i}$ is a parameter indexing retailer monopoly market power exertion; $\lambda^R_{s\,i}$ is a parameter indexing retailer monopsony market power exertion; partial derivative $\partial p_i/\partial Q^d_i$ is from Eq. 2 and partial derivative $\partial w^R_i/\partial y^R_i$ is from the packers' conditional supply function. From Eq. 11, it is clear monopoly market power results as departures between marginal cost and price through the term $\lambda^R_{m\,i}\ \partial p_i/\partial Q^d_i\ Q^d_i$. Similarly, monopsony market power ($\lambda^R_{s\,i}\ \partial w^R_i/\partial y^R_i\ \beta_i\ Q^d_i$) measures departures between the input's marginal value product in production and price paid for the input.

The value of $\lambda^R_{m\,i}$ represents the rotation of the perceived marginal revenue curve away from consumer demand (Bresnahan, 1982). If $\lambda^R_{m\,i} = 0$, the market is perfectly competitive, and the retailers perceive that they face a horizontal demand curve. As $\lambda^R_{m\,i}$ becomes greater than zero, retailers perceive consumer demand to be downward sloping so there is a departure of perceived marginal revenue from retail demand and some oligopoly market power exists. If $\lambda^R_{m\,i} = 1$, full monopoly market power is being exerted and firms are behaving as if a single firm was acting as a monopoly in the market for retail meat products.

The value of $\lambda^R_{s\,i}$ represents the rotation of the perceived marginal expenditures curve away from upstream packer supply of meat. If $\lambda^R_{s\,i} = 0$, the market is perfectly competitive, and the retailers perceive that they face a horizontal supply curve. As $\lambda^R_{s\,i}$ becomes greater than zero, retailers perceive processor supply to be upward sloping so there is a departure of perceived marginal expenditure from processor supply and some oligopsony market power exists. If $\lambda^R_{s\,i} = 1$, full monopsony market power is being exerted and retailers are behaving as if a single firm was acting as a monopsony in the procuring food product from processors.

9.7 Processor/Packer Profit Maximization

To maximize profit, processors must choose the optimal quantity of agricultural products to produce, $y = (y^R, y^X, y^B)$, and the optimal quantity of agricultural input to purchase from farmers, $x^F = (x^H, x^L)$. From Eq. 7, this results in the following first-order profit maximizing equations for choices of $y^R_{i,}$ and x^F:

$$\partial\pi^{P}\left(y,w,u,r,k^{P}\right)/\partial y^{R}=\lambda^{P}_{mi}\,\partial w^{R}/\partial y^{R}_{i}\,y^{R}_{i}+w^{R} -\partial C^{P}\left(y^{R},;,y^{X},;,y^{B},;,u,;,x^{F},;,k^{R}\right)/\partial y^{R}_{i}=0, \tag{12}$$

and

$$\partial\pi^{P}\left(y,w,u,r,k^{P}\right)/\partial x^{F}=-\partial C^{P}\left(y^{R},;,y^{X},;,y^{B},;,u,;,x^{F},;,k^{R}\right)/\partial x^{F}-\lambda^{P}_{sF}\,\partial r^{F} /\partial x^{F}\,x^{F}-r^{F}=0, \tag{13}$$

where $\lambda^{P}_{m\,i}$ is a parameter indexing processor monopoly market power exertion for product i; $\lambda^{P}_{s\,F}$ is a parameter indexing processor monopsony market power exertion in procurement of domestic agricultural inputs produced by farmers for high and low quality agricultural inputs; partial derivative $\partial w^{R}/\partial y^{R}_{i}$ is from retailers' derived demand for food product (retailer optimization of Eq. 5 with respect to y^{R}_{i}), and partial derivative $\partial r^{F}/\partial x^{F}$ is from farm supply, Eq. 10, for producers of high and low quality raw agricultural inputs. From Eq. 13, it is clear the processor monopoly market power is measured as departures between marginal cost and price through the term $\lambda^{P}_{m\,i}\ \partial w^{R}/\partial y^{R}_{i}\ y^{R}_{i}$. Similarly, monopsony market power ($\lambda^{P}_{sF}\ \partial r^{F}/\partial x^{F}\ x^{F}$) measures departures between the input's (farm produce) marginal value product in production and price paid for the input. As before, parameters $\lambda^{P}_{m\,i}$ and $\lambda^{P}_{s\,F}$ measure market power exertion.

10 Model Calibration

Under appropriate conditions, monopoly and monopsony market power parameters can be econometrically estimated (Bresnahan (1982); Lau (1982); Raper et al., 2000). In the simulations that follow, model parameters are calibrated to a typical animal agriculture supply chain with production lags due to changing animal inventories and production cycles. Animal agriculture is selected since Rausser et al. (1986) found that livestock producers responded most to the changing macroeconomic conditions associated with the tax and subsidy periods they investigated. Most parameters are estimated using monthly data. In simulations, the own-price retail demand elasticity is approximately −0.6, while own-price farm supply elasticity is approximately 0.45 in the short-run and 0.7 in the long-run. These estimates are consistent with previous studies that estimate own-price demand elasticity for meat and eggs in the range between −0.31 and −0.61 with an average across studies of −0.52 (see Table 5, Okrent & Alston, 2012). Farm supply elasticity estimates vary widely even for a specific product, but the those used in the study are consistent with those from numerous studies (e.g. Jeong, 2019). Market power parameters are selected to represent alternative market power scenarios. Simulated values vary through time reflecting changes in exogenous data. Market power parameters are related to a Lerner index (0–1) that measures market power as departures in price from marginal cost. Market power parameters are altered for various scenarios to investigate the changing impacts of macroeconomic shocks under different market power relationships in the supply chain. It is important to note that retailers might have monopolistic power in the retail market without having monopsonistic market power in their procurement while processors/packers are assumed to have both monopoly and monopsony power. Import and export prices and all other cost and demand related prices are assumed to be competitively determined, and therefore, are exogenous.

11 Scenarios

The objective of the work by Rausser et al. (1986) is to investigate macroeconomic linkages with agriculture to, first uncover the major linkages between agriculture, and then to investigate the extent of any potential overshooting and its likely magnitude on both the macroeconomy and the agricultural sector. While those issues remain important to investigate within the context of the changes in agriculture and macroeconomic policy discussed above, addressing them would require constructing a full macroeconomic model and additional supply chains within the agricultural sector. In what follows, the investigation is simplified to investigate the likely magnitude macroeconomic shocks might have on various stages in an agricultural supply chain, given alternative expressions of market power exercised at different stages within the supply chain. This represents a partial equilibrium analysis without feedback between the sectors. However, the analysis provides an important step for better understanding how reorganization of many aspects of the agricultural supply chain may affect the transmission of macroeconomic shocks on the food sector.

Three base cases are developed. The first is a base case scenario without any market power, an assumption consistent with the modeling of Rausser et al. (1986). The second sets up an agricultural supply chain in which there is modest market power. The retail sector exerts monopoly market power against consumers but not against the processor, the processor exerts both monopoly market power against retailers and monopsony market power against the farm sector in purchase of the two inputs, a high quality farm input (e.g. branded or premium) and a low quality farm input (e.g. unbranded or generic). The farm sector has no market power. The level of market power exerted is low (0.125 in retail monopoly, processor monopoly and processor monopsony in low-quality agricultural input procurement and 0.05 in processor monopsony in high-quality input procurement). The third base scenario also models the agricultural sector as a supply chain with the same market power exertion as the second base scenario except that the level of market power exerted is much higher (0.25 in retail monopoly, processor monopoly and processor monopsony in low-quality agricultural input procurement and 0.1 in processor monopsony in high-quality input procurement). For the retail sector, high market power exertion against consumers would be consistent with Cournot behavior of 4 firms with identical costs ($\lambda^R = 0.25$). Processors exercise of both monopoly and monopsony market power, is again consistent with Cournot behavior with four firms with identical cost. This market power scenario is consistent with a processor driven supply chain (Park et al., 2011).

The macroeconomic shocks tests are four: exchange rate, disposable income, inflation, and interest rate. The exchange rate is modeled as domestic currency/foreign currency and a rise will impact the demand for domestic agricultural goods abroad and hence domestic prices as well. A rise in disposable personal income perhaps stems from a tax cut or other fiscal policy measures and leads to an expansion of domestic demand for agricultural goods. An inflation rate rise raises the prices of all goods in the economy. A rise in interest rates, likely the result of monetary policy, affects primarily agricultural sectoral production through inventory and ability to have the needed capital to produce. To ascertain the effects, a relatively large upward shock is considered in each case: 25%. A set of 25% downward shocks are also run. These eight scenarios are run and compared to the base scenario for each base case, resulting in a set of 27 scenarios.

12 Results

For each case, 26 months (observations) are provided. The first two observations for each scenario are the same as the base case, the shock is then applied and plays out over the next 24 months. All prices are normalized using the processor output price for the first observation. This normalization permits a scaled comparison across base cases and scenarios and allows analysis focused on the changes induced by the shocks. Results are presented in four graphs for each policy of interest, for a total of 16 charts. One graph presents base cases for comparison. In each case, the presence of market power distinctly moves price away from the competitive solution (base cases with no market power). In general, the higher market power case moves the price level further from the base with no market power.

12.1 Retail Price Results

Retail price is considered first. The base case wholesale and other prices change over the 26 months with movements in other exogenous variables, including world export and import prices, non-farm input costs. A comparison of base case scenarios is in Fig. 1. In the case of no market power, the base case is the blue line, and retail price begins around the 1.8 level, or roughly 1.8 times the first-period processor price and gradually rises to the 2.5 level before falling slightly at the end of the scenario time horizon. When the retailer has low market power in the supply chain and the processor has low monopsony market power, the orange line shows a similar pattern of retail price across time, but elevated in levels that range from 2.4 to over 3 times the first observation processor price. The gray line shows high (25%) monopoly market power for the retailer and for the processor against the retailer. These levels begin just below 3 and end at just below 3.5 times the processor market price. Note that the orange and blue lines have slightly different curvature than the high market power gray line, indicating that market power changes the price response in the model.

Figure 2 shows how the normalized retail price reacts to the various shocks in the case of no market power exertion. The black line is the base scenario with no shocks. The orange lines represent exchange rate shocks. The dashed lines present the exchange rate rising by 25% (a weaker domestic currency) and the dotted orange line shows the exchange rate falling by 25% (a stronger domestic currency). Green

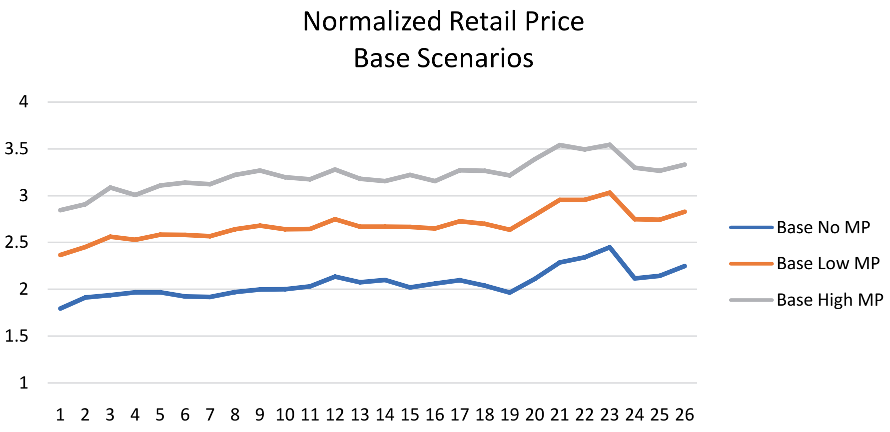

Fig. 1 Retail Price Base Scenarios

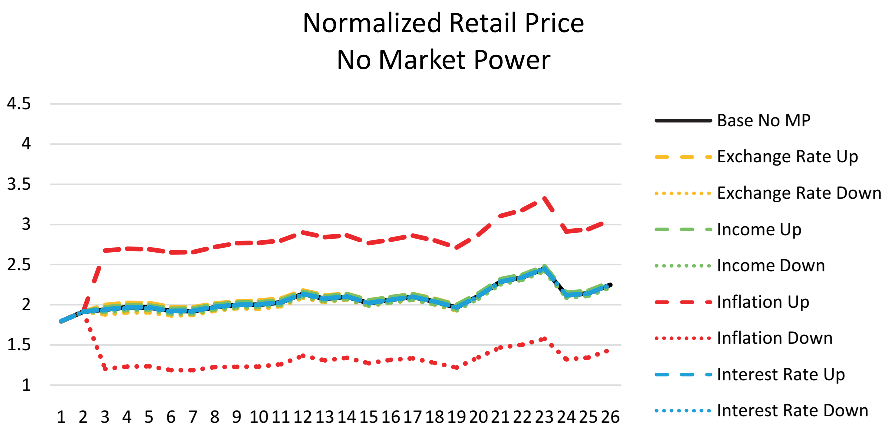

Fig. 2 Retail Price with Low Market Power Exertion

lines report the disposable income up (dashed) and down (dotted) shocks. Red lines denote the inflation up and down scenarios. The interest rate scenarios are shown in blue.

In the case with no market power, most of the scenarios follow the base scenario, indicating that the shocks do not have much effect on retail price. There are small price changes at the beginning of the time horizon due to exchange rate scenario changes, but both return to the base price levels before the end of the first year. In contrast, an increase in inflation sends the normalized retail price soaring immediately and it stays markedly higher than the base price. Also, a decrease in inflation of 25% lowers retail price correspondingly. Low price response in the competitive case from exchange rate, income, and interest rate shocks are, in part result from constant returns-to-scale technology at the retail and processor levels and long

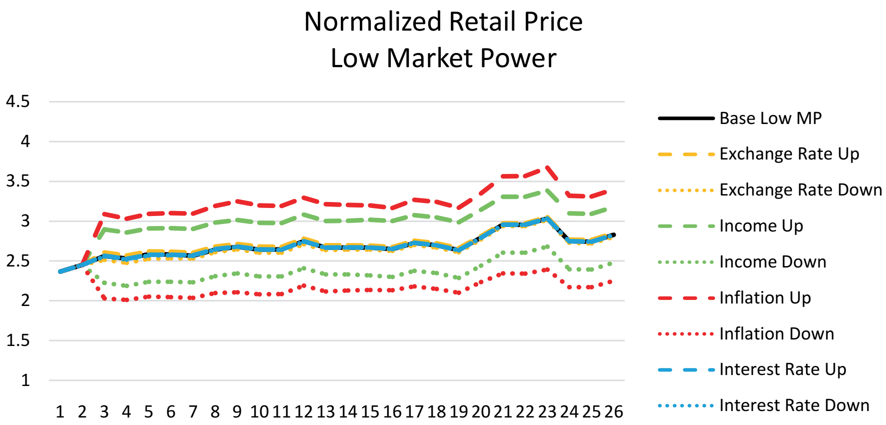

Fig. 3 Normalized Retail Price Scenarios with Low Market Power

delays in animal agriculture supply response. Further, trade in meat is much less than for crops so exchange rate shocks have limited effects on retail prices. These industry characteristics mean that macroeconomic shocks effecting farm supply are not immediately transmitted to the retail level, but that inflation shocks directly affect retail food pricing. With no market power, competitive supply to the retail level from upstream levels is horizontal so that the effects of shocks on pricing is minimal. Similarly, income shocks do result in retail demand shifts, but price effects are minimal since retail supply is horizonal due to constant returns-to-scale processor technology and delays in animal agriculture supply adjustments (Fig. 3).

In contrast, the graph of retail price with low market power shows that shocks for inflation and for income have substantial effects on retail price. The base case begins with a higher retail price of about 2.4. The inflation shocks have a similar effect to when there is no market power, but the level of price is higher. The disposable income positive shock raises retail price, but less than the inflation shock. Similarly, the downward disposable income shock causes retail price to fall, but less than the inflation downward shock. Transmission of shocks is more pervasive and immediate with market power. With market power, both demand and supply responses to shocks are reflected in prices at all levels in the supply chain as retailers and processors seek to gain rents by exercising market power and taking advantage of sloping final demand and farm supply by restricting trade both forward and backward. Hence, even with CRS retail and processing technologies, the observed price responses reflect upward sloping farm-level supply and downward sloping final retail demand and macroeconomic shocks effecting demand and farm supply are transmitted through price changes at all levels in the supply chain

Figure 4 shows the shocks in the model with high market power exertion. The price levels are all higher than in the cases of no and low market power exertion in the supply chain. In this case, both the inflation and income shocks result in marked price changes, but the relative impact is reversed from the low market power case. A positive income shock raises prices the most, while a negative income shock

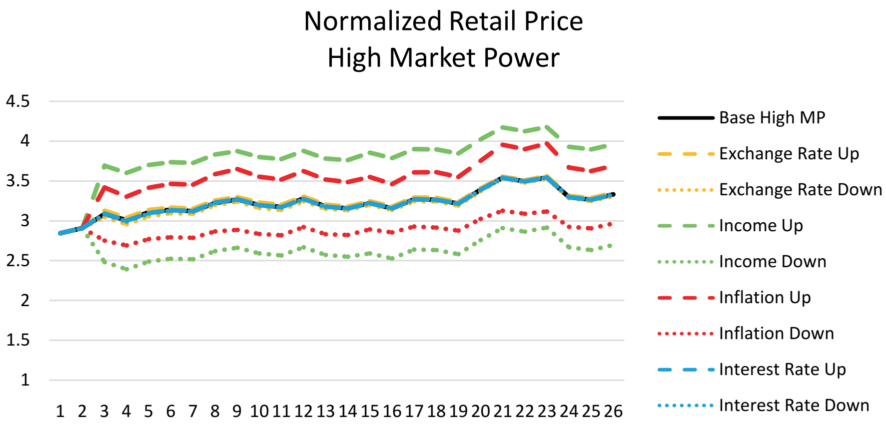

Fig. 4 Normalized Retail Price with High Market Power

lowers them. A positive inflation shock raises prices and a negative income shock lowers them.

Because retailers have no monopsony power in this model, retail prices respond more to shocks that affect consumers than to shocks that impact the production value chain. The exertion of monopoly market power by retailers against consumers significantly affects the retail price level, but not so much the pattern of shock response. Increased market power has the effect of making retail and processor responses more inelastic with respect to transmission of demand and supply shocks, amplifying the effects of macroeconomic shocks.

12.2 Processor Price Results

Figure 5 shows the processor price patterns for the three base scenarios: no market power, low market power, and high market power. The pattern in processor prices across the 26 months is distinct from retail price. Processor price is rising across all market power exertion, but the levels are ordered as before, with no market power showing the lowest prices, low market power in the middle, and high market power showing the highest prices. The price levels begin close to 1.0 (all prices are normalized by the first observation value of the processor price for no market power). High market power begins at around 1.1, indicating that a supply chain with high market power would have about a 10% higher processor price. The low market power first price lays about midway between; 0.125 market power exertion gets about half the increase in price level that 0.25 market power exertion extracts (Fig. 6).

The shock scenarios with no market power show that processor price does not change from the base level for income or interest rate shocks. For exchange rate shocks, a 25% rise strengthens the domestic currency and processor price rises,

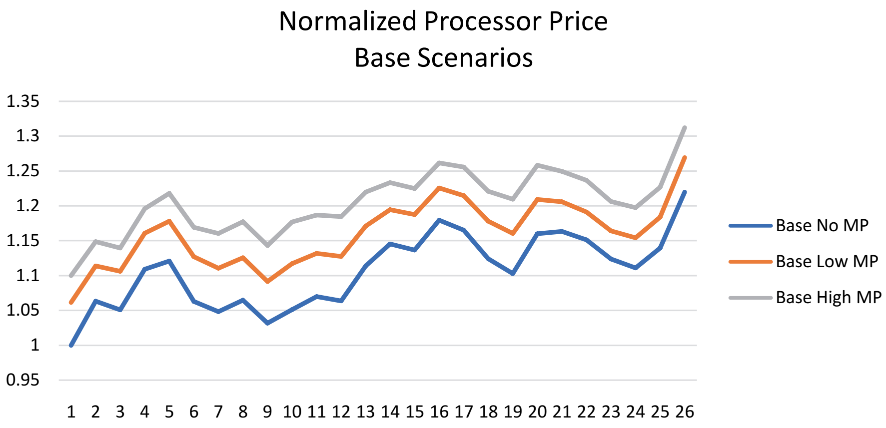

Fig. 5 Processor Price Base Scenarios

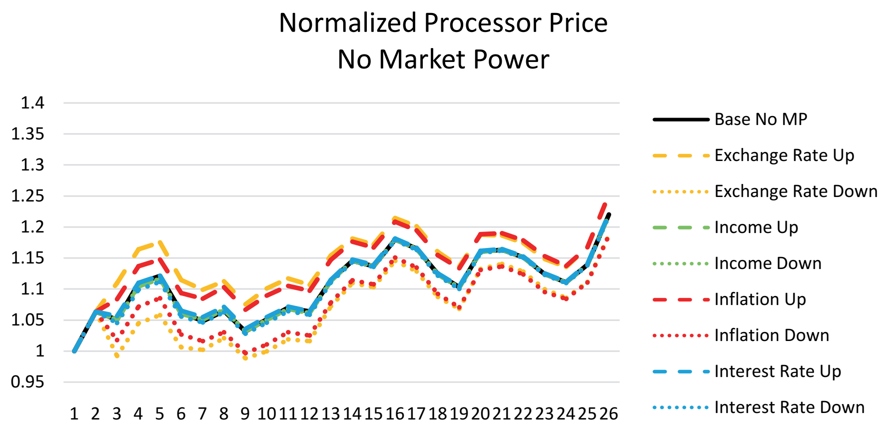

Fig. 6 Processor Price with No Market Power

allowing processors to sell at higher prices to retailers. This shock pattern rises initially above the response induced by an inflation rise, but those patterns are coincident after about a year. Similarly, a negative exchange rate shock initially causes processor price to fall below the inflation downward price response, but the two price lines join after about a year. Both shocks have price lines that return closer to the base level after 2 years. Larger exchange rate effects at the processor level, when compared to the retail level, reflect more livestock trade among North American countries the in the NAFTA era. Though the price level is high after 2 years, the price response lines are vertically closer to the base line than they are at the beginning of the scenario horizon. Return of processor price levels to the base reflect dynamic supply responses that only slowly adjust due to long animal agriculture adjustments. Muted price responses from macroeconomic shocks are related to the CRS technology at the upstream retail level (Fig. 7).

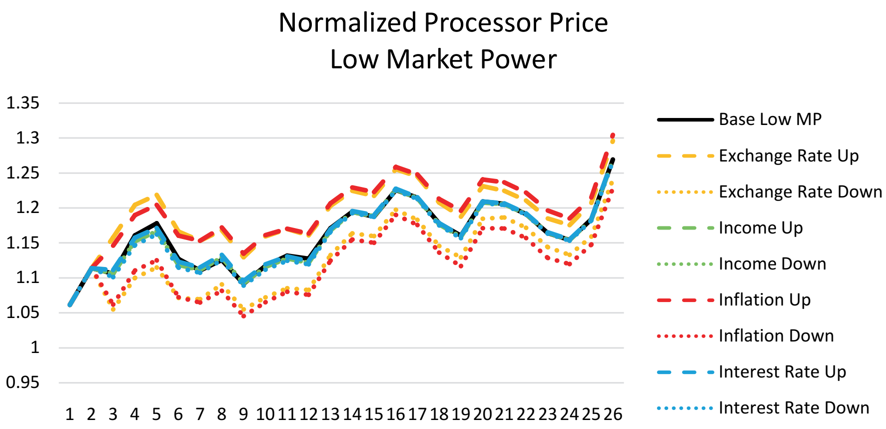

Fig. 7 Processor Price with Low Market Power

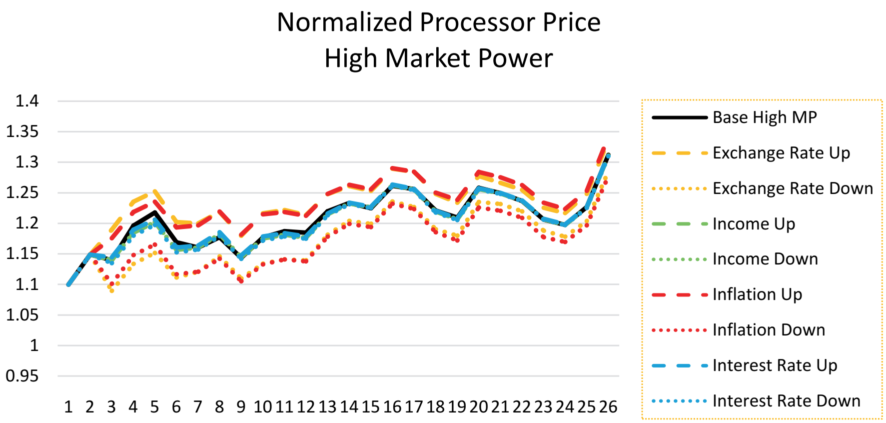

Fig. 8 Processor Price with High Market Power

The presence of low market power has an interesting effect. First, the price level is higher than the no-market-power case. Second, as before, only the inflation and exchange rate shocks evoke a price response distinct from the base level, though the interest rate scenarios both present below the base level in the initial months after the shock, but return to be coincident with the base for the rest of the time horizon. A rise and a fall in interest rates both act to depress prices at the beginning of the timeframe, perhaps because changes in interest rates affect investment decisions and thus processor prices. The exchange rate and inflation price responses are closer to each other early on than in the case with no market power, remain distinct for most of the time horizon and rejoin together only in the final time periods (Fig. 8).

Normalized processor prices respond to inflation and exchange rate shocks. Interestingly, at the processor level, the degree of market power affects the time path of the responses, but not so much the magnitude of the responses.

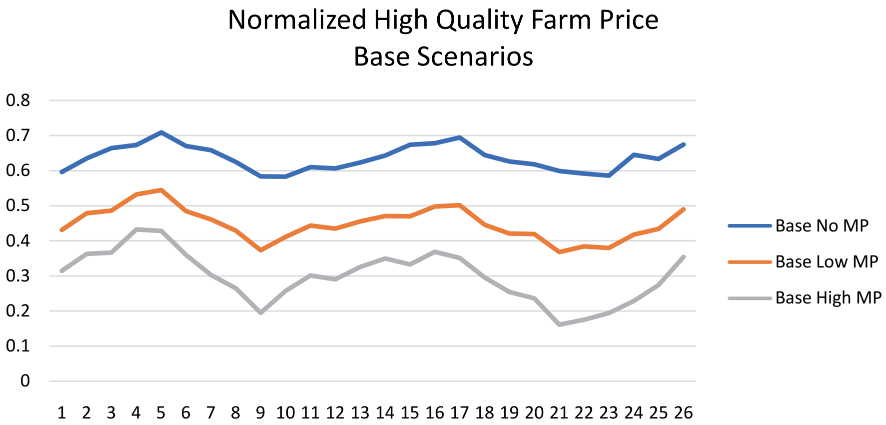

Fig. 9 Base Scenarios for High Quality Farm Price

12.3 High Quality Farm Price

Figure 9 presents the three base scenarios for the high-quality farm input price. This represents the price that processors pay farmers, or others in the upstream supply chain, for the raw material at the processor's plant. The high-quality input is the desired input that processors often contract production for and the output that farmers seek to produce for sale. In the model, we assume that processors exercise lower market power in procurement of high quality farm inputs than for low quality farm inputs since it is assumed that processors want to encourage high quality farm production that will define the quality of the ultimate consumer product.

As monopsony market power increases with the processor, this price falls. The level is at about 0.6 of processor output price with no market power and begins at 0.3 of that output price with 25% processor monopsony market power. Upstream producers must absorb the price adjustment for market power as they have none in this model. Note that the price path differs across the market power scenarios due to differing dynamic effects of macroeconomic shocks on production.

Figure 10 shows the price responses of the high-quality farm price with no market power. An inflation shock seems to have the largest impact, both in response to an upward shock and a downward shock. Exchange rate shocks also elicit price responses. Both income and interest rate shocks have limited effects on farm price compared to the base price level. Constant returns-to-scale technology at the retail/wholesale and processor/packer levels moderate transmission of macroeconomic shocks to the farm level with perfect competition and long-term supply adjustments relating to shocks in both income and interest take longer to realize than the 24-month horizon due to the long-term production adjustments required for animal agriculture. Interestingly, an increase in inflation lowers farm prices while a decrease in inflation raises them. This may be because inflation raises prices at the retail level, which leads to a decrease in demand for the goods and a cutback in purchases

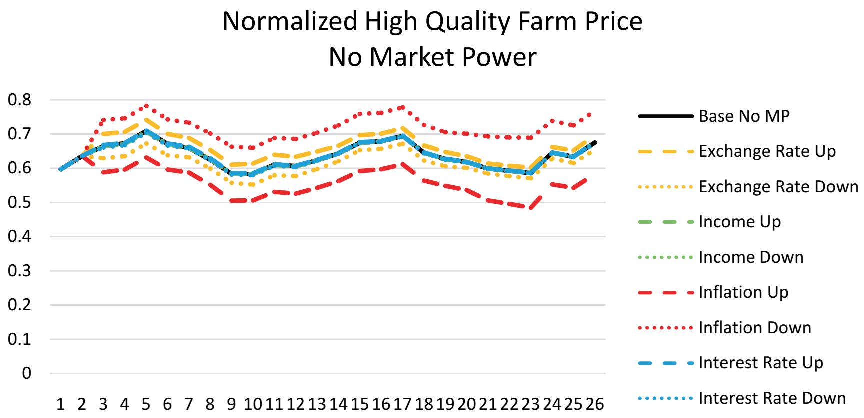

Fig. 10 High Quality Farm Price with No Market Power

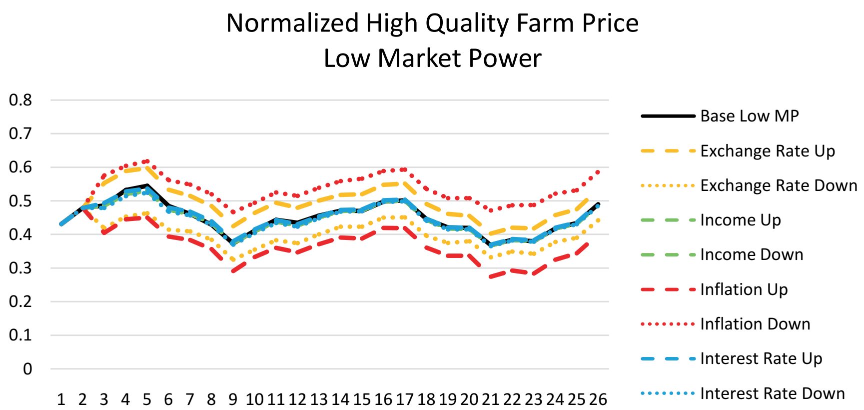

Fig. 11 High Quality Farm Price with Low Market Power

at the farm level. Conversely, a 25% decline in inflation reduces retail prices and the corresponding increase in demand at the farm level pushes up farm prices.

Figure 11 shows price responses compared to the low-market-power scenario. The responses are similar in magnitude for the inflation response (red lines), but the price level is reduced from around 0.6 to just over 0.4 as the processor exerts monopsony market power. The magnitude of the exchange rate response is larger in the presence of market power than without it.

Note that inflation changes have unexpected effects, as with no market power.

In Fig. 12, the high market power pushes the price level that farmers must accept to about 0.35. Interest rate and income shocks produce little price effect, though the interest rate shocks are discernable. The exchange rate shocks evoke the largest responses early on, but are soon overtaken by the price responses to inflation. Again, the high-quality farm price responses to a 25% increase in inflation by falling and a 25% decrease in inflation by rising.

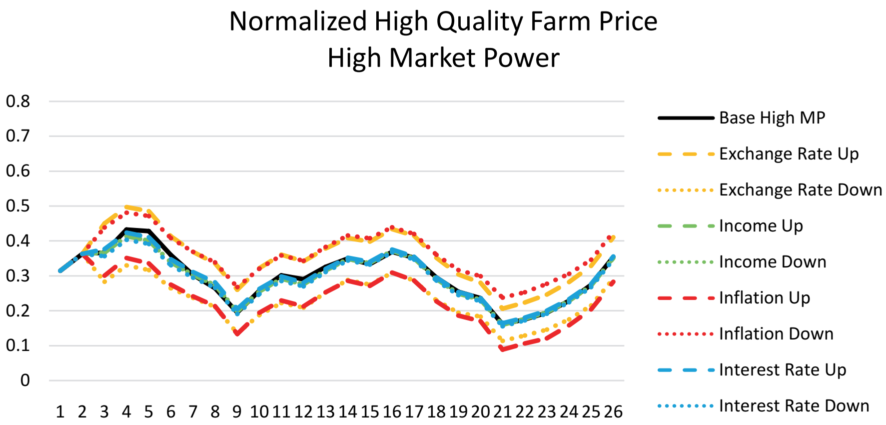

Fig. 12 High Quality Farm Price with High Market Power

12.4 Low Quality Farm Price

Low quality farm price is that paid by processors for low quality (commodity-type) farm output. It is product in the supply chain, but not the primary aim of branded production as would be the case for industry leaders. Figure 13 shows the base scenarios for this price. With no market power, this price is only slightly less than the high-quality farm price at about 0.53. With the exertion of market power, however, this price drops considerably. With low market power (0.125), the initial price drops to just over 0.3 and with high market power, the initial price drops to below 0.3. In addition, these prices show more volatility than the high-quality price over the time horizon. Note that both high and low market power base scenarios have price close together at about 9 months and again at 21 months.

Figure 14 shows the base scenario and price responses to shocks in the case with no market power exertion. As before, neither interest rates nor income evoke a discernable response. Exchange rate shocks change prices more in the early periods, but they return close to the base levels by the end of the time horizon. Inflation shocks have a bigger effect that lasts through the 2 years. Price responses to inflation shocks are inversely related to the shocks for this low-quality farm price (Fig. 15).

Low market power seems to enhance the price responds to exchange rate shocks. The base scenario price is much lower than without market power and the price responses to the exchange rate shocks maintain distance from the base throughout the time horizon. Again, inflation shocks evoke the largest magnitude of price response and the responses are inversely related to the inflation shock direction.

Figure 16 presents price responses in the case with high market power. The base price level is lower and the price seems more volatile. In this case, interest rate rise and fall evokes price responses distinct from the base scenario, especially in the early months. The inflation rate shocks induce a response that maintains throughout the timeline and the exchange rate shocks evoke a similar, but smaller, price pattern. The inflation price responses are inversely related to the shock direction.

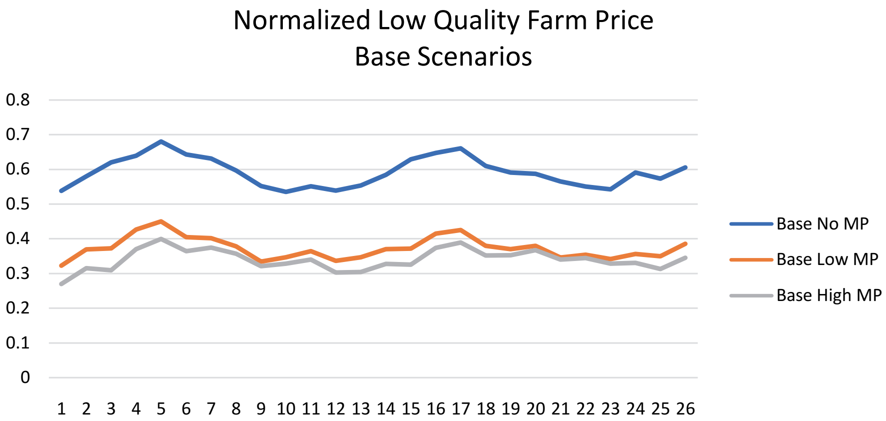

Fig. 13 Low Quality Farm Price Base Scenarios

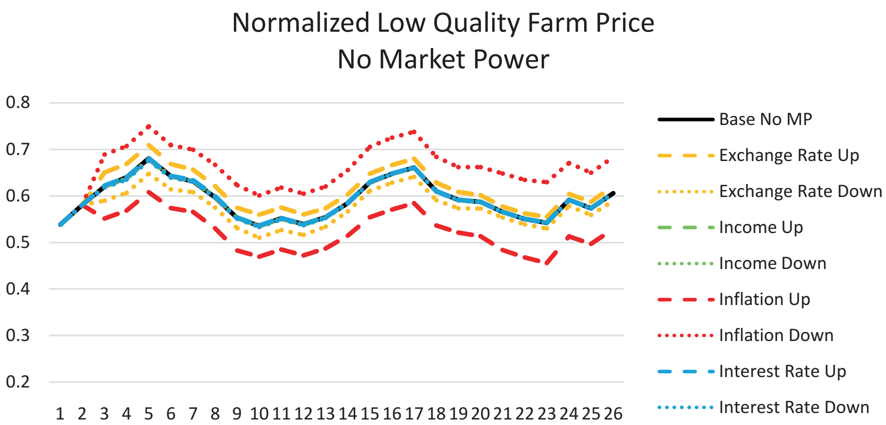

Fig. 14 Low Quality Farm Price with No Market Power

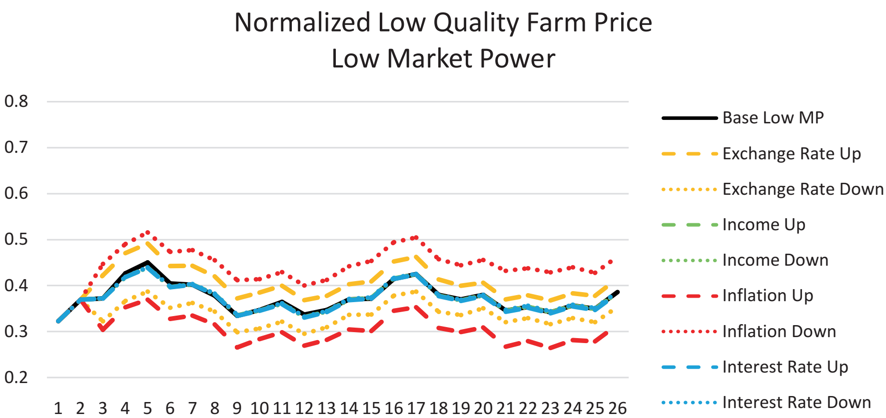

Fig. 15 Low Quality Farm Price with Low Market Power

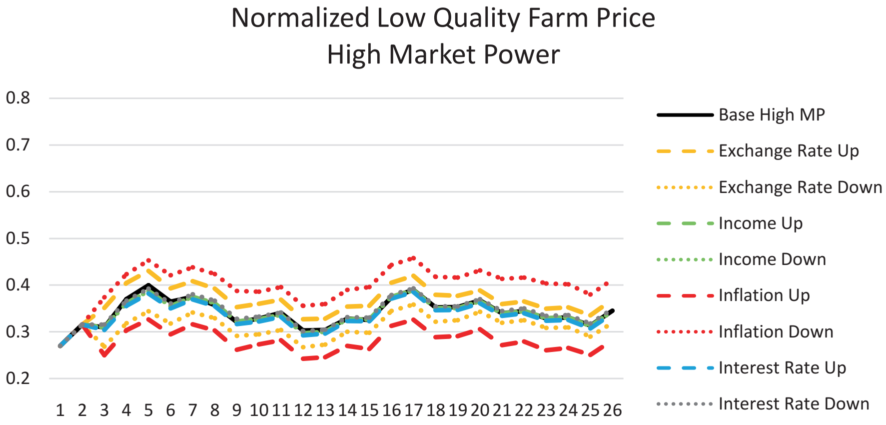

Fig. 16 Low Quality Farm Price with High Market Power

12.5 Price Level Changes in Response to Shocks

Four tables present basic summary statistics for mean, standard deviation, percentage change from the base level and coefficient of variation for the scenarios and shocks. The statistics are computed for the last 24 months of the timeframe, to omit the initial 2 months prior to the shocks.

Table 1 presents summary statistics for the normalized retail price. The base scenario with no market power exertion has a normalized retail price mean of 2.08, which is just over twice the period one processor price (normalization). The standard deviation of the base scenario is 0.13. The third line in the No MP section is the percent change of the scenario mean from the base mean. The last line is the coefficient of variation (CV), which measures the volatility of the price series. With no market power, the only shocks that evoke much price change are the inflation scenarios. A 25% increase in inflation results in a mean price 36.97% greater than the base mean price. A 25% fall in inflation results in a mean price 37.05% lower than the base mean price. Even so, those price series have about the same level of variation as the base, with CVs around 6.

In the case of low market power, the mean base price is 2.71 with a standard deviation of 0.13. The CV is lower, at 4.68 for the base low MP scenario. Income shocks have a greater effect under low market power, yielding percent changes of 12.63% for a 25% increase in disposable income and −12.75 for a 25% decrease in disposable income. Similarly, a 25% increase in inflation results in a mean price of 3.26, a change of 20.33%. A 25% decrease in inflation results in a new mean price of 2.15 a decrease of 20.58%. The CVs are relatively smaller with low market power than without market power.

The high market power scenario base level has a mean price of 3.25 with a standard deviation of 0.13. The exchange rate and interest rate shocks do not change price much. A 25% increase in income results in a new mean price of 3.86, a 18.97%

Table 1 Normalized retail price summary statistics

	Base	Exchange rate		Income		Inflation		Interest rate	
		Up	Down	Up	Down	Up	Down	Up	Down
No MP									
Mean	2.08	2.12	2.04	2.11	2.05	2.85	1.31	2.08	2.08
St Dev	0.13	0.12	0.14	0.13	0.17	0.17	0.10	0.13	0.13
% Ch		1.84	−1.90	1.44	−1.50	36.97	−37.05	0.10	−0.16
CV	6.42	5.91	7.00	6.36	6.51	5.87	7.74	6.37	6.50
Low MP									
Mean	2.71	2.73	2.67	3.05	2.36	3.26	2.15	2.71	2.70
St Dev	0.13	0.12	0.14	0.13	0.12	0.16	0.10	0.13	0.13
% Ch		1.05	−1.17	12.63	−12.75	20.33	−20.58	0.02	−0.14
CV	4.68	4.40	5.06	4.35	5.22	4.82	4.64	4.69	4.76
High MP									
Mean	3.25	3.27	3.22	3.86	2.63	3.60	2.89	3.25	3.24
St Dev	0.13	0.13	0.14	0.14	0.13	0.16	0.11	0.13	0.14
% Ch		0.72	−0.85	18.97	−19.10	10.77	−10.96	−0.01	−0.11
CV	4.12	3.94	4.43	3.73	4.86	4.54	3.78	4.15	4.20

change from the base price level. A 25% decline in income results in a 19.10% decline in price from the base. Similarly, up and down inflation shocks result in mean retail prices of 3.60 and 2.89, respectively. A 25% increase in inflation results in a new mean price 10.77% higher. A 25% decrease in inflation results in a new mean price 10.96% lower. The CVs are smaller than those for low or no market power.

Retail prices respond to those shocks that most directly affect consumers, income and inflation shocks. Market power seems to reduce the volatility in the price series. While price rises are somewhat less under higher market power, the price levels begin much higher. Market power appears to insulate retail prices from changes resulting from shocks and to dampen the variation in the price series overall. Although the response to shocks in income are the opposite. Income shocks have more impact on retail price with market power that without market power.

Table 2 reports the statistics for the normalized processor prices. With no market power, the normalized processor price has a mean of 1.11 and a standard deviation of 0.05 in the base scenario. Exchange rate shocks provide small changes both up and down. Income and interest rate changes do not move prices away from the base level. Inflation scenarios also have minimal impacts.

At low market power and at high market power, similar patterns obtain. Processor prices are at a higher level with low (1.17) and even higher still with high market power (1.21). However, the important pattern is the reduction in variation as market power increases. With no market power, the CVs are around 4, with low market power they are in the high 3's, and with high market power, the CVs are in the low 3's to high 2's. Once more, market power is seen to enhance price stability.

Table 2 Normalized processor price summary statistics

		Exchange rate		Income		Inflation		Interest rate	
	Base	Up	Down	Up	Down	Up	Down	Up	Down
No MP									
Mean	1.11	1.15	1.07	1.11	1.11	1.14	1.08	1.11	1.11
St Dev	0.05	0.04	0.05	0.05	0.05	0.04	0.05	0.05	0.05
% Ch		3.50	−3.61	−0.05	−0.05	2.79	−2.93	0.19	−0.30
CV	4.24	3.60	5.11	4.25	4.25	3.93	4.60	4.15	4.35
Low MP									
Mean	1.17	1.20	1.13	1.16	1.16	1.20	1.12	1.17	1.16
St Dev	0.04	0.04	0.05	0.04	0.04	0.04	0.05	0.04	0.04
% Ch		2.76	−3.07	−0.15	−0.15	3.02	−3.69	0.05	−0.36
CV	3.55	3.10	4.27	3.60	3.60	3.23	4.06	3.52	3.68
High MP									
Mean	1.21	1.24	1.18	1.21	1.21	1.24	1.17	1.21	1.21
St Dev	0.04	0.03	0.05	0.04	0.04	0.04	0.04	0.04	0.04
% Ch		2.43	−2.85	−0.21	−0.21	2.43	−3.08	0.04	−0.38
CV	3.13	2.73	3.88	3.22	3.22	2.91	3.59	3.15	3.30

Table 3 Normalized high quality farm price summary statistics

		Exchange rate		Income		Inflation		Interest rate	
	Base	Up	Down	Up	Down	Up	Down	Up	Down
No MP									
Mean	0.64	0.66	0.61	0.64	0.64	0.56	0.72	0.64	0.64
St Dev	0.04	0.04	0.03	0.04	0.04	0.04	0.03	0.04	0.04
% Ch		3.76	−3.88	−0.06	−0.06	−12.96	12.97	0.22	−0.34
CV	5.64	5.79	5.57	5.61	5.61	7.02	4.72	5.62	5.60
Low MP									
Mean	0.45	0.50	0.40	0.45	0.45	0.36	0.54	0.45	0.44
St Dev	0.05	0.05	0.04	0.04	0.04	0.05	0.04	0.05	0.04
% Ch		10.49	−11.56	−0.54	−0.54	−19.07	20.01	0.32	−1.39
CV	10.48	10.43	9.80	10.04	10.04	13.24	7.75	10.12	9.98
High MP									
Mean	0.30	0.35	0.23	0.29	0.29	0.23	0.36	0.30	0.29
St Dev	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07
% Ch		19.71	−22.76	−1.53	−1.53	−23.45	22.25	0.46	−3.52
CV	24.70	21.88	26.70	23.67	23.67	31.21	18.58	23.51	23.85

Table 3 presents the summary statistics for the normalized high quality farm price. The mean high quality farm price with no market power exertion is 0.64 with a standard deviation of 0.04. The CV is 5.64. While the exchange rate shocks produce small price changes, only inflation shocks really affect this high-quality farm price. A 25% increase in inflation produces a high-quality farm price mean of 0.56, a 12.96% decrease from the base level due to the shock. A 25% decrease in inflation yields a mean price of 0.72, a 12.97% increase in price from the base. With no market power, an inflationary shock increases retail and processor prices, resulting in a decrease in demand and thus a decline in what the farmer can receive.

With market power, these effects are more pronounced. Only the retailer and the processor have market power. The processor exerts monopsony market power against the farmers. When that market power is low, the base mean price is 0.45, with a standard deviation of 0.05 and a CV of 10.48. This price series is almost twice the variability of the base series without market power. Exchange rate shocks create price changes from the base in the 10% magnitude, indicating that this good is traded and so subject to exchange rates. Inflation also has major impacts, creating price changes with magnitudes about 20% of the base price level.

When high market power is exerted, the base price level is 0.30, less than half of the base price level without market power. Interestingly, the CVs are huge, mostly in the mid- 20s. Exchange rate shocks of ±25% results in significant price changes, as do the inflation shock scenarios.

For the farmer, the existence of market power in the supply chain clearly reduces welfare. Price levels drop considerably, and price variation significantly increases. In contrast to the retail and processor levels, farmers (and others upstream in the supply chain) have to absorb the market power exertion by those downstream. The result is lower and more volatile prices for their output.

The last table contains statistics for the low-quality farm price. With no market power, this price level is 0.60. Other than inflation, macroeconomic shocks have less impact on overall price level that is low. However, the variation in these prices is relatively high compared to retail and processor prices, and even to high quality farm prices.

When a low level of market power is exerted, prices for low quality, commodity-like, farm products drop considerably. The mean is 0.38. Exchange rate shocks result in some price changes. Income shocks and interest rates shocks have little impact. Inflation shocks generate similar shocks to those in the high-quality farm price. The variation rises in these prices to CVs of 8 and 9 (Table 4).

High market power exertion results in a further lowering of prices, to a new mean of 0.34 for low quality farm price. The pattern of price response to exogenous shocks is the same. Interestingly, the variation in prices is generally lower with the higher market power than with the lower market power, though slightly higher than without any market power.

12.6 Summary of Simulation Results

Comparison of the effects of macroeconomic shocks at the three stages of the supply chain reveals price responses which vary considerably across levels. Further, important drivers change across different supply chain stages. At the retail/wholesale level, inflation shocks are most readily transmitted to price with income shocks also playing an important role. In the simulations with no market power, the effects

Table 4 Normalized low quality farm price summary statistics

	Base	Exchange rate		Income		Inflation		Interest rate	
		Up	Down	Up	Down	Up	Down	Up	Down
No MP									
Mean	0.60	0.61	0.57	0.59	0.59	0.52	0.67	0.60	0.59
St Dev	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
% Ch		3.33	−3.44	−0.05	−0.05	−12.24	12.26	0.13	−0.23
CV	6.90	7.11	6.74	6.87	6.87	7.97	6.13	6.90	6.85
Low MP									
Mean	0.38	0.41	0.34	0.37	0.37	0.30	0.45	0.37	0.37
St Dev	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
% Ch		9.16	−10.05	−0.45	−0.45	−18.87	19.97	−0.77	−0.12
CV	8.15	8.41	7.51	7.82	7.82	9.68	6.60	7.93	7.72
High MP									
Mean	0.34	0.37	0.31	0.34	0.34	0.28	0.41	0.34	0.35
St Dev	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.03
% Ch		8.01	−9.13	−0.56	−0.56	−18.17	18.53	−1.96	0.84
CV	7.56	7.44	7.75	7.34	7.34	8.73	6.47	7.45	7.24

of an inflation shock on retail price is amplified. Interestingly, market power considerably mutes transmission of inflation shocks at the retail level from ±37% with no market power to ±11% with high market power. The effects of shocks from other macroeconomic variables are not readily transmitted to the retail price when no market power is exercised in the supply chain. However, increasing market power changes the pattern of macroeconomic shock transmission considerably. With market power, shocks in income have important price transmission effects to retail price. With high market power, income shocks have a ±19% effect on retail price, while with no market power, the effects on an income shock are minimal ±1%. Increasing market power has the effect of muting price volatility as measured by the coefficient of variation across all types of macroeconomic shocks.

At the processor/packer level, the effects of macroeconomic shocks are least impactful on price and price variation. Shocks in all macroeconomic variables are only minimally transmitted to processor level output prices across all market power scenarios. This suggests that processor/packer level prices are less responsive to macroeconomic shocks than are prices at other levels in the supply chain regardless of market power. An implication is that processor/packer output prices are most “exogenous” across the three supply chain levels, a finding consistent with Park et al. (2011) that price causality in the US beef supply chain is consistent with one that is processor driven.

Prices at the farm level respond most to shocks in inflation and exchange rate with increasing down-stream market power exertion amplifying the effects of shocks. With no market power, inflation shocks have a ±13% effect on both high- and low-quality farm price and a ±23% and ±19% effect on high- and low-quality farm price. Exchange rate shocks have less impact with no market power, ±3.5% for high- and low-quality farm prices and amplified impacts with market power ±20% for high quality farm price and ±8.5% for low quality farm products. The farm level high quality product producers experience very large increases in price volatility as market power in downstream levels of the supply chain increase. The CV increases from about 5 with no market power to about 25 with high market power. This does not appear to be the case for farm production of low-quality inputs where the CV remains near 7 across all market power scenarios.

Overall, macroeconomic shocks are readily transmitted to the retail and farm levels while prices at the processing/packer level prices are least impacted by macroeconomic shocks. However, market power appears to mute transmission of macroeconomic shocks at the retail level while at the same time amplifying the effects of macroeconomic shocks at the farm level in terms of both price levels and variation in prices, especially for high quality farm products. Farm level prices fall and become more variable with increasing market power exertion downstream. Especially for the high-quality farm input, this variation is pronounced.

13 Conclusion

In their seminal paper Rausser et al. (1986) investigated key linkages between the macroeconomy and agriculture sector using a fully integrated macroeconomic-agricultural sector model. Organization of the food sector has changed significantly since the mid-1980s with much of developed agricultural moving from vertically linked perfectly competitive commodity markets to concentrated supply chains linking production and marketing. A stylized model of a concentrated supply chain is developed to gain a better understanding of how transmission of macroeconomic shocks through the agricultural sector may have changed with this structural change. The experiments reported in this chapter indicate that, given this stylized model, macroeconomic shocks have important differential impacts on prices at various levels in an agricultural supply chain. Importantly, macroeconomic impacts are more pronounced when retailers and processors exert market power. With supply chains where retailers and processors exercise market power, farmers receive a lower share of the consumer dollar and must also absorb much more of the total market response created through macroeconomic shocks. With increasing market power, variation in prices experienced by farmers is greater than that experienced by retailers or processors.

Macroeconomic shocks can be magnified or muted in vertically organized agricultural supply chains by market power, depending on the stage in the supply chain most immediately connected to the macroeconomic shock. Shocks that directly affect the consumer, like inflation and disposable income, have significant effects at the retail level. Changes in demand resulting from inflationary price responses work their way back to the farm and the impacts on farm-level prices can be large, larger than the retail price changes. Exchange rate shocks have important effects at the farm-level as well because products are internationally traded at that level. Interest rates shocks seem to have minimal effects on this supply chain, but that might be because the 24-month timeframe is too short to fully display the dynamics of animal agriculture adjustment.

Though the structure of the agricultural sector has changed markedly in the years since the seminal Rausser et al. (1986) paper, the importance of the research remains. The results in this chapter point out that this is still a fundamentally important area of scientific inquiry. Although some empirical investigations have been conducted, as indicated above, there still remains a huge amount of work that must be done to fully understand how the macroeconomy affects agriculture given its food and agricultural evolving structure. In today's world of agricultural supply chains and bilateral market power up and down the chain, the simulations preformed indicate that the farm level seems to absorb more of macroeconomic shocks than under perfect competition assumed in earlier models. With imperfectly competitive supply chain participants, farm-level prices are more volatile, perhaps overshooting their eventually equilibrium values in response to a macroeconomic shock. However, it also appears that moving to increased coordination of food supply through supply chains with higher market power in the downstream chain may be moving retail food prices to higher and more stable price levels when compared to more intermediate market-like coordination without market power in the coordinating market chain. At the same time, the nature of agricultural markets, and particularly the market power structure of agricultural supply chains, means that farm-level prices still react strongly to stimuli and that farms are likely more vulnerable to policy actions than processors or retailers.

These results suggest new lines of research for agricultural supply chains and their linkages to the rest of the economy. Macroeconomic policies are meant to impact broadly across the whole economy of a nation. Fiscal policies can be targeted or be broad in their effects. Sectoral policies are by their nature targeted in their impacts. Much more needs to be understood about the policy impacts on sectors given their evolving organizational structures.

Acknowledgement The authors with to thank Diana M. Burton for research assistance.

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The Theory of Normal Backwardation and Financialization of the Futures Markets

Colin A. Carter and Cesar Revoredo-Giha

"The genius of trend-following (in futures markets) is not how awesome it is, but its incredible mediocrity, which is far harder to engineer than people think. It's like trying to cheat at the casino, if you're too good then the casino throws you out. Trend following works right at the edge of randomness."[1]

1 Introduction

Over the past 20 years, there has been a large inflow of investment capital into commodity futures markets—the *financialization* of commodities. This chapter analyses the behavior of commodity futures contract returns before and since financialization of the markets. We believe that Professor Gordon Rausser's research in the 1970s contributed to the dramatic inflow of speculative investment into commodity futures, because he showed there were possible profits to be made "right at the edge of

[1] This quote is from a *Financial Times* interview with Mike Adam, one of the founders of the successful hedge fund AHL. Mr. Adam started by drawing price charts by hand in his father's sugar broking firm. https://www.ft.com/content/916ed2e0-d63f-11e9-a0bd-ab8ec6435630. September 16, 2019.

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randomness" with computerized trading rules. Using the methodology in Carter et al. (1983) we find that the financialization impacted the Keynesian risk premiums in the futures market, as the market became over-crowded with speculative money.

This chapter is dedicated to Gordon Rausser, who has been a significant and influential contributor to the literature on the economics of futures markets. He has also shaped the way in which hedge funds and other large investors such as pension funds view the commodity futures market. Some of Dr. Rausser's publications in this area include Cargill and Rausser (1972, 1975); Carter et al. (1983); Just and Rausser (1981); Rausser and Just (1979); Rausser and Carter (1983), and Rausser and Walraven (1990).

Professor Rausser was one of the very first economists to use the latest in computer technology in the early 1970s to study futures price behavior and price patterns. This technique was subsequently picked up by many in the profession and importantly by hedge funds and professional money managers investing in the futures market. The business of hedge funds and other capital managers investing in commodity futures, using quantitative computer models, began after Gordon Rausser's pioneering work with Cargill, see Cargill and Rausser (1972, 1975). Cargill and Rausser studied the stochastic behavior of futures prices, using a very sophisticated methodology for the time. Cargill and Rausser (1972) studied eight markets and their results raised doubts as to whether futures price behavior is consistent with the random walk model as a general explanation of how futures price behave over time. Then a few years later Cargill and Rausser (1975) studied seven commodity futures contracts in more detail: corn, oats, soybeans, wheat, copper, live beef cattle, and pork bellies. Based on a number of serial correlation tests, for these commodities Cargill and Rausser rejected the random walk model. The implication of this finding was that the application of certain mechanical filter trading rules could lead to substantial profits in commodity futures, due to their nonrandom behavior.

Subsequent to the publication of Cargill and Rausser (1975) the futures markets attracted more and more attention from investors from outside of the commodity business–non-commercial market participants. It then became commonplace for trend-following hedge funds and large money managers to begin to use computers for quantitative and statistical analysis of futures prices to inform trading decisions. They started what is now known as the financialization of the futures market and their techniques were no doubt informed by Professor Rausser's work. In fact, the Chicago Mercantile Exchange (CME) held at least four managed futures symposia in the late 1980s and early 1990s, with an agenda that was largely based on Carter et al. (1983). These symposia covered institutional investors' use of commodities and issues related to managed futures. The work of Carter et al. (1983) was presented at each symposia.

In an article[2] entitled *The hedge funds split over following market trends*, the *Financial Times* reported on one of these successful firms that pioneered computer driven investing in commodity futures:

[2] https://www.ft.com/content/916ed2e0-d63f-11e9-a0bd-ab8ec6435630. September 16, 2019

> In 1982, Mike Adam, a scholarship student who had dropped out of Magdalen College, Oxford, took a backroom job in his father's sugar broking firm in London. The new job entailed drawing commodity price charts by hand and tracking the brokerage's trades. To save time, Mr. Adam programmed the first computer to arrive in the firm's offices to do the job for him. Soon, overcome by curiosity, he began to test whether the computer could be coded in such a way that he could make money from trading patterns. Together with his close friend from university, Marty Lueck, who was a programmer, and David Harding, a Cambridge-educated scientist fascinated with finance, he designed a trading system. At its heart was a simple concept—financial markets exhibit trends, and computers can be programmed to spot those trends and profit from them. Amid much skepticism from a finance industry that largely believed using computers to predict market moves was little more than hocus-pocus, the trio in 1987 launched AHL—a name based on the first letters of their surnames. The firm, which now runs $30bn in assets, went on to help spawn a $300bn-dollar industry of similar hedge funds that follow market trends and which have minted vast fortunes.

A risk premium in futures prices is consistent with the Cargill and Rausser (1975) finding that futures prices may have deterministic trends, in violation of the random walk hypothesis. Such a risk premium could arise due to hedging pressure. It was Keynes (1923b) who suggested that futures prices may trend upward, because at any given time the futures price will be below the anticipated future spot price by the amount of the risk premium, paid by hedgers. The existence and size of a *risk premium* in futures markets has been controversial since the famous Telser-Cootner debate in the late 1950s and early 1960s (see Telser (1958) and Cootner (1960)). Based on the belief that trading profits on the long side could be earned from such a risk premium, about 40 years after the debate, the American International Group (AIG) established the AIG commodity index—an index of commodity futures prices—in the late 1990s.[3] The AIG index was established in order to attract outside investors to commodity futures. Investing in the AIG index was a relatively easy way for an investor to add commodities to a portfolio. The work by Gorton and Geert Rouwenhorst (2006) supported AIG's aim to attract investors to futures markets as Gorton and Geert Rouwenhorst argued that commodity futures offer the same return and Sharpe ratio as U.S. equities. The underlying explanation was the existence of a risk premium in commodity futures. However this view was not without controversy, as Erb and Harvey (2006) concluded that average commodity futures returns are not equity-like, instead they are zero. Later, Erb and Harvey (2016) argued that portfolios of commodity futures do not have equity-like returns either.

Index speculation in commodities took off in the early 2000s, so much so that in 2008 the U.S. Senate held committee hearings on the role of index speculators influencing crude oil prices, because oil spiked above $130 a barrel in the summer of 2008. The impact of the increased trading of noncommercial players on commodity prices has been dubbed the *financialization of commodity markets*. Many of the "outside" investors hold commodities through commodity futures indexes such as

[3] The Goldman Sachs Commodity Index was developed in 1991, and the Bloomberg Commodity Index was developed around the same time as the AIG index.

the Goldman Sachs commodity index (GSCI), the Dow Jones index (DJ-UBS) and the S&P commodity index (SPCI). They also invest in over-the-counter (OTC) swaps and exchange-traded-funds (ETFs) linked to commodity indexes. Index speculators are thought to be the largest participants in the futures market today, and nearly all of them are based on passive, long-only, commodity futures positions (Stoll & Whaley, 2010). Pension and hedge funds joined this group of large speculators. For instance, the California Public Employees' Retirement System (CalPERS) began allocating money to commodities in 2007.[4]

Commodity index investments were profitable from around 2000 until 2008, according to the commodity trading adviser—CTA Benchmark Index. As shown in Fig. 1, the *CTA Benchmark Index* peaked around the same time as assets under management in commodity futures peaked (approximately 2012). Since then there has been a degradation in futures returns earned by this class of traders. Could this be due to increased competition for the same source of alpha[5]–a case of more funds using the same approach in the same markets? The question we address is whether *financialization of futures* has impacted futures market risk premia. Previous studies by Hamilton and Wu (2015) and Main et al. (2018) have addressed a similar question but without controlling for changing speculative positions, the importance of which was recognized by Cootner (1960) and Carter et al. (1983)—hereafter

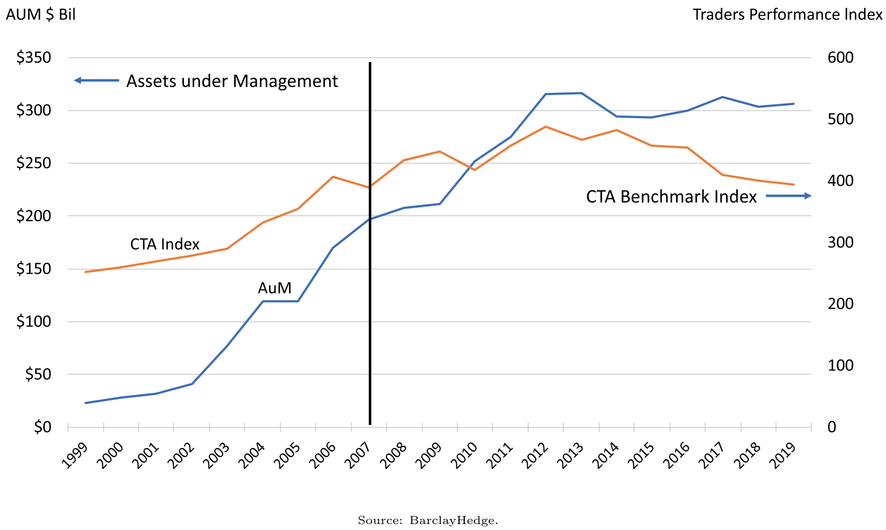


Fig. 1 Managed futures & returns index

[4] In September 2014 CalPERS announced that it was eliminating its hedge fund program. However at the same time CalPERS announced that it was maintaining a portfolio of commodity futures tied to the S&P GSCI.

[5] The excess return of an asset relative to the return associated with the asset's beta is the asset's alpha.

CRS. We investigate the same futures markets as in CRS–wheat, corn, soybeans, cotton and live cattle.

Hamilton and Wu (2015) found that commodity index-fund investing had no measurable effect on commodity futures prices. Similarly, Main et al. (2018) showed that the average unconditional return to individual commodity futures markets was approximately equal to zero before and since financialization of the markets. Controlling for the importance of liquidity provision in the commodities market, Kang et al. (2020) find an empirical relationship between hedging pressure and expected futures risk premiums. However, these recent papers treat commodities as individual assets instead of being part of a balanced portfolio that includes equities and other commodities. In contrast to these studies, we control for weekly changes in speculative positions and model commodity returns in a portfolio context, similar to CRS. As in CRS, we allow for two factors giving rise to futures premiums, hedging pressure and systematic risk. We find that the recent poor returns to managed futures trading coincided with a suppressed risk premium.

The structure of our chapter is as follows: we start by providing a background on the financialization of commodity futures, which is followed by a literature review (Sect. 3) on *normal backwardation* since Keynes and its developments. The next section presents the methodology of the paper. Section 5 presents our empirical analysis and Sect. 6 concludes.

2 Background

The *financialization* of commodity futures refers to the fact that managed money (or institutional funds) investment in commodity futures has grown–i.e., the emergence of commodity futures as an asset class. Assets under management in commodity futures grew from less than $50 Billion in the early 2000s to over $300 Billion recently, see Fig. 1. In Fig. 1 assets under management are shown on the left-hand vertical axis and the Barclay CTA benchmark index showing trader's performance is on the right-hand axis. A vertical line is drawn in Fig. 1 at the year 2007 to represent when financialization took hold, with over $200 Billion invested in the futures market by then. The Barclay CTA Index[6] represents the performance of hundreds commodity trading advisers[7] and it has been declining since about 2012.

Figure 2 provides an annual breakdown of the average performance of managed futures funds, from 2000 to 2018. The funds earned positive returns on average

[6] The Barclay CTA Index is designed to broadly represent the performance of all CTA programs in the BarclayHedge database. The programs included in the index must have a performance history. Only CTAs with 4 years of performance history are included in the index and the performance history begins with year 5. At the beginning of the year a hypothetical portfolio is formed with each constituent program given an equal allocation. The index monthly return is simply the monthly return of this hypothetical portfolio. In 1999 319 CTA programs were included in the index.

[7] http://bitly.ws/6HVK

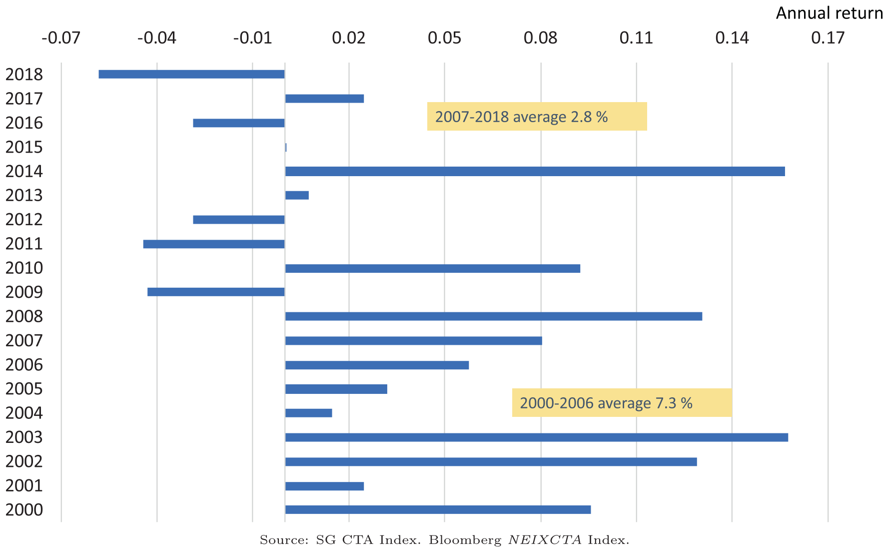


Fig. 2 Managed Futures Performance

from 2000 through 2008. From 2000 to 2006 the annual average return was 7.3%. Average returns then declined in the more recent years. From 2007 through 2018 the annual average return was only 2.8%, with negative annual returns as frequent as positive annual returns.

Further confirmation that futures have not been generating equity like excess returns is shown in Table 1, which reports 2008–2018 returns for the S&P equity index, Barclay's bond index, and the Bloomberg Commodity Index (BCOM). Bloomberg's BCOM is calculated as an excess return and it reflects commodity futures price movements. BCOM experienced an annual average returns of −2.74% from 2008–2018, while the S&P return averaged 6.74% over this same time period.

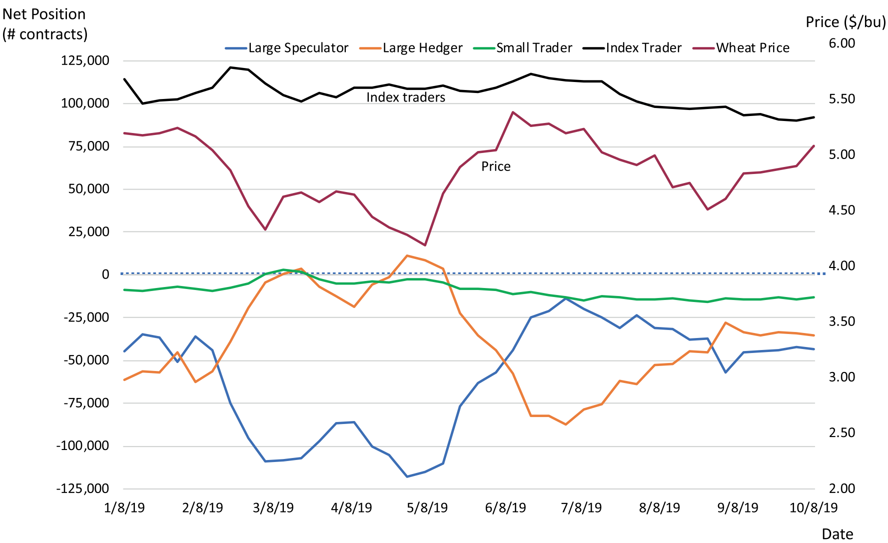
For 13 agricultural commodity futures markets, the Commodity Futures Trading Commission (CFTC) publishes weekly data on the relative importance of index trading in a supplemental commodity index report.[8] These data for 9 months in 2019 are provided in Figs. 3, 4, 5, 6, 7 for CBT SRW wheat, corn, soybeans, cotton and

[8] The CFTC explains that: "Index Traders are drawn from the noncommercial and commercial categories. The noncommercial category includes positions of managed funds, pension funds, and other investors that are generally seeking exposure to a broad index of commodity prices as an asset class in an unleveraged and passively-managed manner. The commercial category includes positions for entities whose trading predominantly reflects hedging of over-the-counter transactions involving commodity indices–for example, a swap dealer holding long futures positions to hedge a short commodity index exposure opposite institutional traders, such as pension funds." see https://www.cftc.gov/MarketReports/CommitmentsofTraders/ExplanatoryNotes/index.htm. The 13 markets included in the CFTC supplemental index report include: CBOT SRW wheat, CBOT HRW wheat, CBOT corn, CBOT soybeans, CBOT soybean oil, CBOT soybean meal, ICE cotton, CME lean hogs, CME live cattle, CME feeder cattle, ICE cocoa, ICE sugar No. 11, and ICE coffee.

Table 1 Equity, bond and futures returns

2008–2018	S&P 500	Barclays Bond Index	Bloomberg BCOM
10 year avg. return	6.74%	3.67%	-2.74%

Source: SG CTA Index. Bloomberg NEIXCTA Index
Note: BCOM is calculated on an excess return basis and reflects commodity futures price movements

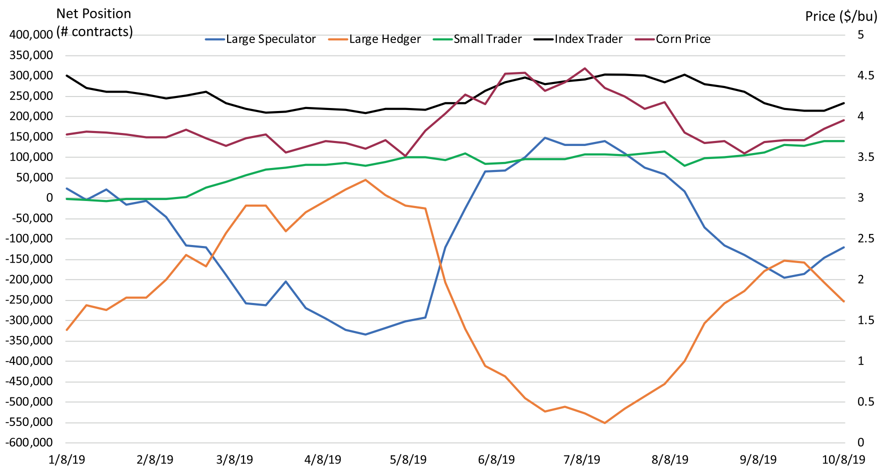


Source: Commodity Futures Trading Commission.

Fig. 3 Index traders large share of the market: Wheat

live cattle, respectively. The left-hand vertical axes in Figs. 3, 4, 5, 6, 7 report the net futures positions (long minus short) for four classes of traders: large speculators, large hedgers, small traders, and index traders. The large hedgers and large speculators are traders who hold outstanding futures positions that exceed CFTC defined thresholds.

For reference, the commodity's price is shown on the right-hand vertical axis in Figs. 3, 4, 5, 6, 7. Unlike other classes of traders, the overall number of contracts held by index traders from week to week does not seem to be correlated with the price at all. It is clear from these Figures that index traders are some of the largest participants in these markets, measured in terms of net positions. The Figures also show that the index traders in net terms were long for the entire time period, for all the commodity markets with information on index trader positions. In the case of CBT wheat in Fig. 3 index traders held on average over 105,000 (net long) contracts, compared to large speculators who held around 59,000 (net short) contracts on average. For corn in Fig. 4, index traders held over 252,000 (net long) contracts on average, while large speculators held around 89,000 (net short) contracts on average. See Table 2 for these summary statistics for the other markets. With the exception of live cattle, the index traders were the dominant group during the time periods shown in Figs. 3, 4, 5, 6, 7.



Source: Commodity Futures Trading Commission.

Fig. 4 Index traders large share of the market: Corn

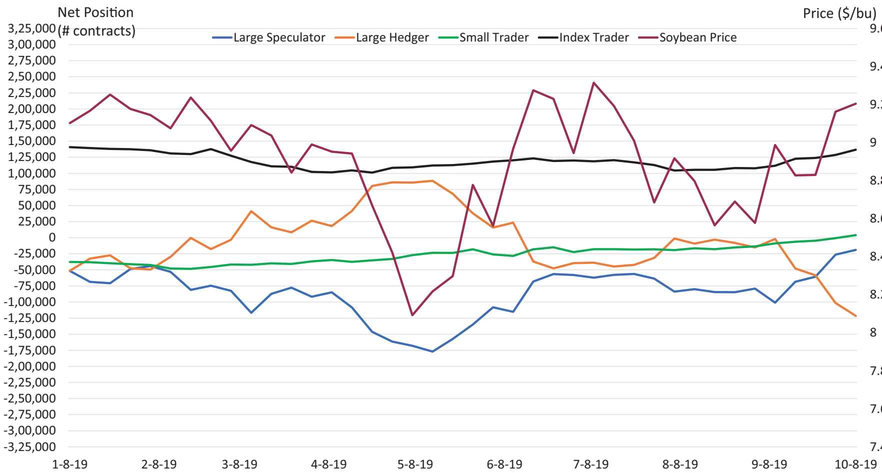
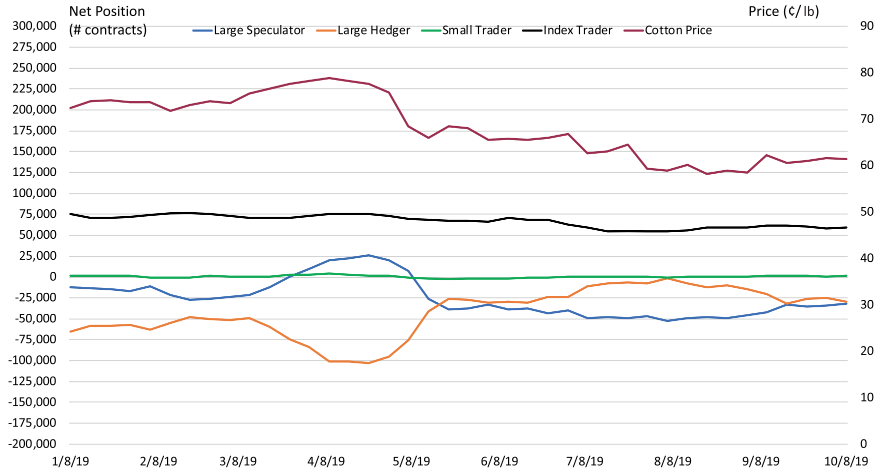
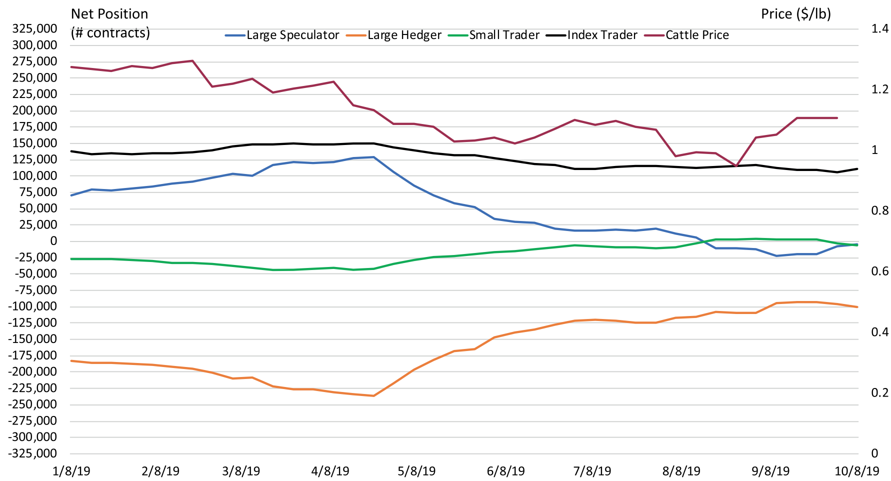


Fig. 5 Index traders large share of the market: Soybeans



Source: Commodity Futures Trading Commission.

Fig. 6 Index traders large share of the market: Cotton



Source: Commodity Futures Trading Commission.

Fig. 7 Index traders large share of the market: Live Cattle

Table 2 Average weekly trader positions: sample from Jan-Oct 2019

Average net position (long–short)			
Commodity	Large speculator	Large hedger	Index trader
Wheat	−59,248	−37,604	105,700
Corn	−88,775	−241,248	252,230
Soybeans	−85,495	−6,810	118,702
Cotton	−25,134	−42,265	66,819
Live cattle	52,460	−160,823	128,291

Source: CFTC

3 Literature Review

As mentioned above, an essay in the Manchester Guardian Commercial in 1923 by John M. Keynes (Keynes, 1923b) initiated the concept of the *theory of normal backwardation*.[9] In his view futures prices are unreliable estimates of the cash or spot price prevailing on the date of expiry of the futures contract. He believed it "normal" for the futures price to be a downward biased estimate of the forthcoming spot price. This theory in effect, argues that speculators sell "insurance" to hedgers and that the market is "normally" inefficient because the futures price is not an unbiased estimate of the subsequent spot price.[10]

The three crucial assumptions of the theory of normal backwardation are: that speculators are net long, they are risk averse (i.e., they require positive profits), and they are unable to forecast prices (i.e., all of their profits can be viewed as a reward for risk bearing). Given these assumptions, two major implications can be assigned to the theory. The first is that over time speculators will earn profits by merely holding long positions in futures markets. The second implication is that there is an upward trend in futures prices, relative to spot prices, as the contract approaches maturity.[11]

Cootner (1960) argued that Keynes' hypothesis implies futures prices should not necessarily rise until after the peak of net short hedging has passed. That is, he interpreted the theory to mean seasonal trends in futures prices should be taken as an indication of a risk premium. Telser (1958) and Cootner (1960) both tested their interpretation of the theory of normal backwardation and obtained conflicting results, even though they used the same data. Cootner found evidence to support the theory of normal backwardation, whilst Telser's conclusions were contrary. However, the problem was essentially assumed away to Telser. He assumed speculators require no remuneration to play the futures market and then went on to conclude they earn no remuneration in a competitive market.

Several other early writers have also tested the validity of the theory of normal backwardation. A succinct summary of their findings was given by Rockwell (1976) who concluded:

> While the theory of normal backwardation may be valid for particular markets under special conditions, it is not adequate as a general explanation of the flow of profits in commodity markets. (p. 110)

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[9] See Cristiano and Naldi (2014) for an interesting analysis of Keynes's own personal speculation in the cotton market as it relates to the theory of *normal backwardation*.

[10] As an aside note, it is not surprising that the insurance explanation behind backwardation appealed to Keynes as he was a director of the Provincial Insurance Company from 1923 until his death. It is also interesting that although he was well aware of the operations of different commodity markets as evidenced by (Keynes, 1923a), the only empirical information presented in (Keynes, 1923b) is a calculation based on cotton futures markets.

[11] Nevertheless, Just and Rausser (1981), and Rausser and Just (1979) demonstrated that commodity futures price forecasts dominate most large-scale econometric price forecasts.

Subsequently Dusak (1973) then tested for the existence of a risk premium within the context of the capital asset pricing model (CAPM). With this approach, she argued, the Keynesian notion of a risk premium takes on a new interpretation. Namely, the risk premium required on a futures contract should depend on the extent to which the variations in prices are systematically related to variations in the return on total wealth. If the CAPM applies, and if the risk of a futures contract is independent of the risk of changes in the value of all assets taken together, then investors will not have to be paid for that risk since they can diversify it away. The original Keynesian "insurance" interpretation, on the other hand, identifies the risk of a futures asset solely with its own price variability. Dusak tested for both types of risk in the futures market, and her results suggested that wheat, corn, and soybeans futures contracts are not risky assets whether they are held independently or as part of a larger portfolio of assets.

In Dusak's analysis it is implicitly assumed that speculators are net long throughout the life of a futures contract. By relaxing this assumption it is believed that one could find at least some degree of specific risk associated with a futures contract. In empirically estimating the capital market line, Dusak uses the return on the value-weighted Standard and Poor (S&P) Index of 500 Common Stocks as a proxy variable for the return on total wealth. An alternative proxy (one which gives some weight to a commodity index, for example) may well yield some degree of systematic risk.

Conceptually, the equilibrium futures price in relation to the expected spot price at expiry can be characterized by examining the net positions of hedgers and speculators. Commercial hedgers are interested in entering into futures contracts in order to eliminate price risk. If commercial hedgers are typically net short, this means that at any given futures price, hedgers as a group want to sell more contracts than they want to buy as illustrated by the line WX in the left quadrant in Fig. 8.[12] The higher

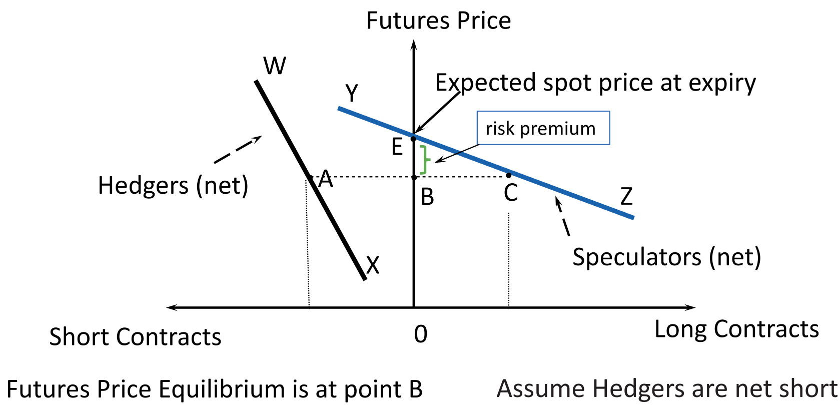


Fig. 8 Theory of normal backwardation

[12] Not all hedgers are not short since there are commercial buyers of product in the market that have an incentive for hedging as well.

the futures price the more contracts they want to sell, and hence WX is downward sloping. Speculators have no interest in entering into futures contracts as a way to reduce risk, instead they enter into futures contracts with the goal of profiting from expected price movements. When the futures price is equal to the expected spot price at expiry, E, speculators as a group will be neither short nor long as there is no potential profit since the expected price change in the futures contract is zero. When the futures price is below the expected spot price at expiry, (the right-hand portion of the line YZ in Fig. 8) speculators will be net long as they anticipate earning a profit from the expected increase in the futures price. Similarly, when the futures price is above the spot price "expected" at expiry, speculators as a group will want to be net short. This is shown by the top portion of the line YZ in Fig. 8.

The futures market will clear only when the total number of short contacts equals the number of long contracts. This market clearing condition along with the net short position of hedgers leads to the futures price equilibrium, B, at a price below the expected spot price (E) at expiry. In Fig. 8, we can see that the equilibrium futures price is at point B and the volume of contracts represented by the net hedgers position, A, equals the speculators net long position, C.

This is why, in the view of John Keynes, futures prices are unreliable estimates of the cash price prevailing on the date of expiration of the futures contract. He believed it "normal" for the futures price to be a downward-biased estimate of the forthcoming spot price. This theory, in effect, argues that speculators sell "insurance" to hedgers and that the market is "normally" informationally inefficient because the futures price is a biased estimate of the subsequent spot price.

CRS built on Houthakker (1957), Telser (1958), Cootner (1960), and Dusak (1973), and found a risk premium in the futures market. CRS measured returns in a portfolio context, as in the equity risk premium literature that focuses on the risk and return of an asset's contribution to a portfolio instead of individualized risk and return. With this framework, futures returns depend on movement with the market—systematic risk and also idiosyncratic risk. CRS found commodities in which hedgers were net short had positive excess returns on average and commodities in which hedgers were net long had negative excess returns on average—supporting Cootner (1960) that speculative pressure matters. CRS estimated non-market and systematic risk as time-varying parameters to evaluate seasonal changes in investors' positions and they modified Dusak's choice of the investor's portfolio. Marcus (1984) criticized CRS for over-weighting commodities in the well-diversified portfolio and showed that with a reduced weighting the hypothesis of zero systematic risk cannot be rejected. This is not surprising because it is essentially a restatement of the Dusak result, and it assumes that a portfolio comprised of only equities is optimal. The CRS finding of seasonality of non-market risk is independent from the debate over how much weight to give commodities in the investor's portfolio.

CRS not only found evidence of systematic risk, but more importantly, they found evidence of *non-systematic risk* that varied seasonally. CRS' finding of time-varying non-market risk encouraged subsequent work to apply more general non-static models of the pricing of futures contracts.

For example, Kang et al. (2020) provided a contrary perspective to the Keynesian theory. They find an empirical relationship between hedging pressure and expected futures risk premiums. Instead of hedgers paying speculators a risk premium, they suggest speculators must pay a premium to hedgers (i.e., commercial firms) in order to generate necessary market liquidity. However, their paper treats commodities as individual assets instead of being part of a balanced portfolio that includes equities and other commodities.

Fama and French (1987) also also tested for a time-varying risk premium in futures prices. Chang (1985), Bessembinder (1992) and De Roon et al. (2000) found that futures risk premia are related to market risk and hedging pressure, confirming the finding in CRS. Erb and Harvey (2006), and Gorton et al. (2012) further linked the commodity futures risk premium to backwardation in commodity futures and the theory of commodity storage.

Gorton and Geert Rouwenhorst (2006), and Bhardwaj et al. (2016) studied monthly returns to commodity futures as an asset class. Their data set went back as far as the 1950s. They conclude that commodity futures have offered the same return as publicly traded U.S. stocks, adjusted for the risk free return equities. Furthermore commodity futures returns are negatively correlated with stock returns and bond returns. The negative correlation arises from commodity futures different behavior over a business cycle because commodity futures are positively correlated with inflation. Implicit in this finding is the implication that speculators in commodity futures receive a return for providing price insurance to hedgers. In the presentations to large institutional money managers sponsored by the CME, mentioned above, Professor Rausser emphasized the portfolio diversification opportunities for risk reduction by including exposure to futures in combination with typical bond/stock portfolios.

Bhardwaj et al. (2019)-BJR found that futures prices have on average been trading at a discount to future spot prices by about 5% (1871–2018 data). Of the contracts that survived longer than 50 years, 91% earned a positive risk premium. BJR found that of the 230 contracts in their sample, 58% earn a positive lifetime "buy-and-hold" risk premium when they rolled expiring contracts forward over time, and the median geometric average premium across commodities was 1.5%.

Tang and Xiong (2012) found price behavior of index commodities has become different from nonindex commodities—becoming more correlated with oil and equities—*outside money* from index investors has linked them together. The intuition for this rise is that institutions that entered these markets have linked them together, as well as with the stock market, through cross-holdings in their portfolios. In a study of 12 agricultural commodity futures, Hamilton and Wu (2015) found commodity index-fund investing had no measurable effect on commodity futures prices (using 1990–2014 data). Main et al. (2018) found the average unconditional return to 19 individual agricultural and energy futures markets was approximately equal to zero before and since financialization (using 1961–2014 data). Most of the literature addressing financialization has treated commodities as independent assets instead of being part of a portfolio. The latter has the advantages mentioned in CRS. Namely, the risk of an asset is properly measured by the volatility of the asset's returns relative to that of a broad market portfolio, rather than viewing the asset's risk separately from the overall market. Moreover the purpose of our analysis is to explore whether financialization affected the systematic and idiosyncratic risks associated with futures contracts.

4 Methodology

Building on Cootner (1960), CRS provided theoretical and empirical evidence to support the notion that the nonmarket rate of return is a stochastic variable that is a function of net hedging pressure. This generalizes the Keynesian theory of normal backwardation to allow for variable traders' positions. Our methodology is based on CRS and the empirical model is shown in eq. (1).

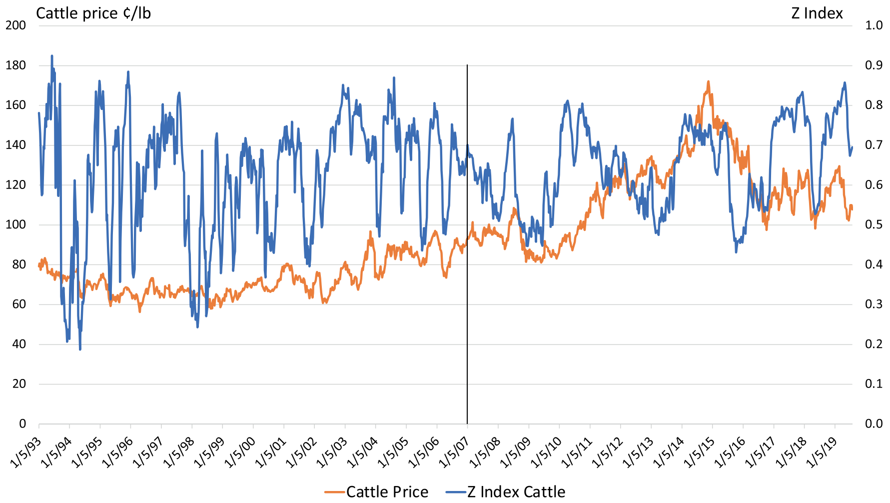
$$R_{jt} = \alpha + \delta Z_t + \beta x_{jt} + \gamma Z_t x_{jt} + \mu_{jt} \tag{1}$$

Where: R_t is the asset return for futures contract j during period t,[13] x_{jt} is the market index minus the risk-free interest rate, Z_t is the (changing) speculative position (same for all contract months for a given commodity), α is the pooled non-market risk (averaged across all contracts for a specific commodity), β is the asset's pooled systematic risk, and μ_{jt} is the error term. As in CRS, $\alpha^* = \alpha + \delta Z_t$ is the expected value of the non-market component of futures contracts' excess return (CRS, p. 328), and $\beta^* = \beta + \delta Z_t$ is the expected value of the systematic component of futures contracts' returns (CRS, p. 324). The total return to holding a futures contract is therefore made up of two components. The first is the systematic risk based on the asset's covariance with the market index, and the second is the excess return. Hedging pressure can influence both of these components of return.

Our data set consists of weekly observations of five commodity futures contracts over the period from January 1986 to July 2019—corn, cotton, live cattle, soybeans and wheat. These are the same commodities studied by CRS. Each futures contract with a specific delivery month over this time period was included in our data. For instance, corn futures have five different delivery months (March, May, July, September and December). Our data set consists of each of the March corn contracts over the 1986 to 2019 time period, each of the May corn futures contracts, and so on.

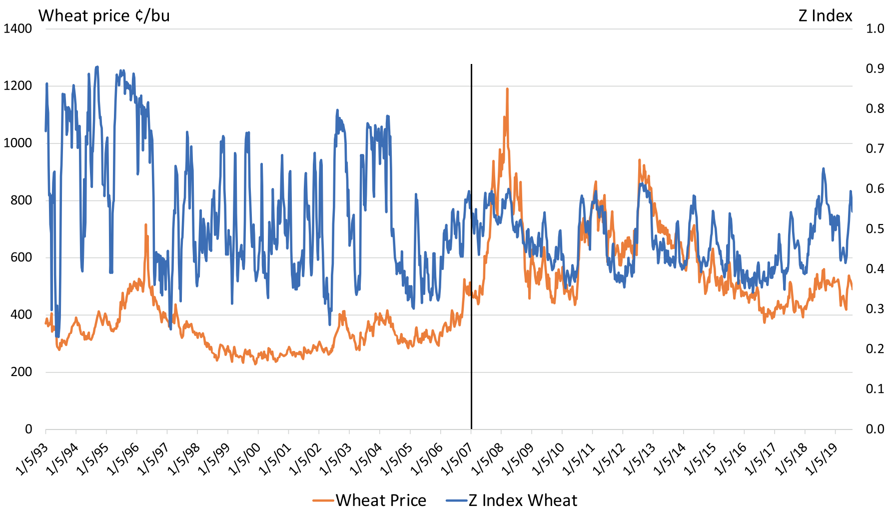
We define Z_t = (non-commercial longs)/(non-commercial longs + non-commercial shorts), sourced from Commodity Futures Trading Commission: Commitment of Traders (COT) weekly reports from January 1986–July 2019. When $Z_t = 0.5$ speculators are neither long nor short on net; when $Z_t > 0.5$ speculators are net long; and when $Z_t < 0.5$ speculators are net short. Therefore, Z_t represents the percentage of reporting speculators that were net long, and lies in the interval between zero and one. Figures 9 and 10 show the Z_t index plotted against

[13] As in Dusak (1973), R_{jt} is interpreted as net of the risk-free rate. In other words, it is interpreted as the risk premium on the spot commodity, i.e., R_{jt} - R_f, where R_f is the risk-free interest rate.



Source: barchart.com and CFTC.

Fig. 9 CME cattle futures and Z index



Source: barchart.com and CFTC.

Fig. 10 CBOT wheat futures and Z index

live cattle and wheat futures prices, respectively.[14] Interestingly the data reported in Figs. 9 and 10 show the Z_t index for live cattle and wheat was more variable before financialization compared to after. The vertical lines drawn in Figs. 9 and 10 depict

[14]Figures 9 and 10 show data from 1993 as that is when the CFTC shifted from bi-weekly to weekly CoT reports.

the cutoff point we are defining with regard to the period prior to financialization versus the period afterwards. The cutoff point is January 2007. In the case of crude oil the Z_t index also trended upward with financialization. Finally, the x_{jt} variable represent first differences of the natural logarithms of the market index (the Standard and Poor's (S&P) and Dow Jones and Company (DJ&C) indices weighted equally) minus the 90-day Treasury Bill rate converted to a weekly interest rate.

As pointed out in CRS the error term of eq. (1) is a function of the errors from the nonmarket α^* and systematic β^* components of the futures contracts (i.e., they are heteroskedastic) and therefore the equation needs to be estimated using generalized least squares. We follow the same econometric methodology as CRS.

5 Analysis

Summary statistics for the weekly returns for all futures contracts, for each of the five commodities studied, are presented in Table 3. The descriptive statistics in Table 3 are calculated by pooling all the contracts for each commodity. The number of observations (N) is reported in the second column. Column three reports the average individual asset returns over the entire time period studied and column four reports the one period return autocorrelation (ρ). Columns five and six report the average Z values and average x (i.e., market index minus the riskless rate) return.

Table 3 reports that the unconditional mean weekly returns for live cattle and soybeans are positive and statistically significant from zero. Alternatively the average returns for corn and wheat are negative and statistically significant. Returns for cotton are not statistically different from zero.

The last two columns of Table 3 present the estimated slope coefficient of two simple regressions of weekly returns on the market index (the θ) and the Z values (the φ).[15] Live cattle and soybeans are the only commodities that have statistically

Table 3 Summary statistics: commodity returns

Commodities	N	Returns	ρ^a	Z	x	$\rho(x, Z)^b$	Bivariate model	
		Avg.		Avg.	Avg.		θ^c	φ^d
Corn	8,810	−0.0009*	0.2308	0.63*	−0.06*	−0.03	0.0016	0.014*
Cotton	8,732	−0.0002	0.2202	0.56*	−0.06*	0.08	0.0003	0.014*
Live cattle	10,485	0.0006*	0.1804	0.63*	−0.06*	0.05	−0.0052*	0.010*
Soybeans	12,335	0.0004*	0.2109	0.64*	−0.06*	0.05	0.0030*	0.012*
Wheat	8,812	−0.0008*	0.2223	0.54*	−0.06*	−0.11	−0.0029	0.015*

*stands for statistically different than zero at 95% significance
[a]One lag autocorrelation of returns
[b]Correlation between x and Z
[c]Slope of a regression of the futures returns on the x variable
[d]Slope of a regression of the futures returns on the Z variable

[15] The t-values in Table 3 are based on heteroskedasticity-consistent standard errors.

significant θs. Overall, with this simple regression approach, the θs indicate varied results regarding statistically significant systematic risk across commodities. However, from Table 3 it is important to note that each commodity has a statistically significant φ. This suggests there is a relationship between futures returns and the net position of speculators, which is explored in more detail below.

Tables 4, 5, 6, 7, 8 present the results from the generalized least squares estimation of eq. (1), following the procedure in CRS. In each of these tables we report the regression results for the entire sample period and then separately for the *before* (1986–2006) and *after* (2007–2019) financialization sub-periods.

As mentioned, the errors in eq. (1) are heteroskedastic and the results of the estimation by GLS are reported in Tables 4, 5, 6, 7, 8. The dependent variables (R_{jt}) used in the regression were the first differences of the natural logarithms of weekly average futures prices minus the riskless rate. As regards the independent variables, the Z_t were obtained from the Commodity Futures Trading Commission (CFTC) weekly Commitment of Trader (CoT) reports. The x_{jt} variables represent the first differences of the natural logarithms of the market index (the S&P and DJ&C indices weighted equally) minus the 90-day Treasury Bill rate converted to a weekly interest rate. In addition, the Davidson and McKinnon (1993) test was carried out to explore the potential indogeneity of the regressors with respect to the error term. All the tests did not reject the null hypothesis of exogeneity.[16]

Table 4 Corn regression results

Contract	N	α	β	δ	γ
Entire sample					
March	1762	−0.0054*	0.036*	0.007*	−0.058*
May	1763	−0.0047*	0.041*	0.007*	−0.062*
July	1762	−0.0041*	0.044*	0.005*	−0.073*
September	1761	−0.0053*	0.039*	0.006*	−0.066*
December	1762	−0.0052*	0.04*	0.007*	−0.063*
1986–2006					
March	1101	−0.0048*	0.037*	0.008*	−0.050*
May	1102	−0.0056*	0.030*	0.009*	−0.043*
July	1100	−0.0064*	0.026*	0.009*	−0.041*
September	1100	−0.0075*	0.021*	0.012*	−0.019
December	1100	−0.0050*	0.040*	0.009*	−0.049*
2007–2019					
March	661	−0.0039*	0.066*	0.005*	−0.111*
May	661	−0.0023*	0.070*	0.003*	−0.104*
July	662	0.0004	0.056*	−0.002	−0.090*
September	661	−0.0013	0.067*	−0.001	−0.114*
December	662	−0.0028*	0.051*	0.002	−0.084*

Note: *denotes statistical significance at the 95% level

[16] We tested the robustness of the results to different combinations of weights for the S&P and DJ&C indices, by computing the correlation of different weights. If we consider the series used for the estimation (50/50) the correlations with (90/10) is 0.9924 and with (75/25) is 0.9960. We therefore conclude that the results are robust to the choice of weights.

Table 5 Cotton regression results

Contract	N	α	β	δ	γ
Entire sample					
March	1728	−0.0073*	0.016*	0.012*	−0.026*
May	1761	−0.0080*	0.014*	0.013*	−0.029*
July	1726	−0.0088*	0.011	0.013*	−0.027*
October	1760	−0.0066*	0.019*	0.010*	−0.031*
December	1757	−0.0053*	0.024*	0.009*	−0.036*
		1986–2006			
March	1067	−0.0064*	0.022*	0.013*	−0.026*
May	1099	−0.0074*	0.016*	0.015*	−0.030*
July	1064	−0.0073*	0.020*	0.015*	−0.033*
October	1099	−0.0061*	0.021*	0.013*	−0.024*
December	1098	−0.0050*	0.026*	0.011*	−0.029*
		2007–2019			
March	661	−0.0107*	0.037	0.016*	−0.041
May	662	−0.0109*	0.058*	0.016*	−0.070*
July	662	−0.0140*	0.039	0.019*	−0.045
October	661	−0.0090*	0.058*	0.012*	−0.067*
December	659	−0.0073*	0.045*	0.010*	−0.048

Note: *denotes statistical significance at the 95% level

Table 6 Live cattle regression results

Contract	N	α	β	δ	γ
Entire sample					
February	1759	−0.0104*	−0.031*	0.019*	0.055*
April	1763	−0.0080*	−0.022*	0.016*	0.039*
June	1761	−0.0095*	−0.021*	0.017*	0.034*
August	1689	−0.0098*	−0.039*	0.017*	0.065*
October	1756	−0.0093*	−0.032*	0.017*	0.050*
December	1757	−0.0086*	−0.024*	0.016*	0.039*
		1986–2006			
February	1099	−0.0070*	−0.013*	0.013*	0.021*
April	1101	−0.0054*	−0.007	0.011*	0.011
June	1101	−0.0061*	−0.001	0.010*	−0.007
August	1054	−0.0066*	−0.017*	0.011*	0.018
October	1098	−0.0076*	−0.024*	0.015*	0.038*
December	1095	−0.0069*	−0.020*	0.013*	0.029*
		2007–2019			
February	660	−0.0120*	−0.023	0.022*	0.046*
April	662	−0.0088*	−0.017	0.017*	0.033
June	660	−0.0110*	−0.020	0.019*	0.037
August	635	−0.0112*	−0.049*	0.020*	0.086*
October	658	−0.0105*	−0.024	0.018*	0.045*
December	662	−0.0094*	−0.002	0.017*	0.010

Note: *denotes statistical significance at the 95% level

Table 7 Soybeans regression results

Contract	N	α	β	δ	γ
Entire sample					
January	1763	−0.0068*	0.000	0.012*	0.011
March	1763	−0.0070*	0.003	0.012*	0.005
May	1762	−0.0069*	0.010	0.012*	−0.007
July	1763	−0.0063*	0.007	0.012*	−0.001
August	1762	−0.0078*	0.001	0.013*	0.005
September	1759	−0.0059*	0.015*	0.010*	−0.017
November	1763	−0.0070*	−0.004	0.012*	0.017
		1986–2006			
January	1101	−0.0007*	0.037*	0.004*	−0.029*
March	1101	−0.0019*	0.030*	0.006*	−0.021
May	1100	−0.0024*	0.032*	0.007*	−0.031*
July	1101	−0.0019*	0.029*	0.007*	−0.023
August	1100	−0.0058*	0.014	0.011*	−0.009
September	1097	−0.0016*	0.040*	0.005*	−0.039*
November	1101	−0.0022*	0.024*	0.007*	−0.004
		2007–2019			
January	662	−0.0120*	0.000	0.018*	0.005
March	662	−0.0116*	0.014	0.018*	−0.022
May	662	−0.0115*	0.025	0.018*	−0.033
July	662	−0.0109*	0.020	0.018*	−0.025
August	662	−0.0088*	0.004	0.015*	0.004
September	662	−0.0097*	0.014	0.015*	−0.024
November	662	−0.0110*	−0.001	0.017*	0.005

Note: *denotes statistical significance at the 95% level

Looking down Tables 4, 5, 6, 7, 8, for both the *before* and *after* periods, we find that corn and cotton are the only two commodities with estimated systematic risk coefficients (βs) that are generally significantly different from zero. These results are consistent with CRS and other literature, which has found mixed results regarding systematic risk. Furthermore, across contract months, for cotton, live cattle, and soybeans there are fewer β values statistically significant in the *after* period compared to the *before* period. This means that updating the CRS results we find that the prevalence of systematic risk is lower after financialization of the commodity markets. If a commodity has no systematic risk then any returns above zero will be due to idiosyncratic (or nonsystematic) risk only (i.e., excess returns).

The γ estimates in Tables 4, 5, 6, 7, 8 suggest that for those contracts displaying systematic risk, the degree of systematic risk is impacted by the Z value. Across all commodities studied the β and γ coefficients have opposite signs. Since the net long position of speculators increases with Z, this finding suggests that an increase in speculative buying will tend to reduce the systematic risk, *ceteris paribus*. In other

Table 8 Wheat regression results

Contract	N	α	β	δ	γ
Entire sample					
March	1764	−0.0057*	0.017	0.007*	−0.040*
May	1760	−0.0078*	−0.001	0.011*	−0.010
July	1763	−0.0069*	0.001	0.010*	−0.012
September	1762	−0.0070*	0.003	0.010*	−0.015
December	1763	−0.0076*	0.008	0.012*	−0.014
1986–2006					
March	1102	−0.0040*	0.030*	0.006*	−0.049*
May	1099	−0.0062*	0.011	0.010*	−0.016
July	1101	−0.0062*	0.007	0.010*	−0.011
September	1101	−0.0066*	0.011	0.011*	−0.013
December	1101	−0.0062*	0.017	0.013*	−0.012
2007–2019					
March	662	−0.0071*	0.037	0.009*	−0.091
May	661	−0.0090*	0.042	0.013*	−0.114
July	662	−0.0099*	0.076*	0.016*	−0.185*
September	661	−0.0078*	0.033	0.011*	−0.094
December	662	−0.0060*	0.031	0.008*	−0.071

Note: *denotes statistical significance at the 95% level

words, increased financialization has tended to reduce the systematic risk component of futures returns.[17]

The nonmarket rate of returns measure (α) and its systematic change associated with net speculative positions (δ), go directly to the question of whether or not there is a Keynesian risk premium. As in CRS, we find the estimated α and δ values are almost all significantly different from zero and the δ values tend to be roughly twice as large as the α values and they tend to have the opposite sign. This is the case across Tables 4, 5, 6, 7, 8. It is also noteworthy that the estimated α and δ values are different in the before/after time periods.

As in CRS, these results provide an interesting interpretation of the Cootner hypothesis. Recall that the value of $\alpha^* = \alpha + \delta Z_t$, represents the expected value of the nonmarket component of a futures contract's return, i.e., the *risk premium*. When Z_t is equal to 0.5, the net position of speculators is neither long nor short; and the results in Tables 4, 5, 6, 7, 8 suggest that the nonmarket returns are near zero. When $Z_t > 0.5$, speculators are net long and the rate of return is greater than the amount predicted by the market model. Similarly, when $Z_t < 0.5$, speculators are net short, and there are negative returns in excess of the market return. Therefore our findings provide support for the Cootner hypothesis of the existence of a degree of normal backwardation in the commodity futures market, given an appropriate interpretation of the net position of speculators.

[17] The increased financialization did not occur just with commodity futures but as well with the introduction of tradable ETFs on commodities. However the ETF managers typically enter into the futures markets to offset their risk exposure to the ETF purchasers

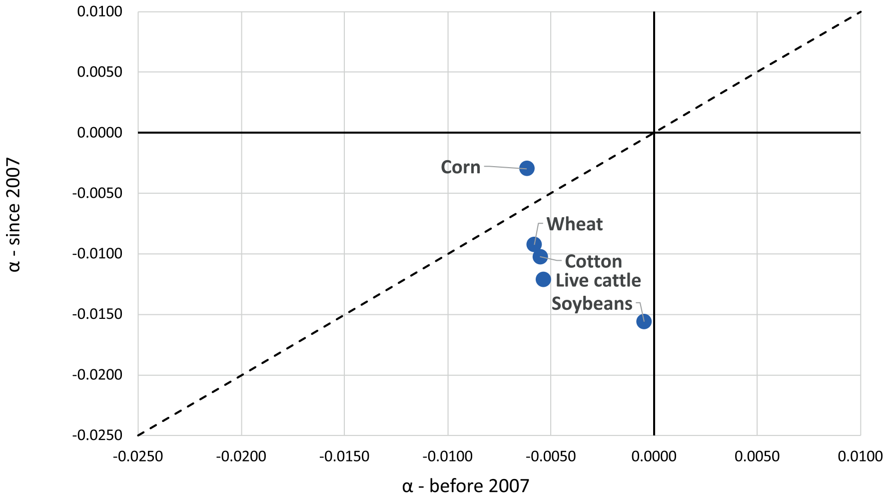


Fig. 11 Before and after alpha-alpha relationship

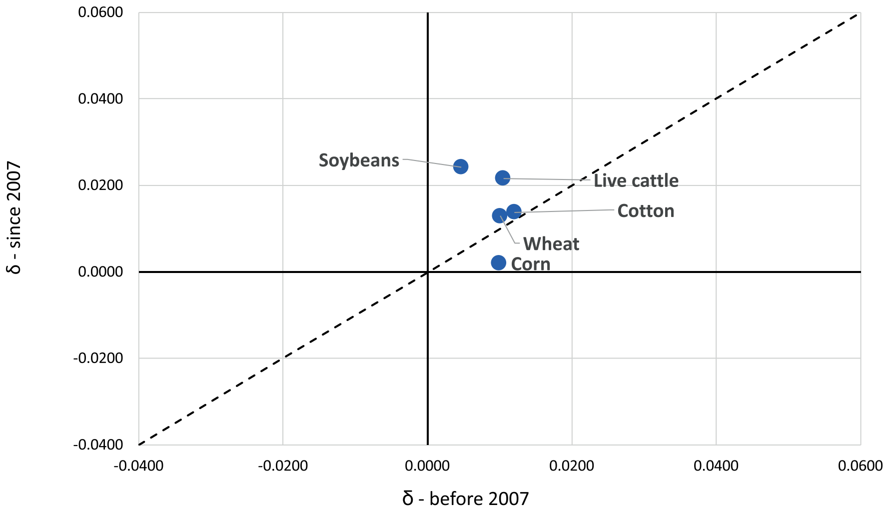


Fig. 12 Before and after delta-delta relationship

Figures 11, 12, 13 present different graphical views of the estimated α and δ coefficients estimated from eq. (1).[18] As shown in Tables 4, 5, 6, 7, 8, the estimated α and δ coefficients in all cases are statistically different from zero, with the exception of corn in the after period. All of the contracts have values of α that are negative and positive for δ (except for corn in the after period), which matches the results by

[18] Since the graphs by contract show very similar patterns as the estimates of the pooled sample, we only present the parameters from the pooled sample. The disaggregated graphs are available from the authors upon request.

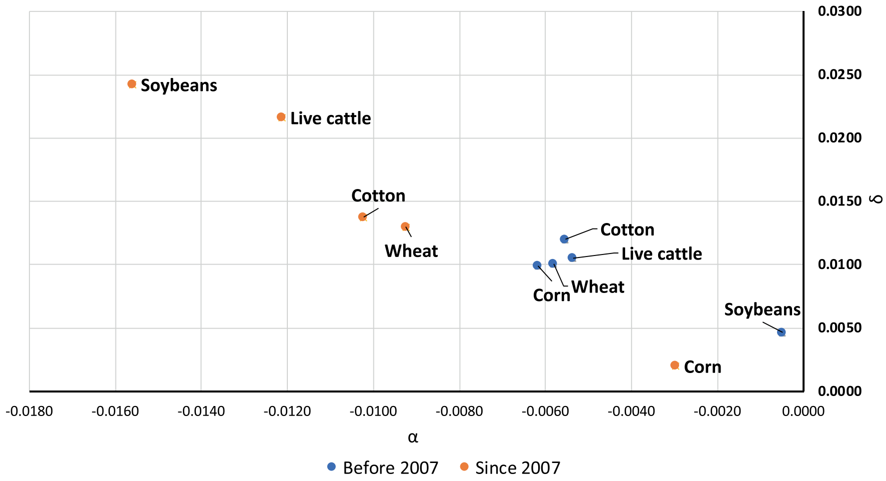


Fig. 13 Alpha-delta before/since relationship

Table 9 Annualized Excess futures returns before and since 2007

Commodity	Average Z before	Z since	Return before	Return since
Corn	0.62	0.65	−0.2%	−8.7%
Cotton	0.50	0.67	2.4%	−5.6%
Live cattle	0.62	0.65	6.2%	9.4%
Soybeans	0.62	0.67	12.5%	3.3%
Wheat	0.58	0.47	0.3%	−16.4%
Mean	0.59	0.62	**4.2%**	**−3.6%**

Note: Nonmarket Futures excess return $\tilde{R}_t^e = \alpha_j + \delta_j \tilde{Z}_t$.

contract presented in CRS. Figure 11 shows the before and after α coefficients, and Fig. 12 shows the before and after δ coefficients. The 45-degree line in these two figures indicates no change in the parameters across the two time periods. Figure 11 shows that all the commodities are characterized by negative values of α in both periods. Most of the commodities (except for corn) show a decrease in the value of α (i.e., the coefficient became more negative). In the case of corn, the value α increased after financialization, although it remained negative. It is important to note that this change in the value of α happened in all the corn contracts when the regressions were run contract by contract.

The values of δ in Figure 12 mimic what is observed in the case of α but in a reverse way. All of the commodities show an increase in the value of δ, except for corn.

Figure 13 presents α and δ pairs for the two sub periods. The Figure shows a clear change in the distribution of the coefficients. However it is important to note that the α and δ relationship is preserved in the after period, it is just shifted. After 2007 the pairs of coefficients moved in the north-west direction, indicating that they all became larger in absolute value, with the exception of corn. The net effect of the shift is that the values of $\alpha^* = \alpha + \delta Z_t$ were reduced.

This impact is shown in Table 9 which reports estimates of the annualized excess futures returns before and since 2007. The table shows a significant decrease in the average non-market returns to speculators after 2006. For instance, cotton returns declined from 2.4% to −5.6%. At the same time, soybean returns declined from 12.5% to 3.3%. Live cattle was the only commodity to experience an increase in returns, from 6.2% to 9.4%. On average, the annualized returns declined from 4.2% to −3.6%. Overall, these result provides evidence supporting the view that the scale of financialization was large enough to reduce the historical risk premiums in the commodity futures markets evaluated by CRS.

6 Conclusion

The popularization of commodities as an investment is commonly referred to as the *financialization* of commodity futures markets. In the early 2000s, investors were attracted to commodity futures as a new asset class. The investors were informed that commodities provided stock like returns, with the added advantage of a low correlation with stocks and bonds. Hundreds of billions of dollars then flowed into the commodities market. Large institutional investors generally gained long exposure to commodities through direct holdings of futures contracts as well as the use of over-the-counter derivatives and swaps. The returns to this asset class initially performed well, but then peaked in about 2012. Since then, the investment benefits have not turned out as promised. For instance, $10,000 invested in one of the larger commodity index funds in the United States–the United States Commodity Index Fund (USCI)–was worth around $5,000 in June 2020.

In this chapter we posit that Professor Rausser's research on futures markets published in the 1970s was influential in leading to the financialization of commodity futures and the rise of commodity hedge funds and their computer aided trend-following investment strategies. There has been discussion in the literature whether the scale of financialization was large enough to reduce the historical risk premiums in commodity futures markets. Our results from an analysis of 5 commodities (updating the findings in Carter et al. (1983)) provides evidence supporting the view that risk premia have declined after 2007.

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Causes of the Great Food Commodity Price Booms in the New Millennium: An Essay in Honor of Gordon Rausser

Harry de Gorter

1 Prologue

Over 40 years ago, I met Gordon Rausser in Ottawa. He was an expert consultant to the government in econometrics and price forecasting. My job was to forecast grain/oilseed prices. He and I speculated in agricultural futures markets. We hit it off and I came to Berkeley to do a PhD in the field of government policy analysis. In analyzing biofuel policies 30 years later, I inadvertently became an expert in grain/oilseed price determination again. In an EBI seminar in 2012, Gordon listened to my model and data, as recorded in this essay. Gordon immediately realized the potential of my approach and asked me to write a paper with him despite him writing a separate piece that had a different take.

It turns out Gordon is the only one (of thousands of economists) to adjust his thinking regardless of his previous writings and include the insights I developed on the unique and significant impact on grain/oilseed prices which biofuel policies have had in the new millennium. For me, Gordon is one of a kind. This essay explores why Gordon, unlike so many others, acknowledged the importance and legitimacy of my findings immediately after first being presented with the new theory and empirical results. As Keynes said "When my information changes, I alter my conclusions. What do you do, sir?" In the end, I realized I had to analyze the life and times of Gordon to find out the answer to this question. The word "life" refers to the events in his life (Gordon grew up on a farm; Gordon takes on great responsibilities early in life; Gordon speculates in futures markets) and the word "times" refers to the historical context (Gordon does not relate to the modern post-truth era; Gordon frets over the demise of the ivory tower and the pursuit of truth and the

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public good). His life and times defined him, and as a result, he has made many defining contributions to the public good.

This essay digs deeper into the state of *Homo Academicus* (the Civil-Academic-Industrial Complex) by drawing on sociology and (behavioral) economics. However, it does not provide recommendations for the necessary changes to the incentive structure and governance of the ÇAÍ, another topic which Gordon has greatly contributed to.

Gordon can be provocative (in a good way) but always comes around to a rational conclusion. He is a maverick but not an iconoclast. He is fair. He is loyal. He has been the greatest of friends. His priority in life are his wonderful children and grandchildren. He has the right values to be the best of the best of academics. Gordon is a legendary figure in our profession.

1.1 Explaining the Grain/Oilseed Price Booms

Corn prices doubled in 2006–2007 and grain/oilseed prices tripled in 2007–2008, 2010–2011 and 2013–2014 from their 2005–2006 averages. Food prices were on top of the G-20 agenda in 2008 and again in 2011. In this section, I summarize the Rausser and de Gorter (2012) paper that outlined a new framework of how corn prices were determined beginning in September 2006. How do we know it began in September 2006? See what happened in the prior 32 months in Fig. 1 (crude oil

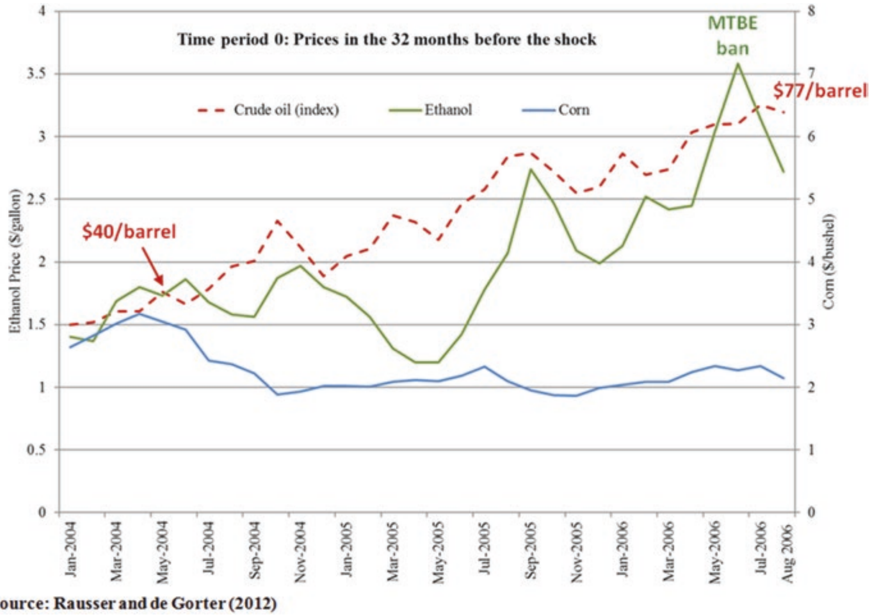

Fig. 1 The Lull before the Earthquake: Key Prices Prior to September 2006. (Source: Rausser and de Gorter (2012))

prices exceeded \$40/barrel early in this period for the first time ever, and kept going up with ethanol prices following, aided by the *de facto* ban on MTBE, while corn prices trended down). Now consider the corn-ethanol price link derived from the first order condition for zero profits in ethanol production: (see Eq. (4) in de Gorter & Just, 2008, and Eq. (2.1′) in de Gorter et al., 2015):

$$P_C = \frac{\beta}{1-r\gamma}\left(P_E - c_0\right) + \frac{\theta}{1-r\gamma} P_{CO} \tag{1}$$

where P_C is the corn price in \$/bu., β is the number of gallons of ethanol per bushel of corn, r is the relative price of the co-product returned to the market as corn (called DDGS), γ is the share of a bushel of corn going into DDGS, θ is pounds of corn oil from one bushel of corn, P_{CO} is the price of corn oil in \$ per pound, P_E is the ethanol price and c_0 is the cost of ethanol production (the latter two variables are measured in \$/gal.). The term outside the first parenthesis averages about 4 so a 51 ¢/gal. Blender's tax credit increased corn prices by \$2.04/bu. (corn prices averaged \$2.35 in 15 years prior to 2016).

How well does Eq. (1) predict corn prices? It is obviously irrelevant in Time Period 0 in Fig. 1 so see Fig. 2.[1] The 13 months of Time Period 1 show predicted

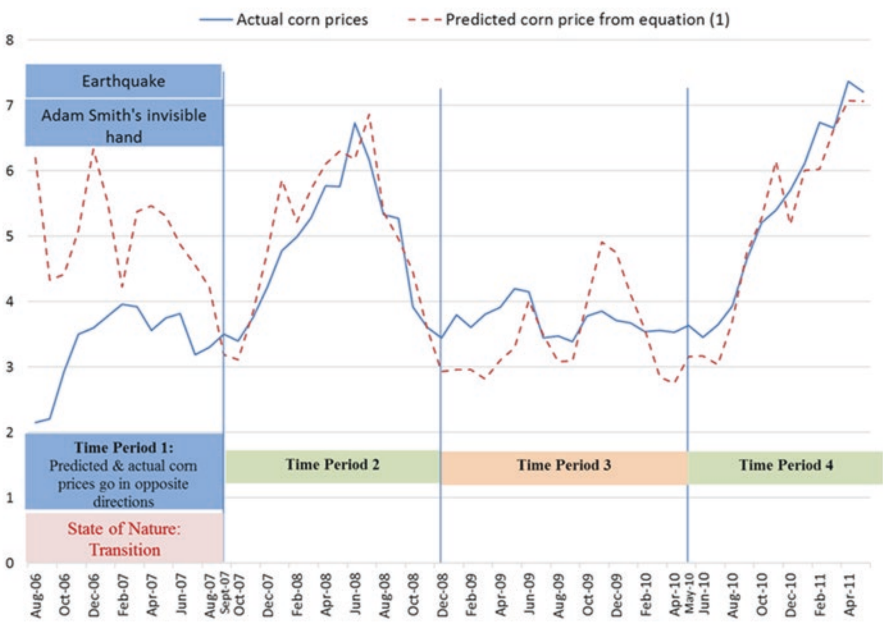

Fig. 2 Predicted vs Actual Corn prices 2006–2011

[1] See Figure 9.3 in de Gorter et al. (2015) for how well my model predicts the soybean oil-biodiesel price link.

prices everywhere above actual corn prices (the prediction error reflects excess profits in ethanol production due capacity constraints), and the two prices go in opposite directions. From August 2006 to February 2007, corn prices rose 88%, culminating in the Mexican tortilla crisis of January 2007 and the ban of wheat exports by India in February 2007. Furthermore, the highest differential between predicted and actual corns prices (reflecting excess profits) is at the beginning of Time Period 1 after which prices converge by the end of the period (as the zero-profit condition begins to hold).[2]

Time Period 1 is the outcome of Adam Smith's invisible hand because entrepreneurs were busily constructing ethanol plants and paying them off in 6 months while ignoring the temporal evolution of prices (that is the job of arbitragers, speculators and the entrepreneurs behind Holbrook Working's (1949) model) and being oblivious to the risk of going bankrupt, as half of them did in 2009.[3] The forces behind Adam Smith's invisible hand caused a doubling of ethanol production capacity in 2006. Excess profits do not last forever—that is not how the marketplace works. Rausser would have offered these words of wisdom: "*If something cannot go on forever, then it will not*." It is a period of transition from the old to the new, and hence our theory provides a coherent and consistent logic behind the forces explaining this transition. No other economic model can explain Time Period 1, not even Holbrook Working's (see Sect. 2).

More importantly, not only is the corn price locked onto the ethanol price (through Eq. (1)) at the end of Time Period 1 (where actual and predicted prices converge) but the ethanol price is in turn bolted onto the gasoline price, which itself is anchored by the crude oil price. This means the corn price was as low as it could have gone in September 2007 (and for the next 15 months in Time Period 2—see Fig. 2). This relationship is important because it makes clear that nothing could have altered the corn price by the end of Time Period 1 (changes in corn inventory or a supply/demand shift affecting corn prices in Time period 1 would have been like shuffling the deck chairs on the Titanic[4]: the resulting change in ethanol production could not have altered the gasoline price was moving with crude oil prices). We conclude that ethanol is the main reason for the corn price increase in Time Period 1, not least because no other dramatic event occurred in this period (other grain/oilseed prices failed to go up). Hence, our model shows that biofuel policies caused the corn price increase in 2006–2007 (Time Period 1).

However, beginning in September 2007, Fig. 2 shows the predicted corn price from Eq. (1) track actual corn prices quite well. As expected, there are prediction errors over time that do not typically last long and are due to unexpected market shocks or capacity constraints in the ethanol market. If predicted prices exceed

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[2] Ever increasing ethanol prices with declining corn prices in the 32 months suggest increasing profit margins in Time Period 0 shown in Fig. 1.

[3] Ignorance is truly bliss as many bought their BMWs and condo's in Bermuda in the meantime.

[4] Time Period 1 was a 13-month "connecting" phase, like a courtship, after which corn and ethanol prices are locked onto one another (and continue to be so into the future for as far as the eye can see).

actual corn prices, then capacity constraints in ethanol production allow for excess profits in the short run until investments in new capacity come to fruition and have driven profits back down. This occurred in the 2007–2008 price run-up as there was insufficient ethanol capacity as ethanol demand ramped up with higher gasoline prices. The excess profits (reflected by the over prediction of corn prices) for late 2009/early 2010 in Fig. 2 were due to fallout from the financial crisis and low gasoline prices that caused huge declines in share values of ethanol companies and an unusual number of ethanol plant bankruptcies. These plants were eventually bought up (for dimes on the dollar), but the financial restructuring took time before production could get back online. This explains the excess profits in that period. On the other hand, if predicted prices are below actual corn prices, excess losses prevail, which are expected in the short run as there are costs associated with shutting down and re-opening plants.

It is important to note that even though corn and ethanol prices are locked onto each other (no causality is implied) for the foreseeable future, it does not follow that corn prices are locked onto crude oil prices through gasoline and ethanol prices. Indeed, there are two States of Nature vis-a-vis ethanol and gasoline prices, and hence between corn and crude oil prices.

State of Nature 1 has ethanol prices equal to gasoline prices on a miles-equivalent basis so the ethanol price is as low as it can go (and locked onto the gasoline price such that the two prices are strongly correlated). The relationship between ethanol and gasoline prices in State of Nature 1 is given by (see Eq. (8) in de Gorter & Just, 2008):

$$P_E = \lambda P_G - (1-\lambda)t + t_c \tag{2}$$

where P_E is the ethanol price, P_G the price of gasoline, λ is 0.70 (ethanol gets 70% of the miles per gallon relative to gasoline), t is the fuel tax and t_c the tax credit (since January 2012, t_c is zero for U.S. corn-ethanol). The first term on the RHS of Eq. (2) represents consumers' willingness to pay for ethanol relative to gasoline, while the second term is the "penalty" imposed on fuel blenders for having to pay a volumetric fuel tax on both fuels when consumers are only willing to pay 70% of this blended price for ethanol. The final term is the consumption subsidy for ethanol. The incidence of such a consumption subsidy is mostly in increasing the ethanol price as crude oil price, which gasoline prices are locked onto, will not decline very much. As noted earlier, the tax credit converted into \$/bu. is huge and is added onto the corn price.

Since corn prices are now locked onto ethanol prices via Eq. (1), State of Nature 1 represents a floor price for corn too; for given crude oil and hence gasoline prices, corn prices cannot fall below a certain level. This represents a new counterfactual level for corn prices, regardless of shifts in the supply/demand for corn or of changes in corn inventories, as these cannot move the crude oil price.

How well does Eq. (2) perform as a floor price for ethanol? Figure 3 gives the results. Ignoring Time Period 1, ethanol prices for Time Periods 2, 3 and 4 are about

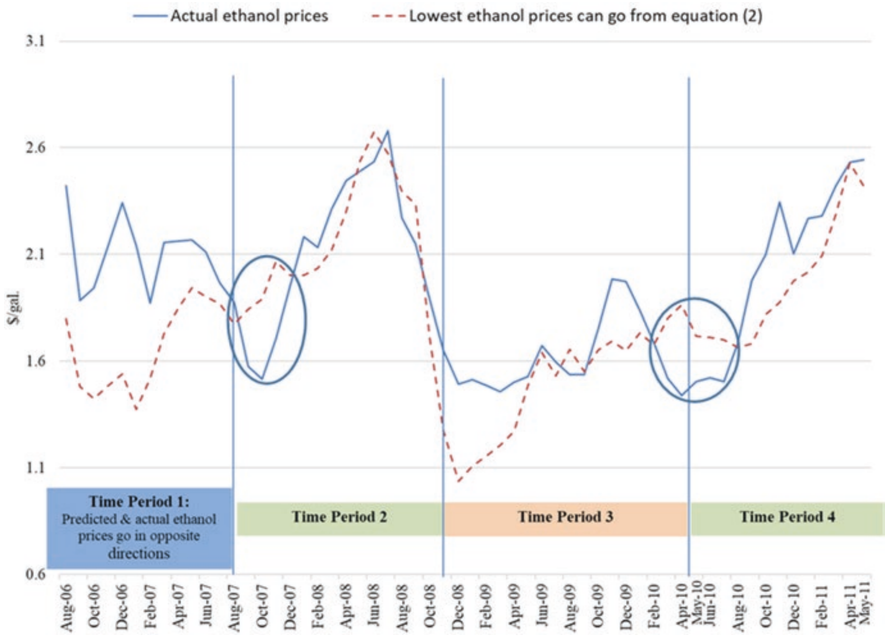

Fig. 3 Predicted Lowest Ethanol Prices Can Go from Eq. (2) (compared to actual ethanol prices)

equal to or higher than the ethanol price predicted by Eq. (2) with two exceptions: periods September 2007 to November 2007, and March 2010 to July 2010 (circled). In this time periods, blending constraints at the consumer level caused ethanol prices to fall below their miles-equivalent value to gasoline prices. However, the corresponding time periods in Fig. 2 shows ethanol producers were willing to suffer losses without bearing the costs of shutting down plants, anticipating this to be a short run disequilibrium (they were correct!)

If ethanol prices are above the level predicted by Eq. (2) (as is most evident in Time Period 3 in Fig. 4), then we are in State of Nature 2 where government mandates force the ethanol price above the miles equivalent price of gasoline as given in Eq. (2) (ethanol prices become delinked from gasoline prices and are negatively correlated in State of Nature 2). In State of Nature 2, actual ethanol prices float up and away from the levels predicted by Eq. (2). In this case, corn prices are higher than in State of Nature 1 by more than the tax credit due to ethanol price premiums caused by a binding ethanol mandate. As we have shown, in two of the price booms, (2007–2008 and 2010–2011—see Fig. 3), high crude oil prices and the tax credit explain month-to-month corn prices. The importance of high crude oil prices activating the otherwise dormant 1978 blender's tax credit along with high ethanol prices due to the ban on MTBE are important forces shaping our story.

Figure 4 highlights the relationship between corn and crude oil prices. In Time Period 1, corn and crude oil prices went in opposite directions but we argue that this

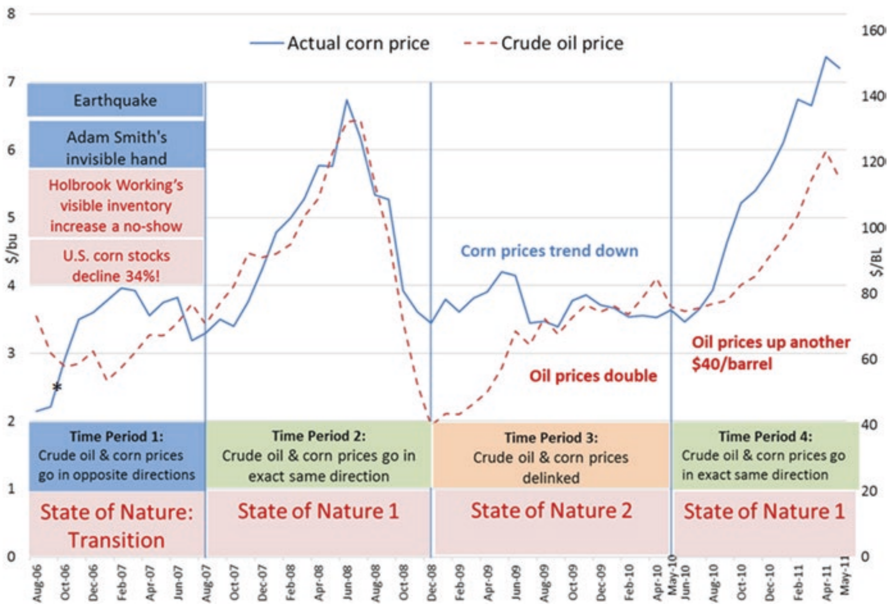

Fig. 4 Corn vs. Crude Oil Prices: The Astonishing Tale of Two States of Nature in Action

divergence is economically meaningless: we just showed biofuel polices were the primary if not the only cause for corn price increases in Time Period 1.

Corn and crude oil prices go in the same direction in Time Periods 2 and 4. Time Period 3 is when corn and crude oil prices are delinked (State of Nature 2). Crude oil prices doubled while corn prices trended down. However, when crude oil prices increased by $40/barrel again in Time Period 4, corn prices rose in tandem.

Note that in Time Periods 1, 2 and 4, no shift in the supply or demand for corn can change the corn price, as the resulting change in ethanol production could not have moved the crude oil price. Not even a change in inventories could move the corn price in these two periods. We can safely conclude biofuel policies were responsible because (a) they caused the link between corn and ethanol prices, and (b) the tax credit was active in that period, accounting for an additional $2/bu. (or more) to the corn price. Our new theoretical model, being completely irrelevant for Time Period 0, took flight in Time Period 1 and now represents a new counterfactual in which the lowest price that corn can reach is when they are locked onto the crude oil price (through ethanol and gasoline prices) plus the blender's tax credit (when positive). Corn prices would have increased by a minimum of 92% from 2007–2008 to 2013–14 regardless of supply/demand shifts or changes in inventory and were even higher due to the mandate that caused price premiums.[5]

[5] To determine how much higher prices above lowest when locked are due solely to biofuel mandates would require very careful statistical analysis as supply/demand shifts or changes in inventory could affect prices too.

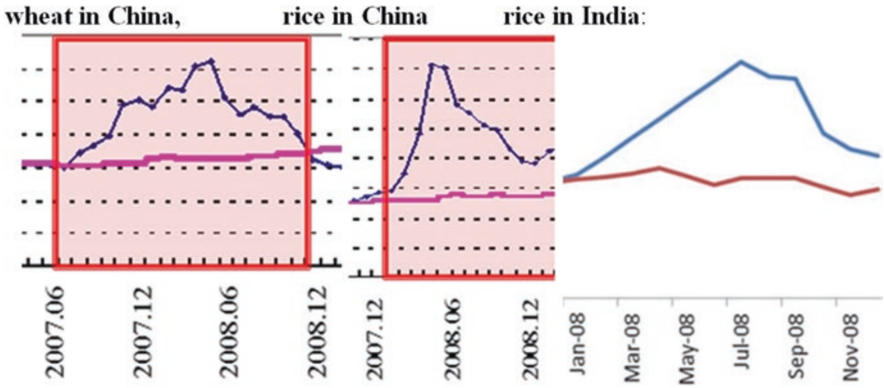

Fig. 5 Prices in 2007–2008. (**a**) Wheat in China, (**b**) Rice in China, (**c**) Rice in India. (Source: Huang et al. (2013) for China; Ganguly and Gulati (2013) for India)

Another implication of our framework is that the incidence of developing country policy responses in 2007–2008 was to reduce domestic prices but had no impact on world prices as corn prices were locked onto crude oil prices. Most economists argue that developing country responses exacerbated the world price increase (e.g., Headey & Fan, 2010, and Anderson et al., 2014, who argue that corn prices rose 50% as a result). Figure 5 confirms our model framework.

1.2 How the Literature Rejects our Model Framework

I thank the reader for just slogging through 3½ pages of theory (summarized in two equations and being brand new and all that; we do not have the advantage of you having studied it in grad school unlike say, the work of Working, 1949) and empirical analysis summarized in Figs. 1, 2, 3, 4, and 5. However, we can now put this understanding of the underlying theory to good use to assess the validity of the literature on the causes of the grain/oilseed price booms, and the role of biofuels.

Given that our model has been essentially ignored, and that the literature on this topic is so vast,[6] it is difficult to know where to begin. But it is important to note that *error is indeed our enemy, but it alone points to the truth and therefore deserves our respectful treatment* (Bloom, 1987). Perhaps an appropriate place to begin is Per Pinstrup-Anderson who commissioned the Rausser-de Gorter paper in 2012. He attended the 2012 conference where I presented exactly the results discussed in the previous section. The discussant Finn Tarp had no criticism whatsoever. Eight months later in 2013 in a prestigious Cornell seminar series to over 100 people launching his book, Pinstrup-Andersen explained the cause of the price boom as

[6] There are over 5000 papers on what caused the great food commodity price booms in the new millennium.

follows: "*There was a 75% decrease in real prices from the 1970s on and there was a need for an adjustment. The correction in 1996 did not amount to much*"! Then he listed other causes: global climate change, speculation, developing country policy responses but no mention of biofuels.[7] Earlier, in late 2012, I reviewed a draft of his introductory chapter and there was no mention of biofuels, so I sent him a very comprehensive note describing what Rausser and I wrote in our chapter (Sect. 1 above). In the end, he inserted a couple of throw away sentences on biofuels in the final version of the book's introduction.

Let's look at another example. Because of the food commodity price boom, the G-20 created AMIS at the FAO as an early warning system for food price increases. It's head declared that he would not read de Gorter et al. (2015) after hearing my seminar because he was convinced that wheat prices responded to specific supply/demand shocks in the wheat market. Likewise, he believed sector specific shocks caused prices of corn, rice and oilseed to rise independently of each other.

In 2009, the World Bank paid me for a comprehensive review of a draft of Baffes and Haniotis (2010) where I again made the arguments in Sect. I above. When the book came out, there was no change in their narrative: in their opinion, it was the "perfect storm" of every possible factor including the kitchen sink. I asked them why no attention was given to my narrative and they responded: "*We did not know how to deal with it*." This chapter was re-packaged into Baffes and Haniotis (2010) which became very influential with over 500 citations (only I cite it negatively).[8]

The *AAEA* award winning paper by Abbott et al. (2009) report that Babcock and McPhail's (2008) estimate that the tax credit added 45¢ per bu. in 2007–2008 "*are generally consistent with our results*…" Furthermore, Abbott et al. (2009) argue that Midwest flooding explains the surge in June 2008 corn prices followed by "*declining prices in the summer of 2008 from better than expected growing conditions*". As explained previously, no supply/demand shock or inventory change could possibly have affected corn prices in Time Period 2. Abbott also writes in 2018 that changes in stocks had huge impacts on corn prices in 2007–2008 so "*Corn is not just the tail being wagged by the energy dog as asserted by deGorter.*" Although accurate for 2007–2008, Abbott otherwise misunderstands our theory: if the mandate is binding, which I have repeatedly written is expected to be the case once the tax credit expired in early 2012, ethanol prices will follow corn prices (just compare the daily prices of corn, ethanol and crude oil in June 2019 with delayed plantings due to rain: ethanol prices followed corn all the way up as crude oil prices continued their way to nowhere). Energy is the tail being wagged by the corn dog! We are in State of Nature 2.

Roberts and Schlenker (2013) found U.S. ethanol increased the price of grains/oilseeds by 20% from 2005 through 2008. Corn prices rose 213% from August 2006 to June 2008. I put a star in Fig. 4 to show how much damage Roberts and Schlenker

[7] We just showed that global climate change, speculation and developing country response could have no impacts!

[8] Later, Baffes claims on the web that he was the first to discover the link between corn and crude oil prices, the latter increasing the inputs for corn production. He missed the whole point about our theory and empirical results.

(2013) think ethanol policy did to corn prices. Obviously, Roberts and Schlenker (2013) conclude "… *other factors likely played a larger role in the 2005–2008 price boom*…" Well, looking at where the star is in Fig. 4, "other factors played a larger role" is a little bit of an understatement - how about a very LARGE role!?

My analysis obviously disagrees with Roberts and Schlenker (2013). They did publicly recognize there was another literature out there (referring to my papers) but said they did not understand it. They gave a series of seminars across the U.S. including Cornell after their paper was provisionally accepted in the AER and they were unaware that 30% of corn processed into ethanol was returned to the market as DDGS. They had to revise the conclusions of their AER paper by asking the reader to prorate their price increase estimates down accordingly, given they had just discovered the reality of DDGS! Well, of course they did not understand my papers! Equation (1) makes the importance of DDGS abundantly clear.

Macroeconomists, like everybody else, analyze issues through the lens of their own expertise so it is no surprise that their general take on this topic is that "*Commodities followed the euphoria cycle that we had along with housing*" (Shiller, 2008).[9] Daniel J. Boorstin wrote "*The greatest obstacle to discovery is not ignorance - it is the illusion of knowledge*." Frankel and Rose (2009) emphasize global growth, easy monetary policy, fiscal expansion, a speculative bubble, risk, 'overshooting', inventory levels, measures of uncertainty, and the spot-futures spread. The IMF sponsored a conference on commodity prices and published 17 papers in a special issue of the Journal of International Money and Finance in 2014. Factors included a weak dollar and speculation with the new "financialization" of food commodities. To add insult to injury, in only one paper is biofuels evened mentioned. The abstract of Avalos (2014) reads: *This paper steps out of the literature's typical emphasis on macroeconomic drivers…*[10] *results show the transmission of oil price… to corn prices has become stronger after 2006 (no changes with respect to soybeans)…also a significant transmission of corn price…to oil and soybean prices."* Corn prices driving crude oil prices? The reaction of corn and soybean prices to energy prices are exactly the opposite?

Baumeister and Kilian (2014) argue that corn prices are "*largely driven by common macroeconomic determinants of the prices of oil and of agricultural commodities*" and that there is *"no evidence that corn ethanol mandates have created a tight link between oil and agricultural markets*".[11] Look at Time Periods 1 and 3 in Fig. 4! Biofuels had a huge impact on corn prices in those time periods. However, the authors admit they are unable to explain Time Period 3 in Fig. 4 and Unalmis, a discussant, points out they are unable to explain Time Period 1 in Fig. 4. If they extend their data to say 2014–2015, they will have another time period they cannot explain (see Fig. 6). So, there is a pretty big chink developing in the armor of the macroeconomists, just from their own analysis. This is a promising development.

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[9] I will not show you the graph plotting housing and corn prices. It would be too sophomoric on my part.

[10] This is great. One paper out of 17!

[11] Baumeister and Kilian (2014) conclude biofuels played no role in causing an increase in grain/oilseed prices.

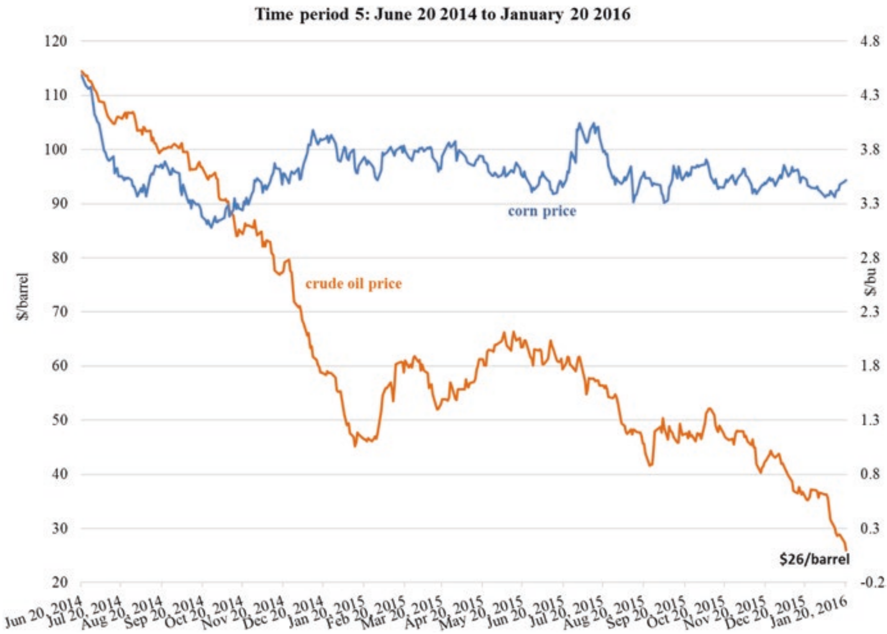

Fig. 6 Corn vs Crude Oil Prices—Did the "Super Commodity Cycle" Really End in 2014?

Many other economists argued that the tripling of grain/oilseed prices in 2007–2008 and again in 2010–2011 was a "perfect storm" of coincidental factors, where some cosmic roll of the dice led to a confluence of forces to suddenly and inexplicably begin to influence commodity prices all at once. In addition to the macro forces described above, these include sector-specific factors (higher input costs due to energy prices, bad weather, crop disease, global warming, changing Asian diets, and low stocks), and policy-related factors (like developing country policy responses, low public R&D in agriculture and failure to adopt GMOs worldwide). There are scores of such papers, but I will only mention one classic example: Trostle et al. (2011).[12] They attribute the corn price in 2010–2011 to all possible demand/supply shocks[13] with no mention of biofuels (see Fig. 7).[14] Figure 8 plots corn and gasoline prices (Time Period 4 in Fig. 4). Q.E.D.

[12] Combined with their earlier 2008 paper, they have over 1000 citations.

[13] They describe a series of supply disruptions (four droughts, one "dryness", one "high temperatures", one freeze and two cases of rain damage), three policy responses (two being by Russia; a ban on wheat exports in the summer of 2010 and the suspension of a wheat import duty in the winter of 2011) and an increase in demand ("importers aggressively buying"). There is an arrow (almost hidden from view) on the top left-hand corner, emphasizing economic growth and exchange rate (the U.S. dollar collapsed a whole 6% in this time period) with "a rising oil price" squeezed in between.

[14] Their abstract identifies three time periods (2002–2006, 2007–2008 and the 2010–2011) and that the same factors contributed but "*the timing, sequence, and relative importance of these factors varied*."

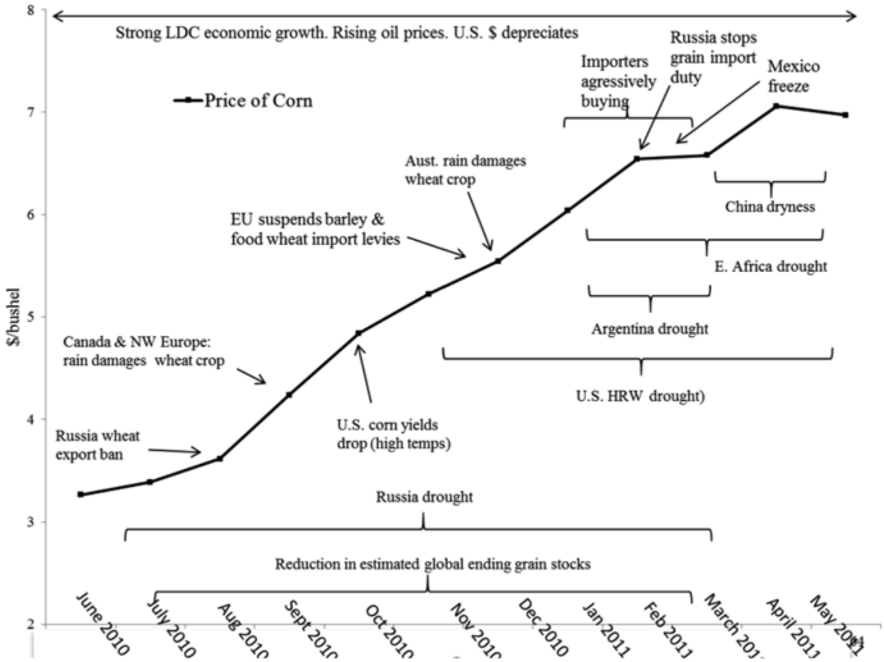

Fig. 7 Trostle et al. (2011) assessment for why corn prices rose 2.5-fold in 2010–2011

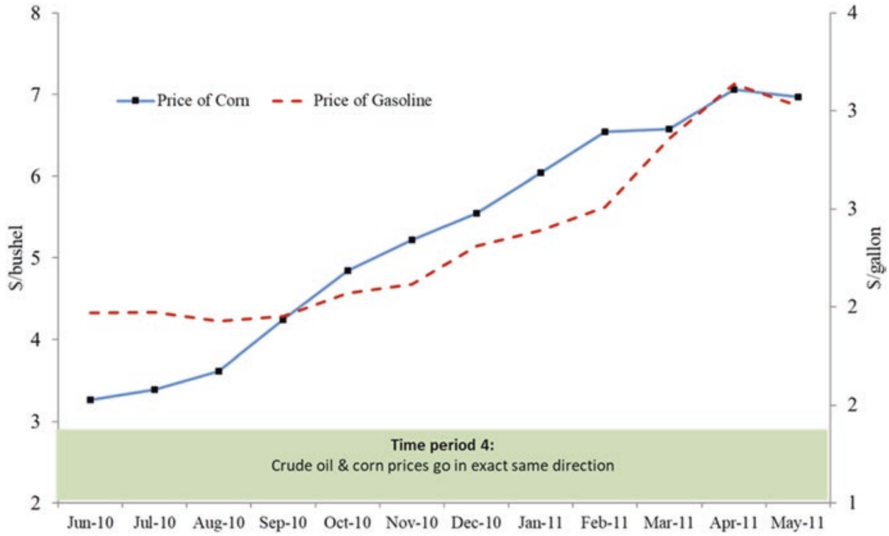

Fig. 8 Corn and Gasoline Prices in 2010–2011

Many studies focus on stockholding behavior to explain the price booms, relying on Working (1949) where crops diverted to biofuels represents a permanent demand shock such that prices increase but so too do stocks, causing even higher prices. Taking the writings of Brian Wright as an example,[15] he uses numerical models with hypothetical data and potentially unbounded price expectations to simulate stock-holding behavior that generate bubble like price behavior or "explosive" price run-ups (however, it depends on the assumed parameters of the model). This explains the tripling of grain/oilseed prices in 2007–2008 and its subsequent fall.[16] Stocks did increase significantly in 2007–2008 but crop prices were locked onto biofuel and crude oil prices so a change in inventories could have no impact.

Wright never discusses the other three price booms (doubling of corn prices in 2006–2007, the tripling of grain/oilseed prices in 2010–2011 and again in 2012–2013), and for good reason. One cannot have four successive bubbles and be consistent with Working's theory, the others being:

1. 2006–2007 when corn prices nearly doubled, yet U.S. corn stocks were 50% higher at the beginning of the 2006–2007 crop year than at the end, so Holbrook Working's visible inventory accumulation was a no show.[17]
2. 2010–2011 when corn prices rose 2.5-fold while locked onto energy prices in State of Nature 1.
3. 2012–2013 when an inventory drawdown moderated corn price increases rather than increasing them.

Ironically, looking at the entire period under discussion, inventories kept corn prices lower on average than otherwise (not vice-versa as argued by Wright and the many other papers in the literature on the role of inventories on prices). "Bubble Troubles" is the title of Wright's paper, but another paper should be written entitled "Are Four Bubbles in a Row Trouble for Working's Theory of Inventory Behavior"? As Taleb remarked: "*Some theories fall apart, not others*."

Still another huge literature uses econometric time series analysis to determine the existence and extent of links among various crop, biofuel, and energy prices. Filip et al. (2017) goes directly to Zhang et al. (2010) who found no link: "*The underlying hypothesis states rising biofuel prices …should then drive up agricultural prices... time-series results do not tend to support such a hypothesis. …Rising sugar prices…[are the] leading cause of higher grain prices*…"[18] They then explain "*This*

[15] Wright (2011, 2014) and Bobenrieth et al. (2013, 2014).

[16] Wright writes crop inventories increased from 2004–05 through the price crisis of 2008. Given the Working theory of storage, stocks should have increased (and therefore they did!) They did not, however, as world crop inventories declined from 2004–2005 through 2006–2007. However, stocks rose sharply in 2007–2008 but then crop prices were locked onto biofuel and crude oil prices so inventories could have no impact on prices.

[17] Besides, inventory changes could not have made any difference as our discussion earlier on what happened in Time Period 1 makes clear.

[18] Sugar prices?! They were flat as a pancake through 2008. Look at Figure 6.4 in de Gorter et al. (2015).

paper replicates the study of Zhang et al. *(2010)…We confirm the findings of the original paper…between March 1989 and July 2008*." Replicates the paper!? Figure 1 shows they are correct up to August 2006 but up to "*July 2008*"!? This includes Time Periods 1 and 2 in Fig. 4!? Corn prices almost doubled in Time Period 1 (Fig. 1) and all grain/oilseed prices tripled along with corn in Time Period 2. We have just attributed most of the price increase due to the formation of biofuel price links in Sect. I.

In addition to their over-exuberance for Zhang et al. (2010), Filip et al. (2017) note that "*the relationships between fuel and food prices followed different patterns when the time series was divided into three periods—November 2003 to June 2008 (pre-food prices crisis period), July 2008 to February 2011 (food prices crisis period) and March 2011 to May 2016 (post crisis period)*." How can June 2008 be in a pre-food crisis period? As we just showed, Time Period 1 (the Transition) saw corn prices almost double in 5 months compared to February 2007 (ending with the Mexican tortilla crisis), and then prices ramped up even more in October 2007, with corn prices peaking in June of 2008, which is part of Filip et al.'s (2017) "*pre-food crisis period*"!?

They write further "*However, some of these contradictions were clarified after post-2010 data were included.*" Post-2010 data!? We just showed in Fig. 8 that most of the price increase in Time period 4 occurred in 2010 when corn prices were locked onto gasoline prices!

There are 1000 papers or more using sophisticated econometrics to find a relationship between corn and energy prices. This literature fails to realize that if there is a strong relationship between ethanol and corn prices, then corn prices are the lowest they can go (State of Nature 1), and if there is a negative relationship, the mandate is binding and prices are even higher than the tax credit would generate. In other words, when we have a negative relationship between energy and corn prices, biofuel policies are having their maximum impact on corn prices! As Taleb notes: "*No, we don't put theories into practice. We create theories out of practice….*"

The entire literature on the effect biofuels had on corn prices is riddled with inconsistencies as outlined above. As Yogi Berra did say, *they made too many wrong mistakes*. However, as Tolstoy never wrote, *all competent data analyses are alike, but each incompetent data analysis is incompetent in its own way*. But the literature is so huge that it would require me to write volumes to expose them. I thereby must invoke the inverse of the Einstein theorem:

> *If I were wrong, then one would have been enough!*
>
> Albert Einstein, commenting on the book <u>100 Authors Against Einstein</u>

Hence, although I offered several critiques of the literature in this section, only one critique should have been sufficient.

1.3 Why the Profession Rejects Our Conceptual Framework

I now explore why the profession behaves as it does, ignoring the approach taken here even though I have sent many papers and given many seminars to the profession at large, including most of the authors mentioned so far. Unlike Rausser, all others in the economics profession that had written on the causes of the price booms, numbering in the thousands, were unable to change their minds in the face of our evidence. Clearly, this refusal to acknowledge a new, and empirically validated, explanation for an important phenomenon runs counter to the public interest of seeking the truth.

Recall that we are trying to explain the tripling of food prices in three time periods while 850 million people are starving, and 2 billion people were not sure where their next meal would come from or if it came at all (Herring, 2015). Lenin would have pointed out that while one starving person is a tragedy; 850 million starving people is merely a statistic. Fine, but now is not the time for everybody to become a Leninist.

Let me take as a starting point the quote I gave in the de Gorter et al. (2015) from a book entitled *Homo Academicus* by the late sociologist Pierre Bourdieux:

> *[A]cademics too often participate in a kind of mutual reassurance scheme: cite me and I'll cite you; praise me and I'll praise you; be clever and facile but do not be too demanding because most of your colleagues want new understanding much less than they seek comforting reassurance that they already know everything worth knowing.*

There are several interpretations of this quote. The first part of the quote points to strategic behavior, which we will cover below.[19] The second part of the quote seems to be pointing to the tendencies of economists appearing to only see what they are already looking for, what they are trained to see and what their mind is prepared to comprehend. It spans sociology and cognitive psychology, including an albeit imperfect definition of confirmation bias (see discussion below).

Gerhard Fröhlich wrote: *Most scientific publications are utterly redundant, mere quantitative 'productivity'*. Never have truer words been written when assessing the papers written on the grain/oilseed price booms of the new millennium and biofuels mostly non-role in this literature. So, I want to dig deeper as it really makes me wonder why it is that supposedly smart people end up believing that such disjoint factors as speculation, macroeconomic events, global warming and China eating more meat were the sudden causes of these four distinct price booms? This pondering led me to the annals of sociology, behavioral economics and economics.

1.3.1 Homo Sociologicus

Once an eminent economist asked an eminent sociologist to name five theories in sociology that economists should understand. The sociologist offered three[20]: imitation and conformity as a basic and very important feature of human behavior[21]; social networks/social structure really matter; and lastly collect some real data (do

[19] How to get a paper cited a lot? Step 1: Write what people want to hear. Step 2: That's it.

[20] I am not sure if there are only three theories in sociology worth knowing or the sociologist figured economists are so shallow that three would be the maximum we could absorb. Looking at the literature explaining the great price booms of the new millennium, one can hardly fault the sociologist if it was the latter.

[21] "*Ten years ago it was difficult to publish a paper in the QJE which included a "present-bias" assumption. These days it is impossible to publish in the same journal which ignores present-bias*" Rubinstein (2006).

not just be "data downloaders", and experimental economics does not count). The sociologist proclaimed "Go out and observe some markets with your eyes and get your hands dirty. Live a little!"

These three simple insights perfectly explain the dynamics observed in this literature: (1) imitate and conform; (2) be part of the social network, i.e., *Homo Academicus*; and (3) only have a cursory knowledge of what is really going on in the real world by downloading some data and executing an AR, VAR, ECM, GARCH or a FARCH, and done. Seems like sociologists have our profession completely figured out, and (apparently) it is universal. But why do these patterns hold? Is it cognitive errors (behavioral economics) or simply rational choice and basic economics?

1.3.2 Homo Mistakus

Of the many cognitive biases in the literature, which one's best help explain the issue at hand? There are several (partially overlapping) theories that seem to fit the bill: Motivated reasoning is when you argue yourself into a belief which, for some ex ante reason, you value holding. Confirmation bias is when you seek out information and data that confirms your pre-existing ideas, while ignoring contrary information. Conservatism is the tendency to revise your belief insufficiently when presented with new evidence.[22] This means economists will be bad at spotting regime changes (the exact issue analyzed in this paper). Sunk costs are argued to be the root cause of conservatism.[23] People make up their minds early and refuse to change them (a great example of the interaction between conservativism and confirmation bias).

Imitate and conform can be explained by several cognitive biases like herd mentality and group behavior. It takes the form of collective rationalization (conservatism), invulnerability (over-optimism and over-confidence), direct pressure on dissenters (e.g., asking me not to publish de Gorter & Just, 2009) and **gatekeeping** under many guises (journal editors, special issues of journals, NBER conferences, various society's annual meetings, the ASSA meetings, proceedings issues, special conferences, etc.) that allows confirmation bias to flourish with self-censorship so that deviations from the perceived group consensus are not expressed (so do not invite Rausser or de Gorter, nor cite their 2012 paper).

[22] Confirmation bias is a special case of "motivated reasoning" and refers to selective updating (putting more weight on information that confirms or that you already believe). Conservatism is insufficient updating (so confirmation bias is like insufficient updating but only in one direction). In the context of this paper, a key question is what factors would trigger motivated reasonings of these types?

[23] Another cognitive bias is Sunk Cost Fallacy. Relating this to the issue at hand, economists continue a way of thinking because of the time, effort and reputation already developed. I do not think this is a bias but rather is very rational, so I term it Sunk Cost Rationalty™.

Going with the group is an innate psychological phenomenon, a survival trait and inborn instinct in most people. Neuroscientists find people are (a) hard-wired for the short term and need immediate satisfaction that arouses the emotional brain, releasing dopamine, making one feel happy; and (b) hard-wired to herd as the pain of social exclusion is actually felt in the brain as real physical pain. These two traits are reinforcing people's tendency to imitate and conform and exhibit herd-like behavior. Imitation and conformity with the large group necessarily means the risk of independent thought and action is sacrificed.

There are umpteen other cognitive biases that would be relevant given the problem we are trying to solve. An example is "system justification" or the "Google effect" (the latter used specifically Mišečka et al., 2019 to explain the great price booms).

1.3.3 Homo Academicus

But let's dig deeper. Why would each economist imitate and conform, as sociologists note, or why would it be simply cognitive biases that explain the behavior of our profession? Perhaps they are being simply rational? What is each economist's objective function, what does it depend on, and what are the constraints individuals face? Surely the *Homo Academicus* comes into play here.

The Bourdieux quote can simply be explained by strategic behavior as well as the embedded incentive structure and institutional setup of *Homo Academicus* which I call the Civil-Academic-Industrial Complex; this setup has become more dangerous than any former outgoing President ever imagined.

The core malaise in academia is that the days of the ivory tower with its noble purpose of increasing knowledge, with academics recognizing each other's work, and with honesty and the public interest as paramount ideals, are over. Bourdieux argues *Homo Academicus* has morphed into an "industry" of "publication factories" and "project mills" concerned only with the number of publications, Google citations, journal impact factors, competing for external grant money and networking with other institutions and universities.[24]

Truly genuine academic achievement is not accounted for because of the institutional context of *Homo Academicus*. The peer-review process is an insider procedure (even though few peers actually read let alone understand the articles) where reviewers assess the articles in accordance with their own work or hardened views. Publications conceal the weak reasoning and poor understanding of the facts, with overuse of complex formal models and impressive sounding jargon. Laymen, politicians and academics not in the specialty are blissfully ignorant in the belief that more publications mean more knowledge.

[24] Binswanger (2014) argues it is a result of two artificially staged competitions by the government to "incentivize the production of nonsense": obtaining as many publications as possible (the only measurable output in *Homo Academicus*) and research funding. There is no concern for content or purpose of research—he calls this "contest illusion."

Several perverse incentives follow, such as strategic citing and praising to get the right reviewer rather than one that may provide legitimate criticism. This limits the debate over new or more relevant approaches to solving economic problems. Established knowledge is constantly re-cycled by elaborating on existing approaches by simply adjusting existing models slightly or doing additional empirical investigations. Just read the hundreds if not thousands of econometric studies trying to determine the relationship between crop and energy prices described in the previous section. For reasons discussed, the net gain in knowledge from these papers is negative.

Another perverse incentive is no deviation from established theories wherever there are eminent authorities who dominate the field and are journal editors at the same time. This allows them to prevent the appearance of approaches or theories that question their own research (classic examples include the 2012 NBER conference, and several conference proceedings on biofuels published (one in the AER), all orchestrated by the reputation hierarchy of *Homo Academicus*). Consequently, authors adapt to the prevailing mainstream approaches to publish in the most prestigious journals and be invited to prestigious meetings. This makes even new researchers in a field inflexible. Hence, traditional, or fashionable approaches are adopted that minimizes resistance to publication. I believe this hinders real scientific progress.

Form becomes more important than content because originality lowers the chances of publication so complex theoretical and empirical methods are developed that virtue signal technical expertise and importance to the reader. Binswanger (2013) goes on to write that maximizing publications and citations incentivizes the use of so-called "salami tactics" where minor ideas or approaches are presented leading to a greater number of publications just by adjusting these models and approaches.[25] These papers become increasingly irrelevant, meaningless and redundant. The literature on what caused the great price booms and biofuels role in it is a classic example of these perverse incentives and the crowding out of good research by bad research (like Rausser & de Gorter, 2012) that Binswanger (2014) describes.

Homo Academicus involves a necessary hierarchy which involves transactions costs and the ensuing principal-agent problem (between the hierarchy and individuals, not to mention that the public good is not being served). This points to the importance of networking and its structures.[26]

The biggest problem I identify from all of this is **gatekeeping** which involves a reputation hierarchy that defines the in- versus out-group, and all the attending mischief that ensues described earlier. Gatekeeping leads to people, especially

[25] Binswanger (2014) also notes the increase in number of authors per article so not only the publication list of participating authors per article is growing, but also the number of direct and indirect "self-citations" which triggers a snowball effect.

[26] This may require engaging economic sociology which "deals with all economic institutions including social relations, culture, cognition, norms, structures power and social institutions as explanatory variables for the interpretation of outcomes."

untenured faculty, having to please the more senior gatekeepers. Tenure should mean that senior people have the freedom to pursue new ideas and not worry about the mainstream (because they are themselves the opinion makers and gatekeepers). But as we have shown, that did not happen regarding *Homo Academicus* and the literature on what caused the food commodity price booms.

1.4 How Does Gordon Rausser Fit into All of This?

Keynes (1924) deliberates on what makes a great economist "… *the master-economist must possess a rare combination of gifts… must understand symbols and speak in words. He must contemplate the particular in terms of the general and touch abstract and concrete in the same flight of thought. He must study the present in the light of the past for the purposes of the future. No part of man's nature or his institutions must lie entirely outside his regard. He must be purposeful and disinterested in a simultaneous mood; as aloof and incorruptible as an artist, yet sometimes as near to earth as a politician*."

There is a lot in that quote so let's parse it. *He must be purposeful and disinterested in a simultaneous mood* means he must overcome his (or her) cognitive biases and yet be passionate, especially about the public good. Confirmation bias seems to be the most serious issue here. Imagine a mouse with such a mindset, bent on confirming its current belief that there are no cats around. It would soon be dinner! Being in the markets every day, Rausser not only survived in the real world but was very successful. He has clearly overcome all the biases, and yet he co-exists with all these economists who ignore the reality of the major cause of the food price booms. How can that be? Obviously in academia there are no cats around to self-select against confirmation (or any other) bias. That is the nature (and flaw) of the incentives and structure of *Homo Academicus*. The rancor in the literature on biofuels, and in academia in general, is a classic example of Sayres law: so great a debate, so little at stake. Gordon does not indulge in that kind of behavior.

Confirmation bias is in direct violation of the principle outlined by the philosopher of science Karl Popper. As Gordon taught us, the only way to test a hypothesis is to look for all possibilities to falsify it. He stressed it in class; he challenged the EU Commission in an IAAE session in Milan in 2015, citing Popper and using this exact framework outlined in Sect. I as an example.

Yet Gordon is passionate (yes, he has an emotional brain and it is wonderful!) but it is about the public good. Look at all the work he did as Chair of Berkeley's ARE, making and maintaining it the uncontested #1, or all the work as Dean. Gordon is fully committed to the public good while not being seduced by the vanity of recognition. He does not spend all day writing papers using "salami tactics" and worrying about the number of Google citations and all the other methods academics use (like gatekeeping) so they can win the World Food Prize, all the while ignoring whether their papers contribute to knowledge and hence the public good. Instead, Gordon engages in meaningful activities with long run positive benefits for the profession and society.

Consider *"No part of man's nature or his institutions must lie entirely outside his regard"* which points to Gordon's breadth, both within a topic and across the many topics he has tackled in his career. It also highlights his thoroughness in addressing each topic.

Consider "*He must contemplate the particular in terms of the general and touch abstract and concrete in the same flight of thought*." When I first worked with Gordon on a paper before I came to Berkeley, the thing that left the biggest impression on me was how he was able to conceptualize a problem. It opened a whole new world for me. The most important lessons Gordon gave to me as a mentor was always insisting that I have a theoretical framework, along with a thorough understanding of what was going on in the real world, and to then confirm it with solid empirical analysis. To this day he complains about papers and research that lacks a sound theoretical framework. Gordon is passionate about the issues of the day and goes where the data and theory takes him, yet he is "*purposeful and disinterested*" at the same time. He has a passion about the issues yet engages his logical brain at the right times.

It is my strong belief that the literature on the price booms and the role of biofuels role uses far too little theory all while employing the most sophisticated statistical techniques known to humankind. But as I have shown earlier, to what benefit? There is a pressing need to produce interesting and creative theory in the issues facing the world for our profession to analyze. But you first need to produce a theory. Rausser is one of the best in this regard and I am grateful to have had him as my mentor and friend which allowed me to make contributions with a theoretical basis that added value and legitimacy to my work. For all these reasons (and many more), I consider Gordon as the epitome of what Keynes calls "*the master-economist who possess a rare combination of gifts*."

Furthermore, Gordon does not suffer from herd behavior. He possesses the intelligence, emotional strength and nobility of character to change his mind when the occasion requires it. He is open-minded and an independent thinker who has the moral and mental virtues to make correct decisions. In conversations with him spanning more than four decades, he is always on top of things (even in explaining before the season opener why the 49ers will be very successful this year). Keynes notes…*as aloof and incorruptible as an artist, yet sometimes as near to earth as a politician…* Gordon has his boots firmly planted on earth, not dangling in the air.

He chose to mentor an ordinary student like me, gave me encouragement along the way, and added value (and lots of it) in the process; he does not just take on whiz kids and make them whizzier. Gordon is honest, he does not patronize. You earn his good will. He always listens. How many prominent economists did not even listen to what I had to say about the price booms, even when they had not heard the story before? Gordon reads. There is a joke going around Giannini that the only one reading PhD students' papers are recruiters when they apply for jobs. Gordon reads everything you put in front of him and gives you thorough comments.

Gordon is not afraid of debate, goes toe to toe with you and does not seek refuge in *Homo Academicus*. The profession at large however takes a different tack. When confronted with irrefutable evidence provided by our framework presented here, rather than debate it, they either engage in Gish Galloping[27] or decide not reference my work. Silence is the best antidote for most. Wright (2014) is a classic example, being fully aware of my work, yet stating that there is no need for new theories: he maintains that the tools at hand can explain the main forces at work. He then cites Engels (1821–1896) (inelastic demand), Working (1949) (stocks go up with prices, causing a bubble), Nerlove (1956) (supply response models) Griliches (1957) (public R&D) Gustafson (1958) (first model of rational expectations model) and….drum roll…. Stock and Trebbi (2003) (a whodunnit mystery on the discovery of instrumental variable regression; was it Philip G. Wright in 1928 or his brother earlier on?) As we have shown, all these topics are mostly irrelevant in explaining the price booms since September 2006 while Sect. I of this paper solves the real mystery.

While the Anderson et al. (2014) paper cited earlier claims that developing country policy response caused world prices of corn to rise 52% in 2007–2008, chapter 6 of de Gorter et al. (2015) and de Gorter and Drabik (2016) showed it had no impact. The first reviewer of the latter paper argued against publication (appealed to Rosegrant & Msangi, 2014 for refuge) while the second reviewer was most unsure but declared it was an important issue and should be published to begin a debate in the profession. How naïve![28] Nobody wants to debate. It reminds me of Easterly (2014) lamenting the lack of a debate between the co-winners of the 1974 Nobel Prize in Economics. "*There was never a debate…he claimed that his approach was "unanimously endorsed by governments and experts" … [Myrdal's] claim of unanimity was correct in a strange way…*".

Cornell hosted a conference for the 16 U.S. intelligence agencies in June of 2012 on national security and food price instability, just as the market volume in futures trading began to escalate in advance of news of the drought. There was no paper on biofuels, the slides presented by Rosegrant from IFPRI had biofuels only on the third slide, there was no mention of them on the last slide (as opposed to food waste and meat consumption which featured prominently). In 2 months, corn prices rose from $5 to $8.50. IFPRI then issued a press release calling for governments to pull back on biofuels as there was a risk of another food crisis (no mention of food waste or meat consumption). Such was the extent of the naivety as to how biofuels impact food commodity prices.

IFPRI's Headey and Fan (2010) is more of the same, emphasizing their "balanced" and "unusually comprehensive assessment of the crisis" like Fox News, where all possible factors (and more) in the "perfect storm" played a role. Information overload results with readers learning more and more about less and less, until we know absolutely everything about nothing. If Rausser and de Gorter (2012)

[27] See https://rationalwiki.org/wiki/Gish_Gallop.

[28] Two other reviewers were strongly positive, however. All four reviews were a long time coming; the editor wrote it was difficult to find reviewers!

conclude biofuel policies were the most important factor by far in explaining the great price booms, then their analysis fails to be either "balanced" or "comprehensive"!?

The Economist (2008a, b) noted that the 2007–2008 price boom was a "silent tsunami" as it caught everybody by surprise; economists did not understand why it happened and policy makers did not know what to do. The price boom had these three principal characteristics: it was unpredictable, it had a huge impact, and after the fact explanations were made up so that the price booms were predictable (the "perfect storm", "economists had tools on hand that can explain", "biofuel demand was no surprise"[29] and the list is endless). In the early days of meeting Gordon, I was suffering from over-confidence bias in trading in the futures market, and Gordon must have noticed it, emphasizing "never underestimate the market". No kidding. The market did not make a mistake in 2007–2008. The market was not stupid—the price boom was just unpredictable without a proper model regarding the role of biofuels.

Once the early literature on the causes of the price booms had been established, there was an incentive to protect each other's findings.[30] The literature clearly suffers from self-serving bias (the innate desire to interpret information and act in ways that are supportive of one's own self-interest) and inattentional blindness (we do not expect to see what we are not looking for). As a result, the profession engaged in a substantial amount of gatekeeping which prevented the contradictory ideas presented in this paper from getting any credence or even attention. Gordon does not engage in gatekeeping.

At this point, I want to highlight one final defining feature of Gordon: He always told me to engage the profession and to not be afraid to take a stand. He was a steadfast role model in those regards. In thinking of the past 12 years reading and writing about the price boom and its link to biofuels, it was clear to me that it is the responsibility of each of us to try to understand issues outside our immediate specialty and take a stand. I came across the website of Paul Romer[31] who criticizes the state of macroeconomics by writing: "*Some economists counter me by saying macroeconomics is a backwater that can safely be ignored… To me, this reveals a disturbing blind spot. The trouble is not so much that macroeconomists say things that are inconsistent with the facts. The real trouble is that other economists do not care that the macroeconomists do not care about the facts.* ***An indifferent tolerance of obvious error is even more corrosive to science than committed advocacy of error****…*" These are powerful words, particularly in context I raise in this paper. Gordon always made a point of knowing what all his colleagues at Berkeley and in the profession are working on. This is a trait we should all aspire to rather than burying our heads in our own silos.

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[29] Wright (2008, p. 8) writes "*Crop diversion [for biofuel] can hardly have come as a surprise in 2006 … usage started no later than 2004 … clearly foreseeable … oilseeds for biofuel use … no surprise*."

[30] Wright (2014) asserts "The most important analytical element in this paper that I have added to … Abbott, Hurt, and Tyner … is the discussion of the dynamic response of stocks …" Everybody agrees with each other and are blocking the out-group.

[31] See https://paulromer.net/the-trouble-with-macro/WP-Trouble.pdf.

2 Epilogue

This paper highlights the exceptional greatness and congeniality of Gordon Rausser as an academic by drawing a sharp contrast between his approach and the general malaise I experienced in the profession when it comes to adopting new ideas. I limited myself to such few pages (in the hope people might read it) and addressed just one example in which prominent researchers failed to concede the persuasiveness of a new idea in order to protect the research that came before. There is no need to go further. I shall once again invoke the inverse Einstein theorem: surely one example is enough! And it is. One or a hundred examples, Gordon is a unique economist in our profession who will be sorely missed in due course.

What would the optimal incentive structure and institutional design of academia and its relationship with civil society and industry be? And how should we reform the incentives and institutional design in order to align researchers' personal interests with the pursuit of the public good? This is the ultimate question facing academia's relationship in *Homo Academicus* and falls right in the wheelhouse of Gordon's great contributions on the importance of governance as head of the Institute of Policy Reform. Clearly more research must be done on this topic.

I therefore recommend Gordon Rausser be appointed (and compensated) for the following two initiatives:

1. A Royal Commission (as Canadians would call it) on the factors contributing to the demise of and recommend reforms for the *AAEA*.
2. The creation of an alternative to the World Food Prize along the lines of a Hippocratic Oath for economists studying food prices and policy which would reward the search for truth and the pursuit of the public good without catering to the type of work that too often dominates in the current *Homo Academicus*.

The following quote may provide insight into what makes Gordon legendary as a role model in our profession:

> A prophet is not someone with special visions, just someone blind to most of what others see.
>
> —Nassim Nicholas Taleb, The Bed of Procrustes: Philosophical and Practical Aphorisms

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From Handshakes to Blockchains: Economic Analysis of Contracts in Agriculture

Rachael E. Goodhue

To date, the economic literature has tended to segregate analyses of contracting in agriculture by its role, such as farmgate contracts between producers and buyers versus agricultural support and conservation policies executed via contracts between producers and government agencies. This chapter integrates these literatures by identifying commonalities and drawing lessons across them. It then presents a schematic for understanding the development of the use of contracts in the agro-food chain. Finally, it addresses an emerging wave of agricultural contracting that integrates new technologies, including blockchain technology.

This chapter celebrates Gordon's contributions to the literature in two ways. First, it highlights specific contributions regarding the incentives underlying the behavior of economic agents and the implications of policy design decisions for economics, the environment and natural resources. Second, it integrates his contributions to historically separate literatures within a single framework. This strategy for the chapter was inspired by something Gordon told me about a fundamental choice researchers make: to be a fox, who addresses topical issues as they arise with a portable toolbox, or to be a hedgehog, who knows one specific topic better than anyone else. Gordon has the career of a fox.

1 Introduction

Agricultural markets are popularly conceived of as spot markets for commodities in which raw commodities are traded for immediate exchange. Just as raw commodities does not represent the majority of value created by the agro-food chain,

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transactions in many agricultural markets are not solely, or even mostly spot sales. Contracts and contracting play important roles in the agro-food industry. A contract is an enforceable agreement between two parties, who have mutually accepted its terms.

To date, the economic literature has tended to segregate analyses of contracting in agriculture by its role, such as farmgate contracts between producers and buyers versus agricultural support and conservation policies executed via contracts between producers and government agencies. This chapter integrates these literatures by identifying commonalities and drawing lessons across them. It then presents a schematic for understanding the development of the use of contracts in the agro-food chain. Finally, it addresses an emerging wave of agricultural contracting that integrates new technologies, including blockchain technology.

2 Classifications of Agricultural Contracts

Agricultural contracts can be classified based on a number of dimensions. Contracts may be formal or informal, written or oral, implicit or explicit, and relational or based on high-powered incentives. More specifically, within a defined category of users and contract objective, contracts are differentiated along a continuum of the extent of coordination.

There is some tension between classifications based on contract use and classifications based on contract structure. Distinctions based on use concern the stage(s) of the agro-food chain considered, whether the contract is between private parties or includes the government, or its objective. Most often contract use defines the contracts examined to address questions related to contract structure regarding design and incidence. For example, contractual choices in land rental markets among crop share rent, cash rent, and custom farming account for a substantial literature. Another example is a standard classification that restricts attention to farmgate contracts between an agricultural producer and a buyer and further separates the contracts into marketing contracts, which only include provisions relevant at the time of sale, and production contracts, which include provisions regarding one or more production decisions and may include time of sale provisions as well (Mighell & Jones, 1963).

3 Modeling Contract Design

Modeling a contract requires first understanding what it is. Legally, a contract is defined by four characteristics. (1) offer: one of the parties must commit to doing or to not doing some action in the future; (2) consideration: something of value must be exchanged for the offer; (3) acceptance: the offer must be accepted by the other party; and (4) mutuality: both parties must understand and agree to the provisions of the contract (Judicial Education Center, n.d.). A legally enforceable contract does not necessarily have to be written, although certain classes of contracts must be written under the Statute of Frauds.

Contract theory models how a principal designs a contract to mitigate information asymmetries: adverse selection and moral hazard.[1] A starting point for analyzing a contract is to ask, what problem is the contract intended to solve? For example, is it a means of managing legal liability? Is it part of a strategy for learning about a new market through a joint venture? Understanding the final objective is the foundation for designing the contract. The structure, including the parameters, must provide the correct incentives to one party, in contract theory's take-it-or-leave-it approach, or to both parties in a negotiated contract. The contract must be enforceable, either self-enforcing or enforceable through a third party, which can be conceptualized as representing the legal framework governing contracts.

When modeling a contract, the first key decision is which characteristics and provisions must be integrated into the model. Economic analysis of agricultural contracts focuses on the first two characteristics: offer and consideration. Economists tend to focus on a relatively limited number of contract provisions, including control rights, allocation of risk, pricing mechanism(s), and characteristics of the production activity or output such as quality attributes (Goodhue, 2011). These provisions are generally central to any asymmetric information problem that exists and are easily modeled using contract theory. Apart from tractability, this limited set of provisions are the ones best-suited for testing hypotheses in experimental settings (e.g. Wu & Roe, 2005, 2007), as well as non-experimental ones (e.g. Goodhue et al., 2010).

However, other provisions of legal contracts, often referred to as boilerplate, can have important consequences for the contracting parties (Goodhue & Hoffmann, 2006). Provisions regarding merchant status, dispute resolution, warrants, and legal compliance and liability will influence returns resulting from the contract. The existence and exercising of boilerplate provisions have significant implications for economic analysis. If a provision simply transfers returns from one part to the other, then it can easily be modeled as part of the principal's profit-maximizing contract. Similarly, if a provision such as one specifying a dispute resolution process simply increases costs for one party, then it can be incorporated explicitly into the analysis. On the other hand, risk-transferring provisions such as a warranty that assigns downside risk to one of the parties require explicit incorporation into the specification of uncertainty used in the analysis because it alters the incentives facing the two parties.

Alternatively, instead of introducing a multiplicity of contract provisions, economists' model incomplete contracts. A contract is considered incomplete if unanticipated events not addressed in a contract can affect its outcome. Rausser and Ameden (2013) present an incomplete contracts model of public-private partnerships. They

[1] "Adverse selection" refers to a situation in which there is "hidden information." The principal would like to condition the contract on information known solely to the agent. "Moral hazard" refers to a situation in which there is a "hidden action." The principal would like to condition the contract on an action by the agent that the principal cannot observe.

argue that such partnerships are by definition incomplete contracts because of their long-term nature and complexity. Accordingly, the contract's specification of which party makes decisions when there is an unanticipated event as well as anticipated ones can alter the total returns obtained by both partners as well as how the returns are distributed between them.

4 Relational Contracts

Moral hazard and adverse selection-based models of contracts co-exist with the relational contracting paradigm that emerged from the foundational transaction cost literature. Contract theory models require enforcement. In contrast, relational contracts are self-enforcing. In other words, relational contracts are ones in which the ongoing value of the relationship is high enough for both parties that they have no incentive to break their arrangement in the current period (Klein & Leffler, 1981; Williamson, 1985; Levin, 2003; Wu, 2006; Dixit, 2011). Relational contracting is a theoretical concept; a relational contract is not the same as an informal contract and may include one or more formal written contracts (Goodhue, 2000; Dixit, 2011). Michler and Wu (2020) provide a thorough assessment of the study of relational contracts in agriculture.

Relational contracting is associated with contexts where reputation may be important, and failing to complete one's commitments now will prove costly in the future. Another consideration is verifiability. If the principle's desired outcome is unverifiable by a third party, then a self-enforcing relational contract may be used (Dixit, 2011). Similarly, if there is a subjective element to the assessment of the variable so that different third parties may come to difference conclusions, monitoring becomes less informative and a self-enforcing contract that does not rely on monitoring may be chosen (Levin, 2003).

Modeling market transactions best characterized as relational contracts as ones designed to address moral hazard using high-powered incentives can lead to failures to account for factors that guide the parties' behavior. For example, many contracts in the almond pollination market between a beekeeper and an almond grower are consistent with relational contracting. Beekeepers and growers contract with the same parties year after year, and growers cite a prior relationship as a key factor influencing their choice of beekeeper (Goodrich & Goodhue, 2020). Although there are often written contracts that specify that the grower has a right to inspect hives, growers in relational contracts seldom do so. The assessment of a honeybee colony has a subjective element, so monitoring is less informative, providing one explanation for why inspections are seldom done. Instead of monitoring, the grower relies on the value to the beekeeper of continuing their relationship in future seasons to ensure that the colonies delivered this year will be sufficiently strong to provide the needed pollination services.

5 Policy Contracts

Many agricultural policies rely on contracts between a government agency and a private entity. Overall, these contracts can be grouped into two broad categories of agricultural policies delineated in Rausser (1982, 1992): Political Economic Seeking Transfers (PESTs) and Political Economic Resource Transactions (PERTs). PESTs do not incentivize agents to address a market failure, rather seeking to address the classic agricultural policy objective of mitigating the effects of low and/or variable prices on farmers. For example, federal commodity procurement contracts are one means of supporting commodity prices, including mitigating price impacts of one-time shocks to demand or supply. Processors bid on supplying products that meet specific federal parameters, which strengthens the demand for the domestic product.

PERTs address market failures. Payments for environmental services (PES) programs are in this class. In the U.S., Conservation Reserve Program (CRP) contracts incentivize farmers to address specific resource and environmental externalities associated with agricultural production. Farmers bid to enter contracts with the government. Winning bids are selected based on cost and the associated environmental benefit. Although the bidding process is effectively an auction, economists have utilized contract theory and mechanism design to analyze the program and its benefits (Smith, 1995; Wu & Babcock, 1996; Khanna & Ando, 2009; Peterson et al., 2014).

Grazing permits are another example of a policy contract designed to address a market failure. A federal grazing permit specifies the animal unit months allowed on a property. These permits are formal contracts with a specified term. The possibility of renewal means that these formal contracts are embedded in a larger informal contractual structure. In the 1990s, changes in rangeland management increased ranchers' uncertainty regarding the likelihood that they would retain federal grazing permits. This change in the informal contract altered ranchers' behavior by incentivizing them to increase stocking rates, reducing social welfare. McCluskey and Rausser (1999) demonstrate that if the likelihood of renewal was a function of ranchers' previous stocking decisions ranchers will internalize the negative externality of overgrazing and move in the direction of the socially optimal use of forage.

Crop insurance contains elements of both classes of policy contracts and can be considered a class of its own. While multi-peril crop insurance is offered by private insurers, it is subsidized by the government. The design of crop insurance contracts takes moral hazard on the part of the farmer into account, while the premium subsidy supports farm incomes. Rausser and Foster (1990) consider the social welfare implications when a government implements a portfolio of PERTs and PESTs; their framework could provide a fresh approach to analyzing crop insurance contracts.

The political economy of agriculture drives the design and hence, incidence of agricultural policy (Rausser & Goodhue, 2002). Policies labeled as PERTs addressing market failures may be PESTs designed to transfer benefits to farmers. Casamatta et al. (2011) examine the WTO debate in the 2000s regarding whether high levels of agricultural subsidies encouraged the joint production of rural amenities with agricultural output, sometimes referred to as multifunctionality. Countries with high subsidy levels, such as the European Union and Japan, argued that they did. Countries with lower subsidy levels, such as the United States and members of the Cairns Group, argued that high subsidies distort production and trade, regardless of the extent and value to which rural amenities exist. The authors demonstrate that when agriculture is multifunctional, the first-best allocation of resources involves a tax on agricultural output, paired with some subsidization of factors of production. A subsidy on agricultural output is never optimal unless the government desires to transfer income to producers.

6 Key Analytical Dimensions

Three key dimensions of a contract can have significant impacts on the conclusions of an analysis. First, the researcher must frame the contractual relationship appropriately. For example, a long-term informal contract may be the superstructure for a short-term formal one. Restricting attention to the short-term contract can distort the identified incentives facing the contracting parties and the distribution of returns resulting from the contract (Goodhue, 2000). Additionally, short-term and long-term reservation utilities may differ in important ways. Second, the full extent of the relationship between contractual parties must be addressed. For example, a formal contract may co-exist with a business relationship that is effectively vertical integration by the same or very similar group of owners. Finally, while a take-it-or-leave-it (TIOLI) approach may be appropriate in some contexts, such as when a meat processor contracts with a farmer, in others neither party may have the power to make a TIOLI offer to the other, such as when a food retailer contracts with a large produce shipper. The next two sections discuss- the second and third dimensions, respectively.

7 Contracts and the Boundaries of the Firm

Contracting is never the only means for addressing an incentive issue. Focusing on vertical coordination, a contract represents a degree of coordination on the spectrum between vertical integration and spot market exchange. The choice of how a transaction is made depends on the cost of each alternative (Coase, 1937). Market actors' coordination choices vary based on heterogeneity in factors such as available capital, technology, and expertise. For example, patent rights can influence choices between horizontal consolidation versus licensing contracts (Marco & Rausser, 2008).

The California wine industry is well-recognized for making extensive use of contracts for vintners' winegrape purchases from growers (Goodhue et al., 2003). Contracting is commonly used across all dimensions of the grape and wine production process, with different actors selecting contracts for different stages. A vintner may work with a vineyard manager, and either party may contract with the landowner. A winery may contract with a winemaker, rather than having one within its own organization, and may contract for bottling rather than investing in the equipment itself. While some grower-vintners have all of these functions in-house, conceptually they could all be outsourced via contract and the "producer" could take delivery of a finished product under its label.

One interesting topic when considering real-world organization choices is the role of legal liability in the transaction cost-based framework conceptualized by Coase (1937). A market actor may choose to separate business functions in order to manage liability. They may do so using the spot market for one or more transactions, or by contracting with an independent actor. Consider the market for hogs. Although a meat packer does not face liability for pollution due to raising and fattening the hogs when buying on the spot market, some degree of vertical coordination could be more profitable because it lowers the transaction cost of procuring a sufficient and consistent supply of hogs. In some cases, vertical integration could result in the lowest transaction cost. However, vertical integration might result in legal liability for pollution from hog production. Depending on the extent to which the meat packer controls aspects of the producers operations, a formal contract can assign liability for pollution, thus insulating the meat packer from paying damages.

Another way a market actor can manage liability is to separate functions into separate businesses, but retain control of all of the businesses. Formal contracts can assign liability to individual businesses, thus insulating the rest of the owner's operations. For example, a grower-shipper in California's produce industry could have a legal entity responsible for production, another responsible for shipping and cooling, and a third that provides transportation of the product. In the absence of knowledge of the ownership of these entities, an industry composed of major players who separate functions in this way would appear to be one coordinated through contracts, rather than through integration. However, the industry structure is, effectively, integration through common ownership.

This common ownership scenario has implications for the structure of the agro-food chain and for any evaluations of it that may be conducted. Most importantly, common ownership can mitigate, perhaps eliminate, differences in incentives facing the contracting entities. This enables them to capture jointly any reduction in transaction costs due to coordination while reducing the potential costs due to legal liability, which can provide a competitive advantage. If that were the case, one would expect affiliated companies to capture a larger share of the market, leading to greater concentration. The implication for studying markets where common ownership plays a significant role is that restricting attention to formal contracts will not capture the true extent of coordination. Thus, choosing the right scope of the analysis requires determining if the formal contract is the relevant unit of analysis or if it is embedded in a larger structure.

8 Contractual Negotiations and Bargaining Theory

Contract theory is grounded in a specific assumption regarding the relative power of the two contracting parties: one makes a TIOLI offer to the other. Under standard assumptions, the party making the offer will extract rents to the greatest extent possible given moral hazard and other informational asymmetries. A TIOLI offer is a reasonable modeling assumption for some contracts, especially policy contracts. However, in many contexts a legal contract is actually the outcome of a negotiation between the two parties. In these contexts, relational contracting provides a trust-based explanation, while non-cooperative bargaining theory provides a game-theoretic one based on relative bargaining power and the default outcome if the parties fail to come to an agreement.

The design of a contract based on a negotiation in which each party has some bargaining power will differ from the design of one based on a TIOLI offer, provided that the parties have different objectives. Because they both have bargaining power, they may both capture surplus above their reservation utilities from the negotiated agreement. Consequently, if the government chooses to restrict the permitted terms of contracts relative to the set of observed contractual provisions can reduce surplus for both parties.

This general theoretical observation translates into specific implications in the context of a contract between a farmer and a buyer. The conventional wisdom regarding relative risk aversion in these situations is that the farmer is more risk averse than the buyer, as well as having fewer financial resources. Policies that specify strict criteria for independent contractor status or prohibit farmers from releasing the buyer from liability related to pollution caused by the production process are sometimes presented, at least in part, as a way of protecting farmers against risk. (Clearly, this argument presumes that other contract terms will not be adjusted by the buyer to recapture any surplus the farmer would have gained by the policy.)

Moreover, if the contract is negotiated there is an additional dimension by which the policy could penalize farmers. While less risk averse players are commonly perceived to be tougher bargainers, Rausser and Simon (2016) demonstrate that risk aversion does not necessarily map to bargaining "toughness." Consequently, when the outside option is sufficiently appealing, then limiting the risk the farmer can negotiate to bear could conceivably weaken his bargaining position.

9 Information, Contracts, and the Evolution of Agricultural Markets

Over roughly the last five decades, four interrelated changes began to alter the structure of the agrofood chain: horizontal consolidation, greater coordination including the increased use of contracts, changes in price and market information available, particularly for agricultural producers, and increased production of value-added and differentiated consumer products. Together, these changes are sometimes referred to as agricultural industrialization (Urban, 1991). It's important to keep in mind that these changes occurred at different times and at different rates by commodity and geographic region, rather than as monolithic shifts, nor were they typically in lock step. Nonetheless, all of them have been observed across American agriculture albeit to varying extents.

As the use of contracts increased and spot markets thinned, price information for an increasing share of farmgate transactions was no longer public. This shift led to two concerns that continue to increase as spot markets continue to thin. One concern regards market segmentation. If transactions characterized by discoverable prices are linked to one market segment downstream (e.g. iceberg lettuce for supermarkets), then they may not be useful as benchmark prices for output intended for other downstream market segments (e.g. iceberg lettuce for fast food restaurants).

The second concern regards the impact of non-spot market transactions on the price in the thinning spot market. One example is California fresh strawberry production, in which some large players moved from the use of the spot market to informal contracts between shippers and retailers tied to the spot price, as well as to formal contracts, including ones with fixed prices. When the informal contracts emerged in the 1990s, small shippers were concerned that they lowered the spot price and increased its volatility. Large shippers who utilized the informal contracts contended that they stabilized the spot price. However, while it was possible to demonstrate that the informal contracting mechanism reduced the variance of the spot price using publicly available information when informal contracts and spot market transactions accounted for the vast majority of sales (Mohapatra et al., 2010), it is not possible to evaluate the role of formal contracts today because their terms are not public information.

Notably, the three mechanisms still co-exist. Neither type of contract always dominates the other. Fixed price contracts have the advantage of eliminating price volatility, accompanied by the disadvantage of an inability to benefit from large changes in the spot market price. They also may include a commitment by the seller to meet the buyer's volume needs, providing the buyer with additional stability. Contracts with a price linked to the spot market price retain some exposure to volatility and hence some ability to capture the benefits of changes in the spot price.

10 Value Differentiation

Increased coordination has been fueled by the adoption of new information technologies to reduce production and transaction costs, micro-target consumers, and initiate differentiation increasingly upstream. Technological advances have enabled the collection and analysis of far more data than ever imagined by the proponents of the agricultural industrialization paradigm. Exploiting that data fully requires vertical coordination to capture complementarities across stages of the production chain, or "value differentiate" by identifying and exploiting heterogeneity in product attributes and consumers' preferences (Goodhue & Rausser, 2003).

Value differentiation conceptualizes each stage of the production chain as having four dimensions: product characteristic measurement (determining the characteristics of the input(s) purchased, product characterization production (modifying product attributes), coordination upstream and downstream, and customer preference detection (identifying customers' desired attributes). The key driver of value differentiation is that there are complementarities across these four activities, meaning that the benefit of intensifying efforts in all of them is larger than the sum of the benefits from intensifying them individually.[2] The existence of these complementarities is consistent with the behavior of firms in the agro-food system and elsewhere in the economy; non-marginal changes in production, organization and management practices tend to occur together.

11 The Future of Contracting in Agriculture: Blockchains

As the volume and value of data grow, innovations to protect data quality become increasingly important. This is true in agriculture, as elsewhere. Blockchain is a technology that facilitates confidence in information by reducing the time and cost of verifying data using a network of participants who agree to share data and maintain a database.

Blockchain addresses the following problem: it is very difficult, if not impossible, to determine how data was entered or changed prior to acquiring it. Specifically, blockchain requires any addition to a database to include information on who added it, when it was entered, and an encryption key. The next change again requires information on who added it and a second encryption key that incorporates the first one. Thus, not only are all entries encrypted, they retain the encryption of all prior entries. This is the "chain" component of blockchain: entries are interdependent. This design means that the blockchain verification algorithm would easily reveal if an entry was changed.

The "block" component of blockchain is the verification process. During a "block" of time, all of the computers in the network communicate with each other and compare databases. If one node's database does not match, it is "off the network." The continuation of the history of the database embeds this information, which provides a basis for enforcement.

Classic responses to an increased demand for differentiated attributes that cannot be created by the final market seller alone include vertical integration and coordination through contracts and other means. Information transmission and sharing is a

[2] Formally, complementarity is modeled using supermodularity. A function $f{:}\boldsymbol{R}^n \rightarrow \boldsymbol{R}^n$ is supermodular if for all $\boldsymbol{x}, \boldsymbol{x}' \in \mathbf{R}^n$, $f(\mathbf{x}) + f(\mathbf{x}') \leq f(\mathbf{x} \wedge \mathbf{x}') + f(\mathbf{x} \vee \mathbf{x}')$ where $\boldsymbol{x} \wedge \boldsymbol{x}'$ is the vector of minimum elements whose ith element is the minimum of x_i and x'_i and $\boldsymbol{x} \vee \boldsymbol{x}'$ is the vector of maximum elements whose ith element is the maximum of x_i and x'_i.

form of coordination, and it can be facilitated using blockchain. A private blockchain can be conceptualized as a private, multi-party contract. Membership is limited by mutual agreement. Formation of a private blockchain requires a base level of trust, because members must be chosen. Importantly, while all participants agree to transmit verified data, blockchain does not require that all participants can see all of the data *within* each encrypted key. The extent of data sharing, as opposed to data transmission, requires mutual agreement.

Like bilateral contracts, a private blockchain can replace the spot market. Unlike bilateral contracts, a private blockchain can link information from multiple levels of the agro-food chain directly at every level, potentially at lower cost than current solutions. Paired with unique identifiers for the physical product, such as advanced radio frequency identification chips, blockchain provides traceability from the field to the final buyer. The chain approach embeds verification of earlier records, which can reduce transaction costs due to disagreements regarding product quality attributes. It can easily include logistical information, such as transportation time and delays, and can document the cost of contamination. Compliance with food safety standards is a natural use, as is any other context in which transparency is advantageous and the creation of the final product requires accumulation of inputs over multiple stages by multiple actors. Obviously, blockchain is not the only solution for verifying information, but could well be the low-cost one. Effectively, blockchains transform contracting into directly mapping information for the entire value differentiation chain, enhancing participants' ability to capture complementarities, including ones that were previously unidentified.

Industry members have recognized the potential of this technology. The blockchain market in food and agriculture is estimated to be worth over $400 million by 2023, from a base of $61 million in 2018 (ReportLinker.com, 2018). IBM has been an early player in the agro-food blockchain market. It initiated a major consortium in 2017 that included Dole, Driscoll's, Golden State Foods, Kroger, McCormick and Company, McLane Company, Nestlé, Tyson Foods, Unilever and Walmart. Blockchain has been adopted for traceability purposes for a variety of products, including beef (BeefLedger),[3] beer (Ireland Craft Beers),[4] seafood (Hyperledger),[5] and turkey (Cargill).[6] Carrefour and JB Retailer utilize blockchain to track large numbers of products. While the primary motivation for blockchain adoption to date has been traceability, the technology can have other benefits.

A pilot program among IBM, Walmart and Driscoll's sought to improve the efficiency of the berry supply chain and improve food safety management. Blockchain does not necessarily result in information sharing; however, information was shared in this instance. By participating, Driscoll's gained additional information regarding

[3] beefledger.io

[4] https://www.irelandcraftbeers.com/blog/view/42/introducing-downstream-the-worlds-first-blockchain-beer

[5] https://sawtooth.hyperledger.org/examples/seafood.html

[6] https://www.wsj.com/articles/latest-use-for-a-bitcoin-technology-tracing-turkeys-from-farm-to-table-1508923801

demand and Walmart gained information regarding supply. Both increased their ability to respond to growers' and consumers' requests to label and track trays of berries from field to kitchen so as to enhance industry's ability to remove contaminated food from the supply chain as soon as a food safety problem is detected. Additionally, integrated tracking until the point of final sale enables better protection of the "cold chain," which enhances quality, by identifying where any breaks occur (farm, cooler, transport and distribution, store) and assigning responsibility for them.

Blockchain has been adopted for other purposes as well. Some large commodity traders, including Louis Dreyfus Co, use blockchain to match data automatically in real time, reducing duplication and the need for manual checks. In October 2020, Bunge and Cargill announced the formation of a joint venture, Convantis, designed to coordinate information sharing and improve port operations by applying blockchain technology to tracking grain and oilseed transactions.[7] Trading companies, originators and grain producers are all participants.

12 Implications for Future Research

The growing use of blockchain in the agro-food sector offers a wealth of research opportunities. Here, I focus on four topics with questions that draw on the existing literature regarding agricultural contracts.

Information asymmetries. Can blockchain be leveraged to mitigate information asymmetries? As a technology, blockchain does not fix information asymmetries. It tracks the transmission of data and ensures that data are not altered; it does not affirm or reject the veracity of the original data. However, there is at least one class of information asymmetry it can mitigate: moral hazard in teams.[8] In such cases a principal cannot separate the effort of a group of agents into the effort provided by each one (Holmstrom, 1982). Blockchain can facilitate the separation of each entity's contribution by requiring them to individually enter data, which then cannot be altered. For example, there would not be scope to assign overripe or damaged produce to a different field, picker, or farmer. Apart from identity preservation as product is aggregated moving through the supply chain, thus reducing the cost of monitoring, blockchain may be able to mitigate other information asymmetries. Information on the timing of each step in the chain could, for example, allow firms to diagnose the precise sources of delays. Sharing information on sales in real time could enable suppliers to restock more efficiently.

[7] https://cointelegraph.com/news/agriculture-giants-team-up-on-blockchain-platform-to-track-grains-in-brazil

[8] Holmstrom (1982) defines a team as "a group of individuals who are organized so that their productive inputs are related." Moral hazard may occur in teams even if output is perfectly observed if individuals' inputs are not because each one has an incentive to free-ride on the input provided by others.

Distribution of returns. How will the complementarities captured by adopting blockchain be distributed across participants? Who will capture the results from increasing efficiency and transparency? Who will pay the costs, including technology investment costs? Its multi-party nature suggests that the formation of a private blockchain may be best analyzed as a multi-lateral bargaining problem within the framework developed in Rausser and Simon (1992), rather than as a problem separated into one or more principals plus agents. Non-cooperative bargaining theory predicts that players' default options are an important determinant of bargaining power, which in turn drives the distribution of returns. Consequently, the formation of private blockchains is unlikely to alter the relative positions of market participants in most instances.

Adoption. What attributes of a supply chain influence the extent to which value differentiation can be enhanced with blockchain? Agriculture is not monolithic, and just as the use of contracts emerged and diffused at different rates for different commodities, the use of blockchain will. Within a sector, which entities are most likely to participate in multi-party blockchain contracts? Are there economies of scale? Of scope? If so, at which levels within a blockchain? Will private blockchains form primarily to increase supply chain efficiency as early efforts have, or will they also form to better target output to meet consumer demand? Value differentiation predicts that the latter will occur. When transmitted upstream, the information captured in a blockchain about the preferences of final consumers adds value that is complementary to efforts to detect and modify product attributes earlier in the production chain. Information about those efforts can be transmitted downstream via the blockchain.

*Market-level implication*s. Although the use of blockchain is increasing at an increasing rate, market-level implications are unclear. What are the competitive implications, if any, of the distribution of returns within private blockchains and the extent of adoption? Will private blockchains foreclose markets entirely for some participants? Who will benefit the most and which actors' interests will be comprised? How will early adoption of private blockchains by some supply chain members affect others? Undoubtedly the answers to these questions will vary based on the context and purpose of blockchain use.

13 Conclusion

Contracts have played an important role in American agriculture for decades, and have evolved with it. Increased vertical coordination and advancement in technology have enabled the sector to meet the demand for increasingly differentiated products, and to capture the complementarities generated by doing so. This chapter has sought to integrate discussion of the various roles contracts have played in agriculture and explore the current efforts to use blockchain technology in agriculture. Research to date can aid in analyzing implications of this new organizational form.

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The Way Forward

William Foster, Jill J. McCluskey, and David Zilberman

1 Introduction

Gordon Rausser has always championed academic excellence through his commitment to developing new research methods to strengthen the accuracy of economics and to make the profession more effective in helping to resolve real-world problems. His career highlights the benefits of a multidisciplinary approach that incorporates insights and knowledge from many fields. This openness to a diversity of ideas and methodologies strengthens economic research, making it more realistic and relevant, and – as a bonus – sometimes the advances in economics translate into an increase in the effectiveness of other disciplines. Economics is an integrating discipline which provides a foundation for improving both science and policy. But, as Gordon's career illustrates, to be effective, economists must engage with the real world and combine research with practice. The relevance of economic research depends on combining a solid, advancing theoretical base, tested and enriched by ex-post studies, with practical ex-ante tools to develop strategies for the future.

Academic economics starts with theories and models. Empirical studies based on past evidence allow for a continuously tested and improving theory which can, in turn, lead to better policymaking. A balanced portfolio of economic research

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includes empirical and historical studies as well as theoretical analyses and future predictions. Gordon has embraced this balanced approach to economics in his pursuit of understanding and contributing to improving the multiple functions performed by markets and other trading mechanisms. His research efforts have addressed a wide range of these market functions, such as the allocation and pricing of labor, capital, land and natural resources, and, in the context of his focus on financial and derivative markets, the discovery and dissemination of signals about relative prices and value. Going further, to be even more realistic and useful, Gordon's work shows that economists can and should strive to incorporate political and institutional considerations, allowing the research to address both the efficiency and distributional considerations of policy, and offer greater comprehension of why we observe the policies we do. This view goes beyond accepting government rules and policies as some exogenously-given structure to the analysis of the operation of the political-economic process itself, the way in which policy is made, giving us the possibility to understand and improve the rules and constraints that underlie the working of institutions and traditional markets.

An economist's contributions to improving policies, institutions and markets can be both at the small and large scale. While Gordon Rausser is a proud Californian, his academic work spans the local and the global. His efforts as both a scholar and administrator show that universities such as the University of California, Berkeley should and can have strong ties with their local communities, contributing to solutions of community challenges and enhancing their resource base. At the same time, the university research agenda should and can be global, collaborating internationally and attracting the best talent available to address research challenges.

In short, Gordon's approach to applied economics has been not only professionally successful but has resulted in a diverse range of contributions of both academic and non-academic significance. And, after these many decades of rewarding work, his approach can offer a way forward and guidance to other economists with ambitions to make a difference simultaneously in the sometimes-inaccessible scholarly literature and in the resolution of major real-world problems and the design of better policies and institutions.

2 Rausser's Approach Applied to the Challenges of Our Times

Society faces many major problems related to agricultural and natural resource markets and policies. Notable pressing challenges include managing the consequences of climate change, the persistence of poverty and food insecurity, and dealing with systemic risks. An additional challenge that makes the resolution of other challenges more difficult is how to address poorly functioning and sometimes unstable and even dysfunctional political systems. Economists and scientists can play a crucial, contributing role in giving to policymakers, analysts, and the general public a clearer idea of the direction to move toward solutions to these challenges.

Gordon Rausser's research career provides several guidelines for a way forward with respect to addressing and resolving these challenges. His outlook on economics emphasizes that the discipline can in fact aim to participate in the development of institutions and policies to solve problems, but it is impossible to design practical policies without bringing together the ideas, evidence and tools from a variety of disciplines. This integrating role of economics pushes economists to engage in "systems thinking." Taking a piecemeal approach can be appropriate for acquiring a deeper understanding of some specific area of economic analysis; but, when pulling together knowledge from various fields to address a larger social issue, without systems thinking, the resulting patchwork solution could be worse than the original problem.

Taking this system-wide view of what economics can achieve, Gordon's research shows us the importance of recognizing and integrating into abstract modeling and practical prescription some complicating aspects of the real world. First, Gordon emphasizes the importance of dynamics, stochastics, and active learning, especially to understand how individual persons and markets respond to policy. Most economic analyses are static, but technology, populations, the climate, and social and political forces are not. Abstraction from the dynamic and uncertain nature of the real world has proven useful to gain greater intuition about some specific problems, both in theoretical and empirical work. But as economists move further toward greater realism, and notably in the context of policy prescription, their analyses require dynamic and stochastic considerations. Gordon has emphasized this dynamic realism, especially with respect to the constraints and incentives that are influenced by evolving policy systems. Moreover, there are underlying explanations for how policy regimes themselves change, and so Gordon has sought to understand the dynamics of bargaining between groups in establishing agreements between interests and the rules by which traditional market participants play, especially with regard to the use of natural resources. Incorporating the dynamic nature of markets and the policy process into analyses will improve solutions from a social-welfare point of view.

A second complication to achieving real-world effectiveness of economic analysis is that the various non-academic audiences who might be interested in making use of it are thinking in terms of the future implications of taking action. Another lesson from Gordon's contributions to resolving large, system-wide problems is that the past mainly matters as a way of calibrating where we are in concrete terms. It serves as a factual prelude to determinate future actions and measurable outcomes. Rausser's research especially highlights that impact quantification matters. The role of economists then should be not only to introduce and integrate concepts from various fields but to provide quantitative evidence and solutions for the future based on and adaptable to observables. The usefulness of these solutions can be enhanced by combining estimation with simulated outcomes under various scenarios in order to guide policy choices. While much of today's applied economics analyzes the impact of policy choices *ex-post,* Gordon's work has emphasized the importance of *ex-ante* policy analysis that could guide action.

A third real-world complication that good economic work should address is that solid theory, good empirical work, accounting for dynamics and stochastics, and an *ex-ante* concern for quantitative solutions are not enough unless the work is coherent, understandable and communicated to decision makers and non-academic audiences. In this setting, Rausser shows us that to deal with this problem, economists should engage with market participants and get involved with the policymaking and implementation processes. Without real engagement with the public and private sectors, economists will lack the experience and contextual knowledge necessary for doing useful analyses, for communicating their results and solutions, and, in the end, for making a difference in the real world. Practical experience affects the selection of a research agenda and a communication strategy. In the domain of policy analysis in particular, an effective researcher needs to have a *de facto* extension program where the intended clients are policymakers. Journal articles meant for professional colleagues are not enough. Rausser has shown the value of this type of experience beyond the university. His interactions in business, law, and consulting have given him insights that many purely academic economists would not comprehend. An academic who can also understand and converse with the non-academic world generates additional benefits in terms of enhancing the very environment in which his own and his colleagues' scholarly work takes place. Gordon's efforts related to public-private partnerships demonstrates that such alliances can leverage talents and funds to make both academic and private researchers more productive and innovative. He has emphasized that a university's value is "enhanced, not diminished, when we work creatively in collaboration with other institutions, including private companies."

Economics sometimes is disparaged relative to the "bench sciences" for not always providing a single and precise solution. For example, in the context of addressing the anthropogenic global warming at the heart of concerns over climate change, some economists promote a carbon tax, and then other solutions emerge from other economists taking other approaches and making other assumptions. In fact, there is a large literature comparing alternative solutions; and, to complicate things, practical economists realize that politics play an important role in various outcomes. And so, to make a difference, good theoretical and empirical work aimed at developing possible solutions will require an emphasis on those which are politically acceptable and sustainable.

This feature of economics, and the often-tentative nature of the answers to the complex problems it aims to address, highlight a final complication to working on big issues that a successful system-wide approach should incorporate: big social problems are almost always "wicked." To address this daunting feature of major social challenges, Gordon's past and ongoing work points to the importance of being adaptable to changing perspectives, information and methods, and to maintaining a willingness to accept that searching for a single, best solution is unrealistic and that, instead, finding a better way forward is the practical goal. There is an inevitability of the "wickedness" of big social problems: First their scope is imprecisely defined and interconnected with other problems. Second, what knowledge is available to us is evolving, incomplete and sometimes contradictory. Third, there is a wide range of views and opinions regarding the urgency of the problem; and even if all agree on its importance, there are many differing analytical perspectives and models that compete for attention. And finally, an aspect that also exacerbates the previous difficulties, any efforts to understand the problem and to move toward resolving it require large amounts of money and resources, which some pursue, and others avoid paying.

These perplexing features of big problems might overwhelm and discourage the young economist, but Gordon's research has shown the importance of efforts to keep pushing ahead, and his work can serve as a guide to a successful approach to applying economics to the major challenges of our times. We now turn to discussing how the insights we draw from Rausser's research and actions can be applied to four broad, wicked problems related to climate change, to food policy, to managing systemic risks, and—perhaps Gordon's favorite area of work—to understanding and improving the political-economic process.

3 Understanding and Managing the Drivers and Consequences of Climate Change

Gordon Rausser's work offers an important perspective on how to address the problem of managing climate change, perhaps an existential threat to humanity. First, his research and efforts demonstrate the importance of "letting no crisis go to waste." A crisis offers the opportunity to reassess the status quo and perhaps make significant changes for future improvements in an otherwise worrisome situation. Advancing toward better ways to mitigate potentially grave problems associated with climate change is inherently a multidisciplinary effort that requires understanding the dynamic nature of the problem, the feasible policy instruments, the political environment, and the public narrative.

The analysis of anthropogenic climate change is multidisciplinary by nature. Chemists and physicists model the basic processes underlying the drivers of a warming atmosphere; climatologists study and model the aggregate, system-wide consequences of energy flows and climate changes; engineers, agronomists and other applied scientists think of physical solutions to the myriad possible consequences; and economics is the integrating discipline that aims to predict economic outcomes, to balance the costs and benefits of potential actions, and to generate viable policy solutions. The Nobel Prize-winning work by Nordhaus (1991) is an example of a multidisciplinary effort that developed a tool set that can link economic activities with climatic outcomes and can be used for policy simulations. It is a model, suitably complex and with a high level of detail, that has a realistic impact-assessment capacity to evaluate scenarios.

And, of course, climate change by its nature is a dynamic and stochastic phenomenon, and concrete, useful economics research should recognize the importance of the time dimension. For example, it is not enough to develop a one-shot, one-size-fits-all carbon tax, but rather a trajectory of policies. Here again, quantification is key. Without producing some practical numbers, and a means of modifying these with adaptive learning, the contribution of economists in this area will be limited. Furthermore, the political process adds another dynamic twist. Economists have several approaches to dealing with strategic behavior in the context of environmental policies (for example, the game theoretic work by Barrett, 1994), but our understanding of how policymakers behave and the political-economic process related to addressing climate change is still limited. For instance, many of the clever solutions suggested by economists have yet to be universally accepted (e.g., a carbon tax). The policymaking environment has not been favorable to what economists would think is a first-order-best way of incentivizing a reduction in carbon dioxide emissions by having emission producers internalize at least some of the additional social costs of their contributions to global warming (Trust us, it works in theory). The core problem is that externalities are not well priced, and so government action can, in principle, correct the problem. But often there is no active learning on the part of the public sector to move in the direction of a first best solution. Economists are frustrated by their favorite policy solution getting the political cold shoulder, and less precise and potentially redistributive regulatory regimes (e.g., low carbon fuel standards and subsidies for alternative energy sources) have emerged. This political-economic reality poses a challenge to economists.

Changing policy and behavior requires a significant shock that spurs interest groups benefiting from the status quo to accept change. As the evidence on climate change accumulates and to the degree that unfolding events will be consistent with predictions made by climate scientists, policy changes will be more likely to occur. When recommendations made by, for example, the United Nation's Intergovernmental Panel on Climate Change (IPCC) and other panels, are not accepted, it does not mean that they are ignored and fall down the memory hole. Rather, they will provide the foundations for future policy changes that usually follow a crisis.

One aspect of the wicked problem of climate change that will continue is the disagreement between basic methodological perspectives and approaches to attempting to forecast the future, not at the level of the basic physics, but at the level of large-scale, long-term predictions and possible climate and economic scenarios. And at the level of the political-economic process that combines the perspectives, findings and claims of differing experts and mixes them with the pressures and opportunism of various interest groups, exaggerations and emotive claims on all sides will continue to confuse policymakers and the general public. Exacerbating things, overreach and missteps undermine the public's confidence in the claims of experts as a class. The IPCC, for example, was strongly criticized for trumpeting poorly substantiated claims in its 2007 report that the Himalayan glaciers would soon disappear by 2035, if current warming trends continued. The IPCC had to issue a statement regretting "the poor application of well-established IPCC procedures in this instance."

And, adding even more noise, is the transformation of a wicked problem into a political football, where the words "climate change" in the public discourse now serve less as referring to a set of important technical and economic problems to clarify and resolve, and more as a means of staking out and defending partisan positions. The Trump administration pursued one narrative regarding climate change, while the Biden administration is expected to pursue another. There are dramatically different consequences with respect to the distribution of economic welfare, but much of the process is driven by hyperbole and polarization. While the scientific evidence on climate change lends credibility to policies aiming to mitigate the worst potential consequences of it and to enhance resilience to climate shocks, the questions of who commands? and who pays? and how much? are the center of attention in the political sphere. The tendency toward polarization is now a major impediment to enacting climate change policies.

The challenge of climate change is a case where political considerations are paramount and understanding them is crucial. Rausser et al. (2020) provide insights into the climate change debate. We have always lived with some degree of polarization, where different parties fight to control the narrative of the debate over big issues. Geopolitical, attitudinal, demographic and, importantly, technological changes have altered the social environment in which narratives compete, evolve, and propagate in and among various groups. And for better or worse the current ecosystem of narratives appears to have amplified the tendency to polarization that underlies all political systems. Skeptics of the claims of severe negative consequences of climate change use a narrative that not only dismisses the degree of severity but points to the huge abatement costs that taxpayers and the middle and working classes would have to pay if the other side gets its way, costs that would result in the loss of employment and the reduction of economic growth. The alternative narrative is one of an otherwise inevitable future of severe economic damage and the environmental degradation of our planet, if immediate and bold action is not taken. One narrative emphasizes the shorter-term impacts on today's families and workers, while the other emphasizes the longer-term and as-yet-unseen impacts, which are more difficult to imagine. Exaggeration has hurt the credibility of both sides.

Finally, as Gordon's career has shown, to be effective, economists have to participate in the policymaking process. In the case of climate change, Nicholas Stern has demonstrated how important it is to be engaged in the public policy process. Economists can learn much about the policy perspectives of different parties by engaging with them. In the case of the problem of climate change this engagement goes beyond government officials and politicians to include major oil companies, technology innovators, insurance companies, and investors.

4 Food Policy for a Productive and Innovation-Driven Agriculture

The basic features of Gordon Rausser's research and work are highly relevant for addressing the continuing major problem of developing an effective food policy that promotes progress in productivity, that addresses food insecurity, and that accounts for and enhances the role of technological innovation. As with other complex problems, successful research endeavors to promote agricultural productivity and resolve food insecurity will require incorporating multidisciplinary perspectives, where again economists should play an integrating role. The problem of designing and sustaining a coherent, efficient food policy will rest on recognizing the importance of developing long-term solutions and cooperatively engaging the public and private sectors.

Technology can play a major role in enhancing food security, and the private and public sectors can direct resources to scientific and engineering work to develop, test and make available productivity-enhancing innovations. But the introduction and utilization of new technologies, such as biotechnology, are subject to political economic conflicts because of their distributional consequences across interest groups and sometime because of public fears of potential, unintentional impacts. Because of these conflicts and past activities, biotechnology's potential has been to date underutilized. This may lead to underinvestment in biotechnology, with one consequence being that low-income consumers are harmed the most. As with climate change, unfolding events and future crises may trigger regulatory changes that could enable biotechnology to reach its potential. Despite controversy, support for advanced biotechnology research should continue to increase knowledge and technological options. It is also important to reassess regulatory procedures and policies based on accumulated evidence.

Rausser's research identifies many flaws in existing agricultural and food policies and suggests avenues for increasing the efficiency and equity of these policies. One simple recommendation is to eliminate a variety of subsidies and transfers associated with commodity programs and other policies. But the historical evidence shows that programs and policies are difficult to change because they reflect political economy obstacles. Transitions to a better policy regime may need to be gradual, involving compensation to constituencies with political clout that benefit from the status quo. Such solutions are possible when policy changes increase efficiency and thus the size of the economic pie. The challenge for agricultural and food policy research is to identify better solutions and avenues to implement them.

4.1 The Role of Public-Private Partnerships and Innovation

At the center of the historical success of farm and food systems in much of the world, especially notable in the United States, is the commitment of private investors, farmers and ranchers, and taxpayers and policymakers to research and development in the basic and applied sciences related to agriculture. If a government's food policy is to go beyond catering to interest groups and aim to elevate its contribution to social welfare, it will stress reducing the transactions costs and coordination problems that might slow investments, especially those focused on biological and technological innovations. Yet despite the past success and importance of innovation for a healthy and dynamic food system, and despite the key roles that university and public sponsorship has played in R&D, there is growing evidence that political support for public research is declining (see Alston's chapter "Woke Farm and Food Policies in the Post-truth Era: Calamitous Consequences for People and the Planet" in this volume). This should be a cause for alarm.

In response to this trend, universities that prioritize academic research which will eventually contribute to the growth of the agriculture and food system have sought solutions to a future of relatively fewer resources deriving from taxpayers. Gordon's work has contributed to helping to resolve this challenge by building on the complementarities of public and private research efforts and maximizing the social gains from whatever level of public support there is for basic research. Political economic reality might result in a continued underfunding of public research (Rausser et al., 2011). Given this reality, universities will seek to pursue other sources of support in the private sector through formal and informal relationships, such as the alliance Gordon engineered between U.C. Berkeley and Novartis, as discussed in the chapter by Stan Johnson, "Scholar, Entrepreneur, and Editorial Innovator," in this volume. In such arrangements, private companies gain easier access to university facilities and the resulting intellectual property from research, but do not control the research agenda. (See the chapter by Jill McCluskey, "Control of the Research Agenda in University-Industry Partnerships."). The university has access to additional research funds and proprietary data. The ongoing arrangements concerning technology transfer from universities to the public sector obviously should continue, maintaining academic research as an important source of innovation and economic growth. On the other hand, university professors should continue to contribute to the implementation and commercialization of their research. Of course, the performance of these technology transfer arrangements should be monitored and scrutinized via public research, and the results should contribute to improve accountability and the design of these agreements and partnerships.

Related to the issue of the role of universities in innovation is the overall mission of a premier public university such as U.C. Berkeley. Gordon's activities in academic administration have emphasized the viability of the land-grant university. A successful university in this mold must balance a portfolio of education, basic research, the production and promotion of practical innovation, and outreach. It must also act as an agent of technological change and improving social welfare. Innovation as an engine for progress also applies to the way universities operate to achieve these goals. In today's context, university extension activities should be prioritized, and universities centers for lifelong learning. As health discoveries make a longer life possible, the population tends to age, and new knowledge emerges, universities should enable practitioners to update their skillsets. Professional training can also be a source of revenue for universities. Furthermore, Gordon's experience highlights that faculty members should engage in the community and contribute to technological and social entrepreneurship. The experience accumulated by academic faculty in industry and public service will improve their effectiveness and skills. Another lesson from Gordon's administrative activities is that one important source of strength for universities is shared governance, where faculty and administration share responsibility for major decisions. The quality of faculty appointments and the commitments of faculty to the university only increase when they justifiably feel that they have a significant say in the university's direction.

5 Systemic Risks

The problems of managing climate change and developing effective policies for innovative and resilient food systems are entangled, and both are related to the even knottier problem of dealing with systemic risk. As discussed in Carter and Revoredo-Giha's chapter, "The Theory of Normal Backwardation and Financialization of the Futures Markets" in this volume, Gordon's scholarly work has advanced the financialization of futures markets. Moreover, as reviewed in Johnson's chapter, "Scholar, Entrepreneur, and Editorial Innovator", his work on developing a commodities futures market hedge fund (and subsequently a hedge fund that extends well beyond futures markets to equity markets and OTC markets) has provided him a set of real-world experiences that few academic researchers have in their toolsets for addressing risks. And his approach to systems thinking, and particularly his focus on dynamics, stochastics, and active learning, are especially useful in analyzing systemic risks.

Of course, the challenge of what to do about systemic risks linked to climate-related shocks and food and interrelated systems has long been a wicked problem, but over time the problem has seemed to get even more wicked. For time immemorial farmers, food systems and human settlements have always been subject to climate-related risks. Through an evolutionary process, for millennia farmers and other decision makers along the food supply chain have adapted to changes in climate conditions, such as the "little ice age" in Europe during the thirteenth to nineteenth centuries. And today in some regions, the geographic disparities, irregularity, and uncertainty of rainfall and water supplies for farming and human consumption are especially important concerns and even major threats, and sometimes are the source of major damage. In response to these threats, there are large private and public infrastructure projects and other costly measures to reduce what would otherwise be large social costs. History reveals that food systems, water supplies and the social structures they support, which are adapted to one climate regime, might not survive a drastic and rapid shift to another regime (e.g., the Akkadian empire of 4200 years ago). The interdependencies of food, logistics, urban and financial sectors, within a single country and between interlinked trading partners, leave the failure of key components to cascade throughout the larger system. Climate, like war, has always been a principal source of systemic risk.

Since the rise of fossil fuels, anthropogenic drivers of potential climate changes have introduced additional uncertainties and possible risks into food and water systems. Over the last several decades, policymakers and the public have become more aware that broader global trends in climate have introduced even greater insecurity with respect to severe weather events. This potentiality opens for existing infrastructures a future range of climate-related shocks beyond that which their food and water systems have adapted and are capable of enduring. Systems, adapted and stable to one type of stochastic climate profile, might be fragile with respect to another; but, even if they could adapt to a new climate state, there are potentially large and unpredictable costs of doing so. And regardless of the expected benefits or costs of climate shifts for certain decision makers, there will be the added uncertainty and risks associated with shifting policy regimes and market adjustments in response to real and perceived climate trends elsewhere and globally.

Whatever the degree to which anthropogenic global warming is implicated in specific events, climate-related shocks cause major damage to property and life, and these costs have risen and will continue to rise due to growing populations, to increasing population densities in vulnerable areas, such as hurricane-prone coastal zones, and to the accumulation of residential, infrastructure and other investments. Future shifts in climate patterns linked to human-caused greenhouse gas emissions add an additional source of uncertainty to quantification of the future risks to economic activity and human welfare associated with extreme weather events. But to take action and enhance resilience, quantitative alternative solutions will have to be the focus of research for planning appropriate mitigating and adaptive measures. Furthermore, the estimation of the impacts of alternative solutions will have to consider the interdependencies across regions, sectors, and markets. The damages to one economic sector, such as agriculture, or to one region, such as California, caused by an extreme weather event can have spillovers to financial sectors, which in turn propagate to the functioning of financial markets. To the extent that extreme weather events become either more frequent or more severe, the financial system, already noted for its endemic, too-big-to-fail systemic instability, might grow even more fragile. Recently, the Climate-Related Market Risk Subcommittee of the Commodity Future Trading Commission reported that climate change "poses a risk to the stability of the U.S. financial system and to its ability to sustain the American economy," (CFTC, 2020).

Gordon's work offers some direction toward addressing the problem of systemic risk and building resilience. Following the Great Recession of 2008–2009, Gordon applied his award-winning work on futures markets and derivatives, and his insights from practical experience with the management of a hedge fund, to respond directly to Warren Buffet's 2002 observation: "The derivatives genie is now well out of the bottle, and these instruments will almost certainly multiply in variety and number until some event makes their toxicity clear. Central banks and governments have so far found no effective way to control, or even monitor, the risks posed by these contracts," (Berkshire Hathaway, Inc., 2002, p. 14). They constitute latent "financial weapons of mass destruction." Motivated by this insight, Gordon Rausser and his colleagues designed a patent entitled "Integrated Electronic Exchange of Structured Contracts with Dynamic Risk-Based Transaction Permissioning." It is an innovative method for negotiating contracts between a plurality of participants, that focuses on counter-party risk and the avoidance of systemic risk.[1] This effort—along with

[1] Note that this patent, issued in 2010, has received 360 Google Scholar citations.

numerous other publications, as well as consulting work with organized futures markets exchanges in the U.S. and England—formed part of the intellectual foundation for the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010.

To push ahead in economics research on this topic of systemic risk and its relation to climate and food systems requires multidisciplinary cooperation, active learning and an emphasis on finding *ex-ante* rules for circuit-breaking, preventing a cascade of failures. Future lines of investigation should focus on potential crises associated with black swan events which can only be effectively controlled *ex ante*. The dynamics and stochastics must be front and center. Once again, a major theme is to identify potential emerging crises—before events take control and private and public actors are left reacting rather than proacting—and put in motion policies that would counter, with feedbacks and active learning, the adverse consequences that might arise.

Economic research in pursuit of the resilience of the farm and food system and of other systems to climate and other shocks will have to go beyond the type of academic work that in the end remains yet another mundane call to be prepared. Economists can point out that changes originating in new technologies, climate shifts and elsewhere are always altering risk profiles, but a key additional challenge to economists is to address why sometimes actors, both individually and collectively, do not adjust their actions to a new environment. One contributing reason could be a lack of information among the public and politicians about potential systemic risks and the nature of so-called fat-tailed events. One lesson from Gordon's career is that economist should integrate communications or messaging strategies into their research programs.

More worrisome is that economists might be contributing to this information problem due to their reticence to go beyond the traditional approaches to inference based on historical data, which rarely contain the rare, system-endangering event. From a traditional econometric perspective, there no room for drawing inferences from the possibility of extreme and fat tails. Most of the time, probability models tend not to account for situations where the trigger for a systemic catastrophe is more likely from a single big event rather than from a series of unlucky draws. Triggering events might be rare, but they are the most important events for survival.

Another likely contributing reason why sometimes various actors fail to adjust to ever-changing risk profiles, and why systems might develop system-dependent critical points, is that the set of rules for individual decisions can encourage taking risks with other people's money. And these rules are often linked to government regulations. In the financial sector, taxpayer-supported insurance to creditors reduces market discipline for banks and financial institutions, permitting them to assume more risk. Limited liability also enhances the willingness to accept more risk by creating an asymmetry between unlimited gains and limited losses; it privatizes the gains and socializes much of losses. The too-big-to-fail attitude of regulatory agencies encourages financial institutions to scale up to gain the too-big status, and, once attained, gives even more incentive to take on risks.

In the case of climate-related risks, there has been a failure of the public sector fully to recognize new risk profiles. This is the nature of the political system: its tendency to shorten decision horizons, its use of other people's money, its inability to hold to time-consistent and credible commitments, and its susceptibility to regulatory capture by industries that it is supposedly accountable for regulating. And there is even a failure of the public sector fully to recognize old risk profiles. The 2020 Texas Chill is a recent example. Texas is not a sub-zero climate, except when it is. Government regulatory agencies of electrical and water systems were simply not *ex-ante* prepared for a rare but inevitable event. The unwillingness to invest in the resiliency of infrastructure is particularly worrisome. The performance of public sector is another problem that exacerbates a purely natural phenomenon, which leads us to the last wicked problem.

6 Understanding and Improving Political-Economic Processes

An overarching theme to the wicked problems of managing climate change, achieving a well-functioning policy to promote an efficient and innovative food sector, and to dealing with systemic risk is the importance of the policymaking process. Gordon's work related to mitigating these problems has emphasized the real-world roles of collective decision-making, bargaining and negotiations. Beyond its importance as a context in which specific problems must be addressed, understanding the policymaking process itself at a more basic level is a worthy research endeavor. And it too is a wicked problem in the sense that scholarly research in political economy has not yet come to a clear and universal definition or formulation of what precisely we are studying; and that, from the analyst's perspective, there are no true-or-false tests of political systems and outcomes, only an evaluation of better or worse along some particular dimension of interest. How does one improve a malfunctioning political economic process? From what perspective does one assess the degree of malfunction? At what level does one take the mechanics of the policy process as simply a given set of incorrigible constraints and at what level can we analyze political outcomes as the malleable products of interactions between politicians, factions, and interest groups? Can practical political-economic analysis address apparently basic questions about the evolution of the rules by which the rules are made?

From early on in his career Gordon's work has been motivated by an interest in understanding not only the consequences of policies—their impacts on prices and on measures of consumers' and producers' welfare—but the "why" of the policies we observe. He has emphasized that the "why" of policy is a useful question to pursue scientifically with a scholar's analytical distance. This diagnostic approach must be capable of evaluating the outcomes of political processes not as how one would wish those processes would work but as they really do. Yet for Gordon this has not been a sterile, intellectual pursuit. The study of political-economic processes is given greater urgency when they are perceived as significantly malfunctioning from the point of view of social welfare. A curious economist, such as Gordon, begins to search for reasons to explain outcomes when Pareto-efficient actions of political actors are apparently available—that is, when it appears obvious that the pie could be bigger for all interest groups to share—and yet the political process has delivered an "inefficient" outcome. Moreover, the understanding of the "why" of policy is useful to demystify the political system, making it clear the process of how bad policies arise and opportunities for good policies are forgone; and so—hopefully—making bad policies easier to avoid and good policies easier to achieve. In a polarized social context, this analytical approach to political economy is perhaps all the more valuable in guiding people away from the Manichean tendency to view political outcomes as a battle between good (our side, of course!) and evil (those who oppose our side's policy preferences).

Notwithstanding the analytical challenges to understanding real-world political systems, Gordon and his many coauthors have pushed forward and their work points toward promising lines of investigation. Gordon's efforts, brought together and integrated in the 2011 book, *Political Power and Economic Policy*, takes the analyst's assumptions about the nature of the political system—the governance structure—as the key basis on which models of how political-economic forces emerge and interact to produce what we see in real life. The demystification of policy-making processes is the serious analyst's starting point, but with a practical end in mind. With a clear-eyed understanding of politics as it is—not as it might be presented as an ideal—one can better advise politicians on how to combine policies—some by themselves "inefficient" transfers or interest-group bribes—to enlarge the pie available for all to share. After perusing Gordon's theoretical and empirical contributions to political-economic theory, serious economists wanting to study the consequences of a government's agricultural and resource policy should not step back and claim that politics is off-limits to their profession's analytical tools. It would be naïve to pronounce on a policy's or a program's absolute normative goodness or badness based on a welfare analysis as if the policy stood in isolation and as if a political system run by angels could magically eliminate or impose it. As highlighted by principle 11 in the chapter "Principles of Policy Modeling in Food and Agriculture" (Chapter 5, Rausser and Just) of this volume one important lesson of Gordon's work is that, in assessing existing and potential policies from the perspective of social welfare and Pareto improvements, one has to take a broader view of the portfolio of policies. In pursuit of a bigger pie for all, the political reality might produce superficially distortionary policies meant to change the proportions of the pie served. One might want to use redistributive policies to different interest groups and factions ultimately to achieve the public interest.

6.1 Linking Political-Economic Models to Reality

An important element emphasized by Gordon's work on examining the underlying forces shaping policy outcomes is the importance of linking theoretical—and sometimes seemingly esoteric—models to the observed reality of the political economic process. A political ecosystem is yet another human institution, subject to material and psychological incentives, strategic game playing, and trade-offs and exchanges between idiosyncratic human actors. One lesson of Gordon's career is that members of professions concerned with planning and policy should strive to see the messy reality of the policy machine at work from the inside. Models of interest group formation and lobbying efforts, politicians' optimization strategies, and the logic of how bureaucracies work are abstractions from the reality of individual persons making their own decisions based on their own incentives within the constraints of complicated rules and oversight systems, and influenced by sometimes eccentric traditions and implicit bargains between political and economic agents. To gain insight into the nitty-gritty of policy making, the scholar who wants to delve into political economy ought to serve in internships or political appointments as Gordon did as the Senior Economist on the Council of Economic Advisors and as the Chief Economist at the Agency for International Development.

From a more scientifically minded academician's perspective—and another lesson for future researchers regarding the importance of linking theory to reality—is that political-economic models, regardless of their complexity with respect to modeling the working of political power and constitutional structures, should be designed to be empirically tractable. Models should allow hypotheses to be testable, supported or refuted by the available evidence. More-speculative theorizing, with models of various factions' preferences, the struggle over narrative control and deeper forces at work beneath the surface, might be intellectually satisfying and worth an algebraically abstruse journal article or two; but without translating our models into observable and testable predictions they will remain in the realm of theological debates and divorced from the practical guidance of real-world policy making.

Gordon's body of work on the agricultural policies of the United States and other countries provides a way forward regarding how to take basic theoretical political-economic structures and turn them into manageable frameworks for testing their reliability with real-world data. At a more intuitive and expansive level, models can be tested by their consistency with broad facts about the workings of political systems, and many times the novel insights from the theoretical models illuminate what would otherwise be puzzling and contradictory, and so open possible avenues for reform. The basic theory proves "true" and useful if it explains what previous theories could not and shows us new tools for action. For example, Gordon's work with Pinhas Zusman on the political economy of water resource management and the dynamic behavior of actors provides a framework first to understand and then to address organizational failures in the administration of a vital resource (Rausser and Zusman, 1991).

Theoretical models sometimes need no complicated statistical treatment to "ring true" and better explain political reality than previous models long taken for granted. But often "consistent with" is not enough, because of the observational equivalence of many competing models with respect to a limited set of observables. Gordon has recognized that in practical policy work to achieve a greater power of the test—to increase the probability of rejecting the hypothesized structure of the model when it is false—sometimes requires econometric sophistication and moving from anecdotes to data. This is not an easy task in political-economic modeling due to the non-observability of key theoretic variables, such as the strength and cost of power, and due to econometric issues related to the identification of an underlying structure from an often-incomplete set of observations of jointly endogenous variables. Nevertheless, empirical models combining economic relations and elements of the political power structure can capture behavioral regularities that either explain observables, or, as a good scientific theory should be susceptible *a priori*, do not.

And the research efforts of Gordon and several colleagues have advanced along several fronts our understanding of how to tackle issues of empirically implementing and testing political-economic models. There have been methodological advances in the estimation of strength functions and political preference functions, in the derivation of the statistical properties of power weight parameters, and in how to "endogenize" policy in modeling agricultural markets. The political-economic approach underlies the estimation of governance functions, adjustment rules for policy instruments, and the possible degree to which political agents deviate from a faithful representation of their purported clients' group interests.

6.2 *Advancing the Analysis of the Policy Mix: The Complementarity of PERTs and PESTs*

Gordon has contributed to providing an analytical and empirical basis for examining the joint determination of both "predatory" and "productive" policies, for understanding the interplay between policies across a spectrum of their attributes and designs. Some policies are more characteristic of delivering a public good or remedying a coordination problem in real-world markets, and some policies are more characteristic of simple redistribution, producing inefficiency by driving a wedge between private and social net benefits of decision makers' actions. Since his work on first distinguishing between and then modeling the mix of these pie-expanding (PERT) policies and wealth-shifting (PEST) policies,[2] Gordon has sought to promote the examination of the role of institutions in the joint determination of these policies in the political economic process.

This has been both a theoretical and empirical project to comprehend within a political-economic context the myriad of ways the observed "portfolio" of seemingly irrational and contradictory policies evolves over time. For future research efforts, a key first step in the examination of PERTs and PESTs is to identify major

[2] Rausser (1982, 1992) offered a framework for policy analysis based on differentiating between "predatory" and "productive" policies. The rules that lead to a reduction of the transactions costs of market activity, and so expand the total social wealth—the pie—Gordon dubbed the political economy of resource transactions, or PERTs. The government interventions that shift economic surpluses between groups—share the slices of the pie—often produce social costs due to misaligned incentives drawing resources from their most valuable social use. These share-redistributing and pie-shrinking policies Gordon dubbed political economic seeking transfers, or PESTs.

interest groups and stakeholders regarding their incentives and their attempts to serve their own self-interest rather than the public interest. Moreover, one should take into account that the reduction in PESTs has PERT-like consequences. Gordon's work with Harry de Gorter, William Foster and others on PERTs and PESTs and their potential complementarity is particularly relevant. Because social-welfare, pie-expanding policies do not guarantee that all groups will gain, there will arise resistance to policy changes. Seemingly "inefficient" policies that redistribute the shares of the pie can then be useful political tools to overcome that resistance and gain an overall advance that would have otherwise been forgone due to blocking coalitions. Gordon's work points toward how analysts might go about isolating the effects of specific PERT policies and PEST policies, discovering how complementarities might be engineered and political conflicts avoided that slow the growth in aggregate welfare.

Gordon's work also makes clear that future research should consider that the interest group or stakeholder "landscape" can change dramatically depending upon what new crises might alter incentives and political organization costs, or what new narratives might emerge to redirect public discourse. With crises there are opportunities to change the more fundamental aspects of the governance structure. As an example, occurring today, the complex social dynamics of Chile have lately produced a crisis of legitimacy of government institutions and of existing constitutional arrangements. The old rules by which rules are made are under a radical reevaluation by various groups in society and a constitutional assembly will soon begin fashioning a new constitution. This political crisis opens the possibility to transform power balances and redirect resources toward problems and challenges related to uneven economic progress, social immobility and a mix of sclerotic policies and institutions, especially policies important for rural development and natural resource use.

Advancing the PERT/PEST framework leads to the idea of "smart subsidies" or "smart PESTs" more generally. In offering prescriptions on the design of agricultural and resource policies there is an obvious blunt rule: more PERTs and fewer PESTs. But Gordon's work has emphasized that, when taking into account the realities of the political economic process and the consequent importance of the mix of policies, the better rule is: more PERTs and better, complementary PESTs. The award-winning article by Foster and Rausser (1993), exploring the mix of food-price-reducing R&D and farmer subsidies, illustrates this approach to the design of a policy mix, in this case by breaking farmers' blocking coalitions via transfers to innovators. But future research can push further. In the dynamics of real-world politics and arbitrage, there is also the problem that the benefits of good policies are eroded by powerful private interest who capture the policy process. On the optimistic side, people will seek to mitigate the costs of bad policies to them. Research should consider other criteria for policy design along these lines. Two are, how might politicians design sustainable constraints on the conversion of PERTs into PESTs, and what design might promote the flexibility eventually to neutralize the worst effect of PESTs or even convert them into PERTs?

More promising still is Gordon's current project to examine the question of how to design smart redistributive policies. There are two dimensions to smart PESTs, not mutually exclusive. First, one would like to design a redistributive intervention or subsidy which accomplishes its initial goal of benefiting some group but, according to its built-in programming, remains limited or perhaps phases-out over time. Arising from the political economic process, the redistribution is either responding to an irresistible interest group demand or is serving as a complement to gain a PERT. The built-in phase-out or sun-setting might be less attractive to politicians with shorter, election-driven time horizons, but economists can contribute to making such designs available and attractive. The phasing-out of PESTs must be a credible commitment, because if not incentives will have been created for overcoming the organizational costs to establish political interest groups that might not have been there before the subsidy was implemented in the first place. These groups will lobby to maintain and perhaps increase the size of their transfer. Without such credible commitments, the governance structure for policy formation will change to reflect the balance of power of these interest groups.

The second dimension of a smart PEST would be one which, while on its surface appears distorting of incentives, is inducing behavioral changes that eventually have a payoff in terms of the mitigation of social losses or maybe even a positive net benefit, perhaps by offsetting the costs of other interventions. These two dimensions could be combined in the design of smart-smart PESTs. An example is a policy of conditional cash transfers where, for example, mothers receive payments conditional on bringing their children to clinics or school attendance. There is a natural limit to who might receive the payment—those with children—and there is a natural phase-out of payments once the children age out of the program. Moreover, there are spillover, future benefits, such as those associated with reducing medical costs and improving adult health, or the benefits of a better educated workforce.

There is a wide array of models explaining government interventions subject to interest-group influence that have been developed over the past half century. In contrast to these other political economic frameworks, the PEST/PERT and governance structure approach emphasizes the mix of redistributive and public-good policies and their potential complementarities. The approach's explanatory, positive model serves as a basis for normative prescriptions, offering an opportunity to orchestrate operational advances to improve the policy making process and move in the direction of smart governance in the public interest.

6.3 Advancing the Analysis of the Policy Mix: More on the Importance of Governance Structures

Gordon emphasizes that economists do yet appreciate enough how the improvement, from the perspective of social welfare, in the policy mix critically depends on the underlying governance structures of the public sector. Not only does a useful political economy approach require some taxonomy of policy types, but that governance structures producing those policies themselves range across a spectrum of attributes and constitutions. And the governance structures within which interest groups come to terms with each other are themselves products of larger, slower-moving political-economic trends. Some policy mixes are more likely to be observed under certain public sector governance structures than others, and yet the institutions and the effective constitutions we might observe might well be the long-term outcomes of different groups struggling and negotiating over the rules by which the rules are made.

Again, Gordon's work on the importance of governance structure is not merely for academics' consumption but is aimed also at aiding in the search for practical ways of moving from the apparently dysfunctional "rules" that exist in various countries toward an improvement from the standpoint of social welfare. This is particularly pressing in the light of the comparatively heightened inefficiency and corruption of government sectors in some less developed countries. But again, there is no definitive formulation of what is the best process by which those engaged in politics are likely to find the best recipe to formulate rules. There are no obvious true or false answers, only better or worse situations, for which there is no ultimate test of whether we have arrived at the solution only that the outcomes have worsened or improved. Nevertheless, there are various broadly defined characteristics of governance structure that one can say are critical for social welfare from the perspective of the Liberal tradition: civil, political and economic freedoms. Moreover, in terms of poverty reduction and overall material welfare economic freedoms appear to have earned a place of prominence in improving people's lives.

To go beyond these general conclusions requires advancing along the lines indicated by Gordon's work towards a more intensive analytical examination of the governance structures as they really are and of the deeper distribution of political power. A major problem facing economic development has been a recalcitrant institutional environment, uncertain with respect to property rights and unconducive to investments and entrepreneurial initiative, and apparently sustained by a political economic process itself debilitated by a maldistribution of power. These are often problems that have existed for decades, and all the available evidence suggests that, without considerable effort to the contrary, they will persist in many countries, some more dictatorial and others more democratic. Gordon's contribution to analyzing the question of poorly performing governance structures is highlighted in the Rausser, Swinnen and Zusman text on political power and policy (particularly chapters 12–14). There are highlighted the roles of interest groups, coalitions, and the balance of political forces in arriving at or avoiding dysfunctional governance structures. Policy prescriptions involve the design of ways to implement compensation to counter blocking coalitions or to powerful interest groups that support the status quo. Their book also explores (in chapters 15–19) the harder problem of the maldistribution of deeper political power and how it might be corrected.

This problem of addressing political power is made more difficult because academics and international agencies often shy away from discomforting powerful interests who are made anxious by an analytical approach to the more profound underpinnings of governance structures. Transparency is an antidote to corruption, and therefore would be a positive attribute to embed in any constitutional reforms of a political economic system. This advice embarrasses those content with how things stand, despite how poorly the system appears to be functioning to outside observers. Boards of directors of international institutions are not immune to the political economic process, and many might well decide that the Rausserian approach to examining the “why” of a country’s policies is a step too far. An inspection of the rules by which the rules are made is not going to be part of the board’s research agenda because it might create conflicts with countries who would object to any serious analysis of their institutions and actual maldistribution of political power. Why take the risk of offending any countries that might discontinue their support?

6.4 A Natural Extension to Policy Prescription: Furthering Mobility and Diversification

Gordon’s work with Pinhas Zusman and others has also highlighted the importance for the political economic process in any country, especially those lagging in development, of asset diversification across all economic agents and of the active mobility of resources to move between sectors. The incentives for individuals and groups to invest in “rent seeking,” to pursue protectionism and other interventions, tend to increase as the benefits are concentrated; and the incentives to invest in efforts to resist the redistributions of PESTs tend to decrease as the social costs are diffused across many losers. On the flip side, when pie-expanding policies, such as trade liberation and agricultural R&D, generate both winners and losers, the incentives to invest in blocking PERTs tend to increase as the costs are concentrated; and the incentives to invest in wealth-increasing efforts tend to decrease as the social benefits are diffused across many winners. An important insight that Gordon’s political economic work has advanced is that much of the malfunctioning of the policy process is directly connected to this concentration-diffusion predicament. More subtly, the concentration and diffusion of benefits and costs are most often not a one-shot deal but are usually in terms of incomes enhanced or diminished over time through the returns to the ownership of resources, such as land or human and physical capital. People can take advantage of policy changes or mitigate their costs by shifting resources between sectors or by making prudent, ex-ante investments in favored activities and divestments in losing sectors. What helps sustain the concentration-diffusion predicament related to malfunctioning political economic process is the immobility of resources and the inability ex-ante to own a sufficiently well-balanced portfolio of resources, regardless of the degree of their mobility, that can avoid the costs and take advantage of the gains of imperfectly predictable but inevitable changes.

During the latter decades of last century, the efforts to negotiate further trade reforms and greater integration of international markets were obvious PERTs from a global perspective, but with clear losers. Gordon and colleagues were particularly focused on the importance of some forms of compensation as essential elements of a larger mix of policy changes aimed at trade and other reforms. Going further, Gordon's work with William Foster and Richard Gray demonstrated that resource ownership diversification and resource mobility decrease the possible compensation requirements of trade reforms. This was especially pertinent in the context of agriculture in some countries, where reducing trade barriers would expose the owners of farmland and specialized, immobile farm investments to the indifferent logic of comparative advantage as reflected in lower international prices.

From a social welfare standpoint, a potentially better mix of policies than one with ex-post compensation to losers of the PERT is one which, ex-ante, addresses the concentration-diffusion predicament. Applying some foresight, some longer-term-thinking political actors—and engaged economists appropriately intellectually armed à la Rausser—might find it profitable to promote ownership diversification and resource mobility as an explicit, durable strategy to facilitate trade reforms and similar policies without having to engage in reactive costly compensation schemes. A corollary is that policy makers, in anticipation of continuously evolving Darwinian market forces, should actively discourage policies that tend to reduce mobility and increase the concentration of the ownership of resources. In an open economy, significant price and wage movements—whether originating in international markets, or surprises linked to technical change or to government reactions to viral epidemics—are unavoidable and almost sure to produce both winners and losers. Without some policy design to short-circuit the usual rent-seeking routine, losers react to changes by seeking and obtaining protection from the vagaries of markets. Again, the notion of smart subsidies or PESTs is applicable here: A natural extension of Gordon's approach to reducing the concentration-diffusion predicament is that, if future pie-expanding changes such as trade reforms are to be sustained, compensation for a PERT that harms a powerful interest group should be delivered in such a way as to promote mobility and diversification of ownership of immobile resources.

6.5 Pushing the Envelope of Modeling Political Economy

After reviewing Gordon's body of work, one can appreciate its span across a variety of areas of political economic analysis. But there is also a natural progression discernable, from the basic understanding of how policy instruments alter producer and consumer decisions, to the welfare consequences on interest groups of government actions, to the correlation of policy outcomes with interest groups' investments in control over the political process, to what factors influence an interest group's formation and its relative ability to steer political processes to its members' benefits, to estimation of the implicit power weights of different actors and the underlying structure of the power game governing outcomes. But wait, there's more. The very vocabulary and tools of thinking and communication—the stories, metaphors and analogies we have available to push the political systems toward our policy preferences—are themselves a field of contention, and so attract the analytical eye of the political economist. The question of how policies are debated in political systems has been a recent, natural extension of Gordon's interest in the political process as an object of scientific inquiry. How debates are framed and how political arguments are initiated, steered and settled—the question of the "narrative"—are obviously complicated and as yet poorly understood questions. Despite its difficult-to-define nature, its social complexity, and the incomplete information at hand—in short, its "wickedness"—the study of the deeper structures underlying political economic processes, which would dismay the less ambitious economist, seems to have irresistibly drawn Gordon's interests.

One might be daunted by thinking analytically about narratives in the political process, because, after all, narratives are bigger than individual economists' minds; we cannot escape the narratives that we take for granted and might not even know are—and can never be sure are not—guiding our thinking. But the profession can push at the edges of our understanding of how persons and groups struggle over narrative control, as Gordon and colleagues have recently done (see the chapter "The Evolution of Political Hyperbole and Polarization: Echo Chambers and Voter-Elite Feedback Loops"). And by clarifying the role of persuasion and narratives in setting the terrain over which interest groups engage and fight we might better understand and avoid the worst outcomes of political economic processes. The theme of narrative control is then an interesting intellectual area of study, but it also has a practical end in sight: ultimately to improve policy reforms from the perspective of social welfare.

7 Some Final Words

To conclude this review of how Gordon's career might illuminate a way forward for economists seeking to contribute to the resolution of major social problems, it seems that what remains is not to address specific roadmaps or recipes, but economics and life. The overall message of Gordon's career is a call for an economic discipline that provides both understanding and guides for decision making, at the micro and macro levels. Inherently, it integrates knowledge from multiple disciplines, both natural and social sciences, and occupies the nexus between policies, institutions, and the market.

Economists should be renaissance people, well versed in commerce and trade, capable of conceptual thinking and generalization, familiar with political science and the political-economic process, and with quantitative skills that allow them to provide the numbers needed for sound decisions. The nature of economics requires that the scholar be a practitioner, and the rate of technological change suggests that methods and techniques will continue to improve, requiring lifelong learning and research teams with complementary skills. Training in economics, therefore, requires the development of communication skills, analytic skills, empirical skills, and real-world experience. Major priorities should be linking academic departments with successful practitioners and developing informal contacts that provide both internship opportunities to students and the capacity to stay up-to-date.

Economic research should mix *ex-post* learning with *ex-ante* analysis and advice. Research results should be translated and communicated to the public, which will improve the implementation of research results and allow the assessment of various methodologies and perspectives. This view advocates constant interactions between researchers, teachers, and extension specialists, and the removal of silos isolating various academic communities. Economists should strive to expand their data use as information and data continue to become more available and less expensive, and in the future economists should expand their research beyond just the numerical data to the active analysis of the best means of communicating to non-academic audiences what the data are really saying. Given the importance of economic literacy in everyday activities, economic principles should be included in school curricula from a young age. Citizens should be familiar with basic principles of finance and economics, criteria for decision-making and resource allocation, and how to quantify them. Furthermore, a realistic approach to political economy and notions of win-win outcomes and cooperative games should be incorporated into civic education, leading to a demystification and depolarization of political processes, and to policies and actions that aim to improve the welfare of all. Gordon's life story also suggests the importance of hands-on experience, whether on the farm or other enterprise, or in government. Education should include internships and other experiential programs that will augment classroom learning. Developing these curricula and assisting educators are important roles played by university economics department.

Land-grant universities and colleges such as UC Berkeley should aspire to be centers of global knowledge that identify problems, develop technology and policy solutions, educate future leaders, and provide training and information for practitioners. These colleges will be drawn to take on some of the "wicked" problems of the future, including climate change, food security, and biodiversity, and the imperfect workings of government, in a collective effort to produce the ideas and people that can tackle them. To do this, these colleges need to maintain academic excellence and strong relationships within their communities, local, national, and global. A community that appreciates the university becomes a foundation of support, allowing for continuous renewal that results in relevant and useful research. Accordingly, colleges and universities should build traditions of excellence but should be always on the lookout to update their programs to adjust to changing times. Gordon's experience in USAID highlights the importance of high-quality university research and educational activities.

This chapter has aimed to summarize some of the lessons from Gordon's body of work and how they apply to the challenges we face going forward. Yair Mundlak's remark, "There are many scholars, but only one Gordon Rausser," echoes throughout this book. Gordon's career invites us to look for opportunities to capture the complementarities between government service, investments, consulting, and entrepreneurial pursuits, all intertwined with scholarly academic research structured to serve the public interest. To us, his students and colleagues, Gordon has been a larger-than-life role model. He taught us the power of ambition, hard work, self-improvement, loyalty, and generosity. He challenged us to lead meaningful, productive lives and to contribute to the making of a better world.

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