Eskil Ullberg *Editor*

New Perspectives on Internationalization and Competitiveness

Integrating Economics, Innovation and Higher Education

Springer

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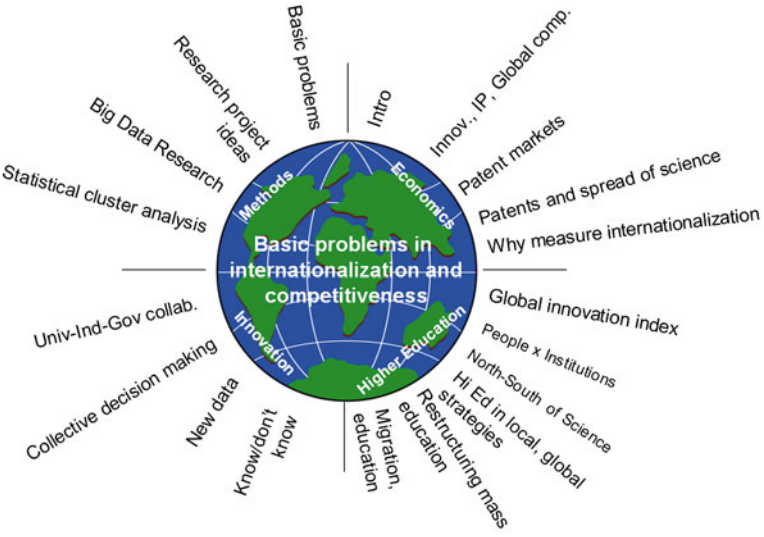

Interdisciplinary themes and workshop presentations form the basis of this book

Preface

This collection of research and idea papers is build around two workshops covering the theme of internationalization and competitiveness. The first workshop was held at George Mason University (GMU) in Arlington, VA, USA, on March 1–2, 2013,[1] and a second, follow-up workshop, building on the key results from the first, was held at the Royal Institute of Technology (KTH) in Stockholm, Sweden, on October 3–4, also 2013.[2] The two kinds of essays are: *research papers*, which are built on research already carried out prior to the workshop and thus reflect some of the literature in the respective disciplines; and *idea papers*, shorter outlines of key initial observations and a first discussion of these issues and questions to ask with respect to internationalization and competitiveness today. I am very grateful to the National Science Foundation[3] (NSF) and especially to the program director of SciSIP, David Croson, who proposed the idea of a workshop on this theme. The Swedish Foundation for Internationalization of Research and Higher Education[4] (STINT), subsequently granted core funding for the follow-up workshop in Stockholm, together with NSF and KTH, who contributed from the Center of Excellence for Science and Innovation Studies (CESIS).

The essays presented here are divided under two themes which came out of the second workshop – science and economic, and innovation policy and its measurement – giving the economic theme to the book: the relationship between science and economic development, in a globalized world, including emerging markets and developing nations.

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[1] See workshop web page for program and presentations: http://www.ssrn.com/link/ICES-GMU-Workshop-Intl-Competitiveness.html.

[2] See workshop web page for program: http://www.kth.se/en/itm/inst/indek/avdelningar/entreprenorskap-och-innovation/forskning/konferns-1.407755.

[3] **NSF Award number: 1251643**. For further details see: http://scienceofsciencepolicy.net/award/ices-gmu-workshop-internationalization-and-competitiveness.

[4] **STINT Dnr IB2013/5234**. http://www.stint.se/en/scholarships_and_grants/initiation_grants.

To these papers, I have added an introduction, a brief summary of each paper and some initial comments. They serve as an overview of the questions discussed during and immediately after the workshops, and to stimulate generation of research projects in the future.

This volume is thus a collection of academic articles and idea papers written from multiple disciplines, each intended to contribute to an interdisciplinary understanding of basic, researchable problems in internationalization and competitiveness. They include both policy and measurement problems. It does not pretend to complete coverage – far from it – but rather has the declared ambition of creating work in this field. A number of basic problems have been identified as a direct result of the workshops. The hope is that these will stimulate further interdisciplinary discussion and research.

Arlington, VA, USA Eskil Ullberg

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Author Bios

Dr. Ángel Cabrera was named the sixth president of George Mason University effective July 2012. Mason is an innovative, entrepreneurial institution with global distinction in more than 200 academic fields. Prior to joining George Mason University, Cabrera served as the 11th president of Thunderbird School of Global Management in Arizona from 2004 to 2012, being designated President Emeritus in April 2012. He was Professor and Dean of IE Business School in Madrid, Spain, between 1998 and 2004. Thunderbird is regarded as the world's leading graduate school of international management, and IE Business School has been ranked by the *Financial Times* among the top 10 business schools in the world. During the last decade, Cabrera pioneered efforts to educate women entrepreneurs in emerging markets and co-founded The Oath Project, an international initiative to establish a code of conduct for business leaders. In 2011 the *Financial Times* recognized him as one of the top 20 business school leaders in the world.

Otaviano Canuto is the Senior Advisor on BRICS in the Development Economics Department, a new position established by President Kim to bring a fresh research focus to this increasingly critical area. He previously served as the Bank's Vice President and Head of the Poverty Reduction Network (PREM), a division of more than 700 economists and other professionals working on economic policy, poverty reduction, gender equality and analytic work for client countries. He also served as an Executive Director of the Board of the World Bank from 2004 to 2007. Outside of the Bank he has held leadership positions at the Inter-American Development Bank where he was Vice President for Countries, and for the Government of Brazil where he was

Secretary for International Affairs at the Ministry of Finance. He also has an extensive academic background, serving as Professor of Economics at the University of São Paulo and University of Campinas (UNICAMP) in Brazil.

Dr. Åke Edlund is a Senior Researcher in Computer Science and Communications at the Department of High Performance Computing and Visualization (HPCViz), KTH Royal Institute of Technology, Stockholm. Sweden. He is Leading the HPCViz Data-Intensive Computing research group and the PDC-HPC Cloud (resources).

Research focus is on Data-Intensive Computing for eScience. Dr. Åke Edlund has a Ph.D. from Technion – Israel Institute of Technology and Tekn Lic from Uppsala University. Before joining KTH he was the chief architect for customer services IT (world-wide) at Sony Ericsson and managing part of a number of software startups. Dr. Edlund is currently advisor at Severalnines – the DBaaS company – and a member of the EU Cloud Expert Group.

Daniel Houser is Professor of Economics, Chairman of the Economics Department and Director of Nobel Laureate Vernon Smith's Interdisciplinary Center for Economic Science, all at George Mason University, where he is also on faculty in the Neuroscience Program.

Prior to his arrival at Mason, Dr. Houser taught economics at the University of Minnesota and University of Arizona. Dr. Houser is lead author of the most widely cited theoretical and empirical analysis of online markets, providing evidence that decentralized reputation institutions promote economic efficiency. He has also collaborated in pioneering work connecting improved economic outcomes to institutions that offer opportunities for expressions of emotion. In addition, Dr. Houser was co-author of the first published study in the emerging field of neuroeconomics, and he continues to make fundamental contributions to this area. His research has garnered substantial media attention, including reviews in general interest publications such as *The Economist*, *Wired*, *Harvard Business Review* and *The New Yorker*.

In addition to research, Dr. Houser is committed to excellence in the classroom, and he has won numerous awards for outstanding teaching. His scholarly activities have been sponsored by numerous public and private organizations, including the National Science Foundation, the Earhart Foundation, the Russell Sage Foundation and the Searle Freedom Trust. Dr. Houser graduated from the University of Wisconsin at Madison with BA degrees in both Mathematics and Mathematical Economics. He earned a Ph.D. in Economics, with a focus on Bayesian Econometrics, at the University of Minnesota.

Jason E. Lane is the SUNY Provost Fellow as well as Director of Research and Senior Fellow at the Nelson A. Rockefeller Institute of Government, the public policy think tank of the State University of New York. He is also an Associate Professor of Educational Policy, Senior Researcher at the Institute for Global Education Policy Studies, and Co-director of the Cross-Border Education Research Team (C-BERT) at the University at Albany (SUNY).

Lane's research focuses on the organization and leadership of higher education institutions as well as their relationship to governments. Most recently he has been studying the globalization of higher education, with a specific interest in the emergence of the multi-national university and the role of internationalization in public diplomacy and economic and community development. Lane has written numerous articles, book chapters, and policy reports and authored or edited seven books, including *Multi-National Colleges and Universities: Leadership and Administration of International Branch Campuses* (Jossey-Bass, 2011, w/ Kevin Kinser), *Academic Leadership and Governance of Higher Education* (Stylus Press, 2012, w/Robert Hendrickson, James Harris, and Rick Dorman) and *Colleges and Universities as Economic Drivers* (SUNY Press, 2012 w/Bruce Johnstone). He has won numerous awards for his research and policy work.

Dr. Callie Le Renard was a research assistant for University President (2012–2013) and School of Public Policy Professors, co-authors papers for publication and blog posts for University President's website, researches and prepares talking points and conducts data analysis. She has also conducted European energy policy and transatlantic energy relations.

As part of her dissertation she has conducted energy research at the Wilson Center on the energy policies of Poland, Lithuania and Bulgaria and their relations with Russia. She is a co-author of the chapter with Dr. A. Cabrera.

Hans Pohl is Program Director at the Swedish Foundation for International Cooperation in Research and Higher Education (STINT) and Senior Researcher at Viktoria Swedish ICT AB. Previous positions include analyst at Sweden's Innovation Agency (VINNOVA), engineering consultant at Grontmij AB, science officer at the Swedish Office of Science and Technology in Bonn/Berlin and area manager at ABB Switchgear. His area of interest is in the intersection between research, innovation, environment and transport.

In 2010, he was awarded his Ph.D. from Chalmers University of Technology with a thesis entitled 'Radical innovation: Management and Policy for the Development of Electric and Hybrid Electric Vehicles'. STINT offers a range of funding and scholarship programmes in support of strategic internationalization at higher education institutions. STINT's aims are to:

- Enhance the competitiveness of higher education institutions
- Assist Swedish higher education institutions in developing into attractive scholarly environments for Swedish and foreign researchers, teaching staff and students
- Stimulate change through new or alternative means of international collaboration

Dr. Rong Rong is an Assistant Professor of Economics at Weber State University. She specializes in experimental method and applied micro-economic theory.

Her current research focuses on the economic applications of social networks. She is a co-author of the chapter with Prof. D. Houser.

Folke Snickars is Professor Emeritus of Regional Planning at the Royal Institute of Technology. During the 10 year period, 1993–2003, Folke Snickars was first Chairman of the Department of Infrastructure and Planning, and then Dean of the School of Industrial Management and the Built Environment at the Royal Institute of Technology.

He worked as the elected Faculty Dean of the Royal Institute of Technology, 2003–2011. In this capacity he was responsible for academic matters across the institute and for the recruitment and promotion of academic faculty. He is currently the Chairman of the Stockholm Region Academic Forum. Folke Snickars has been President of the European Regional Science Association during 1989–1995, and Editor in Chief of the *Papers in Regional Science* 1995–1997. Since 1997 he is the Coordinating Editor of the book series *Advances in Spatial Science* published by Springer Verlag.

Dr. Eskil Ullberg is a Visiting Senior Research Scholar and Visiting Assistant Professor at the Interdisciplinary Center for Economic Science at George Mason University, and also a management consultant for firms, international organizations and government (agencies). His field of research is in markets in patents, studying performance and behavioral properties of these institutions.

Current research includes trust between firms focusing on mechanisms (personal and impersonal) that create trust in each other's actions in an impersonal exchange of technology based on the patent system (funded by the Swedish Research Counsel). His recent work has been presented at The United Nations Economic and Social Council (ECOSOC) in New York and their Annual Ministerial Conference in Geneva (2013), the World Trade Organization, and reported in a special report on patent markets for the economic counsel of the French prime minister. Dr. Ullberg is the author of *Trade in Ideas*, a summary of two experimental studies in this field, published by Springer. Prior to his academic work he worked for 20 years with international management consulting in strategy: management of risk/uncertainty and patent system policy. He has an M.Sc. in Physical Engineering and Computer Science from TEKNIKUM, an MBA from INSEAD and a Ph.D. in Economics.

Chapter 1
Introduction

Eskil Ullberg

Abstract This book is about the integration of science and technology in an increasingly international and competitive environment for firms, universities and nations. Two workshops were held to discuss internationalization and competitiveness. The purpose was to identify basic problems, i.e. extant in several disciplines, which could help in better integrating economics, innovation and higher education. Fields covering policy and its measurement across economics, strategy, higher education and new research methods where discussed in one joint forum allowing for multiple angles to this over arching theme. Nine papers, which make up a chapter each, are summarized to give a first overview, and four identified basic problems: the including of time to think in economic theory, i.e. creative *and* operational processes, universities as economic actors, strategic dimension of team work, and agency in measuring innovation. In particular the integration of global markets (including emerging markets), invention/innovation and higher education attracted special interest among participants. The introduction is a first take on these basic problems, which are also inputs to future interdisciplinary research projects, whose results in turn are input to policy and its measurement, and better theoretical economic understanding. The hope is thus that a further discussion will follow, through other publications.

This book is about the integration of science and technology in an increasingly international and competitive environment for firms, universities and nations. Science is here referring to higher education and research. Technology is referring to technical solutions (which may be patented, trade secrets or "open source") and its application in new product and service innovations. What tie these topics together are economics and their respective measurement, hence the subtitle: integrating economics, innovation and higher education. This scope makes the book an input to today's global socio-economic development in terms of policy and measurement.

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The articles and idea papers were originally discussed using a workshop format to present in an interdisciplinary fashion, areas of current research and thought related to internationalization and competitiveness with the aim of identifying *basic problems*–problems extant in all disciplines–to inform new research projects which in turn could inform policy.

The contributions to the first workshop were intended to include disciplines from: economics, higher education, strategic cooperation and culture. In the follow-up workshop which built on the findings from the first workshop, in particular the strategies, take a look at those strategies adopted by businesses and governments for institutional development, emerging market development, faculty entrepreneurship and Big Data as a research method. (Unfortunately, the culture theme was not possible to cover in the end. It was replaced by a scientific "culture" of methodologies.)

The papers are organized in two main sections: science and economics, and innovation policy and its measurement. Within each section are first the policy related papers and then the measurement related. The 9 papers–a selection from 27 presentations from both workshops–include 4 with policy focus and 5 with measurement focus. The structure of the book was inspired by D. North (1981) who contends that "the second economic revolution" was the integration of science and technology.

A range of problems were discussed during and after the workshops and a few initial basic problems were identified. These are certainly only a beginning of a long list and, hopefully, many more basic problems will be identified by the readers of this book. They are, in short:

1. *Time to think*: A better balance between the creative process and operational process, to allow for new solutions to be created. People need "time to think", to create "new" which is in contrast to activities on the margin in operations of "more".
2. *Higher education as economic agents*: Policy implications of universities as input to economic development, in close, international, cooperation with economic and government agents.
3. *Agency in measurement of innovation*: Behavioral properties of institutions for efficiency that includes entrepreneurship. Study of "people x institutions", not only institutions needed to include human behavior in policy analysis.
4. *The Strategic Dimension of Team work: Diversification of ideas as a new measure:* A structural element that structures higher education and research in more interdisciplinary ways that facilitates international cooperation, but also between firms, universities and government, creating increased competitiveness.

The key discussions in each paper, and their relation into this bigger picture of analysis, are now summarized, after which an outline is presented of each of the initial basic problems.

Part One

The articles in the first part of the book focus on higher education and economics.

In *Internationalization, Higher Education and Competitiveness*, A. Cabrera and C. Le Renard discuss the challenges to the existing university business model. In addition to increasing the reach and quality we also need to make our students more competitive in the global marketplace, *as part of* the university experience. One way to do this is through internationalization of universities, an area where America is falling behind, in particular compared to China, a major trading partner. Shifting the focus to prepare students to be globally competitive include policy recommendations such as increasing the length of study-abroad programs, a language component and more joint degree programs.

The paper points at the *role* of the universities are shifting in the economic system, from traditionally supporting certain *regional* or *national* industries to also preparing students for work that is global in nature, thus reaching beyond any national industry perspective, i.e. an institutional policy issue. In this way the universities may add valuable experience to the regional or national firms, universities and governments, contributing to their global competitiveness.

In the second policy article, *Higher Education Internationalization: Why Governments Care*, J. Lane stresses that the internationalization of higher education has become a major theme in policy discussions, as governments begin to realize that higher education has an important role in their relations with other nations. The key argument is that the universities contribute in educating the workforce and contribute in producing innovations that drive economic development and competitiveness; and their educational exporting activities can have significant public diplomacy and national security implications.

This de facto soft diplomacy tool, is increasingly in the hands of more or less independent universities, and has less government influence, appears to respond to international demands of knowledge such as from the developing world, rather than government's own international strategies alone. In this sense they appear to become economic actors in their own rights, driven by economic motivations in turn motivated by giving students what they need to contribute to firms, universities and governments in a global world, thus more impersonal (less national policy) motivation.

In *Why measure internationalization of higher education?,* Hans Pohl begins to discuss the challenges to *measure* internationalization, discussing two new indicators covering some aspects of internationalization of research and higher education. Globalization is seen as a driver of the internationalization process, leading to students (and firms) having international networks and requirements, and enabling more people to access higher education. The measurement approach proposed is based on student and staff diversity, likely to capture these networks and requirements. Publication data is used for research in attempts to use several ranking approaches.

The approach appears to map the international economic reality and then measure how well the university environment in question represents that reality. This approach thus attempts to capture how well one could expect students to be prepared for the diverse social and economic environment they will encounter when working.

In *Economic and Social Impact of Universities: A Research Assessment Exercise*, F. Snickars and others discuss the role of the university system and its relations to

society. An impact study is reported assessing the social and economic impact of a Swedish university's research results and recommendation how to systematically work with industry and society in different scientific areas. The study tries to create a link between academic impact and social and economic impact of research, by stating goals for each area. Forward-looking strategies of creating impact are among these areas.

A key message is that universities are becoming economic actors in their own rights and that relations with industry are under-studied. They are attracting businesses through their internationalized collaborated reach, not simply serving national businesses. This is thus indicating a change in possible business model, and dynamics, of the regional/national university.

In *Productivity* versus *Creativity*, E. Ullberg (with input from N-E Sahlin) discusses, in this idea paper, the contrasting demands of doing more and doing new. As economic theory, public policy and universities all are pushed towards increased productivity, measured by number of students output, and other business and economic measures, both trust in universities ability to deliver what students need goes down and, most importantly, creativity in research appears to suffer. The basic proposition is creating incentives to think up new things, not only produce more of the same.

The message relates to the way we think about science, business, and economics, in terms of marginal returns and economies of scale and how creativity, i.e. making new things, not simply more things, is lacking in policy. Furthermore the way we aught to measure creativity, a 0/1 change in output, is very different to productivity, a percentage change in output. We need to develop new ways to manage creativity and productivity in order to shift the balance for a long-term growth in ideas, knowledge, and students.

Part Two

The articles in the second part of the book focus on innovation policy and its measurement.

In *Stagnation and Emerging Market Economics: Keynesian* versus *Schumpeterian approach to world issues*, O. Canuto, reports on economic policy response after the "Great Depression", in particular the emerging economies. Given the possibility that, for Keynesian and/or Schumpeterian reasons, advanced economies may be facing strong headwinds to return to significant growth, much attention has been directed to emerging market economies and other developing countries as potentially alternative sources of growth to the global economy. Such a potential may only be realized provided that these countries pursue their *own* country-specific agendas of structural reforms.

The message underlines the importance of an international approach, including emerging market countries. The Schumpeterian approach thus ties directly in the discussion of integration of economics, innovation ("creative destruction") and higher education.

In *The Language of Trust: Strategies of self-restraint in patent markets*, E. Ullberg reports on a study of about 14 of the most patent licensing and patenting active firms in the world and what they do to create trust in each others actions, as they exchange technology based on the patent system. To manage, or resolve, risk you need information, an economic problem, but to resolve uncertainty you need trust, a sociological problem. This article explores the strategies firms use to resolve such uncertainty. Four such strategies are identified. The common theme in these strategies implements a contracted mutual (multilateral) self-restraint, not to sue, hold-up or behave opportunistically. Generalizations of the application of this concept appear to be found in international relations, family and other organizational structures.

The approach deals with the question of managing international expansion of the integration of technology and science. The article findings may be useful in broader context of internationalization based on cooperation between firms, universities and nations.

In *Data-Intensive Computing and the Future of Research*, Å. Edlund, discusses in this idea paper the potential of massive data sets that are being produced in industry and academia today. This has resulted in that increasingly exploratory research areas evolve, mining large datasets to find new phenomena and patterns. The bottom line is information, how to gather it, how to manage it, and how to make timely and informed decisions based on what we find. This article look into the characteristics and evolution of information technology, discussing in more detail the latest paradigm shifts, and the new challenges and opportunities facing the companies and scientists. A list of suggested research topics in this area is proposed.

This article thus outlines a new research methodology enabled by "big data" useful in all of the above discussions of producing and analyzing information.

In *Exploring Network Behavior Using Cluster Analysis*, R. Rong and D. Houser, discusses the use of a statistical methodology of cluster analysis applied to situations where firms cooperate in networks. Identifying the innovator players is key to understanding the process of innovation. One such tool, cluster analysis, organizes a large data set into discrete groups based on patterns of similarity. It can be used to discover data patterns in networks without requiring strong ex ante assumptions about the properties of either the data generating process or the environment.

This article thus enables further analysis of relationships and a learning of characteristics of agents in networks, such as in internationalization of higher education.

Basic Problems Summarized

From these discussion articles and idea papers, the other presentations during the workshops and discussions, a fist summary of basic problems have been created. A list follows here and is developed below.

1. *Time to think*

Cutting through all presentations was an emphasis of productivity. This is of course a key goal of economic development, as it will reduce the use of resources.

However, setting aside time to think, i.e. develop new knowledge, technology, etc, appeared to be driven towards the margin. Being productive meant not so much to think up new knowledge and technology as to use extant knowledge in a more productive way.

For example, higher education is becoming an economic actor in its own rights – which is probably good – but the thinking behind this appears to have its roots not in education but in economic performance, "producing" as many students as possible. Not "searching for the truth", as in theory of science, expanding the world of knowledge, but to transfer extant knowledge to as many students as possible. It was less of a tool to think further, explore further, but a tool to be productive, in much more of a short-term way. Innovation followed the same way where measures were targeted towards institutions, not the agents making the change. Economic theory is also very much interested on what happens on the margin (rather than on the whole), and how the dynamism of development of new economies is taking place is still much shed in clouds. On the topic of creativity, it appeared that the university model had simply adopted the business model of "productivity" resulting in lack of trust for the institutions and, much more important, lack of creativity. Academic research is clearly more frequently honored by marginal contributions that can be published in journals, than groundbreaking research that cannot be published so easily. In area after area, the message was rather consistent: Small changes, marginal development, marginal measures, and marginal inventions, and marginal economic theory. This is of course in stark contract to Coase (1960) who suggests one aught to look at the problem on the margin *and* as a whole, i.e. comparing economic systems.

What is suggested here is that what is missing are policies giving incentives not only to short-term marginal gains but for people to be given incentives to *take time* to think up new ideas, solutions, etc. Such change in incentives would thus come through change in *property right regimes*. See (North 1981; Smith 2004) and others. These regimes span across higher education, invention, labor markets and many other markets and institutions. A proposal here is therefore to shift the emphasis from productivity towards creativity (an invention, innovation, entrepreneurship, i.e. developing "new") by looking at the property rights regimes and their measurement to provide incentives not only "producing at the margin" but specifically for *time to think*.

Such an endeavor is a major societal issue, in my view. For example, the Aviation pioneering Wright brothers, financed their highly scientific experiment with private money from their local bike manufacturing shop, thinking on their free time. In Europe, monks developed key technologies during the Middle Ages, such as the water wheel, and other inventions, in pursuit of time to think. Universities used to have tenure with the meaning of pursuing new ideas, not producing more papers as a machine. During the discussions it was commented that it was the creativity, or quality, of their thoughts that mattered, not the volume of articles and books.

This simple shift towards more time to think, and incentives that allows economic and social activity to be motivated by them, founded on property rights, is clearly a global issue. It is in some sense also questioning consumption as a sole

goal of productivity, and instead emphasizing productivity of new knowledge and ideas, the more creative the better.

What is proposed here is to begin to better be able to define such property rights on ideas, labor and capital. There may, after all, not be "only two God given dimensions" in the productivity function, as Solow once put it, but three. An attempt to elaborate some on the dimension of measurement with respect to such a policy is the note on "Productivity vs. Creativity", which is a discussion that is a result of the workshop.

2. *Higher education as economic agents*

Another concept was discussed by several higher education researchers: The link between regional universities and economic development. The universities appear now to be taking a more *independent* role in internationalization and competitiveness, by creating networks through offering students a global experience, in turn attracting industry to their work. This appears to be a change in internationalization and competitiveness as universities often were started to support local or national industry (with research, teaching). The causality appears thus to be that these institutions now appear to become economic agents in their own rights. This shift makes a more dynamic interaction between higher education and regional industry than in the past.

A concept here is thus to study these globalized educational institutions, increasingly facilitated by MOOCs, to better understand policy issues regarding the character and impact of universities as independent actors.

3. *Agency in measurement of innovation*

A third concept was observed in several presentations on measurements, rankings, etc. It became clear that today most emphasis has been made on the *institutional* dimensions of promoting innovation, and less on the personal, i.e. the individuals actually inventing or creating. The basic proposal here is to expand on the concept of measurement to "people x institutions".

4. *The Strategic Dimension of Team work: Diversification of ideas as a new measure*

Work by Hollingsworth (2007) point out that a key in break through research is the ability of internalizing different knowledge areas, which allows you to see through the problems. I would like to propose that measuring basic research problems that are interdisciplinary is a measure of potentially successful research.

A problem in interdisciplinary research appears to be the *structure* by which much university research is organized. A series of attempts to realize such team work failed as the traditional functional departmental approach appears to have limited interest in strategic collaboration across themes, but more driven by personal research agendas.

A better shift, towards creative and productive research, would thus be to provide the possibility to change the structure, and selection mechanisms for excellence, combining funding sources, etc. that would be more relevant for team work.

Such flexibility aught not to be simply "allowed" by university leadership, school or department heads, but the organizing *principle* aught to be promoted to be more team based, allowing for some focus of research efforts beyond an individual's relations and instead to a team level. This means that some researchers give up their agenda and instead joint certain thematic focused interdisciplinary teams. The principle of organization is thus focused around the problem–and the senior researchers–rather than the discipline.

The break-through research institutions appear to be organized in such, or similar to such, structures. Maybe it is time to introduce more team work at universities, 50 years or more after being introduced in business? That may, at least, facilitate integration of science and technology.

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Part I
Science and Economics

Chapter 2
Internationalization, Higher Education, and Competitiveness

Ángel Cabrera and Callie Le Renard

Abstract Competitiveness, higher education and internationalization are deeply intertwined. However due to changing conditions, the existing university business model is becoming unsustainable. Universities will have to adapt in order to meet future challenges, attract students and maintain quality while making higher education more accessible. In addition to increasing the reach and quality of higher education in America and thereby fueling our international competitiveness, we also need to ensure that students get the most from their experiences while at college thus allowing them to be more competitive in the global marketplace. One important way we are doing this is through internationalization. In terms of enhancing our competitiveness through the internationalization of higher education, the United States is falling behind, particularly when compared to China. This paper provides policy recommendations such as increasing the length of study abroad programs, including a language component and developing more joint degree programs that will ensure that the US and its graduates continue to remain competitive in the future.

Higher education is being shaped by globalization and contributing to it. Globalization creates new competitive and collaborative dynamics between universities across national boundaries, and universities contribute to massive flows of ideas and talent around the world that in turn increase our interconnectivity and interdependence. As the world economy becomes more and more reliant on knowledge and innovation, national, regional and local competitiveness become determined by flows and stocks of human talent. Competitiveness, higher education and internationalization are deeply and increasingly intertwined.

More important than natural resources in today's economy is the ability to generate new ideas and translate those ideas into new products, services and forms of production and distribution. Investments in research and development are a good proxy for innovation, as is the productivity of a country's top research universities. Furthermore, "that research capability represents the core of the positional goods

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that rank universities globally."[1] The best research universities attract the best talent, thus perpetuating their standing and contributing to their country's competitiveness.

As globalization has progressed, "the old assumption that higher education is comprised of relatively closed national systems, readily separable for comparison, is undermined by the growing inter-dependency of nations, and universities; powered by world-wide flows of technologies, people, finance, language and ideas especially the instantaneous transmission of data and ideas in real time."[2] Universities are becoming more and more international through activities like recruiting and hosting foreign students and faculty, sending domestic students on study abroad programs, and opening branch campuses in other countries.

Higher Education Drives Competitiveness

Every year, the World Economic Forum (WEF) in Switzerland issues the Global Competitiveness Report that tries to assess how prepared each country is to prosper in an interconnected global economy relative to one another. The WEF defines competitiveness as "the set of institutions, policies, and factors that determine the level of productivity of a country."[3] National competitiveness is impacted by many factors such institutions, infrastructure, the macroeconomic environment, health, technology, innovation and both primary and higher education.[4]

Our analyses indicate a strong correlation between the number of top research universities per capita in a given country and that country's national competitiveness. A strong higher education sector is very likely to be a factor impacting a country's competitiveness. This relationship is illustrated by the simple regression in Fig. 2.1 below. The ranking of top research universities was taken from the Shanghai Jiao Tong rankings, which are based on research output, and the competitiveness index was taken from the World Economic Forum's Global Competitiveness Report 2012–2013. These two organizations are completely independent of one another, seek different goals and use entirely different methodologies.

As many would guess, the United States accounts for the largest share of top research universities in the world – 85 of the top 200 and 8 of the top 10 according to the Jiao Tong Rankings. However, when normalized for population, the United States falls from number one to number nine, trailing after Switzerland, a number of other European countries and Israel,[5] as indicated in Fig. 2.2 below. In terms of

[1] Hugo Horta Global and National Prominent Universities: Internationalization, Competitiveness and the Role of the State. *Higher Education* 58 (2009): 388.

[2] Simon Marginson and Erlenawati Sawir, "University Leaders' Strategies in the Global Environment: A Comparative Study of Universitas Indonesia and the Australian National University," *Higher Education* 52 (2006): 345–346.

[3] "The Global Competitiveness Report 2012–2013," ed. Klaus Schwab, World Economic Forum, 2012, http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2012-13.pdf, 4.

[4] "The Global Competitiveness Report 2012–2013," 4–7.

[5] "Academic Ranking of World Universities," Shanghai Jiao Tong University, http://www.shanghairanking.com/ARWU2012.html.

Fig. 2.1 Top 200 universities per capita predict nearly 30 % of variation in competitiveness

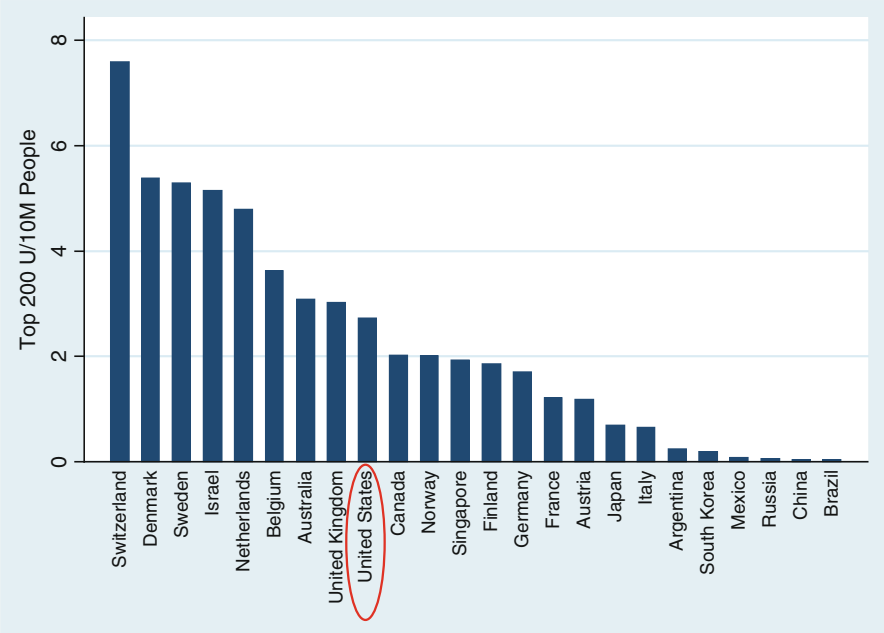

Fig. 2.2 Top 200 universities per capita by country

national competitiveness, the United States is predictably ranked by the WEF at number 7 in the world for 2012–2013. Switzerland ranks number one both in competitiveness as well as top research universities per capita.[6]

Research is only part of the relationship between higher education and competitiveness. Productivity in the modern economy relies on a predictable supply of a well-educated workforce. Experts project that the US won't "have enough credentialed workers to meet labor market demand or to remain globally competitive in the coming decade."[7] In addition, "a recent study based on Bureau of Labor Statistics data found that by 2018, more than two-thirds of the 47 million projected job openings will require some level of postsecondary education or training, including industry certification."[8] Indeed, while other countries have increased their credential attainment rates, the US with an attainment rate of 41 % has fallen to 15th place among OECD member states in the percentage of 25–34 year olds with an Associate's degree or higher. Canada, South Korea and Japan all have attainment rates of over 50 %.[9]

These trends may in part be due to the increasing cost of a college education, which has been exacerbated by decreases in state funding. While still a low-risk, high payoff investment, college is becoming less affordable as students have been called upon to pick up a larger share of the tab for their education. Indeed, "thirty-seven million Americans share about $1 trillion in student loans, according to Federal Reserve Data. It's the biggest consumer debt besides mortgages, eclipsing both auto loans and credit cards."[10] Due to these changing conditions, the existing university business model is becoming unsustainable. Universities will have to adapt in order to meet future challenges, attract students and maintain quality while making higher education more accessible.

While the economics of higher education in the United States are quite unique, these trends are not unheard of across the Atlantic, where imbalances on public budgets are creating unprecedented inflationary pressures on traditionally near-zero tuition levels.

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[6] Klaus Schwab, "The Global Competitiveness Report 2012–2013," World Economic Forum, http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2012-13.pdf.

[7] Heath Prince and Vicki Choitz, "The Credential Differential: The Public Return to Increasing Postsecondary Credential Attainment," Center for Postsecondary and Economic Success, April 2012, http://www.clasp.org/admin/site/publications/files/Full-Paper-The-Credential-Differential.pdf.

[8] Prince and Choitz, "The Credential Differential," 1.

[9] Ibid.

[10] "Loan Education Becomes Prerequisite as Student Debt Balloons," NPR, April 6, 2013, http://www.npr.org/2013/04/06/176442821/loan-education-becomes-prerequisite-as-student-debt-balloons.

Internationalizing Higher Education

As globalization continues to transform the way we learn, live and work, universities are confronting the challenge of educating new generations of students who are ready to interact effectively with individuals and organizations from other cultural and national settings. Perhaps the most effective way to achieve this objective is by internationalizing campuses and programs.[11] In a globalized world students must be prepared to flourish in different environments at different times, and they can no longer expect to operate in the same locale throughout their careers. The internationalization of higher education both offers opportunities and prepares students to recognize opportunities provided by interconnectivity in a globalized world. According to the OECD, approximately 4.1 million students worldwide now study abroad.[12]

In 2010/2011, nearly 274,000 American students studied abroad for credit. And while these numbers still only represent approximately 1.4 % of the total US student population, participation in study abroad has more than tripled in the last two decades.[13] Though the number of American students studying abroad is on the rise, we still have far to go to realize many of the benefits of international education, which include enhanced competitiveness as it diversifies networking and expands cross-border social and business connections.

To compare, approximately 339,700 of China's students studied abroad in the same year (2010/2011), and of every seven students who study abroad, one is Chinese.[14] One out of every 5, or 20 %, of international students from China seek an education in the United States,[15] and 194,029 Chinese students are now studying in the US. Although China is one of the top five destinations for American students, the number of American students in China is still only 14,596 despite the fact that China is both the world's second largest economy and America's largest trading partner.[16]

One reason for this disparity is that many American students "view a period abroad as an opportunity to travel and explore other cultures, with less emphasis on the academic experience or job prospects afterwards."[17] In 2009, President Obama announced the creation of the '100,000 Strong Initiative,' which was launched by

[11] Cabrera, A. & Unruh, G. (2012) Being Global: How to Think, Act and Lead in a Transformed World. Cambridge, MA: Harvard Business Review Press.

[12] "Education at a Glance 2012," OECD, http://www.oecd-ilibrary.org/education/education-at-a-glance-2012_eag-2012-en.

[13] "Fast Facts," Open Doors Data, Institute for International Education, http://www.iie.org/en/Research-and-Publications/Open-Doors/Data.

[14] John Wang, "China Sends More Students Abroad Than Any Other Country," Epoch Times, September 21, 2012, http://www.theepochtimes.com/n2/china-news/china-sends-more-students-abroad-than-any-other-country-295022.html.

[15] "Education at a Glance 2012," OECD.

[16] "Fast Facts," Open Doors Data, Institute for International Education.

[17] Yojana Sharma, "What Motivates Brits and Americans to Study Abroad?" University World News, March 6, 2013, http://www.universityworldnews.com/article.php?story=20130306074941643.

the State Department in 2010 with the goal of sending 100,000 American students to study in China over a 4 year period. The 100,000 Strong Foundation was established in 2012 to continue this mission.[18] However, even if we meet this goal we will still have far fewer American students in China than there are Chinese students in America.

In terms of enhancing our competitiveness through the internationalization of higher education, the United States is falling behind. Although the number of American students studying abroad is increasing, 58 % of these students are participants in short term programs.[19] These short term programs don't allow students the time to absorb cultural norms and expand their professional networks that longer programs provide. Furthermore, the top four destinations for US students studying abroad are the UK, Italy, Spain, and France,[20] reinforcing the idea that American students view their study abroad primarily as a chance to travel. This needs to change.

Policy Recommendations

These changes could be made in many ways, including how we market study abroad programs, developing more and better funded study abroad options and collaborative degree programs. Study abroad programs should be marketed as more than just an opportunity for travel. While it is true that students benefit from travel opportunities and exposure to other cultures, short term programs often emphasize travel and a broad exposure to topics and institutions over networking and cultural contacts. Indeed, students should also be encouraged to study languages so they are able to engage more deeply with students and faculty in their study abroad country of choice. Language study also allows students to spend more time in their country of choice as they are better able to function in society on a daily basis.

Another obstacle to increasing the number of American students studying abroad is cost. Study abroad programs can be very expensive, and student debt has already become an issue for many. Expense already weeds out many students who could benefit from these programs, and funding options are vital to both increase the number of American students studying abroad and the duration of their programs.

Finally, international dual and joint degrees enhance the competitiveness of students and of institutions. Students become more competitive by extending their academic competencies as well as enriching their skill sets by being able to approach research problems or social issues from a broadened perspective. At the same time international dual degrees lay the groundwork for future collaborations between institutions and meet the goal of enhanced international visibility.

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[18] "FAQ," 100,000 Strong, http://100kstrong.org/faqs/.

[19] Elizabeth Redden, "International Exchange Increasing," Inside Higher Ed, November 12, 2012, http://www.insidehighered.com/news/2012/11/12/report-shows-growth-international-enrollments-study-abroad.

[20] "Fast Facts," Open Doors Data, Institute for International Education.

Chapter 3
Higher Education Internationalization: Why Governments Care

Jason E. Lane

Abstract Internationalization of higher education, once of interest primarily of college and university leaders, is increasingly garnering attention among government leaders and other policy makers. As globalization leads nations to become increasingly interconnected in economic, cultural, and political modalities, higher education has emerged as critical connecting point. Colleges and universities facilitate the mobility of students and scholars, serve as vehicles of public diplomacy, and support economic competitiveness. This chapter explores the ways in which colleges and universities as international actors and describes the ways in which governments engage with the internationalization of higher education.

Introduction

The internationalization of higher education has emerged as a major theme of discussion and action in many countries and regions. With the relentless advancement of globalizations, higher education leaders have come to recognize the important of fostering greater relationships with scholars and institutions in foreign lands as well as to transform their own curricular offerings so to prepare students to be globally competitive. Amidst the transformations occurring at the institutional level, governments are beginning to recognize that higher education plays an important role in their relationship with other nations. It is a nation's colleges and universities that educate the workforce and produce the innovations that drive economic development and competitiveness; moreover their educational exporting activities can have significant public diplomacy and national security implications.

Over the last two decades, the internationalization of higher education has become both more complex and dynamic. Every year an increasing number of students are leaving their home nations to pursue some or all of their postsecondary education in a foreign environment. Indeed according to OECD (2012), the number

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of students studying abroad has more than tripled in the last two decades, increasing from 1.3 million in 1990 to 4.1 million in 2010. Moreover, the amount of foreign direct investment by colleges and universities continues to grow as they expand their global footprints through the creation of more and more international branch campuses, teaching sites, research locations, and outreach offices (Lane and Owens 2012). And, these activities do not account for the countless number of research partnerships, service projects, and faculty exchanges pursued by institutions.

This is not to argue that every college and university is (or should be) transforming into a multinational institution. Yet, the totality of these efforts across all higher education sectors and across all nations clearly illustrates a growing trend in the internationalization of higher education. And, this trend has very real implication for the competitiveness of industries and nations. The discourse about higher education internationalization, however, usually focuses singularly on institutions, examining internal efforts to internationalize. Yet, these institutions can (and often are) international actors in their own right, supporting the competitiveness of industries, regions, and nations.

Recognizing higher education institutions can serve as international actors is very different from actually measuring their activity in this area. The reality is that while there has been much research on the internationalization of higher education, there has been very little research on higher education internationalizes economies, communities, or nations. The literature is so limited that it resides mostly in grey material such as policy reports, national strategy documents, and media articles. The purpose of this paper is therefore threefold: (1) describe how higher education institutions have emerged as international actors; (2) present a typology of the areas of government involvement in these activities; (3) review different ways in which government involves itself in the internationalization of higher education.

Before proceeding, it is important to be clear about the purpose and scope of this paper. This paper is an initial foray into describing and conceptualizing how to measure higher education impacts on internationalization. It is not an exhaustive examination of the idea nor is it meant to provide a fully developed framework. There is no standard definition what exactly is higher education's role in internationalization, nor does this paper put forth such a definition.

Higher Education Institutions as International Actors

Colleges and universities have historically been domestically oriented entities. They were founded and funded to primarily serve the local community. Yet, regardless of whether they are public or private, for-profit or non-profit, 2-year or 4-year, liberal arts focused or research oriented, a large number of higher education institutions have internationalized and, in return, helped internationalize their communities, economies, and nations. Most dominant is the mobility of students and scholars, enabling institutions to attract foreign-born talent to the local region. Institutions have also begun developing their own foreign outposts, creating branch campuses,

research labs, and outreach offices in multiple countries. Furthermore, an increasing number of colleges and universities are entering into relationships (e.g., dual degrees, joint degrees, collaborative research projects, consulting contracts, and others) with foreign higher education institutions. These outposts represent the creation of multi-national educational enterprises and position colleges and universities to be international actors.

The purpose of this section is to provide basic descriptions of some of the various forms in which these institutions engage as international actors. At times I do speculate as to potential ways in which such engagements may influence the relationship between nations; these speculations are based on anecdotal evidence and included only to illustrate potential connections and should not be taken as hard facts. My intention is to provide foundational information to those who might be unfamiliar with such institutional activities and to illustrate potential areas of further study.

International Branch Campuses (IBCs)

IBCs are one of the more extreme forms of foreign educational outposts. An IBC is "an entity that is owned, at least in part, by a foreign education provider; operated in the name of the foreign education provider; engages in at least some face-to-face teaching; and provides access to an entire academic program that leads to a credential awarded by the foreign education provider"(Lane 2011, p. 1). The size and scope of these entities vary widely and such differences can affect the level of influence each may have in their adopted homelands (Lane and Kinser 2011b). According to a recent survey, an IBC may offer one degree program or more than a dozen. Student enrollments vary from fewer than 50 students to several thousand. And, while most of them focus on teaching, an increasing number are engaging in both research and service work (Lane and Kinser 2011a).

As of 2014, there were approximately 220 known IBCs.[1] These institutions are located on every inhabitable continent. Institutions in the United States operated just more than one third of all IBCs, with Australia and the UK being the other largest exporters. It is important to note that nations as varied as Russia, China, Malaysia, the Netherlands, and Venezuela have also created IBCs. And, the phenomenon does not seem to be strictly a movement of institutions in the global north into those in the global south (Lane and Kinser 2011a). Historically, the majority of all IBCs were created in a North-North relationship; however, more recently we have also seen South-South and South-North movements. Moreover, some nations both import and export IBCs. Australia, the United Kingdom, and the United States all host a few IBCs, though they export many times more than they host. Others that import and export institutions are Canada, Malaysia, Belgium, France, Italy, Mexico, the Netherlands, Russia, South Korea, and Switzerland.

[1] www.globlahighered.org

The overall impact of IBCs on international relations will likely vary based on a number of factors. In some countries, there might be only one IBC in a myriad of other domestic institutions; however in places like the United Arab Emirates (UAE) and Qatar, they are the dominant educational provider. Indeed, in Qatar, they not only educate students, but also provide technical assistance to local industries. This support is not just in the area of science and technology such as with Texas A&M – Qatar providing assistance with the nation's petroleum production; but also with locally-located international actors. Northwestern University provides assistance to Al Jazeera, the widely-watched Arabic News Channel; and Georgetown-Qatar is charged with training international affairs specialists for the region.

In many ways, these institutions serve as cultural embassies for the exporting nation. While often not directly linked to the exporting government, the basic idea of the IBC is to replicate what is offered in the home country and provide that in the host country. Even in nations where there have been heavy restrictions on internet access and criticism of the government, these bastions of academic freedom have been allowed to operate. While some faculty may self-censure themselves out of fear governmental retribution; the mere presence of these institutions has likely helped to foster greater appreciation for the concepts of academic freedom and, more broadly, freedom of speech.

Furthermore, there are some potential downsides to colleges and universities becoming internationally engaged. While studying the development of cross-border higher education in the Arab gulf as a Fulbright New Century Scholar in 2009, I saw firsthand how the actions of foreign education providers could be construed as those of the home government. I was hosted by Michigan State University (MSU) – Dubai and arrived just after George Mason University (GMU) in the nearby emirate of Ras al Khaimah closed its doors. While recruiting local students, admissions counselors from MSU-Dubai would often be asked about the closing of the George Mason campus. One question that they often encountered was, "Why would America pull out of the UAE?" It seemed that the students saw the closing of the GMU campus as an action of the US Government, not just that of an institution that happened to be located within America. Moreover, this particular action apparently had a negative effect on the view these students had on the United States. And, it did not help that Michigan State-Dubai also closed its doors a year later.

Joint and Double Degree Programs

Joint and double degree programs are examples of the increasing collaboration that is occurring among higher education institutions in multiple nations. A survey by the Institute for International Education and the Freie Universität Berlin concluded that interest in these types of programs are widespread and growing IIE-FUB (2011). Of the 250 respondents in 28 countries, 95 % indicated that they wanted to develop more of these initiatives. The most popular form of collaborative academic programs remains the double degree, rather than the joint degree. Double degrees

allow institutions to retain absolute control over their degree programs; while joint degrees require shared agreement on course requirements. Despite the seeming unwillingness of many institutions to share a degree, these programs require that faculty cooperate with each other in the creation and delivery of the academic program and often provide students with international exposure. Even if they never leave their home campus, students are likely to be taught by faculty from a different country, engage with students from a foreign land, and even participate in an academic setting based on different cultural assumptions.

Institutional Consultancies

For decades academic institutions have been providing consultative services for colleges and universities in other nations, particularly those in the developing world. Depending on the situation, this allows the established peer a great deal of influence over development of the partnering institution. In some cases, a foreign institution seeks to learn from their more well-established peer about particular program development or administrative issue. In other cases, an institution might be contracted to help establish an entirely new academic entity. For example, in the 1960s and 1970s MIT helped to establish the Indian Institute of Technology in Kanpur, India; the Birla Institute of Technology and Science (BITS) in Pilania, India; and the Aryamehr University of Technology in Iran (Leslie and Kargon 2006). More recently, Houston Community College was contracted by the Qatar government to help establish the Community College of Qatar (Spangler and Tyler 2011).

Some governments have required educational institutions in their borders to contract with foreign institutions for advice and assistance. When Oman first began allowing the development of private higher education institutions around 2008, the government mandated that each new private institution contract with a foreign education provider to provide guidance on the institution's development. Several Omani private institutions developed contracts with institutions from Australia, the United Kingdom, and the United States. This resulted in a rather messy higher education system in which the private institution mirrored the educational program offered by its consulting institution. One of the most evident differences was that those partnering with American institutions offered a 4-year degree program while those partnering with commonwealth schools offered only a 3-year degree program.

Setting aside the domestic policy problems that might exist; this example illustrates the amount of influence a foreign institution can have as a consultant. In addition, the impact of such consultancies goes beyond being able to influence the development of a specific institution. These activities allow the institution to develop a relationship with institutional leadership, governmental officials, and students. Each of these relations may have a long term impact on the relationship between nations.

Research Sites and Outreach Offices

Research and teaching is not bounded by national borders. For decades, some of the leading research universities in the United States have developed research outposts and labs in other countries to facilitate faculty studies and provide students with hands-on experiences. Some of the most serious problems facing humanity (e.g., famine, water shortages, the need for renewable energy, and dealing with climate change) transcend nations and have helped to foster greater collaboration among scholars and students in different countries.

These research outposts can take on a wide range of appearances and configurations. Many of these outposts tend to be idiosyncratic; established by faculty for the purposes of a specific study. However, many institutions are becoming more engaged in the development of overseas offices to help facilitate research and teaching. For example, Michigan State University has created offices in Burundi, China, Dubai, Kenya, Mali, Mozambique, India, Tanzania, and Zambia to assist their faculty researchers coordinate projects in foreign countries. Columbia University's Graduate School of Architecture, Planning, and Preservation has created its Sudio X program.[2] With architecture studios located in the heart of cities in Latin America, the Middle East, Africa, Eastern Europe, and Asia, the Studio X program is designed to aid faculty and students to engage in research in some of the most rapidly developing metropolises in the world. Furthermore, MIT has offices in Africa, Asia, Europe, and South America to help create internship opportunities for their students.[3] There is no full accounting of how many of such offices exist; but each of these locations, in their own way, bring the institution and its people in direct contact with the culture, politics, and economies of foreign nations.

Accreditation

While not an exact example of how institutions are operating as international actors, the role of accreditors in international affairs is worthy of note. In the United States, institutional and programmatic accreditors are private, non-profit entities; whereas in most other countries quality assurance mechanisms are overseen by the government. This rather unique aspect of the American accreditation systems allows it to move beyond the national borders, choosing to accredit not just foreign outposts of American institutions; but also foreign owned colleges, universities, and academic programs. For example, the U.S. based institutional accreditor Middle States Association of Colleges and Schools has accreditted institutions attesting to be based on an "American" curriculum such as American University of Cairo, Paris, and Sharjah. They also accredit foreign institutions, such as Zayed University, a

[2] http://www.arch.columbia.edu/studiox

[3] http://web.mit.edu/misti/

public institution in the UAE. Yet, it is still not exactly clear what it means for a foreign owned institution to receive accreditation from an accrediting agency based on the U.S. higher education system. How accreditors influence the international relations of institutions remains murky, but they represent another way in which higher education entities engage as international actors.

Rationales for Government Involvement in Higher Education

For decades, the relationship between nations has been largely defined by military might and other types of hard power. However, the past two decades has seen a shift toward the growing importance of a nation's economic stature and cultural influence. While not always recognized as such by governments, higher education can be one of a nation's greatest tools for building economic capacity and extending its cultural influence to other nations. In fact, so many nations have come to recognize the importance of higher education in these areas, that they have fostered a *great brain race* among nations for the world's best and brightest minds (Wildavsky 2010). The idea is that nation's need new knowledge in order to foster innovation that will help grow the nation's economy. At the same time, higher education institutions have emerged as important tools for expanding a nation's cultural influence. This may come by educating foreign students on the home campus or setting up a campus in a foreign environment. Thus, governments have come to recognize that education can be an important tool of public diplomacy. Of course, internationalization assumes a movement of individuals and knowledge across nations. These types of activities can raise national security concerns as they may provide opportunities for with questionable motives to enter a nation or facilitate the delivery of privileged knowledge to those whom the government does not want in transmitted.

This section provides a description of three areas wherein governments engage in the internationalization of higher education: economic competitiveness, public diplomacy, and national security.

Economic Competitiveness

Higher education has come to be recognized as an important form of international trade for many nations as well as a critical support structure for a nation's other areas of economic competitiveness (Lane and Owens 2012). As the competition for new knowledge and innovation solidifies as a salient component of nation's international strategy plans, so too will the nation's efforts in these regard affect the work of higher education institutions.

Fist, international students are an important form of international trade. In Australia, Canada, and the United States, education has become one of the largest

export services for those countries, totaling $15 billion (AUD), $300 million (CAD), and $21 billion (USD), respectively (Australian Education International 2009a, b; NAFSA 2011). In fact, the United States experienced an almost 10% growth between 2009 and 2010. And, these numbers tend to reflect only the flow of students across borders, that is mostly the contribution of international students who study within the host nation or at one of the institution's branch campuses or foreign education outposts. Of course, more than simply bringing new revenue into a country via tuition and living expenses during school, many international students also choose to remain in the country where they perform their studies, contributing to the local workforce and tax base.

A second, and rarely noticed, aspect of how internationalization of higher education contributes to economic development is through foreign direct investment (Lane and Owens 2012). Foreign direct investment (FDI) occurs when an organization invests resources into an entity in which it has some ownership stake, but is located in a different country. As colleges and universities grow their global footprints, we are seeing an increasing amount of financial and academic capital crossing borders to support these foreign outposts.

For example, there are now nearly 200 international branch campuses operating around the world. These branch campuses often, although not always, facilitate the attraction of FDI to the importing nation. In order to develop and sustain these entities, the home campus has to invest financial resources into the development of facilities, marketing of their academic programs, and the hiring of personnel. Moreover, the home campus must transfer its academic capital through curriculum development and administrative infrastructure to the branch campus. This can result in a spillover effect in that this academic capital can then influence the development of the higher education sector or local industries than can benefit from the academic programs offered.

Finally, higher education is a critically important component of building the competitive advantage of nations. In his book *The Competitive Advantage of Nations*, Porter (1990) speculated that the economic prosperity of a nation in the twenty-first century would be created, not inherited. That is, a nation's ability to be economically successful would not be based on having natural resources or an expansive workforce, which had been the strategy in previous centuries; rather, it would be based on their ability to innovate and innovation be created and sustained through local innovation systems. The leaders of developed and developing nations began to realize that investment in higher education could be one strategy for advancing innovation and fostering greater economic success. Leaders in the developed world began to advancing funding to support higher education's linkages with economic development programs and some, though not all, of those in developing world recognized the importance of investing in higher education more substantially than in past, hoping that such investments would help advance the economic position of the nation by fostering innovation.

Public Diplomacy

For more than a century, many governments and government-affiliated organizations in the developed world have invested in programs that use education as a tool for public diplomacy (Guruz 2008). One of the first such endeavors was the creation of Alliance Francaise, which was organized in 1883 in France and now operates nearly 1,000 schools in 129 countries to help achieve their mission of spreading the French culture and language. However, it was the two great world wars that propelled substantive government involvement in this area. Following World War I, the Institute for International Education was created in the United States; Germany founded the Akademischer Austauschdienst, the predecessor to Deutcher Akademischer Austausch Dienst (DAAD); and in the United Kingdom formed the British Committee for Relations with Other Countries, which would evolve into the British Council. These programs served a variety of purposes from facilitating student and faculty exchanges, fostering multi-institutional academic partnerships, and expanding understanding (and possibly acceptance) of one culture into others.

World War II also spurred government involvement; though this time governments were mostly interested in academic exchange programs. This era saw multinational organizations such as NATO, the Soviet Bloc and the EU's predecessor (European Economic Community) develop programs and scholarships to facilitate the movement of students among member nations (Klineberg 1976). In addition, several national governments saw the potential benefit of such exchanges. The United States funded the Fulbright program (described below) and the United Kingdom and France both allocated funds to bring students from former colonies to study at their colleges and universities (Guruz 2008). The USSR, in 1960, created the Patrice Lumumba Peoples' Friendship University. While the institution presently caters mostly to Russian students, its original charge was to spread Russian culture and political beliefs to nations in Africa, Latin America, and Asia by bringing poor students to Russia to obtain their education and then return home. The Colombo Plan, created in 1950, initiated international cooperation between countries in Southeast Asia and resulted in a rapid buildup of foreign students studying in Australia and New Zealand. The efforts spurred by the Colombo Plan resulted, in 1969, in the creation of IDP Education Australia, charged with providing educational assistance to other nations in the Asia-Pacific region.

Today, government involvement in international education initiatives continues; though the countries involved are much more numerous and diverse. Furthermore, governments seem to be as interested in economic competiveness as they are in public diplomacy, though it is sometimes difficult to disentangle the two drivers. Some of the older initiatives have attracted critics, questioning their continued relevance. However, a quick scan of the global political environment quickly evidences that many nations continue to invest in and see the important role that higher education can play in the economic and political relationship between nations. This paper is not meant as an argument for or against such programs; instead it is intended to provide an overview of the ways in which governments have and continue to use

higher education as tools in international relations strategies. I have also not discussed the role of higher education in international development initiatives as such programs are so vast and varied as to warrant a separate discussion.

National Security

By its very nature, the internationalization of higher education is part of the larger national security policy arena as internationalization supports the movement of people and knowledge across borders. For the most part, internationalization has proven to be a successful way of promoting cross-cultural awareness, appreciation, and cooperation. But, there are those that have used internationalization programs for alternative means. One of the most egregious examples is that many of the terrorists associated with the acts on 9–11 in the United States entered the country on student visas. International students who study in advanced science labs can take that knowledge back home with them or to another foreign government to support the development of technology or weaponry that could, in theory, be used against the nations in which the student was educated. To be clear, such threats are limited and should not be a reason to completely forestall the internationalization of higher education. However, the threats are real and both government and institutional leaders need to be aware and vigilant in attempting to deal with them.

More importantly, though, the benefits are also very real. International students and scholars provide for an improved institutional community, contributing to the learning, research, and innovation cultures at institutions. In the United States, for example, the enrollments of a vast majority of science, technology, engineering, and mathematics programs are comprised of international students. Were these students unable to enter the United States, many of these programs would have to be closed, limiting the institution's that can contribute to the nation's innovation culture. While some of these students may eventually return to their home nation and use their newly acquired knowledge there, many of them will stay in the country where they pursued their education, becoming post-docs, faculty, and/or scientific leaders in the corporate world. When immigration controls limit their ability to stay, this can have a negative impact on a nation's innovation culture.

National security is an area where governments and institutions should find ways to collaborate. Governments have an important role in protecting their citizens from those that mean them harm; however, their nation also benefits greatly from the flow of individuals and knowledge across border.

Current Government Engagements

The previous section reviewed several broad areas where governments might have an interest in promoting or restricting the internationalization of higher education. The activities within these areas are generally meant to affect the actions or

programs at individual institutions. However, there are a number of areas where governments have demonstrated an active interest in and direct funding of internationalization activities that may not be directly tied to one (or all) of their domestic institutions. This section provides a brief review of some of these activities.

Student Exchange Programs

The most well-known use of higher education in international relations is through student exchange programs. In the United States, the Fulbright program, founded in 1946, funds the exchange of students, scholars, and teachers in multiple nations. The program provides U.S. citizens with the opportunity to study in another country and foreign nationals with the chance to study in the U.S. With initiatives in more than 150 nations, the Fulbright program has funded more than 300,000 persons to study in a country other than their own. The US is not the only nation to fund such initiatives. The German DAAD and British Council, for example, also administer similar student exchange programs.

In addition, some nations have specific scholarship programs that target high achieving international students (Government Accountability Office 2009). The Australian Development Scholarships program, which works in cooperation with foreign governments, provides international students with funding to study in an Australian institution. Other programs such as the Chinese Government Scholarships Program, the United Kingdom's Chevening Programme, the U.S. Edmund S. Muskie Graduate Fellowship Program, and Germany Study Scholarships and Research Grants provide merit-based funding for foreign students to pursue their studies in the respective nations.

Marketing Campaigns

A relatively new endeavor by several nations has been the formal marketing of their higher education sector. Similar to how companies create brands, these nations are pursuing strategies to highlight their educational offerings. Programs such as *Study in Germany*, *Study in Australia*, and *Education UK* seek to inform prospective foreign students (and probably others) about the strength of and opportunities within their higher education system. These initiatives also help lower the barriers to access by providing students with the information they need to identify an institution, gain admission (if merited), and negotiate the student visa process. In the United States, there are multiple marketing campaigns. Since education is a function that primarily falls under the responsibility of states, many of the states have developed campaigns such as *Study New York*, *Study Oregon*, and *Study Maine* to attract international students to study within their state. At the federal level, the US Department of State has an initiative called *Education USA* designed to brand US education. In addition,

the US Department of Commerce hosts a series of recruiting fairs under the program *Study USA*. This bifurcated approach between the Departments of State and Commerce illustrates the dual purposes that governments see for international higher education: public diplomacy and economic competitiveness.

Cultural Centers at Colleges and Universities

Another public diplomacy strategy used by governments is to sponsor cultural centers in foreign lands, many of which are located at foreign colleges and universities. For example, the Russkiy Mir Foundation, founded in 2007 by the Russian government, is charged with "promoting the Russian language, as Russia's national heritage and a significant aspect of Russian and world culture, and supporting Russian language teaching programs abroad" (Russkiy Mir Foundation 2008). The Foundation funds Russian centers located at foreign educational institutions, and provides support for the teaching and learning of the Russian language and culture outside of the Russian borders. The German Goethe Institute operates cultural centers in 25 countries to support the acquisition of the German language and promote international cultural exchange. In addition, China, starting in 2004, began expending significant resources to support the teaching of Chinese language and cultural in other countries through their Confucius Institutes. At the end of 2009, news sources reported that there were 282 Confucius Institutes and 272 Confucius Classrooms in 88 countries (Hanban 2010).

Importing Institutions

The previous sections reviewed how governments have worked to export their higher education offerings either by bringing foreign students to study at their institutions or to send their own cultural centers to other nations. Another recent phenomenon has been the efforts of governments to import higher education institutions from other nations. This has been the most common in the Middle East and Asia, though we are beginning to see evidence of it in Africa and South America. There are many reasons for why governments may want to import higher education; among them is the desire to bolster their own soft power through enhancing their cultural legitimacy (Lane 2011). For example, world-recognized institutions such as New York University, Texas A&M, and Cornell possess a degree of cultural legitimacy that is very difficult to replicate. By building a campus in Abu Dhabi or Qatar, the institution, whether it intended to or not, shares some of its legitimacy with that government/country. Even institutions with lesser reputations, but from nations with highly regarded higher education systems (e.g., Australia, UK, US) carry with them a degree of cultural legitimacy because of the national affiliation. Thus, importing nations are directly associating themselves with America, Britain, and

Australia; raising awareness of their own reputation and, perhaps, increasing their own soft power. It is difficult to imagine that that by New York University building a campus in Abu Dhabi, near branches of the Guggenheim and the Louvre, that the culture legitimacy of the emirate is not somehow improved.

Conclusion

Governments have been using higher education to advance their own international strategies for decades. Most of these strategies involve the exporting of higher education to other nations. However, in recent years, developing nations have also seen the advantage of importing education from well-regarded institutions and higher education sectors. How successful these endeavors have been, however, remains in question.

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Chapter 4
How to Measure Internationalization of Higher Education

Hans Pohl

Abstract Proper management of internationalization of higher education institutions requires proper measurement methods. In this paper, two common indicators for internationalization are discussed and further developed, one for research and one for education. In both cases, the proposed indicators make use of existing data in a more sophisticated way. Through concrete examples, the differences between the existing and the proposed indicators are illustrated.

Introduction

Internationalization has become a major aspect to deal with for higher education institutions (HEIs). In order to manage internationalization, there is a need for good instruments to define goals, strategies and visions. However, for various reasons developed below, it is a great challenge to measure internationalization. This paper addresses the measurement issue and forwards two new indicators for improved understanding of selected aspects of the internationalization of research and higher education.

Based on a review of some definitions of HEI internationalization and one of the frequently referenced frameworks listing internationalization activities and rationales (Knight 2007), the difficulties in finding a set of indicators covering all aspects of internationalization are demonstrated. Thereafter two central indicators are described, one for research and one for education, and in both cases suggestions for improved calculation methods are proposed.

One possible use for indicators is ranking. Both indicators addressed are used in established ranking systems such as the Times Higher Education World University Ranking. In other approaches aiming at facilitating comparison of HEIs, further indicators are used. One recent ranking method, the European initiative U-multirank uses several dozens of indicators (see u-multirank.eu). A closer look at the results indicates that this potentially quite comprehensive approach brings difficulties in

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gathering correct and complete data. Independent of the number of indicators, there is almost always a problem when combining them into one single index for the final ranking, as the weight of each indicator typically is arbitrary.

In the next section, we argue that internationalization has become more important. Thereafter we forward some reasons why internationalization is difficult to measure. This problem description is followed by one section outlining examples of how internationalization of research can be studied using publication data. In this section, we also propose a new indicator to be used instead of the standard indicator. Next section argues for the importance of diversity among students and staff in relation to the education mission. It proposes a development of a common indicator, the share of international students and/or staff, into an indicator that better accounts for diversity in the population. Finally discussion and conclusions follow.

Internationalization Is Important

International relations are and have always been inherent in higher education and research (Smeby and Trondal 2005). However, internationalization of higher education institutions exhibits a growing trend, as illustrated by bibliometric data (cf. The Royal Society 2011). The main driver of internationalization is globalization. Within the concept of globalization lies increased international competition as well as increased international collaboration (cf. McKelvey and Holmén 2009). A global market develops which leads to students and firms having international references and requirements. Partly due to globalization, individualization and marketization follow (Frölich 2006), with increased privatization (Altbach et al. 2009). Amongst other things, these trends challenge the leadership of the HEI and lead to changes in management structure (Sporn 2007).

One important enabler of internationalization is global economic growth. This has enabled many more people to advance to post-secondary education. Expanding student numbers are leading to increasing demand and a more diverse student body. Another enabler is technologies, particularly information and communications technologies but also the supply of lower-cost international transport (Wildawsky et al. 2011). The expanded use of English is a further factor facilitating the internationalization of higher education (Svensson and Wihlborg 2010).

On the policy side, important regulatory mechanisms include tuition fee requirements and the trend towards increased and broader use of tuition fees for students (Altbach et al. 2009). As noted by Healey (2008), the introduction of tuition fees partly discourages internationalization. Free-trade agreements for services act as enablers of international higher education (Altbach and Knight 2007) and harmonization; the Bologna process, for example, is another policy measure which might support internationalization (van der Wende 2001). Finally there are traditional funding schemes, which sometimes, as in the EU Framework Programs, call for international collaboration. Student and faculty mobility are also specifically funded, through such programs as Erasmus.

Internationalization as a Concept

According to Bartell (2003), internationalization is far from a clearly defined and understood concept. However, a number of attempts to define internationalization of higher education have been made. One relatively open working definition is proposed by Knight (2003, p. 2) "Internationalization at the national, sector, and institutional levels is defined as the process of integrating an international, intercultural, or global dimension into the purpose, functions or delivery of post-secondary education." A more focused definition is suggested by Rudzki (1995, p. 421): "Internationalization of higher education can be understood as […] a defining feature of all universities, encompassing organizational change, curriculum innovation, staff development and student mobility, for the purposes of achieving excellence in teaching and research." In line with the second definition, this study considers internationalization a tool to better achieve the HEIs' missions.

Knight (2007) suggests a framework covering activities and rationales for HEI internationalization. She lists a number of strategies and organizational measures for incorporating the international dimension into all parts of the institution, from top-level governance via the operations to various service functions, see Table 4.1.

Knight (2007) also presents rationales for internationalization for each of the traditional four groups: social/cultural, political, economic and academic. In addition, five national-level and six institutional-level rationales of emerging importance are mentioned. Some of these rationales are given in Table 4.2.

The impressive lists in Tables 4.1 and 4.2 illustrate clearly that internationalization of higher education and research is encompassing a wide range of activities and motives which are difficult to separate from 'business as usual'. The lists also explain why it is a challenge to measure internationalization as all these dimensions not only pose a problem in terms of definitional issues, some of them are also difficult to represent in quantitative data. One previously popular but currently less so is the number of agreements that a HEI has with other (foreign) HEIs. The main reason why this count of agreements is given less attention now is the sometimes legitimate criticism that most agreements are just 'love letters' without much substance in terms of concrete activities. Instead, the trend is towards strategic partnerships with broader collaborations covering both research and higher education.

The needs to measure internationalization differ slightly depending on the actor. For the HEI management, there is a need to learn from on-going internationalization endeavors when planning for new ones. Even though there are strong requests for academic freedom, this should not mean that approaches to systematically learn from current and past activities are unnecessary. For organizations funding (the internationalization) of research and higher education, such as the Swedish Foundation for International Cooperation in Research and Higher Education where the author of this paper is employed, the learning aspect remains the same but there might also be a more emphasized need to justify why particular investments are made. Previous literature provides some guidelines about how to evaluate public investments in research and development but it also highlights how difficult it is to make a sufficiently precise and reliable evaluation (Klette et al. 2000).

Table 4.1 Internationalisation strategies or activities (Knight 2007)

Academic programs	Student exchange programs	External relations: domestic and cross-border	*Domestic:*
	Foreign language study		Community-based partnerships with NGO groups or public/private sector groups
	Internationalized curricula		Community service and intercultural project work
	Area of thematic studies		Customized education and training programs for international partners and clients
	Work/study abroad		*Cross-border:*
	International students		International development assistance projects
	Teaching/learning process		Cross-border delivery of education programs (commercial and non-commercial)
	Joint/double degree programs		International linkages, partnerships and networks
	Cross-cultural training		Contract based training and research programs and services
	Faculty/staff mobility programs		Alumni abroad programs
	Visiting lectures and scholars		
	Link between academic programs and other strategies		
Research and scholarly collaboration	Area and theme centers	Extra-curricular	Student clubs and associations
	Joint research projects		International and intercultural campus events
	International conferences and seminars		Liaison with community based cultural and ethnic groups
	Published articles and papers		Peer support groups and programs
	International research agreements		
	Research exchange programs		
	International research partners in academic and other sectors	Organisational strategies	

Table 4.2 Internationalisation rationales (Knight 2007)

Social/cultural	National cultural identity
	Intercultural understanding
	Citizenship development
	Social and community development
Political	Foreign policy
	National security
	Technical assistance
	Peace and mutual understanding
	National identity
	Regional identity
Economic	Economic growth and competitiveness
	Labour market
	Financial incentives
Academic	Extension of academic horizon
	Institution building
	Profile and status
	Enhancement of quality
	International academic standards
	International dimension to research and teaching
National level rationales of emerging importance	Human resources development
	Strategic alliances
	Income generation/commercial trade
	Nation building/institution building
	Social/cultural development and mutual understanding
Institutional level rationales of emerging importance	International branding and profile
	Quality enhancement/international standards
	Alternative income generation
	Student and staff development
	Networks and strategic alliances
	Knowledge production

An assessment of the internationalization impact has to be aligned with the core missions of the HEI (Hudzik and Stohl 2009). Successful internationalization activities depend on several factors, including the profile and strength of the HEI, the character and quality of its local, regional, national and international environment and networks, and its internationalization capabilities. These capabilities include language proficiency, administrative routines to manage international students and staff and much more. There is a need to manage and measure various internationalization aspects:

> Without a clear set of rationales, followed by a set of objectives or policy statements, a plan or set of strategies, and a monitoring and evaluation system, the process of internationalization is often an ad hoc, reactive, and fragmented response to the overwhelming number of new international opportunities available. (Knight 2005, p. 15)

Internationalization of Research

In relation to research, one very useful and popular method to study internationalization is analyses of scientific publications and citations. As publications and citations also serve as one of the main indicators when research is evaluated on individual, group, institutional or national level, it is seldom questioned even though there are weaknesses also with this type of data.

Publication data for the USA and the European Union shows a very clear and relatively rapid development towards increased collaborative publications at the expense of single author contributions. The trend is particularly pronounced for international collaborations (Elsevier 2013a). During the period from 1980 until 2009, the average distance between the collaborators has increased annually with 5.4 %, from 334 to 1,553 km (Tijssen et al. 2011). It has also been shown that the size of the country inversely relates to its share of internationally collaborative publications (Luukkonen et al. 1992).

There is a strong link between the field-weighted citation impact (FWCI) of a publication and the distance that the collaboration spans. International collaborations outside the European Union for a member country have an impact of 1.73 times an institutional collaboration. Analogously the fold increase in impact for the USA is 1.49 (Elsevier 2013a). All countries benefit from international scientific collaborations but it is particularly beneficial for less advanced countries (Glänzel 2001).

To illustrate how publication data can be used to inform about the value of international collaboration with a number of partners, Fig. 4.1 plots the most prolific collaboration partner countries for Sweden. The size of the bubble indicates the total volume of collaborative papers over the period 2008–2012.

The position along the x-axis indicates the FWCI of the collaboration with each country. The y-axis crosses the x-axis at 1.93, which is the average FWCI for all

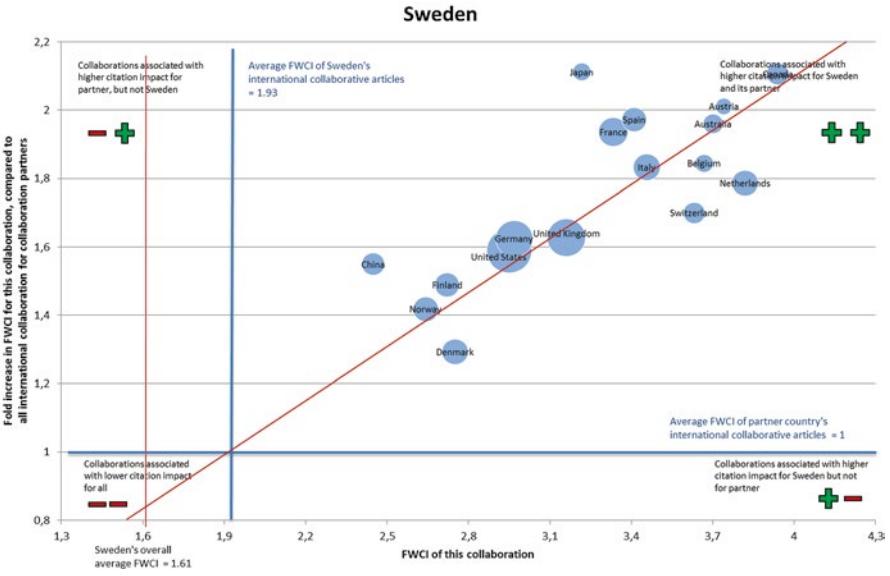

Fig. 4.1 Collaboration quadrant for Sweden (Elsevier 2013b)

international collaborative articles for Sweden. This figure can be compared with Sweden's overall FWCI of 1.61. Along the y-axis, the position indicates how much better a collaborative article is in terms of FWCI compared to the average FWCI for the partner country's all collaborative articles.

Consequently, all Sweden's most prolific partner countries exhibit win-win collaborations as the bubbles are positioned in the upper right quadrant. The three largest partner countries are in the middle of the quadrant with 50–60 % better FWCI than the average international collaborative article. Collaboration with neighboring countries exhibits slightly lower mutual FWCI.

One common indicator when measuring internationalization of research is the share of international co-publications, i.e. publications with authors from at least two countries. This share is often used in rankings and other situations when internationalization of research is to be described in quantitative terms. If all HEIs had the same scientific profile, this figure would allow for a fair comparison. But, as Fig. 4.2 indicates, scientific sectors differ a lot in their share of international co-publications. Data covers 28 Swedish HEIs over three years (SciVal® database, Elsevier B.V., http://www.scival.com downloaded on 2014-06-05). This means that a HEI with a high share of research in sectors with an on average low degree of international co-publications receives a lower total figure than a university focusing on highly international scientific sectors.

There is also a change over time in the share of international co-publications, see Fig. 4.3, which shows the share for 28 Swedish universities.

Against this background, it becomes obvious that a trivial share of international co-publications does not allow for a good comparison in all cases. Instead, an indicator such as the FWCI, which shows the relative strength of one publication compared to all similar publications would provide more information.

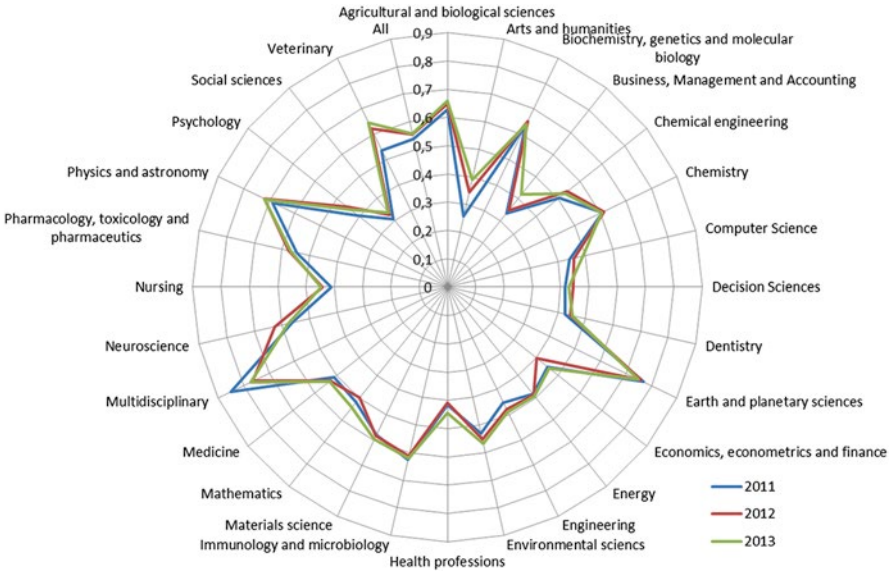

Fig. 4.2 Share of international co-publications in different scientific sectors

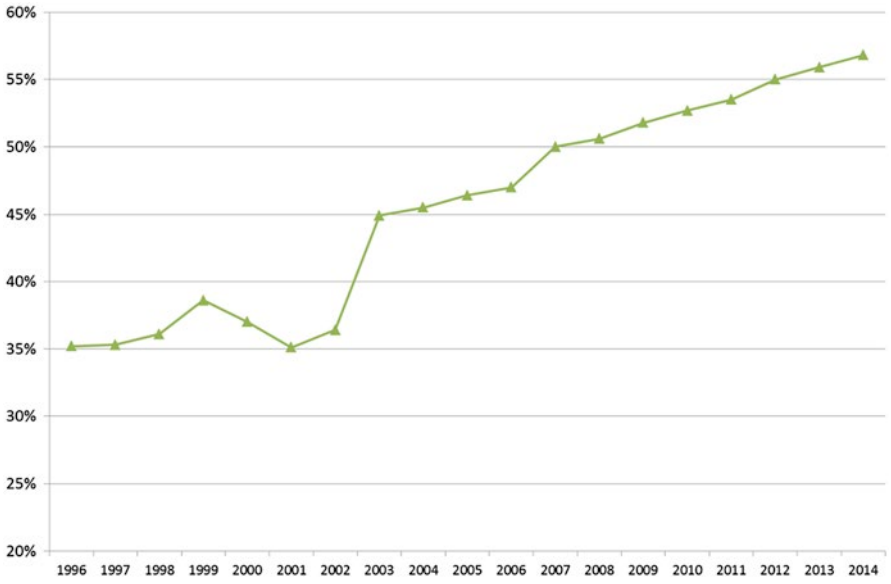

Fig. 4.3 Share of international co-publications for the years 1996–2014 in Sweden

A more advanced indicator takes the scientific profile and changes over time into account. Basically, a share of international co-publications year 2012 in, let us say Arts and humanities, should be compared with the global share of international co-publications for the same year. To express it in more general terms, it is proposed that the indicator compares the share of international co-publications to the global share within each scientific sector for every year. The result is an indicator like the FWCI, i.e. a relative figure which is 1 for the global average and higher than 1 if the studied organisation is more international than the average. This allows for a fair comparison of HEIs or countries with different scientific profiles. It is also possible to use for smaller groups of researchers (with some caution).

To exemplify, assume that the global share of international co-publications in 2012 in Arts and humanities is 20 %. One institution with a share of 40 % of international co-publications in Arts and humanities receives thus a factor 40/20 = 2, i.e. a very strong position. If the same institution is compared to an average for all international co-publications (in Sweden around 55 %, see Fig. 4.3), i.e. the traditional method, the outcome is below the average and implies a poorly internationalized institution.

Internationalization of Education

The internationalization of higher education is often studied using the proportion of international students or faculty as an indicator. For example, in the Times Higher Education World University Rankings, the main part of the 'International outlook' scores is based on the proportion of international students and staff (Bowman and Bastedo 2011). Another example is that some countries, among them Finland and

Italy, use such internationalization metrics as one of the indicators for decisions relating to the public funding of the HEIs (Quist et al. 2013). A high share of international students or staff might indicate that the HEI is popular but there are obviously also other potential explanations. A potentially more relevant and direct consequence of a high share of international students or staff is that it contributes to diversity. Previous studies argue that diversity brings important benefits for all students:

> A racially and ethnically diverse university student body has far-ranging and significant benefits for all students, non-minorities and minorities alike. Students learn better in a diverse educational environment, and they are better prepared to become active participants in our pluralistic, democratic society once they leave such a setting. (Gurin 1999, p. 1)

Interactional diversity reflects the extent to which students from diverse backgrounds actually come in to contact and interact in educationally purposeful ways. Such diversity has positive effects for virtually all students in all types of postsecondary institutions, as argued by Hu and Kuh (2003). They base their conclusions on data from more than 50,000 students at 124 American colleges and universities.

The use of the proportion of international students or staff is a rather crude proxy when it comes to the assessment of their impact on diversity. For example, it appears quite probable that a person from a very different culture brings more diversity than a person from a neighboring country. In Switzerland the share of international professors is about 45 %, which is very high compared to other countries. However, nearly 70 % of these international professors come from neighboring countries (Wissenshaftsrat 2009).

Diversity can be decomposed into variety, balance and disparity. There is no single formula to calculate diversity and different approaches are used in various contexts. One diversity index potentially matching all requirements is:

$$\Delta = \sum_{ij(i \neq j)} \left(d_{ij}\right)^{\alpha} \times \left(p_i \times p_j\right)^{\beta}$$

where p_i and p_j are proportional representations of elements i and j in the system (balance) and d_{ij} is the degree of difference (disparity) attributed to elements i and j. The exponents α and β can take all possible permutations of 0 and 1 (Stirling 2007).

In the classroom or campus internationalization context, variety, balance and disparity correspond to the number of nationalities, the share of each nationality, and how different each nationality is. Whereas the calculation of p_i and p_j is relatively straightforward, the disparity factor has to be defined for this context. One common approach is to define disparity as the distance or length of the vector between the different elements. In this case, we assume a three-dimensional disparity vector, cf. Table 4.3.

The resulting vector length when comparing two students in these three dimensions is normalized to a value between 0 (no disparity) to 1 (disparity in all three dimensions). Similarly the total diversity indicator is normalized to values between 0 % and 100 %.

With this simple model it is possible to calculate the diversity in the classroom or campus or even national context with some more detail than traditional calculations of the proportion of international students or staff. Using Sweden as a home country, we give some examples to illustrate the proposed method to calculate diversity.

Table 4.3 Dimensions of disparity

Dimension	Comments
Language	People having the same maternal language tend to cluster and thus a difference might contribute to diversity
Region	The region reflects to some extent cultural differences. We use the same seven regions as the World Bank; East Asia & Pacific, Europe & Central Asia, Latin America & Caribbean, Middle East & N. Africa, North America, South Asia and Sub-Saharan Africa
Economy	The economic situation in the home country reflects to some extent a cultural and material difference. In this model we only use two groups of countries; low or high income. The grouping is based on GDP per capita

Table 4.4 Highly international group of students(?)

	Diversity	15 %	
Total number of students		20	
Economy	Region	Language	No. in category
H	Europe and Central Asia	Swedish	2
H	East Asia and Pacific	Chinese	18

Table 4.5 Students from different cultures (disparity variation)

	Diversity	6 %			Diversity	10 %	
Total number of students		20		Total number of students		20	
Economy	Region	Language	No. in category	Economy	Region	Language	No. in category
H	Europe and Central Asia	Swedish	19	H	Europe and Central Asia	Swedish	19
H	Europe and Central Asia	Norwegian	1	L	Latin America and Caribb	Spanish	1

In Table 4.4, one group with almost only international students gives a diversity of 15 %. The traditional method to capture internationalization result in 18/20 = 90 %. This demonstrates clearly the difference between the proposed new method to calculate diversity and the current standard one.

In Table 4.5, two groups with just one student from abroad are compared. For the student from a neighboring country (Norway), the resulting diversity (6 %) is lower than for the student from Colombia (10 %).

In Table 4.6 one group with two types of students is compared with a group with an equal number of national students but international students from a larger number of countries. The latter group has a higher diversity as the variety is larger.

Finally, a calculation is made using real data for one university, KTH Royal Institute of Technology. Diversity is calculated for the year before and after the tuition fee reform in Sweden, which requires full cost tuition fees for students from outside the European Economic Area and Switzerland, see Table 4.7.

Table 4.6 Students from several countries (variety)

		Diversity	43 %				Diversity	66 %	
Total number of students			20		Total number of students			20	
Student type	Economy	Region	Language	No. in category	Student type	Economy	Region	Language	No. in category
1	H	Europe and Central Asia	Swedish	10	**1**	H	Europe and Central Asia	Swedish	10
2	H	East Asia and Pacific	Chinese	10	**2**	H	East Asia and Pacific	Chinese	2
					3	L	Latin America and Caribb	Spanish	2
					4	H	Latin America and Caribb	Portugese	2
					5	L	Sub-Saharan Africa	Swahili	2
					6	H	North America	English	2

Table 4.7 Student population for KTH Royal Institute of Technology

2010/2011					2011/2012				
Diversity		36 %			Diversity		31 %		
	Variety	61				Variety	48		
Total number of students		8,970			Total number of students		7,039		
Student type	Economy	Region	Language	No. in category	Student type	Economy	Region	Language	No. in category
1	H	Europe and Central Asia	Swedish	6,365	**1**	H	Europe and Central Asia	Swedish	5,186
2	H	Europe and Central Asia	Belgien	23	**2**	H	Europe and Central Asia	Belgien	14
3	H	Europe and Central Asia	Estland	9	**3**	H	Europe and Central Asia	Estland	11
4	H	Europe and Central Asia	Finland	34	**4**	H	Europe and Central Asia	Finland	27
5	H	Europe and Central Asia	Frankrike	321	**5**	H	Europe and Central Asia	Frankrike	297
6	H	Europe and Central Asia	Grekland	39	**6**	H	Europe and Central Asia	Grekland	50
7	H	Europe and Central Asia	Irland	5	**7**	H	Europe and Central Asia	Irland	8
8	H	Europe and Central Asia	Island	12	**8**	H	Europe and Central Asia	Island	15
9	H	Europe and Central Asia	Italien	111	**9**	H	Europe and Central Asia	Italien	93
10	H	Europe and Central Asia	Lettland	11	**10**	H	Europe and Central Asia	Lettland	6
53	H	Middle East and N. Africa	Libanon	5	**53**	H	Middle East and N. Africa	Libanon	0

54	H	South Asia	Malaysia	5	**54**	H	South Asia	Malaysia	0
55	L	East Asia and Pacific	Nepal	10	**55**	L	East Asia and Pacific	Nepal	0
56	L	East Asia and Pacific	Pakistan	85	**56**	L	East Asia and Pacific	Pakistan	11
57	H	South Asia	Singapore	89	**57**	H	South Asia	Singapore	86
58	L	East Asia and Pacific	Taiwan	7	**58**	L	East Asia and Pacific	Taiwan	14
59	L	South Asia	Thailand	14	**59**	L	South Asia	Thailand	0
60	L	East Asia and Pacific	Vietnam	7	**60**	L	East Asia and Pacific	Vietnam	0
61	H	East Asia and Pacific	Asia <5	34	**61**	H	East Asia and Pacific	Asia <5	42
62	H	East Asia and Pacific	Australien	33	**62**	H	East Asia and Pacific	Australien	38
63	H	Europe and Central Asia	Unspecified	112	**63**	H	Europe and Central Asia	Unspecified	121

As Table 4.7 shows, there is a clear decrease in diversity. The number of nationalities is also reduced from 61 to 48. Similarly, it is possible to calculate diversity for even larger populations such as all incoming students to Sweden. It should also be mentioned that the same methodology is possible to use for other types of diversity such as gender or social background.

Conclusions

This paper argues that internationalization has become more important for higher education institutions, HEIs. There is thus a more articulated need to manage internationalization and linked to this need, there is a need for measurement. Two central indicators are described, one for research and one for education, and in both cases suggestions for improved calculation methods are proposed. The revised indicators proposed in this paper make use of existing data in a more sophisticated way.

The suggested indicator for internationalization of research is outlined methodologically but not calculated in this paper due to lack of appropriate data. Data exists but is not available to the author (yet) with the sufficient resolution. In a future paper the differences between the current and the proposed indicator will be illustrated using real data. In the case of internationalization of education, real data is used to illustrate how different the results might be between the current and the proposed indicator. The proposed indicator is also used to quantify the (negative) impact of the tuition fee reform in Sweden on diversity among students.

To conclude, this paper contributes with two new concepts to be further discussed and tested. Given the importance of internationalization for HEIs, such potential improvements of indicators might lead to better management of internationalization in the future. Potential users and benefactors of these indicators exist in several parts of the HEI system, from students with an interest in comparisons and rankings to HEI managers and policy actors.

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Chapter 5
On the Economic and Social Impacts of University Research

A Follow-Up Study of the KTH Research Assessment Exercise 2012

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Abstract We have come to realise that the work presented below is only a beginning of a long-term commitment to dig deeper into a complex issue for the university system. While there is a long tradition, and a number of supporting research studies, on the academic impacts of research and the economic and social impacts of higher education the question of economic and social impacts of university activity as regards collaboration is still under-studied and under-researched.

It is important not to end up in the same dead end discussion in this field as has been the case for some of the use of bibliometric investigations as indicators of academic research excellence. In order to have a constructive development in this field it is essential to use systematic and experience-based knowledge creation through peer reviewed expert reports, thesis project at master and doctoral level and, indeed, research. Some such research is ongoing at KTH using external funding but it is also important that KTH puts in research resources from its internal grants to finance research studies. The economic and social impacts of university research at KTH are much wider than anticipated as indicated in this follow-up study of the KTH Research Assessment Exercise 2012.

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Introduction and Summary

This follow-up project of KTH RAE 2012 has contained three parts. The first one is a further documentation of a selection of the case studies collected in the preparation for the research assessment exercise.[1]

The second one is the preparation of documentation in book or other media form to inform on the economic and social impacts of KTH research for a larger audience. This has materialized as a presentation of these materials as a newspaper supplement to be distributed widely among others to KTH alumni.

The third written output of the project is this short document containing summary presentations of the activities performed together with a set of recommendations to KTH for further work, see the bullet points below. The recommendations aim to illustrate both the internal and external benefits for KTH of engaging systematically in work in the field of engagement with industry and society in different arenas. The most important external arena in the coming years is to contribute the KTH view on the future Swedish system for allocating research funding to higher education institutions.

Impact and Time Perspectives

- In the international discourse a distinction is made between the forward looking perspective of research excellence and the backward looking one.
- The forward looking perspective applies in particular when researchers go for competitive funding. In that system the importance of claiming future economic and social impact of research is increasing in importance.
- The UK REF 2014 project aims in particular to show the impact of funding streams in a backward looking perspective. This is where the massive amount of quality work is currently done in the UK. According to recent estimates some 5,000–7,000 impact stories are being produced within the 160 universities.
- The future work of KTH must combine these perspectives. By engaging in the backward looking activity we are further valorizing the research which we have produced historically. By systematically establishing this knowledge base we will stand strong in showing the dynamics of our research environments.
- This effort will facilitate our work on providing forward looking assessments of our future research both in project applications and in faculty development. In this context, we must make sure that the Schools have their own strategies and action plans for systematic work with impacts.
- We assert that the work to understand the scope of impact and the incentives to create impacts has only just started. This must be a top priority for the leadership

[1]We acknowledge the financial support of KTH though President's decision UF-0913 and VINNOVA through grant 2012-03899.

team headed by the President. Special resources must be provided for instance through the School contracts.
- The time perspective is matching the recently started work on the national Swedish system for research funding. It also matches the time frame for our fund raising campaign.
- There is a substantial potential to be realized but also pitfalls of double-counting and difficulties of discerning long-term effects. The recent evaluation of the effects of the first wave of Swedish competence centres indicates that the long-term effects might be larger than anticipated. There is reason to compare this observation to the long-term effects of basic and applied research even in terms of citations.

Broaden the Concept of Impacts

- We must continue to take initiatives concerning the economic and social impacts of research at KTH. The main reason for this is that the effort to gather information in the field in association with the RAE 2012 must not be a one shot event.
- The initiatives should include incentives given to the Schools to benefit from being systematic about impacts. It is essential that this work is directed from the top research leadership level and that the work is properly resourced.
- In this context, we must broaden the concept of impact from being exclusively directed towards research to also consider impacts of education related to research.
- The most evident addition is doctoral education which was covered to a rather limited extent in the RAE 2012. If the concept of impact is taken seriously one should also handle impacts of KTH graduates at large for economic and social development.

Organization and Communication

- We must immediately make more professional the impact work area as a task for KTH business liaison through formulation of tasks, delegation of responsibility, and expertise recruitment, which in the main implies that the work will have to be done by internal staff.
- In the context of reporting, we must increase our knowledge of the role of centres of various kinds as instruments to create economic and social impacts of research. This will have clear consequences for the mission of platforms and strategic research networks. In view of the importance for impact creation the role of these centres is clearly underestimated for the moment.

- It is important that the vice rector function associated with the area is given additional support. This support must be given on a sustained basis to create a lasting impact within KTH.
- We must develop our knowledge and assessment of how to communicate our economic and social impacts both in terms of self-reflection and as a strategy to create impact by that activity itself. In the same way as with scientific communication this is a shared responsibility between the central level and the individual research groups.
- In this context, we must broaden our communication of achievements from having a focus on short-term media novelty information to include a stronger focus on in-depth information on how results have been attained and how they have been used by other actors.
- Our impression is we leave to the media to give their picture of KTH while it would be strategically advantageous if KTH would be more active in promoting its own picture of what we do to the general public.
- It is foreseen that a catalogue of impact cases will be as natural for yearly reporting as publications. The Research Office will have a central role in designing and monitoring this work.

Collaboration and Learning

- The impacts we produce are contextual. We create them with a starting point in the economic structure of the Stockholm region. Academic research is the first global sector of the economy but economic and social effects of that research are definitely not.
- We must participate actively and proactively in the national dialogue about impacts of higher education institutions. The work to do this has been intensified through the current project via initiatives towards VINNOVA and other government agencies. It is important that this work becomes a more central concern for the Schools.
- In this context, we must find ways of actively learning from the experience of other Swedish and international universities. One of the most difficult challenges in this regard is finding a sustainable correspondence for economic and social impacts of the notion of field normalization in scientific output.
- In this work there is rapid learning to be done by collaboration with the UK in its work on the REF 2014. First contacts have been made and KTH has taken a leading role in the VINNOVA work.
- It is essential that KTH continues to deepen the understanding of how impacts are created, and assessed. From this perspective the recent development towards engaging in research in the impact field, and using the KTH experience as basic data, is highly commendable. We have several research environments at KTH where such research is ideally placed.

Measurement and Quality Assurance

- We must deepen and give a further profile to the work we do regarding collaboration through bibliometric analysis, analysis of financing patterns, and other quantitative measures of impact. This implies among other things a continued dialogue with the Schools on collecting and quality-assuring further impact cases.
- We must realize that the work on impacts performed during the RAE 2012 process to the overwhelming part focused on the assertion of impacts rather than the verification of impacts. Such verification would have implied a much larger emphasis being placed with the perception of economic and social benefit among the partners of KTH.
- This does not mean that the many cases put forward have not led to direct and indirect effects. It just calls for further systematic verification across the field of technology areas. A simple example of illustration is the clear distinction made in the UK system between patent generation and patent use.
- We must also realize that the selection of measurement of impacts put forward during the RAE 2012 process is by no means unquestionable. In fact, evaluations of economic and societal impacts of our research is performed all the time both as a part of our regular reporting of projects and in the concluding phases of research programmes. Much can be learnt for the work done in other universities, and in other countries, in this regard.

Following Up the RAE 2012

Impact Statements

A systematic analysis has been done of all the 94 impact cases provided. Descriptions of impact statements vary markedly both as regards process and content. Therefore, attempts have been made to collect information on cases prepared but not submitted to the RAE.

Impact statements have been scrutinized to assess the most common lines of argument. A majority of cases mention words related to success factors for the research environment in question. A general observation is that the impact statements generally focus on economic implications of research.

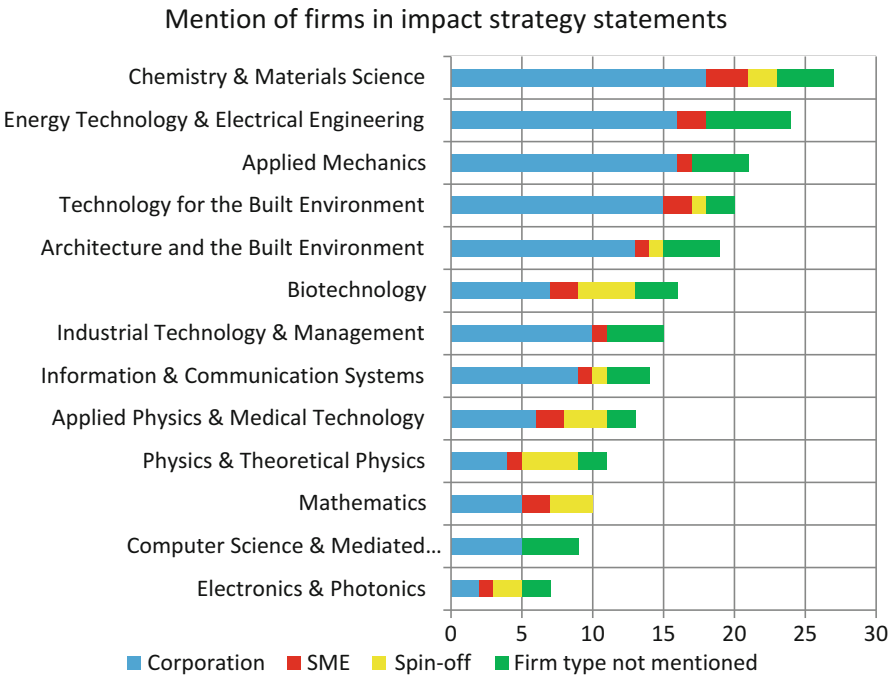
Impact statements should be an essential part of the development plans of each School (and at the UoA level) to show the degree of priority of the cooperation goal. Some work has been done here. Much more work in this vein will be performed in the meta-evaluation underway commissioned by the Faculty Board.

Words mentioned in strategy	Research fields (13)	Cases (94)
Success	12	39
Environment	11	37
Market	12	35
Stockholm	10	33
Patent/patents/patenting	12	26
Innovation	13	23
VINNOVA	9	20
Spinoff/spin-off	10	18
Government	7	17
Ericsson	9	11
Chalmers/CTH	6	9
Scania	5	7
Stockholm University/SU	1	2
Incubator	1	1

Strategy statements include mention of firm names to a varying degree. For some technology fields firms are formed giving rise to spin-offs and SMEs whereas other research groups mention cooperation with large corporations to a much larger degree. Large firms are mentioned most frequently for the technology fields oriented towards basic engineering areas.

SWOT-Analyses

All UoAs have performed SWOT analyses the majority of which have been rather static in nature. In 40 out of 47 cases there has been a reasonably complete SOWT-analysis according to the standard model. Seven of the UoAs have elaborated their competitive context in a thematic fashion describing the situation in terms of financing, science, and organization. We have assessed all of them but not performed a deeper comparative analysis. Most of them have focused on opportunities rather than threats and challenges. It is more common to use challenges as a heading for that part of the SWOT comprising both weaknesses and threats. Evidently, it has been seen as less inspiring to provide the international peers with strengths and opportunities than the reverse.

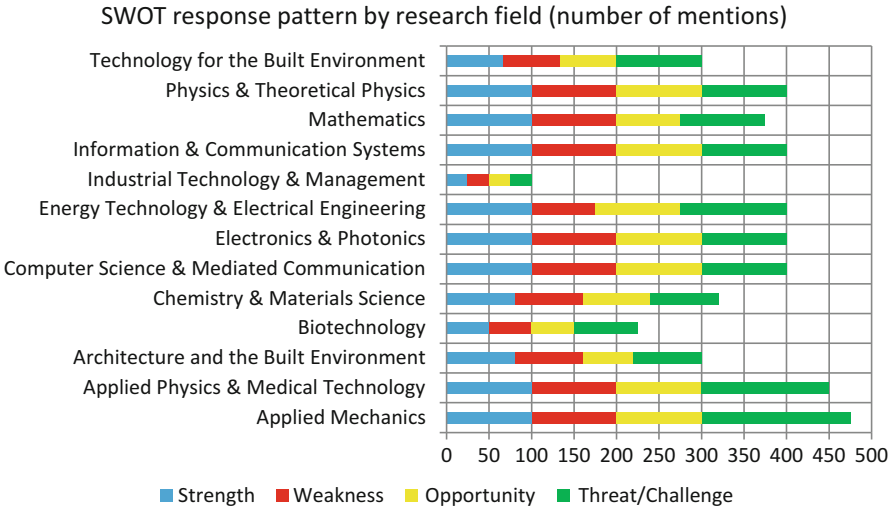


Some UoAs have used them for qualified strategic analysis with the UoA comprising industrial production and fluid mechanics as well elaborated examples. Some UoAs have detailed theirs SWOTs by research group within the unit.

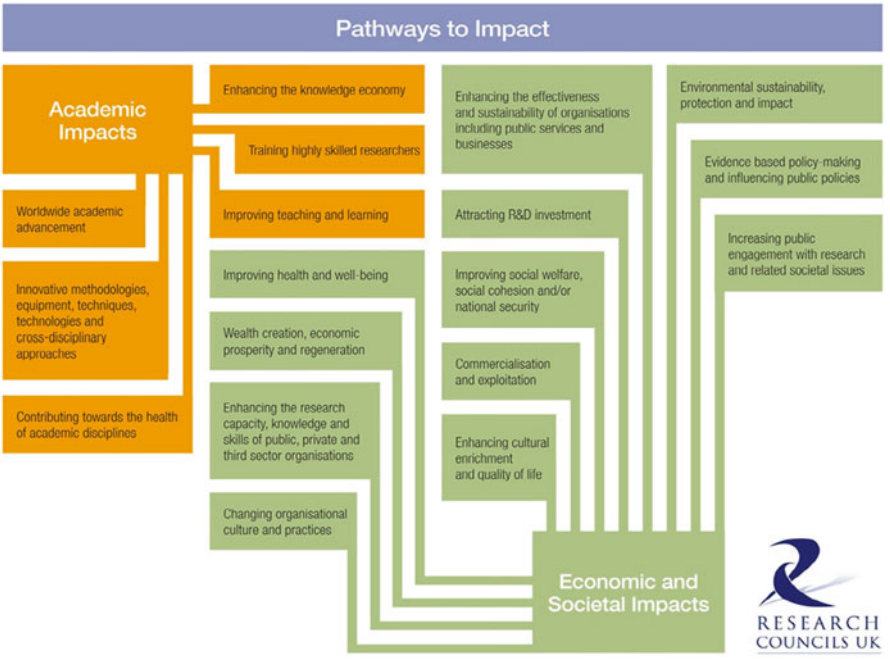
Pathways to Impact

We have used the model developed by the Research Councils UK as the overriding way of making our analyses systematic. The model used in our RAE 2012 has some inspiration from that but it was not the overriding scheme. The reason was partly that the UK scheme covers any university while the one used in the RAE 2012 was somewhat adapted to a technical university.

Source: **Hope page of Research Councils UK**



The model used in the RAE 2012 regarding economic and social impacts is given below.



When working further on impacts to provide cases for the first part of the follow-up projects, to present a selection of typical impact narratives for successful cases, we used the following scheme. This is also the way the cases were organized in the final report from the RAE, see KTH (2012).

Recommendation 1: The two criteria for assessing impact, reach and significance, are appropriate and should be broadly applicable across all panels without a hierarchy of spatial reach.

Recommendation 2: Broad generic definitions of the impact profile are workable across the range of disciplines.

Recommendation 3: A distinction should be made between those case studies that are not eligible and those that fail to demonstrate significant impact.

Recommendation 4: Panels will not make comparisons of the impact of research units submitted to different areas, nor provide a mechanism for comparing the relative impact of disciplines.

Recommendation 4: Case studies should explain clearly how the research contributed to the benefits, regardless of whether this was direct or indirect and whether there were other factors beyond the institution's influence:

Recommendation 5: It should be the responsibility of submitting institutions to justify the quality of underpinning research and case studies should only cite research directly relevant to the case.

Recommendation 6: A timeframe of up to 15 years between the impact and the underpinning research is broadly appropriate, provided that the institution remains active in the area of research.

Recommendation 7: Case studies should normally include details of key users who could potentially be contacted, and/or references to other independent sources.

Recommendation 8: It is essential to include research users in all panels to provide a balance of expertise in assessing impact and to ensure stakeholder confidence in the outcomes.

Source: REF (2012)

There is a strong need to elaborate the criteria for putting together impact case studies, to assess their eligibilities, and to develop criteria to assess the cases in a comparative fashion. The recommendations listed above have been put forward as a part of the ongoing REF 2014 project in the UK, see for instance Rosenberg (2013).

In the REF 2014 the following categories of impacts have been selected for the universities to choose from. Any particular case might have elements of several of the dimensions. It should also be noted that the scheme below is quite useful in singling out those case descriptions which do not represent economic and social impacts but rather academic ones. Some of the impact cases put forward in the RAE 2012 would not have qualified in the UK scheme but would rather have been seen as academic impacts.

Source: **REF (2012)**

Impact Cases

A large amount of work has been put into selecting a proper mix of cases for the KTH impact publication. The collection of extra cases has been done in two ways, through lists submitted from the individual UoAs and through dialogue conversations with Schools and UoAs which have been used to decide whether the cases were appropriate for publication in the KTH impact case publication catalogue. A listing of the cases is provided for information in an appendix.

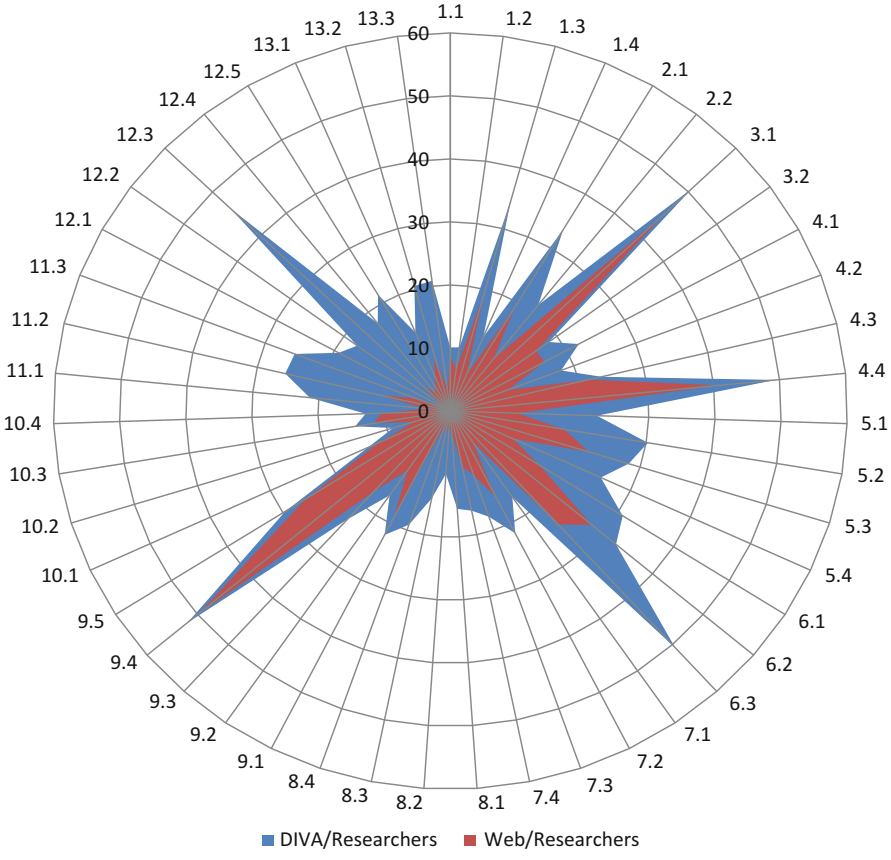
This deepening of impact cases does not necessarily follow the same logic as the selection of cases for the RAE 2012 process. As least two further perspectives need to be added. The first one is to attain a reasonable coverage across the Schools of KTH and to select those cases which have been brought through enough stages in the impact generation process. A further demanding part of this work is to verify that impacts have indeed been created along with the assertions in the case descriptions. This work has been done by persons with long professional experience in the field. Such experienced persons are important carriers of quality in the impact work process.

The recommendation from this part of the work is to formulate an impact policy for KTH and in addition produce an action plan in a process similar to the one used when forming the quality policy and the quality action plan.

We should also continue to secure impact path statements through a combination of methods. The main method for the moment is to use the narrative method from the humanities as a way to bring the chains of impacts of KTH research to life in industry and society.

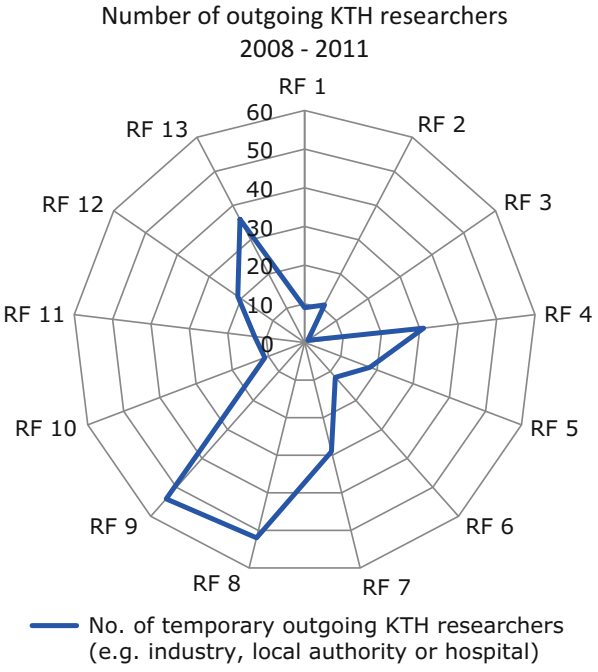
Bibliometrics

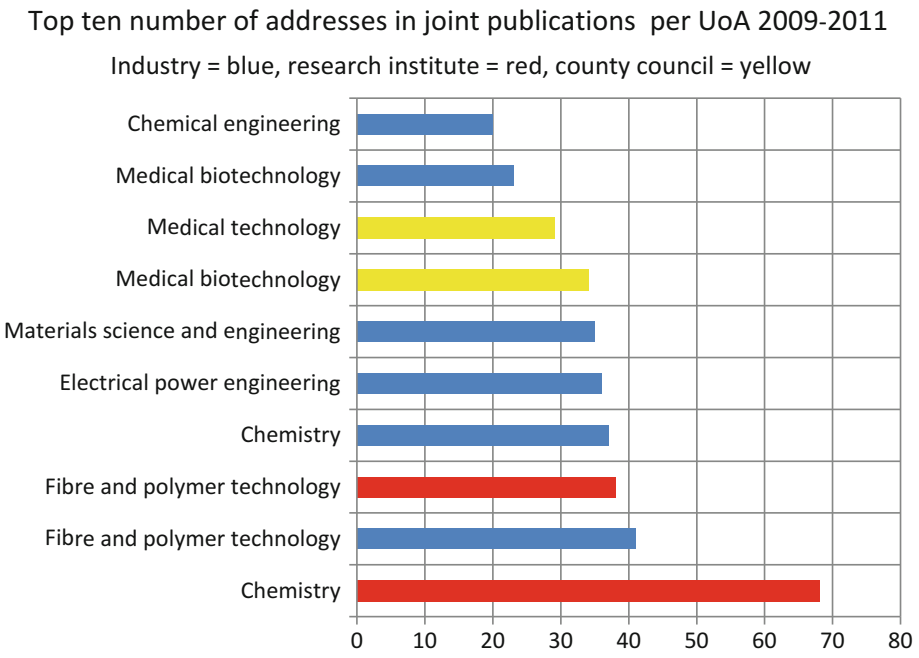
The follow-up has contained a sub-study to illustrate the use of bibliometrics to get a grip on the impacts produced by KTH research. Several methods can be used to do this, for instance, to check for names of firms appearing in the case descriptions, and to show which Swedish or international firms and organisations that are present in the publications of KTH. A first picture of new knowledge on the publication profile of KTH is given below where publications within Web of Science per researcher are combined with publications in other channels than Web of Science journals. This extension more than doubles the KTH research output per researcher.

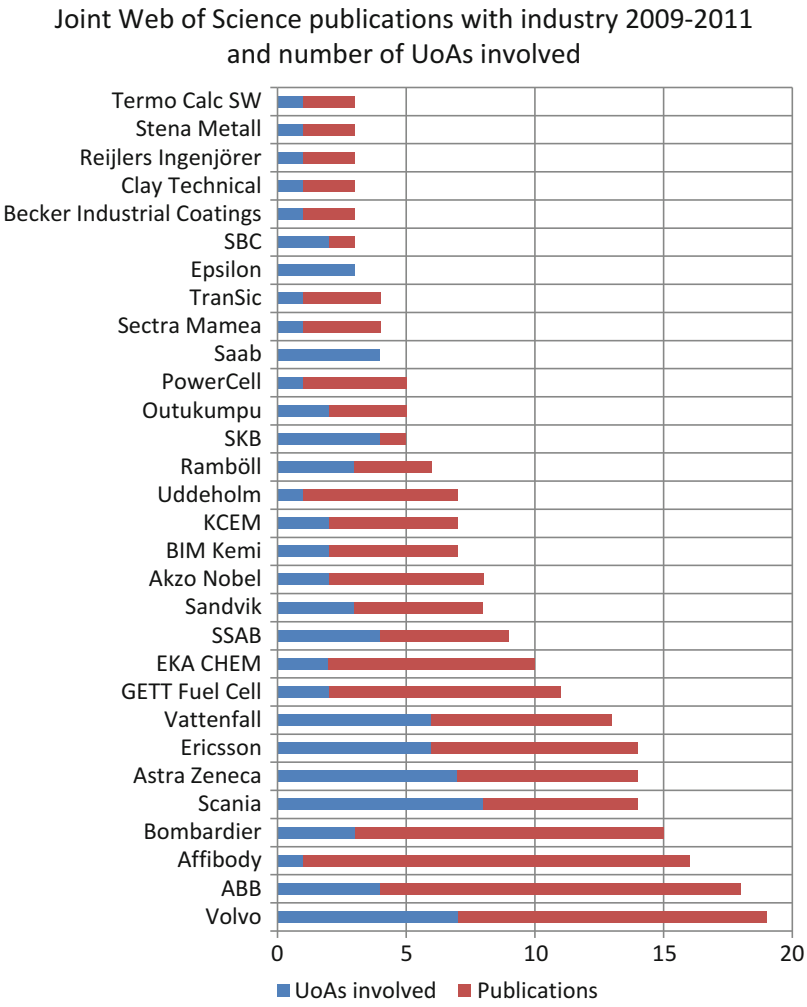


The pattern of industry publishing varies across the UoAs of KTH. For instance, in some areas as the fibre and polymer areas such joint publishing is common. The recommendation is that we should continue analysing the impacts patterns using statistical methods. Such work is particularly useful when trying to follow impacts in the longer term.

A brief comment is that industrial firms, research institutes and County Councils are the most common organisations that show up in the listings of external collaboration in publishing. Another comment is that a large number of industrial firms are not engaged in any collaboration with KTH researchers giving rise to joint publications. In this analysis, we have assumed that those industrial firms which have more than a single publication yearly with KTH researchers represent continuous cooperation. The same analysis shows that there are some UoAs which do not have any continuous cooperation with Swedish industry measured in this way, see also the mobility map extracted from RAE 2012 data below. The notation in the graph represents research fields which are given in full text in conjunction with the SWOT analysis tables.




Top ten number of addresses in joint publications per UoA 2009-2011
Industry = blue, research institute = red, county council = yellow
Chemical engineering
Medical biotechnology
Medical technology
Medical biotechnology
Materials science and engineering
Electrical power engineering
Chemistry
Fibre and polymer technology
Fibre and polymer technology
Chemistry
0
10
20
30
40
50
60
70
80



Using address data to trace out joint publication we find that UoAs of chemistry, fibre and polymer technology and medical biotechnology seem to be most active with joint publication activity with different external actors. We have not found any strong correlation between industrial firms mentioned in the cases and the collaboration schemes in terms of joint publications in the current exploratory analysis.

Some Recommendations

The recommendation is that an RAE exercise should be complemented with an EAE exercise at a suitable point in time. The most important reason for this recommendation is that as soon as economic and social impacts of university activity are

brought to bear the productivity impact of university graduates cannot be disregarded. The unanimously mentioned prime impact of universities is persons with high-education skills who leave universities at different levels of education.

The next phase in the internal quality work related to RAE is to determine how the results are to be transformed into incentives to increase efforts both in academic terms and terms of economic and social impacts. Ideally, any bonus system to affect funding allocations should be directed towards economic and social impacts if that is the direction to prioritize. In general, it is important to increase the understanding of how the three quality dimensions of academic excellence, excellence in acquiring economic and social impacts, and excellence in creating a research environment are related to one another.

Do we have the right institutional structure to create impacts through our research? How should we combine working with platforms, scenarios, policies to increase researcher status, and being proactive and creative in materialising latent potentials?

Our recommendation is that KTH should deepen and give a profile to the internal work on bibliometrics, financing streams and other indicators related to impacts. This implies, for instance, a continuing dialogue with the Schools to regularly and systematically collect cases.

The strong recommendation is to continue and further develop the work on following impacts through statistical and econometric methods as a complement to working with cases. This is particularly important in studies of longer term impacts are to be performed.

It is important to have a special documentation of how we wish to continue the work with bibliometrics and other studies of academic impacts of university research. It should be noted that the impact scheme presented in the second part of this report also widens and systematizes the perspective of what are academic impacts. This work should be given priority also as a part of general quality work.

Feeding Back the RAE 2012

Internal Dialogues

Six dialogues have been performed with KTH researchers who submitted materials to the RAE 2012 especially concerning economic and societal impacts. The response from the faculty at large and from the School Deans and Vice Deans has been well above expectations. There have also been some further follow-ups with Schools which have wished more concrete inputs into their internal planning processes.

The summary recommendation from these dialogues is for the leadership level of KTH to continue to take the initiative in continuing the collection of basic data on collaboration. The peer review group visited KTH in June 2012. The current part of the year contains the follow-up cycle when achievements are summarized for the earlier academic year and plans are made for the coming year. An obvious

recommendation is that the School dialogues should contain a substantial discussion on how the Schools have continued their work in making impact a natural part of the academic discussion at the School level.

The further recommendation is to continue to create internal incentives to systematically collect evidence of impact. There is a risk that the effort made at the time of the assessment preparations for the international peers becomes one-stop event at the research group level. Since the methods to work with cases are not fully developed there is a need for further experiments which go substantively beyond the work put together for the KTH alumni publication. It seems logical that a working group should be composed, headed by the vice rector for research and coordinated by the Research Office, where Schools are represented together with experts from the Research Office, ECE School, from the KTH Business Liaison Office. We must aim for creating incentives for proactive learning rather than enforcing reporting schemes that do not seem warranted for the individual researchers.

A further suggestion is to design a course in the field of creating, assessing and measuring economic and social impacts to be offered to students at advanced level, research students, and junior faculty. This effort might be combined with presenting the publication on KTH hot cases also to this staff category as well as to alumni.

External Dialogues

Two external dialogues have been performed as a part of the study. The first one consisted of representatives from government, funding bodies, and industry. The second one had participants from a set of other universities.

The summary statement of the results of these two dialogues is that the first one was somewhat more constructive than the other. There was a positive interest among the external participants to learn first-hand about the work done by KTH in focusing on this part of research quality. Positive reactions were reported by VINNOVA in particular, for which the study was a timely input into the process they had just started in coordinating the national work in the field. Positive reactions were also reported from the representatives of the Swedish Research Council who were also just starting their part of the new national project on finding a quality based system for research funding allocations.

The reaction from representatives of large companies was more hesitant than expected. A likely reason for this reaction was most likely that the question of research assessment exercising in general in the main a university-internal question for them. As soon as the perspective shifted to collaboration between university and industry the interest increased markedly. There were no representatives for small and medium sized firms present in the dialogues. The expected reaction from them would be one of less concern with the general matter of academic excellence in research. The role of SMEs if the collaboration perspective is introduced becomes much more crucial.

A strong recommendation from the dialogues is to work hard on getting the industry partners into the loop of inquiry especially as a part of the strategic alliances. Another observation is that the KTH affiliated faculty with our adjunct professors as the core group should be much more activated.

It became clear from the dialogues that the work on impacts must have a strong connection to external actors to become relevant. KTH activities are generally evaluated and compared to other universities when asking for funding. Our work is also assessed in evaluations concerning excellence centres. These evaluations are looking at our achievements with an outside view. The RAE 2012 did the same thing from the insider's view of KTH. These two perspectives need to be merged in the coming process.

Two other facts also became clear from the external dialogues with other universities. The first one is that several universities have been testing their own models for collaboration with industry and government. Two examples are Mälardalen University and the Swedish University of Agricultural Science. The schemes set up by those are good starting points for further discussions on similarities and differences. The other observation from the dialogue was that it does not seem likely that other universities are planning an effort in the RAE tradition in the foreseeable future. The period is regarded as too short from the earlier ones. There are also expectations that the VINNOVA-led work will lead to new incentive structures and uncertainty seems to be treated by a wait-and-see strategy.

Some Recommendations

A general observation is that the dialogues should be continued as a part of a task that KTH would like to develop in conjunction with the VINNOVA announcement of grants to study university-industry collaboration from the engagement with society point of view. Such initiatives have already been taken.

Another recommendation is for KTH to take the initiative to work with other universities in defining impacts and impact dimensions. The dialogue made it clear that other universities had a host of useful experiences to share. This was the case for both large universities and smaller ones. It was especially acknowledged that the KK Foundation had several ongoing evaluation projects of high quality and high relevance for future work.

Contextualising the RAE 2012

Role in KTH Development Work

The current work group has been a temporary nexus in a number of KTH activities relating to impacts of research. It is essential that this temporary work should be transferred to tasks and work missions formulated for the personnel of the KTH Research Office as well as for personnel of the KTH Business Liaison Office.

The division of labour is obvious. The focus of the responsibilities of the KTH Research Office must be with the academic impacts of research including the cooperation among universities and the cooperation with industry and government in the research excellence centres and through the platforms. The focus of the responsibilities of the KTH Business Liaison Office must be with the instruments and cooperative schemes for engagement with industry and society.

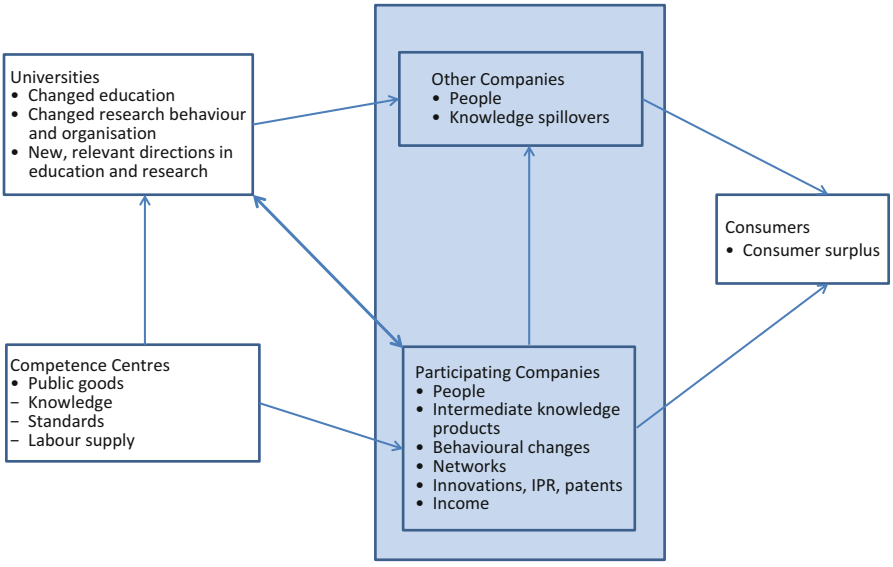
The recommendation is that these tasks will have to be formulated over a long enough time period to match the ongoing national development work. It also needs to link with the ongoing fund raising campaign and other elements of the emerging KTH model for external cooperation.

It might be added that the time is now ripe for a review of the KTH innovation policy. The innovation activities have been going on for a number of years in a given format. There is now a national innovation policy, and regional innovation policies are being produced, also for Stockholm, in which KTH experience has played a substantial role. The suggestion is that this work is given academic priority in the near future.

Impacts from Competence/Excellence Centres

Results from the preliminary study of the impact generation emerging from competence/excellence centres should be pursued further. It is important that KTH is proactive when it comes to the external evaluations of the economic and social impacts of those centres that go beyond what could have been achieved without that organisational structure. Is it only the money we have been after or is there a further set of values from the research cooperation in theses constructs?

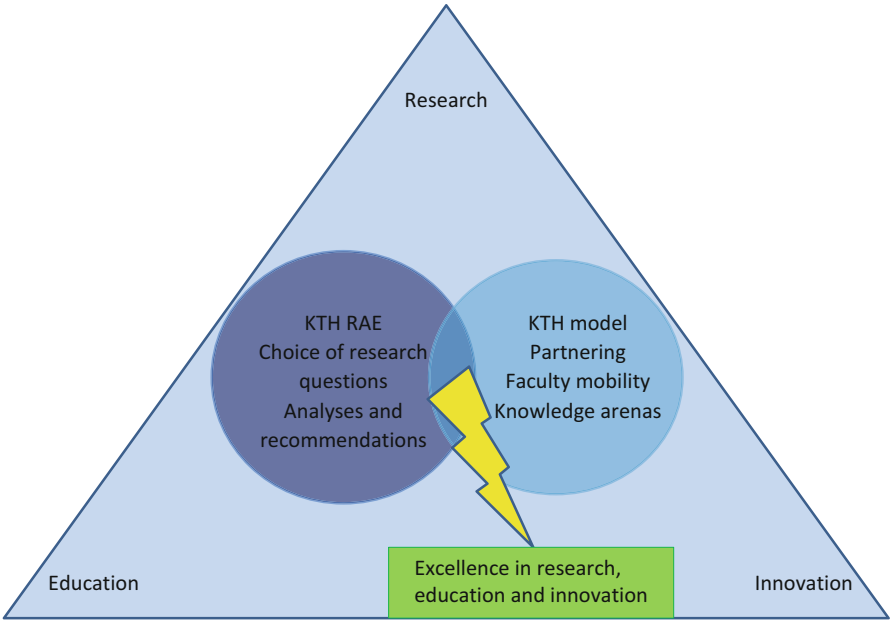
Source: **Adapted from Arnold et al. (2013)**



The result of the Technopolis evaluation of the NUTEK competence centres, see scheme of analysis of hypothesized impacts above, Arnold et al. (2013), in fact defines a new or rediscovered role for KTH as a long-term custodian of knowledge amassed in temporary arrangements of cooperation. One of the most important long term effects is the training of new researchers. The careers they choose early on in the career seem to be determining their long term career paths. The new professors of KTH will have to be trained in such open contexts.

Some National Development Initiatives

Work by VINNOVA, the Knowledge Foundation, the Swedish Association of Engineers, IVA and other universities is being planned and launched during the first part of 2013. It may be noted that no other universities than KTH seems to be engaging in full scale follow up studies in relation to earlier RAE projects.



KTH will be engaged in two specific feasibility studies in the VINNOVA context. One such study relates to the further deepening of the so-called KTH model for External cooperation. The other relates to a comparative study of models of external cooperation among ten Swedish universities in the context of the knowledge triangle.

New materials will also be available in the autumn of 2013 from the ongoing evaluation by the University Chancellor Office on engineering degrees in Sweden.

Some International Perspectives

It is of fundamental importance to systematically learn from the ongoing work with the REF 2014 in the UK university system. There are lessons to be learnt of both theoretical and practical nature. They relate to resource use, work organisation, and impact model schemes. There is no expectation that all research has made an impact beyond academia. There is also a recognition that there are time-lags from research to impact and there are many ways in which research can lead to impact so that no presumed model of research-to-impact can be expected. A case study approach will allow academics to explain impact in their own terms using quantitative and qualitative evidence as appropriate to the case being made. Underpinning research must meet a quality threshold and the research contribution not the attribution is focused. Assessment is to be performed jointly by academic and user experts.

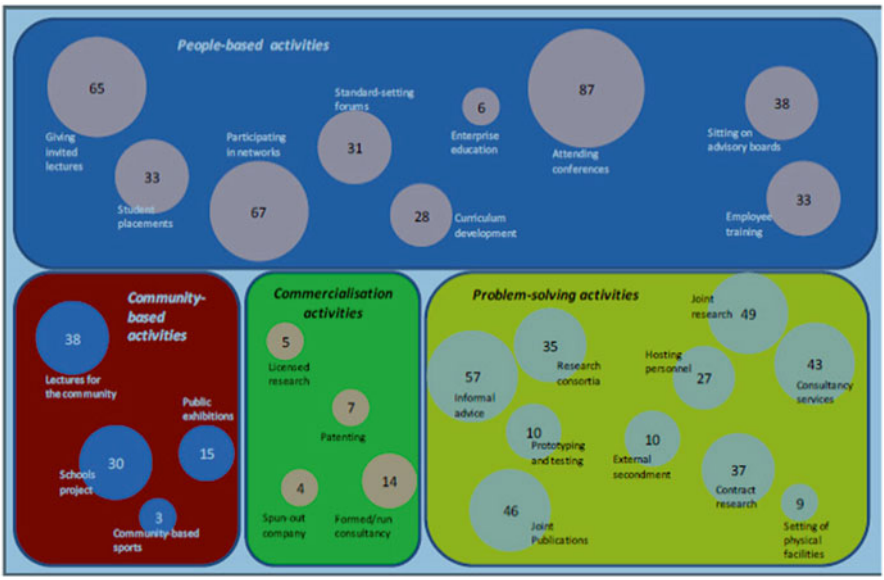
First-hand experience from the work at Cambridge University conveys the impression that the level of ambition is very high. Essentially, a correspondence to the Web of Science versus other publication channels is emerging in the discussion. Only the top research will be selected for case studies. These cases studies will be strictly quality assured within the university before they are brought to the national system. The expectation of further funding is low. On the other hand, the expectation seems to be that results will be signalling excellence in creating impacts will be the main outcome of the assessment.

Impacts from activities at higher education institutions present themselves as private returns to the individual attending these and as social returns from the fact that the institutions generate productivity spillovers. The impacts can be assessed within the market part of the economy as well as in the non-market part, basically the public sector.

Source: **Development of illustration in MacGregor (2011)**

	Private returns	Social returns
Market impacts	Higher wages Higher employment	Productivity spillovers from university R&D Productivity spillovers from graduates to non-graduates and other graduates
Non-market impacts	Better personal health, improved longevity and child health Better educational acheivements, enhanced cultural consumption and happiness	Acceptance of rule of law, human rights and political stability Democratisation, civic society and lower crime rates

Note that the market impacts from the activities at universities are generally more tangible and higher from education than from research. R & D effects are more long-term and are often more difficult to contain within the region or country. The productivity effects of well-educated university graduates follow the career patterns of these individuals.
Source: **Hughes et al. (2013)**



The figure emphasizes the scope of academic pathways to impacts with external organisations in the UK system. The data arise from a series of consecutive RAEs in the UK analysed by Hughes et al. (2012). Pathways based on commercialization constitute a small part of the pathway landscape. Involvement is heavier in problem solving and people based modes of interaction. The UK study exhibits the patterns of interaction by propensity to acquire external grants. Academic networking and presence in advisory boards are more common among those researchers who are skillful in grant acquisition.

The EIT work is developing a set of indicators to monitor the performance of KICs during and after their completion. There are cross-KIC scoreboards involving core KPIs Jointly developed by EIT and the existing three KICs. The following set of indicators are mentioned in current presentations:

- Attractiveness of education programmes
- Number of new graduates
- Number of business ideas incubated
- Number of start-ups created
- Knowledge transfer/adoption
- New or improved products/services/processes launched

The importance of these key performance indicators stems in essence from the ambition to create a joint system across Europe.

Some Recommendations

The main recommendation to the KTH leadership is that resources must be created internally and in combination with external actors to continue to learn from the international experiences. Several existing networks that KTH is engaged in can be brought in, for instance, Cluster and/or Nordic 5 Tech. This learning process must be brought to faculty through different methods, for instance, through special courses for persons in the different steps of the tenure track system.

It is also strongly recommended that knowledge trips continue to be made both among academic staff and among persons holding expert functions within the administration. KTH should continue to take advantage of the contacts created with leading German, Swiss and UK universities, for instance, TU Munich, EPF Lausanne and Cambridge University.

Reflections for Future Work

We have come to realise that the work done is only a beginning of a long-term commitment to dig deeper into a complex issue for the university system. While there is a long tradition, and a number of supporting research studies, on the academic impacts of research and the economic and social impacts of higher education the question of economic and social impacts of university activity as regards collaboration is still under-studied and under-researched.

It is important not to end up in the same dead end discussion in this field as has been the case for some of the use of bibliometric investigations as indicators of academic research excellence. In that context some leading researchers in the strongest research environments criticised the quality of the work as well as its relevance. The criticism also extended to some of the persons involved in the investigations. The solution to this question is systematic and experience-based knowledge creation through peer reviewed expert reports, thesis project at Master, Licentiate and Doctoral level and indeed research.

Some such research is ongoing using external funding but it is also important that KTH puts in research resources from its internal grants to finance research studies. A workable idea is to have people working within KTH becoming industrial PhD students in-house. This path has been followed for instance concerning education, and in systematic quality work.

Currently, KTH has attained a special role in Sweden and internationally through the decision to perform one of the most complete reviews of its research ever produced among Swedish universities. It is essential that KTH continues to work on creating stronger links with other leading universities in Europe, USA, and Asia, in this field. It is in fact even more strategic for the future research quality that these international linkages among universities are developed further than focusing on university-industry cooperation.

In this context, it is essential to contribute to developing the strategic work of the Swedish Research Council on forward-looking strategies of creating research impact. This work in as important as continuing to develop our schemes and instruments of cooperation to create economic and social impact. Impact creation must be an integrated aspect of our future research.

Appendix: KTH Cases Selected for Deepening of Impact Narratives

Technology field	Case name	Impact type
Mathematics	RaySearch	Health
Mathematics	COMSOL	Economy
Mathematics	EFIELD	Economy
Physics & Theoretical Physics	Radioactive orchestra	Society, culture and creativity
Physics & Theoretical Physics	GROMACS	Economy & practitioners and professional services
Physics & Theoretical Physics	Medical images	Economy & practitioners and professional services
Applied Physics & Medical Technology	Micro dose mammography	Health & economy
Applied Physics & Medical Technology	Tissue doppler imaging	Health & economy
Applied Physics & Medical Technology	Micro Delta AB	Economy & environment
Energy Technology & Electrical Engineering	High performance electric drives	Economy & environment
Energy Technology & Electrical Engineering	Smartgrid policy making	Public policy and services
Energy Technology & Electrical Engineering	KTH centre for heat pump development	Economy & environment
Electronics & Photonics	TranSic	Economy & environment
Applied Mechanics	Rupture risk assessment of aneurysm patients	Economy & health & practitioners and professional services
Applied Mechanics	Laminar wing design	Environment
Industrial Technology & Management	Inclusive design for the life-long dwelling	Public policy and services & health
Industrial Technology & Management	Gender equality work at Volvo Group	Society, culture and creativity
Industrial Technology & Management	Materials for the future from Swedish forests	Society, culture and creativity

(continued)

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Technology field	Case name	Impact type
Chemistry & Materials Science	Novel polymer concepts in full scale production	Health & economy
Chemistry & Materials Science	New material concepts for forest raw materials	Health & economy
Biotechnology	Parallel sequencing and high throughput biology	Economy & health & practitioners and professional services
Biotechnology	Pyrosequencing DNA	Economy & health & practitioners and professional services
Biotechnology	The human protein atlas	Economy & health & practitioners and professional services
Technology for the Built Environment	The Stockholm congestion charging system	Public policy and services & environment
Technology for the Built Environment	Public transport service reliability	Practitioners and professional services
Architecture and the Built Environment	More science-based chemicals policies	Public policy and services
Architecture and the Built Environment	The livable city	Public policy and services & practitioners and professional services
Computer Science & Mediated Communication	Scandinavian tradition of collaborative design	Public policy and services

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Chapter 6
Productivity Versus Creativity

Eskil Ullberg

"If you want to be creative, you should not go where the money is, but do what you believe in.", H. Rohrer, Nobel Laureate in Physics, Nano technology pioneer and inventor of the scanning tunneling microscope while at IBM.

Abstract The high cost and quality issues of higher education in many countries need a solution. What is being proposed, and acted on, appears by and large to be the nineteenth century industrial paradigm of productivity to achieve such efficiency, technology being the important factor in cost reduction. However, how does this need for efficiency through productivity–doing *more* of the same with fewer resources–affect *trust* in the universities in teaching future generations, i.e. *transferring* extant knowledge, and especially *creativity*, i.e. discovering *new* knowledge, developing new solutions, and expressions of art? In particular, the economies of scale thinking in producing "more" versus creativity in producing "new" are elaborated on. Creativity and productivity are both individual and social concepts however creativity is much more at the individual and small team, personal exchange end and productivity on at specialized, large scale, impersonal exchange end. A key point is that creativity cannot be easily measured in a continuous variable–a solution is either creative or not–and measuring productivity in the economic sense–on the margin and as a percentage change–appears insufficient as a guide to higher education. It turns out that universities my not only loose trust in its mission to teach and do research–as financial returns on (or increasing funding of) universities do not appear to translate into comparable social gains–but *creativity* is also lost, creating more questions on the use of standard productivity measures on higher education. This may reflect a loss of purpose in higher education, abandoning the thought of solving problems.

The article proposes to include *individuals'* creative characteristics in the thinking on socio-economic productivity in order to sustain creation of "new", in a better balance with "more", to avoid the crises in higher education. That would require a change in

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financial and operating structure. The problem appears to be common across western societies and may therefore be considered a core issue in internationalization and competitiveness for these societies in a global economy. The role of the state in higher education must be reconsidered, in order to have creativity back in the sciences. Patrons with a vision for "searching for the truth", funding that which is "new"–by means of diverse structures like networks, projects, etc.–may therefore have an important role for creativity in science.

Introduction

Creativity can be seen as an *individual* concept that organizes ideas and knowledge in a novel and original way.[1] However, channeling the creativity into productive use is a *sociological* process as well, where the creative person interacts with others to make the creative work productive (being careful not to destroy the novelty or originality). Breakthrough academic research institutions, appear to be run by people with unusual ability to take in the world ("high cognitive complexity"), managing small *interdisciplinary* teams and structure others' work, such as in broad themes, to enable and realize the results of the creative process by finding solutions to (scientific) problems (Hollingsworth 2007, 2009). These institutions can be seen as creative *organizations*. To be creative, or innovative, it has been suggested that "extraordinary vision"[2] may be required. It is goal oriented – even purpose driven – by that vision. The point here is that the individual perspective and (often) small team leadership appears critical in channeling this "most striking human characteristic": creativity (North 1981). Creativity does not appear to be a large scale manufacturing process of "more", but more of a small scale process of "new". It also requires a social (and economic) structure that gives the individual incentives to be creative, thus the structural element is important in developing creative solutions and turning these solution into productive use. The view of man is thus different from a "worker", without much individuality, and more an individual "creator" of new things. Including such processes in the thinking of higher education today appears of outmost importance.

Similar processes in the business world include people and teams like: Steve Jobs of Apple (notoriously creative and single-minded in his implementation of (his and others') ideas), Edison (relentlessly pursuing the light bulb by a vision of the carbon thread he in the end produced after some 1,500 experiments), fashion and industrial designers (work closely with their production teams), Michelangelo's art (master and students).

[1] This article originated after the second workshop out of a discussion with Nils-Eric Sahlin at the University of Lund, whose input on creative environments was instrumental in arriving at this article.

[2] Ref. to presentation by E. Phelps at the World Bank 2013, discussing "Mass flourishing".(Phelps 2013)

Productivity, based on rationality is also an individual and sociological concept but the preeminence of the individual's creative process appears much less pronounced, reduced (in theory) to the selection between extant alternatives (choices) where the price variable is critical in coordinating activities (integrating dispersed private information/knowledge). In economic terms, when people choose, they appear to maximize value, or profit, given the institutional norms or rules (as in institutional economics). They make choices on the marginal, short-term value, not long-term value. This leads to the concept of productivity, in particular in terms of economies of scale to produce (products) or perform (services): more of the same at a lower cost, also with marginal changes to process and product/service. The future, creative, dimension is simply not in there.[3]

The concept of mass production of things is now with some success being copied for services and the "knowledge worker",[4] but when people interact with other people the sociological dimensions overshadows the systemic dimensions of a (rational) manufacturing system. The same productivity gains achieved in manufacturing – from raw materials to products – appear more difficult to achieve for services (how do you measure "customer satisfaction" in a meaningful way for productivity?). What you manage are people–using and creating knowledge–and this "raw material" cannot simply be extracted with more technology. It is fair to say that the same productivity gains have not yet been found in services as in manufacturing. In higher education, the worker is a "knowledge creating and using worker" and thus has these problems of productivity that are social, making an only economies of scale approach difficult. In economics, Baumol's decease identifies this characteristic. The problem is that today, industrial productivity measures applied to universities, such as student output, etc, appears to be the norm in where most universities are heading, incentivized by cost restraints and "more (of the same) is better than less" thinking. This thinking appear to turn many education institutions into a manufacturing type business (encountering the unsolved service logic). Productivity has been studied over at least a period of 200 years. The institutional approach, based on property rights has been studied by economists mainly since the 1950s. Creativity however, appears understudied in comparison, in particular its relationship to (rationality and) productivity.

Creativity appears to be outside the traditional analysis of institutions, based on a rational approach, whether in turn based on choices, transactions, or contracts. Institutions that promote creativity as well as productivity – emphasizing the individual side and the sociological (and management) side – is then a paramount task for anyone attempting to work with higher education today. It is necessary to experiment to discover the new, but there also has to be a creative step with each new experiment. Institutional learning may come closest in implicitly capture the output of creativity (in terms of norms and rules), but perhaps less its characteristics (such as what constitutes creativity).

[3] See for example E. Phelps' Center on Capitalism and Society, the discussion on lack of dynamism in economic theory http://capitalism.columbia.edu/

[4] Ref. to Peter Drucker who coined this term in the 1950s/1960s.

Compared with the EOS process, the creative process is much different and less understood. Here "new and original" has less economies of scale. The "scale" is 1. Creativity is here seen as a much more individual and small team concept than rationality, promoting productivity (through exchange) on the margin, which puts constraints on structures to give people incentives to be creative (as well as productive). If universities aught to pursue scientific research *and* transmit that knowledge to the next generations, what does the concept of productivity do to the creativity in discovery of new knowledge, technical solutions and human expression in the arts?

This article attempts to give some input on the application of these concepts to higher education and research, and discuss the *direction* development of higher education has taken by overemphasizing productivity, in particular economies of scale, *to the detriment of* creativity, observed in the last four to five decades. This shift interestingly coincides in time with the decline in "flourishing" of the economic system (Phelps 2013) and apparent decline in inventiveness and innovation (Ullberg 2009, p. 44 section d.), a flourising that lasted about 100 years from around 1840 to 1940 (see work by Gordin, Mokyr).[5]

First we will look briefly at some consequences of productivity on higher education and then give some input on how to have creativity in research environments. We conclude with a short discussion on measurement and institutional policy, to save higher education from the problem of loosing its creativity.

Productivity and Higher Education

Economies of Scale Approach in Higher Education

Productivity in economics is thus an affair in part of economies of scale, "copied" from manufacturing of "more", not "new". The concept may be applicable to "producing" students with the intention of *transferring* extant knowledge. However, that does not necessarily advance knowledge or science with new knowledge and creative concepts. Nor does it give the most striking human characteristic of creativity much space to create (until *after* school). It is more like learning by doing and while focusing on the process of learning/teaching, adding new knowledge on the margin. Little breakthrough thinking or few ideas are likely to come out of such a process. Such a focus would give students the incentive to graduate fast get a job and then, off you go. The process appears to more promote learning from others (who learned from others, who learned…), preserving a sort of "common knowledge" and culture, and even enforcing certain ideologies in a deterministic manner, than thinking up new things, creating with others.

[5] See recent discussion in WSJ, by Gordon and Mokyr on whether technology will save the world or not: http://online.wsj.com/articles/economists-duel-over-idea-that-technology-will-save-the-world-1402886301

In economic theory, the view of man is much that of an "automat", always preferring more to less and always being rational in the narrowest sense (making decisions bases on complete, common information). It is true that people often do prefer more to less but not always. The reasoning leads to decisions on the margin, in order to maximize social gains. But there are many cases – even laws like anti-trust laws – against not making decision on the margin in order to preserve a competitive environment, for example famous predatory pricing by Standard Oil of undercutting the marginal cost to run competitors in bankruptcy and then buy them out, in the end raising the price well above the marginal cost. "Consumers" made decisions on the margin, bankrupting the firms with less deep financial pockets than S.O. As Coase puts it, "it is difficult to imagine firms acting in the way they are described in text books (maximizing profits by equating marginal cost with marginal revenue) … one reason one could be doubtful of this way of thinking is that firms never calculate marginal cost".[6] These statements do not reject the rationality in price theory but points at that the economic system is more complex and people are more complex in their behavior than simply to be reduced to automats.

The way to compete successfully in this paradigm is thus lowering the marginal cost through Economies of Scale (EOS) and/or Economies of Scope. There is thus little room to invest in new knowledge in this model, except to increase EOS, thus a *process* focus more than a (new) *product* focus.

It is my impression from own experience in teaching in the USA that the focus of the *students* is heavy on grades, completions of diploma and job (the process). Thinking critically and creatively, appears much less of a focus, except among a small group of "elite" students (who probably would behave like that in any system). This probably holds true for most, if not all, western education systems.

The structure of such an institution would be very compartmentalized, specialized in functions (departments) and then leave it up to the *students,* the "produce", to integrate these concepts into a whole. Such interdisciplinary thinking and approach appears critical for creativity. Pushing such a productivity paradigm appears counter productive when it comes to creativity. True, there exist increasingly interdisciplinary degrees, and similar concepts, to try to deal with this lack of interdisciplinary teaching and research lacking novelty and originality, but interdisciplinary does not necessarily lead to creativity. Those approaches also appear more to be individual faculty initiatives–through for example centers–than a university strategy, with few exceptions. One problem is that most universities are run by (mostly risk adverse) professional administrators, not the faculty who teach and research (potentially more willing to take the risk to test new ideas), treating professors like "knowledge workers". However, these "knowledge workers" are not only "producing" students but new knowledge and recognition through publications (books, articles, new classes). The faculty–however highly educated and renowned–appears too often to be seen as automats in the process of producing students. Pushing productivity–without understanding creativity–can only result in a more

[6] See Ronald Coase "Markets, Firms and Property rights" at IEP conference in 2009 in honor of Coase 1959 article. http://www.youtube.com/watch?v=ZAq06n79QIs

efficient knowledge transfer process of extant knowledge, but for what purpose? To be creative, professors need external, often private, funding, which then makes them fundraisers as well, further reducing "productivity" in terms of students. The premise of creativity–novelty and originality–does therefore not appear well integrated in today's higher education *systems* instead promoting a kind of narrowly rational productivity. New ways of thinking about creativity through institutions appears needed both when it comes to the process of creativity and the structure of higher education to better include for that process.

Just to make a point of the value of productivity, it obviously has a role in making education available to more people and at lower cost (a "red hot" current policy topic today). The *transfer* of knowledge can be given to more, i.e. the general level of knowledge is important for society. However, turning that knowledge into usefulness in a global competitive economy requires institutions that are more adaptive over time and incentive-compatible with some broader social goal. It also requires new solutions to future, clearly global, problems which make the education system inseparable from creativity, if it should remain a developing force in society.[7] Technology is currently revolutionizing this field through MOOCs (massive open online courses), however the structured environment with a teacher-led class is hard to compete with as students learn differently and at different speeds. The personal relation has room for creativity in pedagogy, something that is hard for systems, possibly reinforcing inequality.[8] Pushing productivity as a policy thus risk resulting in a structure that becomes "efficient" in more of the same and not in the new we collectively need to solve today's global problems.

Loss of Trust and Creativity

The effect of such policy of productivity appears first of all to be a *loss of trust* in the higher education institutions (Hermerén et al. 2013). As the purpose may lead to producing students productive in the narrow sense (with a useful degree on the margin in the job-market), getting the tools and experience to be mindful in a global world, appear less obvious (there are of course, as always, exceptions). True, many schools for example INSEAD, the European business school, and often other business schools have tried to create an education "experience" much closer to the applied world, in an attempt to learn about these more complex issues. However, in many cases it appears more to be words of marketing than a *structural* change,

[7] An interesting reading here is a book by John Haughey, 2009, Where is Knowing Going?, Chapter 8 with the same title.

[8] See for example Economist June 28, 2014: Higher Education, Creative Destruction. http://www.economist.com/news/leaders/21605906-cost-crisis-changing-labour-markets-and-new-technology-will-turn-old-institution-its

change in property rights and property rights of communication[9] within universities and with funding agents, or an expression of policy change given a different vision of higher education. Such repackaging using marketing is again an expression of changes on the margin based on the same structure. Real change can only come through change in incentives, motivating students, faculty, technology developers and funding agents to act with a different motivation, which means change in property rights on higher education.

Secondly – and more importantly – *creativity is lost* by pushing productivity in an "industrial scale". Investment in higher education must mean investment in new solutions for today's global problems, which can only come through creative thinking (Hermerén et al. 2013). These comments suggest that universities need to have a purpose of their own, something that cannot be run by the state (because of legal capture by interest groups). Such a purpose would transcend mere productivity – which is a goal in it self – and somehow integrate the creative process in teaching and research. The universities must have a view of their own: moving in a direction they believe in, not simply following the money.

Such universities would have a different structure, be run more by teams and be funded through a variety of means. Vouchers with a short "mission statement" (not detailed regulations) may be one such avenue of funding; philanthropy, companies and NGOs may be others.[10]

A Measurement Problem

"You cannot manage what you cannot measure", is a saying in management. But measuring number of students/resources including teachers, and other productivity measures, are clearly not sufficient. What is indicated here is that creativity is an individual concept but also a sociological one which appear to thrive in small groups, lead by people with unusual ability to take in the world interdisciplinary. Creativity is more of a "zero-one" problem, either it is creative or it is not, like an application or adaption of existing ideas and thoughts.

A possible measure could be the impact of peer reviewed articles in *other* fields (interdisciplinary impact). Such *process* measures may be useful. That requires journals willing to publish such risky work, which is not the norm. But these peer reviewed article are run by specialists, not generalists. Some use patents (who aught to be an expression of advancing the state of the art) but they are also quite specialized

[9] In exchange, the rights to say something, participate at the table, is given not only by ownership rights but right to express opinion, for example regarding curriculum. These rights are today often constrained to the states, who fund most of the higher education in the world. A discussion on these rights would enable a more interdisciplinary approach to which direction curriculums aught to go. See (Smith 1982, p. 925) on a theoretical discussion on property rights in messages.

[10] Such experiments are taking place around the world, but the main bulk of education is still state funded, driven by the purpose of the states, often captured by special interests groups.

and on the margin and there is a continuous fight about the generality of claims. To advance this discussion more emphasis may have to be put on the individual's expression of solutions to problems presented and small team work, indicating that the ideas are realizable in a social context. The productivity measures have to be more social in a sense, which invokes the notion of purpose.

A Common "Asset"

In order to analyze creativity and productivity/rationality in an interdisciplinary way one needs some common activity between them. In productivity, Commons (1932, p. 4) postulated that the *activity* that coordinates economics, laws and ethics "must contain in itself the three principles of conflict, mutuality and order. That unit is the *transaction*." This approach drew its inspiration from the hard sciences where common activities of analysis had been found in physics, chemistry and astronomy (interaction of electrons and atoms). Williamson (2009) expanded on this concept for *governance* "the means by which to infuse order, thereby mitigate conflict and realized mutual gains". The transaction is made the basic unit of analysis here as well. According to Williamson, Buchannan (1975, p. 29) further elaborates on this perspective arguing that economic organization was going down the wrong way with the science of choice and optimization. If "mutuality of advantage from voluntary exchange is … the most fundamental of all understandings in economics" then the lens of contract approach is an under-used perspective.

Thus decisions are not based on the margin in the strict rational economic choice sense where law, ethics have nothing to say about the outcomes, but in an environment of negotiations between humans where contracts, governance (and ethics) matter. This stresses that the institutional structure clearly matter as well at the economic environment for transactions.

The question here is then what effect this more sociological experience approach (Smith 2008) has on creativity? Productivity in its rational sense can be analyzed based on transactions as an activity. However, creativity is not a transaction: it is (here viewed as) the process by which new and original solutions to problems are created. What common activity could allow for the analysis of creativity and productivity? The result of the creative process is more like an asset, or a contract, to be used in transactions, rather than a transaction. Thus, negotiating over the price of a created or discovered asset can then be analyzed similarly as the process of creating or discovering the asset. This leads inevitably to a property rights discussion on creative solutions, some of which are captured, to some economic useful extent in intellectual property rights. These rights can be exclusive at the level of an individual or team or firm or nation or other basis for exclusivity, providing ownership that can be shared and traded through transactions. The common activity between creativity and productivity is perhaps then more the assets created in a creative process and its use in a productive process.

Structure and Funding

One key characteristic that can be observed it that as places of learning and later universities went from essentially being created and run by the Churches during the Middle Ages (in Europe), carrying over and expanding the heritage from antiquity to the renaissance,[11] to thereafter essentially be run by private philanthropists (foundation universities) and governments (state universities), were motivated by "searching for the truth", often imposing their respective agendas, as tools of educating man. These approaches have struggled with the same economic problem of productivity, expressed by Drucker in the "knowledge worker" productivity problem. Today there is a discussion on whether these social services aught to be run more like companies with profit goals or non-profit institutions, or somewhere in between. This would thus potentially reduce the governments' agendas on education, opening for a more demand response to firms, governments and society at large. Philanthropists may here play an increasing role anew.[12] As costs have been rampant in the last decades, in some cases quadrupling student fees, investment in new solutions and ideas, which are inherently risky are much less attractive for funding by cash strapped governments and donors than less risky (but short term) marginal development. The point here is that only with a clear purpose for higher education, and its economic-social integration, can one arrive at an economic solution where both the creative and productive dimensions are taken into account.

A More Individual and Social Concept

This section has attempted to provide some basic ideas for a framework to better think about the relationship between creativity and productivity. The main idea is that the individuality of creativity has to be supported by a structural side giving incentives to create a better balance between the creative process of "new" and productive processes of "more". Both access (more) and novelty and originality (new) in solutions are needed to solve today's global problems. Pushing productivity paradigm alone results in loss of trust and creativity in higher education. Investing in creating a more productive activity (under risk and uncertainty) is then to be compared to producing more given current assets. The return on assets, a fundamental concept in business, may therefore be a way to analyze, at least ad hoc, the performance of creative processes. The next section will shed some light on what it takes to create structured, creative, institutional environments that may be incentive compatible with some broader social goal.

[11] North (1981, p. 125) concludes that from the classical world to the Middle Ages the Church was as sort of a repository of learning, with monastic advances in agriculture – "a lonely center of learning".

[12] See book by Z. Acs, 2013, Why Philanthropy Matters: How the Wealthy Give, and What It Means for Our Economic Well-Being, http://press.princeton.edu/titles/9964.html

Creativity and Productivity Focus: Effects on Education System

All scientific creativity is problem solving, but not all problem solving is creative – assuming, of course, that "creativity" involves the generation of a truly novel idea, a scientific breakthrough, a new solution to a hard problem involving an ingenious conceptual reformulation of a theory, or an amendment of that theory's fundamental laws.[13]

Science needs good problem solvers. It needs people who can unravel difficult problems both with and within a theory. The Nobel laureates Francis Crick and James D. Watson are probably the best and most renowned *un*creative problem solvers. They were jointly awarded the 1962 Nobel Prize for Physiology or Medicine. By contrast, their colleague Barbara McClintock, who was given the same prize in 1983, is an example of a creative problem solver. Unraveling the DNA molecule, Crick and Watson revolutionized genetics, biology, medicine and many other sciences. But they did not change the existing conceptual framework, nor did they break away from, or change, any of the fundamental rules of the sciences they used to solve the puzzle. McClintock, on the other hand, solved her problem by expanding our conceptual framework of genetics, by making a rather static system dynamic.

These are examples of first-rate problem solving and in the McClintock case creativity as well. How do we promote creativity and problem solving? Is there a simple recipe for establishing creative research environments? Can we identify negative factors that hamper creativity and the formation of innovative environments?

First we present a simple recipe describing how to establish a creative research environment. Then swiftly we explain why you and I are unlikely to follow the prescription successfully even if we try and try hard.

A Creative Research Environment

What is it that creative environments possess that uncreative environments don't? In asking this, the ambition is limited. We want to home in on a few of the factors that make the academy work – and make it fail.

Generosity

Creative environments are generous environments. In them knowledge and experience is shared. In the light of this feature the structure of scientific careers looks far from conducive to creativity. The young PhD student fiercely clutches on to his

[13] This section is a modified version of and based on the "recipe for creativity" presented and discussed in (Sahlin 2001), *Kreativitetens filosofi*. Nya Doxa, Stockholm; the English version on which this essay is based can be found here: http://www.nilsericsahlin.se/kreativitet/index.html.

ideas so that no one else will pip him to the post. Many academics do likewise. And so it goes on. The quest for higher, and more prestigious, positions makes the researcher unwilling to impart any of his as yet partially developed ideas. He is more than happy to discuss what he has already done, and what he has published, but reluctant to reveal anything about work in progress. Generosity is counterproductive. Better say: "I will help you if and only if I find my name among the authors."

This behavior is completely understandable and rational in the conditions under which so much research is now undertaken. It is nonetheless a serious impediment to creativity. Unfortunately, it is extremely difficult to do anything about the mechanisms that encourage the behavior in the first place.

A Sense of Community

A creative environment without a true sense of community would presumably be impossible to build. A colleague once told me the story of two interdisciplinary research projects he had taken part in.

He described the first in the following way. On day one, the project leader called together the research group and went through all the formalities, allocating rooms, giving out keys and security passes, and then wishing everyone the best of luck with their work. The project never achieved the results it was set up to produce. The researchers spent most of their days in their offices. They carried on doing the research they had previously done at home, without making anything of their opportunity to be with their new colleagues.

The second project started off in a slightly different fashion. On day one, the project leader called together the researchers, maintenance men, assistants and secretaries and took all of them off on a week-long bus trip. The official purpose of the trip was to visit renowned medieval German churches, but since the project was on the foundations and the history of statistics and probability, the researchers' interest in that was likely to be somewhat limited. After a couple of days on the road, and too many churches already, some were ready to quit the project. Others had turned to mutiny and were discussing how to get rid of the project leader. But the real purpose of the trip was obviously not to enhance the historical knowledge of the researchers, but rather to generate a sense of belonging in the group – to create a community. And the bus trip did that job. According to my colleague, the project is one of the most successful, productive and creative experiences he has had.

It's a commonplace that it takes time to get to know someone from a different background. It's no less true that it takes time to get to know someone with a different academic background. Scientists can share the same mother tongue, but nonetheless speak very different languages. My experience has taught me that genuinely creative environments are somehow able to overcome the differences that carve up the world of science without sacrificing any individual's sense of his own identity.

Qualifications

One thing characterizing the creative environments I have been party to is the solid scientific qualifications of the researchers. Researchers display awareness both of what they do know and what they do not know. One thing that most definitely does not promote scientific creativity is a lack of scientific qualifications.

Secure knowledge of your own specialist area equips you to step out into unfamiliar territory.

Diversity

While uniformity can serve to promote productivity, it seldom promotes creativity. In one sense, then, all universities and institutes of higher education are organized in completely the wrong way. For the purposes of education, it is important to have separate departments of philosophy, mathematics and psychology. This facilitates the passing on of knowledge. But from the point of view of research, this kind of organization tends to favor repetitive, unimaginative work. We let scientific space be determined by artificial boundaries governed by disciplinary frontiers, and as a result we become entrenched in mechanical research in isolated subject areas. The result is a fruitless departmentalization of work.

Much has been written about cultural differences, and the awkward behavior of Westerners in unfamiliar cultures is a popular theme in literature and film. A similar sense of dislocation can be felt by the scientist, but this needn't be a bad thing. I have occasionally worked with psychologists and lawyers, and researchers from other disciplines, faculties and scientific cultures. My experience is that it takes both a long time and plenty of goodwill to achieve an understanding of one another's scientific idiosyncrasies, but that it is well worth the trouble. When we enter into other traditions or activities with a little open-mindedness, we nearly always find that it promotes our own work. A measure of dislocation can be an indispensable ingredient in the creative environment.

Trust and Tolerance

Psychologists have shown that trust is an important commodity– particularly when issues requiring effective risk communication and risk management are at stake. Among other things, it has been found that it takes time to win someone's trust, and even then it is very easily eradicated by one, or just a few, foolhardy acts.[14]

There is also evidence that events eroding trust tend to be more "explicit" than the factors that create and maintain it, and this is quite simply due to our all-too-human

[14] Slovic, P. (1999). Trust, emotion, sex, politics, and science: Surveying the risk-assessment battlefield. *Risk Analysis, 19*, 689–701.

readiness to spot another's mistakes and frequent tardiness in appreciating others' achievements.

We can carry out a hundred good deeds without anyone noticing them; a single mistake is always eagerly noted. The argument concludes that one trust-breaking occurrence carries more weight than the trust-creating process itself. Given that bad news is considered more reliable than good news, the bad news carries enormous weight when it comes to the breakdown of trust. If you have been untrustworthy on one occasion, then, fairly or unfairly, you will be marked with the same untrustworthiness on another.

A creative environment must be built on foundations of reciprocal trust and tolerance.

Trust-breaking mechanisms have to be controlled and their effects neutralized.

If ideas are the bearers of creativity, then it is important to cultivate an environment in which people are receptive to alien thoughts and courageous enough to break the rules.

To generate trust is to safeguard against ridicule. With this security, a person can afford to be bold.

Equality

Another prerequisite of creativity is equality. This does not, of course, mean equality in its naïve sense, in which the need for a boss, a treasurer, a secretary or a maintenance man is denied. On the contrary, the creative environments I have experienced have had very well defined structures of responsibility. A researcher's time should be spent doing research and not making photocopies, attending to administration and fixing computers – for the very obvious reason that more often than not there are others who are far better trained to do this kind of work. A creative environment cannot afford the waste of resources that an "all do all" workplace requires. In any case, equalizing does not necessarily produce equality.

In the creative environments I have in mind, no one has ever been elevated to the status of a guru. Everyone has worked with the same status, generosity, enthusiasm and power towards a common research goal.

The environments in which I have seen a guru, on the other hand, have shown signs of stagnation. The reason for this is very simple. A great deal of energy in such institutions is spent on tributes to the guru. And in places with a guru at their head other people in the environment tend to be little more than poor imitators. What you will be listening to is but a choir of epigones.

Curiosity

Can an environment be curious? Of course not, but it is possible to generate an atmosphere in which curiosity between colleagues and co-workers is really encouraged. In the best creative environments every kind of curiosity between heaven and

earth will be given full rein. It is impossible to underestimate the stimulation that radiates from colleagues who share a wealth of different interests. A genuine interest in film, cooking or animals, for instance, gives a greater scope of experience, which is extremely important for creativity and problem solving.

One striking difference between the creative and uncreative environments I have visited is the intellectual acuity and curiosity about life in general displayed in the former.

In the creative environment, a traditional research seminar on human decision making can quite easily end with an animated political discussion or the analysis of a film shown on TV the night before.

Freedom of Spirit

There is a story of a Finnish long-distance runner who applied for supplementary funding in anticipation of a European championship. His letter of application was as simple as this: "I intend to win both the 5000 m and the 10000 m races at the European championship." He received the funding and duly fulfilled his promise.

A creative environment does not define the finer details of an activity. There is a goal. The precise way to it is not determined in advance – the means to the end are willed but not diarized. The very idea of finding a creative solution to a problem implies that one has the freedom to reach that solution in unanticipated ways, to take the road less travelled. One must be entitled to solve a problem with methods that have yet to be invented and tested.

A common complaint here is that one cannot simply dish out research resources or funding so haphazardly. But why not? If you want to reach a goal, win victories, or gain new skills, you have to be willing to take risks. If you back the wrong horse and fall short of your own or others' expectations, you are under no obligation to back the same horse the next time.

Funds that require the researcher to describe the route to the goal in detail, to say how the scientific problems are to be solved, to set out in what ways exactly the training will be approached, or to show how the experiments will be carried out, do not encourage creativity. Such a system may give some assurance in advance, but sadly it also guarantees repetition and lack of imagination.

Small Scale

A creative environment should not be too large. My experience suggests that a group of between 10 and 15 people is perfect – say, 12. The environment must be substantial enough to have critical mass, but not so big that the colleagues lose contact with each other. This is why a university, or a larger company, can never generate a creative environment across the board. It is possible, however, to create small, relatively autonomous, islands of creativity within large organizations.

For obvious reasons, it is difficult to pursue research on creative environments. At least, it is hard to undertake the type of research that delivers not only indirect knowledge but direct knowledge based on well-designed experiments. In trying to characterize creative environments, we must rely largely on comparative historical studies, anecdotal evidence, and past experience. Creativity is a demanding activity, a special type of problem solving, requiring us to be, among other things, imaginative, ready to take risks and willing to break rules. Language is here an important tool. To be creative, we need an environment offering trust, tolerance, generosity and fellowship, and one that allows for mistakes. My guess is there is an upper threshold of a creative team of around 12 individuals.

Parallelism with Other Environments

The observations above are based on my own personal experience of universities and research institutes. This raises the question whether there are any important differences between the way in which creative research environments function and the way in which creative environments function in other areas. As far as I can see, there is no evidence to suggest that there are.

It is also easy to see that a creative environment is fragile – fragile, in the sense that even the smallest change can lead to the collapse of its structure. To maintain its structure, a creative environment needs to recruit people who will "fit in". Recruitment should therefore be carried out on a holistic basis, rather than by allowing publication lists and CVs to dictate decisions on their own.[15]

The Problem Is Hardwired in Our Behavior

Why are there so few creative environments? In effect these factors offer a kind of recipe for them. The ingredients are as simple as they are self-explanatory. Yet despite the artlessness of the recipe, there are very few genuinely creative environments. Why is this?

The answer is not very pleasant: we are hardwired by pride, greed, gluttony, envy, lust and anger, shot through with an arrow of sloth. We have all met them, the *peccata mortalia* hooligans. They act among us, but still worse, they act for and within us.

In order to overthrow these "hardwired" behaviors, institutions can help to some extent as they introduce "constraints that structure our political, economic and

[15] See also (Hollingsworth 2004) in support of this argument, how teams are built at Rockefeller Institute and University in Biomedical research. The research team leader, a professor, makes discretionary decisions on hire within the team, to meet highly specialized competence needs to address specific problems *believed* to be important in solving the research problems.

social interactions" (North 1991), but only if based on a sense of shared values. In diplomacy there has to be both equilibrium of power (to control these non-creative behaviors) and of moral based on shared values. An institutional arrangement where there is a stable structure is necessary but does not curb the desire to be non-creative. The shared values deal with the willingness to create rather than not, when individual contributions are justly honored.[16] In explaining cooperation which resulted in 100 years of stability in Europe, Kissinger notes:

> This unique state of affairs occurred partly because the equilibrium was designed so well that it could only be overthrown by an effort of a magnitude too difficult to mount. But the most important reason was that the Continental countries were knit together by a sense of shared values. There was not only a physical equilibrium, but a moral one. Power and justice were in substantial harmony. The balance of power reduces the opportunities for using force, a shared sense of justice reduces the desire to use force.

Creativity in Science

The paradigm of science has been formulated as "Trust, but verify", which was not a rejection of faith but rather parallel to faith, studying nature, limited to our five senses. At the core of science is thus the falsification program that knowing what is not the way forward is the basis of the way forward in science. This approach is in stark contrast to the views of productivity, which merits a positivist approach. The *processes* of creativity and productivity appear to differ here: Creativity includes falsification as a method in arriving at a solution, where as productivity, in the narrow rational sense, is all about positive outcomes. Abandoning falsification as a scientific method and subject taught in higher education can only weaken creative outcomes.

A Scientific System Based on Productivity Does Not Allow for Failure

Ghost-writing, salami publications, misconduct and distrust are all symptoms of a system that is none too healthy. Do we find unethical, low quality research and pseudoscience in truly creative environments? Probably not. If you want to solve really difficult problems, do something that has not been done before, as Crick, McClintock and Watson did. Then there is no time for nonsense.

[16] A parallel case here is the 100 year peace that was forged in Europe, 1814–1914, after the Napoleonic wars where this dual equilibrium was created. See Diplomacy by Kissinger (1994, p. 79).

We encounter all these problems because we have confused the issues. Creativity and serious scientific problem solving is not the same as productivity. The academy is not a market – not an industry.

A few years ago I had a graduate student from the Faculty of Engineering who wanted to take a course in philosophy of science. She hadn't thought about this field before, but during the course she realized she could construct an experiment that falsified her hypothesis (theory). It was a simple but ingenious experiment. She told her supervisor about it. He said: "Don't falsify anything. You only have four years to complete your thesis. Falsifying gives you nothing – make sure you verify the hypothesis."

Another student of mine, this time a young professor, came to my class and told me that he had just been awarded a substantial research grant. He was very happy, but at the same time worried. He had to sign a contract saying that he promised not to do science for the sake of science.

These examples are genuinely worrying. If we mistake productivity for creativity, if we believe that what matters is the number of papers we write, or the number of students we produce, or the size of the grants we have, if we think that creativity is measurable– well then, as sure as fate, we will find ourselves supporting ghost-writing, salami publications, scholarly misconduct. We shall do nothing but promote distrust.

Today very few large scientific projects fail. Isn't that odd? Isn't science all about taking a leap into the unknown? We should formulate new and bold hypotheses, try them, fail, and then start all over again. Good science is as much about failure as success.

History teaches us that successful failures have been the impetus of science. But a scientific system based on productivity does not allow for failure. For failure – however much serious research, problem solving and creativity you put into the flop – you never get brownie points.

If we need creativity, but the research environment we have created tends to stamp it out, what shall we do? With luck volcanic islands of creativity will emerge from the sea. Universities might even follow the example of some multi-national companies and outsource creativity.

Conclusions: The Role of Creativity (New) and Productivity (More)

Developing Solutions to Problems Requires Creativity

The creative process of "new" and original has to be balanced with the productive process of "more" in a why that allows people in higher education to think up new solutions, and teach them. More of the same seems to be putting more proverbial buckets to fix the leaking roof, rather than fixing the roof – where "more buckets"

may be a poor solution (new tiles may be better). Such a rebalancing requires a shift in institutional policy, from an industrial productivity paradigm towards some other paradigm better integrating creativity in higher education. That requires a purpose of not only transferring extant knowledge developed to solve past problems, but a "searching for the truth", releasing a creative process for solutions to current, and possibly future, global problems.

The process of creativity is a more individual and small-team process, where personal exchange is the norm, has personal trust, and most importantly *individual* creativity. The process of productivity aims at scaling up from one, where impersonal exchange is the norm, trusting the education institutions in doing the job, and functional specialization.

We aught to integrate this process of creativity in the way we think about economics, innovation and higher education, balancing demands for creativity and productivity. Such a new process must start with a better understanding of human behavior in small groups and using institutions, in higher education, based on human dignity.

Structural Setting

Such a creative environment of new is different from a productivity environment of more. The marginal decisions in producing one more student has to be replaced by a decision of pursuing work towards new solutions, in the end attracting students to a unique knowledge and insights. Individuals, in small teams, pursue new solutions to problems, shaping the institutions in a different way than a streamlined production process.

Creativity is more of a 0/1 problem than productivity which is on the margin and can thus be expressed as ratios like percentages. Furthermore *falsification* of a hypothesis is critical in learning, leading up to a creative *solution*. Productivity measures only positive solutions, thus a number of (necessary) falsifications leading to a solution would then be less productive. Therefore only marginal, low-risk, initiatives are typically rewarded, not risk-taking learning experiences which may – or may not – lead to breakthroughs. With productivity measures on higher education, people between Edison and Jobs would probably not have invented their transforming ideas, neither many Nobel laureates. In the end these creative efforts resulted in whole new concepts and businesses.

Creativity is more an individual concept than sociological, but needs to be measured from a sociological point of view, like productivity. To distinguish the source of the input, what is creative has to be distinguished from what are marginal additions to knowledge. Also teaching creativity is a small team concept, rather than teaching extant knowledge which can be done for 100,000 students or more at a time through MOOCs. Teaching creativity includes the interdisciplinary problem and a management problem sometimes driven by unusual vision of how to solve a problem. From the societal perspective, purpose then has to be defined.

The *individual* creative behavior is therefore maybe a management question more than a money question, creating an environment rewarding creativity (interdisciplinary journal publications, etc.) This puts the focus on the measure of performance and behavioral properties of institutions in terms of the creativity of the *outcome* not only productivity. What is created is a new "asset". This view thus ties creativity and productivity together; the first creating an asset the other using it.

A project is here proposed to studying the creative process (to arrive at a knowledge asset) and then the productive process (making use of it in higher education and society), building on previous studies of breakthrough research on markets and networks.

In the end creativity has to be included in the thinking–and measuring–of higher education, balancing needs for profitability and creativity. In a globalized setting, universities may therefore need to have their *own* opinion on what is taught and researched preparing students for a future demanding both creativity and productivity.

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Part II
Innovation Policy and Its Measurement

Chapter 7
Stagnation and Emerging Market Economies: Keynesian versus Schumpeterian Approach to World Issues

Otaviano Canuto

Abstract Policy makers in the advanced economies at the core of the global financial crisis can make the claim that they prevented a new "Great Depression". However, recovery since the outbreak of the crisis more than 5 years ago has been sluggish and feeble. Since these macroeconomic outcomes have to some extent been shaped by policy mixes adopted in those economies in response to the crisis, the appropriateness of those policy choices is a question worth revisiting. This is particularly the case as one considers the hypothesis that a long-run trend toward stagnation may have already been at play during the pre-crisis period, even if temporarily countervailed by pervasive asset price booms.

On the other hand, there is a core divergence among those "Keynesian" and "Schumpeterian" economists who have proposed such stagnation hypotheses. While both groups agree that asset bubbles momentarily offset underlying stagnation trends before the crisis and that the recovery has been subpar, they point to different underlying factors for continued anemic levels of growth. "Keynesians" argue from the "demand side" and believe that fiscal policies have been far too restrictive, with too much emphasis on monetary policies recently, whereas "Schumpeterians" believe that the necessary force of creative destruction has not been allowed to fully take place for a long time now.

Given the possibility that, for Keynesian and/or Schumpeterian reasons, advanced economies may be facing strong headwinds to return to significant growth, much attention has been directed to emerging market economies and other developing countries as potentially alternative sources of growth to the global economy. We argue here that, despite such possibility, it will become material only provided that these countries pursue their own country-specific agendas of structural reforms.

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Actual GDP Has Lagged Behind Its Potential Along the Recovery

Figure 7.1 – from Davies (2013) – depicts several key features of the ongoing recovery in advanced economies. First, the aggregate growth trend exhibited prior to the crisis is no longer there, either because it was not really sustainable in the long run and/or as a legacy of the crisis. Second, a new "Great Depression" has been avoided but actual GDP has remained subpar relative to the latest IMF/OECD estimates for potential output. Finally, despite the possibility of catching-up with potential GDP in 2 years, as outlined in the central GDP projection, such an outcome remains subject to policymakers properly calibrating their responses to a wide range of idiosyncratic challenges ahead (Canuto 2014).

As shown by Kose et al (2013), the ongoing recovery in advanced economies has been sluggish and fragile when compared to the three previous ones. While real GDP per capita returned to positive trajectories soon after previous temporary downturns, this time it not only started decelerating well prior to the global recession year (2009), but has not yet fully recovered its peak levels.

At first glance, this is not surprising, given the nature of the factors underlying the crisis: the pervasiveness and magnitude of asset booms and busts; design flaws of the Eurozone fully revealed as the crisis unfolded; the degree of synchronization of recessions; policy uncertainty associated with a loss of confidence on the sufficiency of established policy blueprints; and so on. Moreover, any such transition from a previously booming economy to a "new normal" would necessarily entail a significant reallocation of resources, with creation/destruction of jobs and productive assets. As remarked by Rajan (2013):

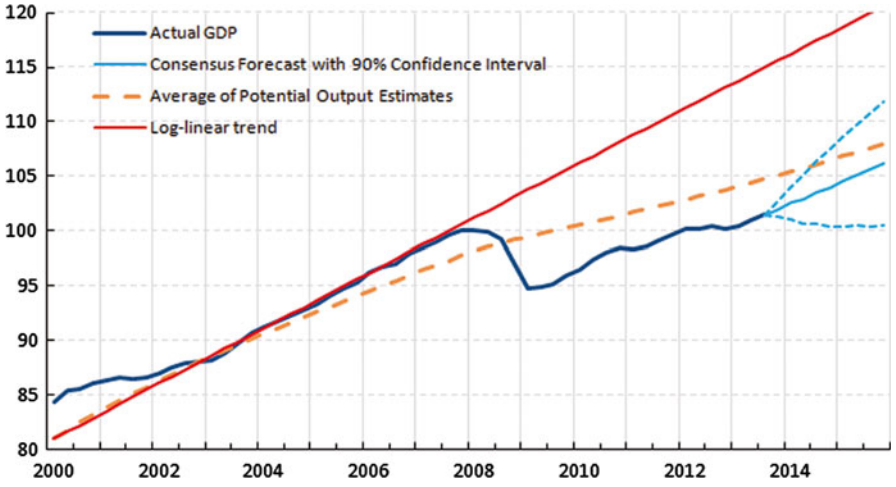

Fig. 7.1 Aggregate G4 (US, Euro Area, Japan, UK) GDP, potential and trend. *Note*: Potential output is average of IMF and OECD estimates. PPP weighted average (Source: Fulcrum Asset management)

> (…) the bust that follows years of a debt-fueled boom leaves behind an economy that supplies too much of the wrong kind of good relative to the changed demand. Unlike a normal cyclical recession, in which demand falls across the board and recovery requires merely rehiring laid-off workers to resume their old jobs, economic recovery following a lending bust typically requires workers to move across industries and to new locations.

On the other hand, gauging by the size and persistence of the gap between actual and potential GDPs exhibited in Fig. 7.1, one may question whether such a transition might have been made faster with appropriate macroeconomic policies. After all, while economists often assume that, no matter where potential GDP might be, actual GDP will eventually move to it, convergence can occur in the reverse direction. Losses associated with prolonged periods of significant output gaps – e.g., labor de-skilling, foregone R&D efforts, and resource idleness – then become permanent.

The Crisis Response Has Been Single-Handedly Based on Monetary Policy

Kose et al. (2013) point out how the recovery in advanced economies may have reflected peculiarities of the policy mix adopted as responses to the recent economic downturn, as compared to previous experiences. While both fiscal and monetary policies have been implemented in a countercyclical direction in the past, that has not been the case this time.

Monetary policy has been extremely accommodative. As policy interest rates approached the bottom – the lower zero bound – central banks went so far as to expand their balance sheets, in conjunction with other unconventional monetary policies (Canuto 2013a). Figure 7.2 illustrates that by matching short-term interest rates during previous and current (the "Great Recession") experiences.

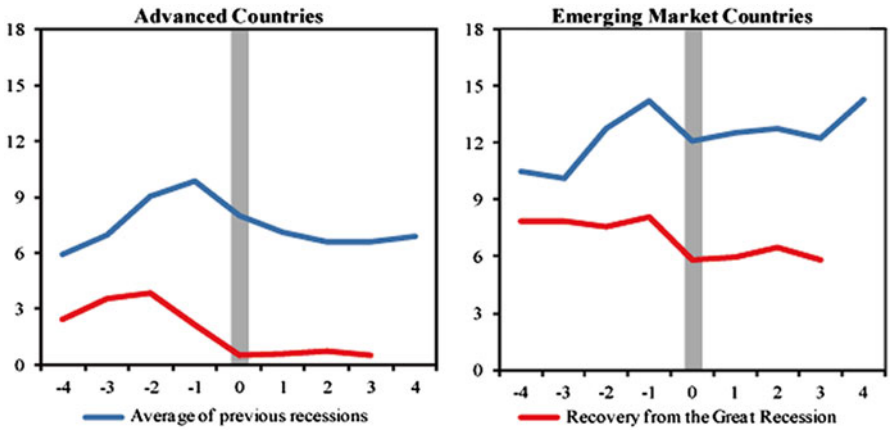

Fig. 7.2 Short-term interest rate during global recessions and recoveries (percent). *Notes*: Zero is the time of the global recession year. Each *line* shows the PPP-weighted average of the countries in the respective group (Source: Kose et al. 2013)

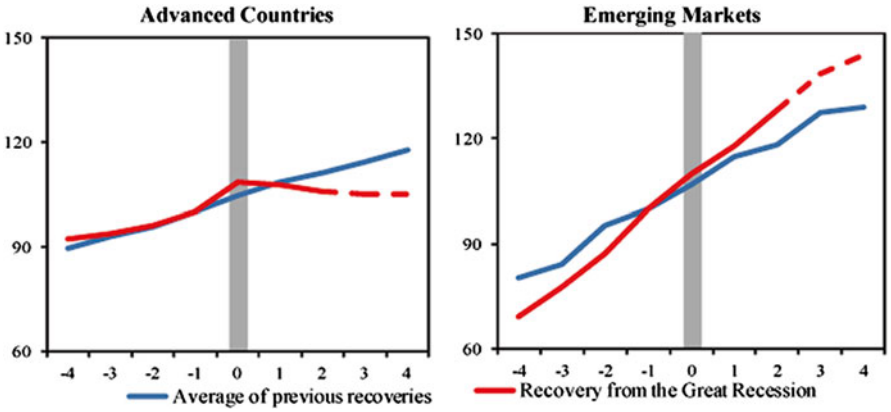

Fig. 7.3 Real primary expenditure (index, PPP weighted) *Notes*: *Dashed lines* denote WEO forecasts. Figures are indexed to 100 in the year before global recession. Zero is the time of the global recession year. Each *line* shows the PPP-weighted average of the countries in the respective group (Source: Kose et al. 2013)

Conversely, while previous recovery experiences were supported by the expansion of public spending, fiscal policy has this time moved in the opposite direction (Fig. 7.3). The fiscal stimulus implemented in the US at the outset of the downturn was reversed not long after, followed by fiscal contraction. In the Eurozone, in turn, fiscal austerity policies were implemented as financial havoc morphed into fiscal unsustainability of its crisis-ridden members. Austerity has also been favored in the UK.

Why has the fiscal and monetary policy mix been so different? On the fiscal policy side, as shown by Kose et al. (2013), public debt levels in advanced economies were much higher than in the past when the macroeconomic downturn took place. Public deficit levels had soared in the run-up to the recession, given the scale of financial support measures and substantial revenue losses. However, one may also say that a policy option for austerity was exercised. In the cases of the US and UK, financial markets were not imposing any substantial short-term fiscal retrenchment – especially if medium-to-long-term structural adjustment plans were to be announced. In the Eurozone, in turn, the intensity of fiscal adjustment in crisis-ridden members could have conceivably been lower provided that a correspondingly higher financial support from outside had been made available.

Unconventional monetary policies, in turn, came out of the urgency of halting potentially catastrophic processes of debt deflation and bank-credit freezes that threatened to transform solvent-but-illiquid balance sheets into insolvent ones. In the case of the Eurozone, such risks of financial meltdown were compounded by negative feedback loops between banks' portfolios and rising risk premiums associated with crisis-ridden national public debts.

Very loose monetary policies smoothed the process of private-sector balance-sheet deleveraging by keeping yields at low levels and propping up asset values. In the Eurozone, risk premiums abated after the European Central Bank pledge to do "what it takes" to keep currency convertibility.

The phasing out of unconventional policies has been protracted as a reflection of the sluggishness and feebleness of the macroeconomic recovery and the absence of fiscal stimulus as an alternative. In the Eurozone, the debt overhang is still salient and balance-sheet deleveraging still has some way to go, but certainly in the case of the US, where debt deleveraging has already been substantial, fears regarding consequences of the unwinding of quantitative easing have made it a measured and paced process.

Can one point out the single-handed reliance on monetary policy to counter downturn as a factor underlying actual GDP tracking behind potential levels? After all, most analysts attribute an asymmetric capacity to monetary policy in economic downturns: the ability to countervail risks of asset-debt deflation is not accompanied by an equivalently strong capacity to induce agents to invest in new productive assets. As the saying goes, "one can pull a string, not push it!" Furthermore, after a certain point, ultra-loose monetary policy would only lead to a repeat of the bubble-blowing process seen before the crisis.

In this sense, countercyclical moves by policy makers might have reduced the length and size of the observed output gap had fiscal policy operated as a countercyclical tool complementary to monetary policy. However, as we approach in the following, this issue is far from being settled.

What If a "Secular Stagnation" Trend Has Been at Play? Which One?

The role of asset bubbles pulling up the pre-crisis growth trajectory depicted in Fig. 7.1 is now widely acknowledged. In the case of the US:

> (…) the liquidity-generating machine inflated US asset values and fed the exuberant growth of US household spending. US consumers have accounted for more than one-third of the growth in global private consumption since 1990. Increasingly, their spending was made possible by the wealth effect generated by the rising prices of housing and household financial assets and stocks, whose values were in turn expected to more than outstrip those of household debt. It was this upswing in consumption by US households, and others as debt-based consumers-of-last-resort in the global economy that essentially made possible the extraordinary structural transformation and productivity increases experienced by some manufacturing exporters and commodity producers among developing economies. (Canuto 2009)

A similar bubble-led growth process could be found inside the Eurozone, starting with the downward convergence of perceived risks and interest rates throughout the zone after the introduction of the new common currency. Today's countries under stress were able to sustain domestic absorption much above domestic production capacities for a long period, easily financing the difference because of fallen-from-heaven

domestic asset value appreciation. The underestimation of fiscal risks can also be seen as a manifestation of such euphoria.

Asset-price dynamics has now been mainstreamed as an important subject to be addressed by policy makers. Macroprudential policies are now a component of the macroeconomic stabilization toolkit (Canuto 2013b).

However, enhancing the policy framework by revamping financial regulation and supervision and combining monetary and prudential policies in order to ensure both financial and macroeconomic stability may not be enough if some underlying secular trend of stagnation is at play. If the pre-crisis growth trend depicted in Fig. 7.1 was inextricably dependent on the overspending induced by the financial frenzy – credit and house bubbles – then running its course, avoiding future asset price booms and busts might simply lead to stability around low growth rates.

Such a view underlies the possibility of a "secular stagnation" trend as discussed by economists like Krugman (2013) and Summers (2013):

> Manifestly unsustainable bubbles and loosening of credit standards during the middle of the past decade, along with very easy money, were sufficient to drive only moderate economic growth. (…) short-term interest rates are severely constrained by the zero lower bound: real rates may not be able to fall far enough to spur enough investment to lead to full employment. Summers (2013)

They and other – say, "Keynesian" – economists have suggested an array of possible causes for the US economy and others to display a propensity of aggregate demand shortfalls, in the sense that, as a result of structural conditions, aggregate spending would be enough to ensure full employment and use of potential output capacity only in the presence of negative real interest rates. Such an "investment drought" – or, as a flipside, a "savings glut" as measured by levels of non-consumption expenditures required to sustain income at full employment – could be seen as underlying the evolution depicted in Fig. 7.4, obtained from Fatas (2013).

Beyond the legacies of the crisis – higher risk aversion, increased savings by states and consumers, increased costs of financial intermediation and major debt overhangs – several long-standing factors could be pointed out as dampening investment. Among them, I would single out two as most significant.

First, rising income concentration – rising shares of income accruing to capital and the very wealthy – would be leading to overall under-consumption, only occasionally countervailed with unsustainable over-indebtedness by the poor. Second, features of technology evolution might also be contributing to an investment drought. Steep declines in the costs of durable goods – especially those associated with information and communication technology and/or outsourcing – would mean less spending levels associated with investment plans out of corporate savings. Furthermore, the trajectories of technological evolution currently unfolding would not carry an array of high-return investment opportunities comparable to past ones.

Summers (2014) argues that:

> *(…) our economy is held back by lack of demand rather than lack of supply. Increasing capacity to produce will not translate into increased output unless there is more demand for goods and services."* He strongly recommends establishing *"a commitment to raising the level of demand at any given level of interest rates through policies that restore a situation where reasonable growth and reasonable interest rates can coincide.*

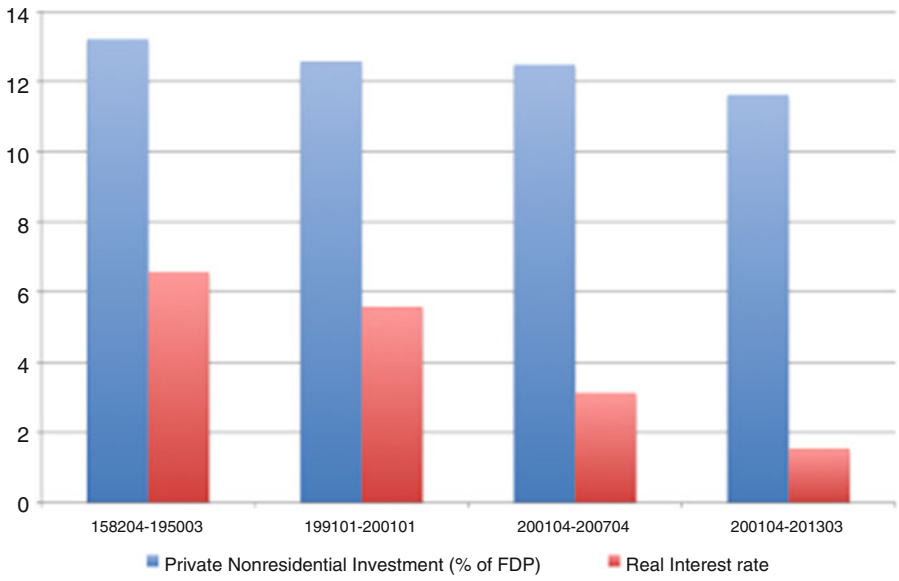

Fig. 7.4 US – Private nonresidential investment and real interest rates (Source: Fatas 2013)

It follows from this view that the policy mix that has prevailed since the aftermath of the crisis has been inappropriate. Instead of relying single-handedly on ultra-loose monetary policy, public spending – on infrastructure, energy and others – should be rescued from the retrenchment to which it has been submitted. By the same token, pro-active public policies to ignite private investment spending should also be implemented.

On the other side of the debate, there are those – say, "Schumpeterian" – economists who have offered supply-side based hypotheses of a long-run stagnation trend already in course for some time. Like Joseph A. Schumpeter, they lay emphasis on growth as a process of "creative destruction" in which obsolete forms of resource allocation and wealth – jobs, fixed-capital assets, technologies, and balance sheets – are replaced by higher-value ones. Although accepting an eventual role of monetary policies in avoiding systemic financial meltdowns, they tend – also like Schumpeter - to be more skeptical of fiscal or other types of countercyclical stimulus if these are designed in ways that retard the process of creative destruction. As for the post-crisis policy mix, even if it is acknowledged that fiscal policy may have moved precociously to the contractionary side, ultimately public policy action to prop up aggregate demand is not considered to be a key component of the fight against stagnation: "*If you are postulating a stagnation across the longer run, ultimately it will have to boil down to supply side deficiencies.*"(Cowen 2013). The evolution of declining investments in tandem with lower interest rates shown in Fig. 7.4 would be seen as stemming from disadvantageous rates of return not related to the pace of aggregate demand expansion.

Technological evolution leading to stagnation trends has been for some time now put forth as a hypothesis by Gordon (2014). Nevertheless, his arguments are about low productivity-raising features of current technological trajectories rather than on their supposedly dampening implications regarding aggregate demand.

Cowen (2011) has in turn approached stagnation as an outcome of the exhaustion of a significant set of "low-hanging fruits" reaped in recent history, namely one-off supply-side opportunities associated with post-war reconstruction; trade opening; diffusion of new technologies in power, transport, and communications; educational attainments and others. Other supply-side possibilities of stagnation recently suggested are associated with features of resource allocation – e.g. over-sizing of financial activities, as discussed by Canuto (2013c).

As outlined by Rajan (2012), such line of proposition about stagnation trends suggests that:

> (…) the advanced countries' pre-crisis GDP was unsustainable, bolstered by borrowing and unproductive make-work jobs. More borrowed growth – the Keynesian formula – may create the illusion of normalcy, and may be useful in the immediate aftermath of a deep crisis to calm a panic, but it is no solution to a fundamental growth problem. If this diagnosis is correct, advanced countries need to focus on reviving innovation and productivity growth over the medium term, and on realigning welfare promises with revenue capacity, while alleviating the pain of the truly destitute in the short run.

Keynesian and Schumpeterian hypotheses of stagnation trends are based on non-directly observable factors. Therefore, the struggle for hearts and minds of public opinion and policy makers will likely remain unsettled. Nevertheless, a broad policy statement can be offered as takeaway of this confrontation between Keynesian and Schumpeterian beliefs of an ongoing secular stagnation:

Regardless of the size of public outlays, public action and spending should be both designed in ways that "maximize the bang for the buck" in terms of overcoming obstacles to the process of creative destruction. Take the case of Japan: the third arrow of Abenomics – on structural reforms of the services sectors and others – will be a condition for successful results from its fiscal and monetary arrows. In the Eurozone, quicker action to restructure/consolidate "zombie" balance sheets and companies, in line with a more pro-active stance taken by monetary and financial authorities, should also hasten the path out of the current stagnation.

What Happened to Emerging Market Economies as an Alternative Source of Global Growth?

Regardless of whether advanced economies are indeed facing either demand- or supply-side stagnation trends, a major bet for the global economy to escape remains on the developing world's economic transformation as a source of growth. However, for that to happen, developing countries themselves will also need to pursue their own country-specific agendas of structural reform (Canuto 2013d).

Financial markets and the news media have one thing in common: they tend to oscillate rapidly between hype and gloom. Nowhere is this more apparent than in analyses of emerging economies' prospects. Since last year, enthusiasm about these countries' post-2008 economic resilience and growth potential has given way to bleak forecasts, with some economists declaring that "the emerging-market party" is coming to an end.

Many now believe that the recent broad-based growth slowdown in emerging economies is not cyclical, but a reflection of underlying structural flaws. This interpretation contradicts those who, not long ago, were anticipating a switchover in the engines of the global economy, with autonomous sources of growth in emerging and developing economies compensating for the drag of struggling advanced economies (Canuto and Giugale 2010; Canuto 2011).

To be sure, the baseline scenario for the post-crisis "new normal" has always entailed slower global economic growth than during the pre-2008 boom, as we saw in the discussion of "secular stagnation" hypotheses. For major advanced economies, the financial crisis 5 years ago marked the end of a prolonged period of debt-financed domestic consumption, based on wealth effects derived from unsustainable asset-price overvaluation. The crisis thus led to the demise of China's export-led growth model, which had helped to buoy commodity prices and, in turn, bolster GDP growth in commodity-exporting developing countries.

Against this background, a return to pre-crisis growth patterns could not reasonably be expected, even after advanced economies completed the deleveraging process and repaired their balance sheets. But developing countries' economic performance was still expected to decouple from that of developed countries and drive global output by finding new, relatively autonomous sources of growth.

According to this view, healthy public and private balance sheets and existing infrastructure bottlenecks would provide room for increased investment and higher total factor productivity in many developing countries. Technological convergence and the transfer of surplus labor to more productive tradable activities would continue, despite the advanced economies anemic growth.

At the same time, rapidly growing middle classes across the developing world would constitute a new source of demand. With their share of global GDP increasing, developing countries would sustain relative demand for commodities, thereby preventing prices from reverting to the low levels that prevailed in the 1980s and 1990s.

Improvements in the quality of developing countries' economic policies in the decade preceding the crisis – reflected in the broad scope available to them in responding to the global financial crisis – reinforced this optimism. Indeed, emerging countries have largely recognized the need for a comprehensive strategy, comprising targeted policies and deep structural reforms, to develop new sources of growth.

It has become apparent, however, that emerging-market enthusiasts underestimated at least two critical factors. First, emerging economies' motivation to transform their growth models was weaker than expected. The global economic environment – characterized by massive amounts of liquidity and low interest rates stemming from unconventional monetary policy in advanced economies – led most

emerging economies to use their policy space to build up existing drivers of growth, rather than develop new ones.

But the growth returns have dwindled, while imbalances have worsened. Countries like Russia, India, Brazil, South Africa, and Turkey used the space available for credit expansion to support consumption, without a corresponding increase in investment. China's non-financial corporate debt increased dramatically, partly owing to dubious real-estate investments.

Moreover, nothing was done in anticipation of the end of terms-of-trade gains in resource-rich countries like Russia, Brazil, Indonesia, and South Africa, which have been facing rising wage costs and supply-capacity limits. And fiscal weakness and balance-of-payments fragility have become more acute in India, Indonesia, South Africa, and Turkey.

The second problem with emerging-economy forecasts was their failure to account for the vigor with which vested interests and other political forces would resist reform – a major oversight, given how uneven these countries' reform efforts had been prior to 2008. The inevitable time lag between reforms and results has not helped matters.

Nonetheless, while emerging economies' prospects were clearly over-hyped in the wake of the crisis, the bleak forecasts that dominate today's headlines are similarly exaggerated. There are still a number of factors indicating that emerging economies' role in the global economy will continue to grow – just not as rapidly or dramatically as previously thought.

Last year, the mere suggestion of a monetary-policy reversal in the United States sparked a surge in bond yields, which triggered an asset sell-off in several major emerging economies. Perhaps this experience will serve as a wake-up call for these countries' leaders. Only by recognizing the weaknesses of old growth patterns and pursuing the needed structural reforms can emerging economies achieve strong, stable, and sustainable GDP growth – and fulfill their potential as the global economy's main engines. The whole world would then be grateful!

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Chapter 8
The Language of Trust: Four Strategies of Self-Restraint in Patent Markets

Eskil Ullberg

"Honoring the inventor" created the basis for global trade in ideas. First known patent law, (Venice 1474).[1]

Abstract Firms exchanging technology using the patent system as a trade system (through licensing, cross-licensing, transfer, and other mechanisms) appear to face uncertainty that cannot be resolved by information alone; trust in each others actions appears to be needed. Information is needed to resolve risk (a probability distribution can be constructed) but uncertainty (where no distribution *can* be made) requires trust in each others *actions* to be resolved and allow for rational decisions to be made. This article explores, based on interviews with some (about 14) of the most active patent licensing and patenting firms in the world, what *strategies* firms use to create such trust in each others actions, which allows for exchange in (uncertain) extant and new technical ideas based on the patent system. In the case of patents, the rights and their economic value are particularly risky and uncertain, as new inventions may be in pipeline that can be held private (as trade secrets), creating hold-up

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[1] *The first known patent law (Venice 1474)*. And should it be legislated that the works and contrivances invented by them could not be copied and made by others so that they are deprived of their honour, men of such kind would exert their minds, invent and make things that would be of no small utility and benefit to our State". Adopted by the Venice Senate (not a King) on March 19, 1474, as economic policy of the city state. It was apparently the senate, with representatives from business, polity and religious communities that could break the tradition of granting royal monopolies.

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and other non-cooperative behavior, and the right to sue (enforce) have uncertain outcome. A distinction is thus made between uncertainty in state of *the art* (new technology) and the *process* of managing the uncertainty using diverse strategies, and treatment of risk based on state of *nature* and probabilities, hoping to expand on Arrow's and other's work, to provide a treatment of uncertainty in economic theory.

A systems analysis is done, where messages firms send to each other in implementing a strategy to create such trust (not to hold-up, sue, etc.) are analyzed, making up a "language of trust". The analysis indicate that, irrespective of strategy, messages aim at creating mutual/multi-lateral self-restraint, and take the form of informal (norm based) and formal (rule based) *contracts of self-restraint*. This is thus a sociological problem the firms appear to solve and not an economic one (exchange), in order to sustain trade in ideas (based on the patent system). Four such strategies are identified, defining a *process* of what firms do to create trust in each others actions. This process seems to have some generality in that it can be found in other areas such as international relations, sports, families, and other organized cooperation. As economic theory is based on information (Arrow 1962), these findings may be useful to include uncertainty in economic theory, based on a sociological analysis, at least in the case of developing patent markets.

Introduction

Firms exchanging technology using the patent system as a trade system (through licensing, transfer and other mechanisms[2]) appear to face uncertainty that cannot be resolved by information alone; trust in each others actions appears to be needed. Uncertainty comes from imprecise claims (language), enforcement procedures (courts), agreements (contracts), and most importantly, new better technology that has been created and/or patented *after* a transaction is consummated thus impossible to predict, creating hold-up and other situations, potentially impacting value. (Risks come from timing of patenting, exhaustiveness of prior art searches (presumed validity), unclear ownership, etc.) Information is necessary to resolve risk (a probability distribution can be constructed) but uncertainty (where no distribution *can* be made) appears to require trust in each others actions to be resolved, in turn allowing for rational decisions to be made. Risk–resolved by information–can therefore be said to be an economic problem of rational decision making whereas uncertainty–resolved by trust in each others *actions*–a sociological problem, involving what firms *do*, i.e., their behavior given norms and rules of patent markets. This article explores, based on in-depth interviews with some (about 14) of the most patent licensing and patenting active firms in the world, the *strategies* firms use to

[2] Which may include cross licensing, securitization of patent portfolios, licensing of standards essential patents under FRAND (Fair, reasonable and non discriminatory terms), open access licensing, mandatory licensing and many more given the type of business *strategy*, industry agreements of government patenting policy used.

resolve uncertainty by creating trust in each others actions which then allows for exchange in technical ideas based on the patent system.

Internationalization of exchange in human ideas was first impersonalized with the creation of the first patent system, in Venice in 1474, creating a competitive environment for technical ideas. Trade secrets, tightly personally held, were challenged as a strategy in favor of patents – publicly disclosed and enforced private exclusive and tradable rights on a new technology useful for economic development[3] – creating tradable private property rights on technical ideas. The policy was an economic policy of trade, giving incentives to import (trade) technology invented elsewhere to the then city state. Today *personal* exchange in ideas practically takes place across the globe through the advent of the digital economy, making new information and learning accessible, moving the exchange in ideas to a global level. An *impersonal* exchange of patented state-of-the-art technology yet requires a final step towards integration and exchange (especially North-South). This complex process of inventing, protecting, learning and exchange based on private property rights, contracts and ultimately market prices (in organized markets), still remains to be trusted by the trading parties to compete with trade secrets and other mechanisms (such as open source approaches) globally. The paper attempts to analyze the *process* of creating *trust in each others actions*, enabling impersonal exchange in technology based on the patent system, with policy implication for a global market.

In order to analyze this process we need to separate the sociological and economic problems. To do this the *messages* that are sent between firms in order to coordinate their actions are analyzed. The economic system's analysis builds and expands on the microeconomic system analysis presented by Smith (1982) and others. Economic outcomes are there decided by agents interacting with each other through institutions, arriving at an outcome by means of exchange of rules-based *messages*. The rules of the patent system (office and courts), exchange by means of (enforceable) formal and informal contracts between firms and the particular economic environment are studied at the level of the messages firms send to create the trust formulating strategies (the sociological problem), in turn supporting exchange (the economic problem).

In the economic literature much of the treatment of "uncertainty" goes back to Arrow (1952, p. 19, 1962) where markets in "state of nature" are used to trade risk, which appears to be built on an understanding that there exists symmetric information on which a probability distribution can be based for each state of nature. In the exchange studied here, such information *does not* exist ex ante with respect to the technology that is not yet invented but will (perhaps) be invented. The state of *nature* is here state of *the art*, a *human idea*, a technical solution that can be patent protected, which cannot easily be parameterized as alternative states of nature (the

[3] WTO TRIPS agreement (Geneva 1994, Article 28) defines these rights as follows: *"1. A patent a product, to prevent third parties not having the owner's consent from the acts of: making, using, offering for sale, selling, or importing for these purposes that product; (b)where the subject matter of a patent is a process, to prevent third parties not having the owner's consent from the act of using the process, and from the acts of: using, offering for sale, selling, or importing for these purposes at least the product obtained directly by that process. 2. Patent owners shall also have the right to assign, or transfer by succession, the patent and to conclude licensing contracts."*

states are not known and cannot be known as they are new creations that never existed before, adding to the state of the art, a sociological undertaking by people, not events by nature to which probabilities could be assigned[4]) perhaps better described as *genuinely* uncertain.

Building on Coase (1937) and Commons (1932), Williamson (1979, pp. 245–254) in his seminal article on transaction costs focus on intermediate product-market transactions, contracts and governance structures for investment decisions under "uncertainty". A higher uncertainty would lead to a more unified governance structure (coordination through hierarchy, i.e. a sequential process) and reducing uncertainty to market governance (coordination through markets, i.e. a simultaneous process).

At hand here is the *process* of managing genuine uncertainty, with respect to *new* patented technology, not the current technology used in products and services, i.e. investment value of what is currently offered, but of what *could be* offered, in terms of a resolution (reduction of) uncertainty through trust in each others actions. This process has states which may be characterized by strategies used by firms. It is the strategies used, in given economic organization (hierarchy, market, other) and thus the process of reducing uncertainty that the paper hopes to shed light on, through studies of strategies and messages.

Hart (1988) and Grossman and Hart (1986) discusses incomplete contracts (where all the states of *nature* have not been listed due to (prohibitive) transaction costs) and residual rights of control over *physical* assets, opening for a discussion on *ownership* to resolve the un-contracted states of nature through new negotiations (if the owner wished to do so). The approach then leads to resolving hold-up situations. This work on ownership has been expanded to discuss different kinds of ownerships, such as investors, managers, workers and consumer co-operatives. Here the residual rights of control, or ownership, are uncertain as *new* technology can be developed ex post contracting, creating new *intellectual property* assets, which can be contracted (viewing the patent as an asset). The key problem being potential future claims and their investment value, ex ante they were invented, a quality issue of patents to some degree (hard to specify) but also an expression of the uncertainty of value of current and future patent assets. Ownership contains both problems of risk (symmetric information on who owns what) and uncertainty (here trust in each others actions). This line of thinking also appears to be useful to apply to patent pools, zero royalty patent licensing and open source cooperation and other mechanisms of ownership based on the patent system, building on Ostrom's (1990) research on common pool resources in particularly applied to open source software.

[4] However, Aumann (2004) proposes a unified treatment of strategy against nature (with "objective probabilities", in the sense of Nash (1951)) and people (forming "subjective probabilities"), a proposition that appears to rely on symmetric information. Here, as pointed out, the information may be symmetric (as in patent disclosures), asymmetric (as in trade secrets) but also non-extant at time of contracting as patents represent human inventions creating a situation of uncertainty that cannot be resolved by information (leading to formation of a probability distribution) but only by trust in each others actions (not to hold-up, sue for infringement or otherwise harm).

What is possible to privately claim, and enforce in order to trade (here publicly disclosed and privately excluding rights on patented technology) can possibly be seen as a matter of uncertainty in ownership of (current and future) state of the art.

Coase proposed in (2009) that the way we aught to look at the firm was as a *sociological* problem, not as a problem of nature with decreasing marginal returns like in agriculture, but instead studying the relationships between firms as a way of operating in an economic system. It is this tradition that has been followed here, as firms create trust in each others actions, exchanging human ideas on state of the art technical solutions based on understanding of nature. This process can be seen as a process of firms moving from managing risk based on state of nature as a random process, to managing uncertainty and state of the art, based on a human creative process, in an economic system.

The attempt is thus to study the sociological problem of creating trust in each others actions to resolve uncertainty, separated from, but preparing the way for, the economic problem of exchange with rational investment decisions, motivated by gains and leading to specialization and growth.

The findings are that the way firms create trust in each others action in the case of patent markets is through strategies built on formally and informally (multilateral) *contracted self-restraint*. The seller (or the buyer or intermediary traders) develop the contracts (and mechanisms) to act with self-restraint when new technology is developed (by either party), not to sell to a competitor (or hold-up, hold-out), or sue each other for infringements. Uncertainty in each others actions is thereby reduced – by enforcing the self-restraint (different in each strategy) – paving the way for rational decisions to realize (sustained) gains from trade.[5] They thus exclude certain actions in these coordinated strategies, in particular avoiding hold-up, suing each other and certain opportunistic behavior. If self-restraint is not observed (contracts are not honored) trust is enforced by moving (or the threat of moving) to strategies with less cooperation (other states of operating the economic system, ultimately changing economic structure), thus reducing the possibility to realize the higher gains from trade, making the first strategy choice unsustainable. This "negotiation for trust" is done through a set of messages creating a "language of trust" (see Table 8.3). The actions observed thus go beyond simple information sharing mechanism (to resolve risk).

Four strategies have been identified which can be seen as steps leading to impersonal exchange. These contract mechanisms may therefore also be seen as an example of how institutions develop towards realizable and sustained exchange, based on creating trust in each others actions. The strategies firms appear to use are:

1. "Staying clear" of each other's patented technology using a MAD (mutually assured destruction) strategy to enforce lack of self-restraint in using the other's rights. Patent enforcement costs (administrative or court) will outstrip gains from

[5] However, there is always an alternative to patenting, keeping your ideas to a single hierarchy as trade secrets, not sharing the state of the art with the world through patent disclosures, but then one remains exposed to reverse engineering, transfer through former employees, industrial espionage etc, of products and services. This makes patenting attractive given the trust problem can be solved.

infringing. Technology is then "cleared" in the product and service markets, not in the technology market.
2. "Strategic alignment", which gives both parties access to each others new patented technology during a pre-defined period (3–5 years) by a so called capture period contract. It is thus not possible to sue (or otherwise harm), since all extant and *future* patented technology is licensed (or cross-licensed) and openness of information is institutionalized (periodic audits).
3. "Marginal transactions", where parts of patent portfolios, standards patents or individual patents–often well established technology in use–is licensed and cross-licensed. This is enforced, when possible, in patent courts. The trust is here completely in the patent office and courts (validity).
4. "Systemic abuse", where firms assert (often low value) patents for infringement to extract rents in face of high court costs for the defendant. This is enforced by (larger firms) through an all out attack on the litigants (thus often lousy) patents, forcing a *value* judgment by courts, thus destroying the business model of these firms (this includes an asymmetric information problems as well). Trust is thus here created by giving incentives to sell valuable technology or be run out of business.

In all strategies self-restraint appears to be the resulting behavior of the parties, supporting sustained exchange, enforced by destroying or eliminating gains from exchange through a less cooperative strategy if parties behave opportunistically.[6] The self-restraint is thus created through contracts and enforced with help of institutions of the patent system and civil law system.[7] This can be seen as an emerging market in patented technology on its way to institutionalization. The property rights that can be enforced thus structure the economic system[8] in a series of steps.

In addition to (the sociological concepts of) self-restraint the economic concept of "search costs"–making sure there is no infringement–mattered considerably for firms in their choice of strategy. High search costs resulted in situations where staying clear or systemic abuse strategy were chosen, whereas low search costs appeared important for strategic alignment and marginal contract strategies to be chosen. This is a risk problem and further institutional development was called upon by several firms such as a registry of ownership of patents (which does not exist in any updated or transparent form[9]) and "quality patents" (high presumed validity).

[6] In a general sense (covering a range of informal and formal contracts) this finding is in support of Smith (2004, p. 69): "If monitored and externally enforced rights can never cover every margin of decision, then – contrary to the notion that markets depend on selfishness – opportunism in all relational contracting and exchange across time is a cost, not a benefit, in achieving long-term value from trade."

[7] Patent infringements are a civil offence not a criminal offense.

[8] Compare North (1981): It was not a change in activity that created the first economic revolution (agriculture) but a change in property rights which in turn shifted the incentives to invest in agriculture.

[9] As this is written a bill is proposed in the US to deal with this problem. However, it is unclear if the bill is written in the spirit of trade and exchange.

The strategies indicate that a contract has to include provisions for self-restraint and enforcement mechanisms and has to be accessible for all firms engaging in inventive activity, in order to move from 1, and 4 "litigation" strategies to 2 and 3 "negotiation" strategies allowing for gains from exchange in patent markets, higher growth in technology and potentially higher economic growth.

These finding create policy input on a number of areas such as contracts (as a first step towards institutional development), patent quality and publicly listed ownership, and enforcement practices. A policy proposal is discussed to reduce cost of using the patent system as an exchange system to the individual (or small team) inventor(s) level. Such a policy would allow exchange in human ideas across the economic system at an unprecedented level. This thus has implications for North-South exchange in technology, addressing economic inequality issues through trade.

The strategies appear to have general applicability beyond patent markets and anecdotal examples from international policy and other fields are elaborated on for a general research agenda.

The findings have been tested in an economic experiment in a 2×2 design with contract types and search cost as independent variables and are reported elsewhere. Given that the experimental findings can be repeated, a theory of sociological (contract) and economic development would be the next step on this agenda.

The paper is organized as follows: introduction of the study, messages to create trust in each others actions, four strategies of self-restraint, discussion, economic consequences in particular regarding contracts and search costs, proposed experimental investigation, conclusions and implications for other fields.

A Sociological Problem: Exchange in Ideas Requires Trust

> It was quite clear that firms dealing with one another did not depend solely on the contract, but had… trust in each others actions. The economic system operated differently than if it all depended on contracts. We aught to study the relationships between firms, as a way of operating in an economic system. (R. Coase 2009)[10]

To analyze the strategies of firms I will first give some background on the patent system as a *trade* system and the sociological and economic dimensions.

The patent system made *exchange* in technical ideas (technology) possible in a market with prices, by giving the holder *excluding rights* (to prevent use by others and to assign, transfer and license the patent by mutual consent) *in exchange for* public disclosure (teaching) of the invention to the world.[11] In this way the patent

[10] Markets, Firms and Property Rights – A celebration of the research of Ronald Coase. Video Message from Prof. Coase 2009: http://iep.gmu.edu/conference-markets-firms-and-property-rights-a-celebration-of-the-research-of-ronald-coase/

[11] Under the WTO agreement on Trade-related aspects of Intellectual Property Rights (TRIPS) there are 7 rights. A patent is granted for mostly technical inventions that are new (no prior art exists), have an inventive step/are non-obvious and an industrial applicability/useful. Most patent

system makes higher growth in technology possible through (often dynamic) cooperation between specialized inventor firms, innovators and nations, motivated by gains from exchanging technical ideas, in a highly competitive manner, driven by demand for new technology. This *producer market* in patent protected technology is input to today's global manufacturing and service system. Product and service innovators are the source of such demand, in turn motivated by gains in those markets. The distinction between invention and innovation markets is important for a better understanding of policies that may create a more dynamic economic system today, when explicit trade in technical ideas is taken into account in the economic growth process, driven by a goal of a more efficient (and sustainable) economic system. The patent system of 1474 to "honor the inventor" can therefore be seen as an economic policy motivated by trade in ideas, institutionalizing self-restraint (not stealing from but honoring the inventor's investments in new technical solutions) through somewhat enforceable property rights.

Such exchange is both risky (asymmetric information) and uncertain (as there is no way one can encompass what solutions every human will creatively come up with in the future). All exchange has these characteristics but here the "product" may be less valuable, given new inventions – human creations – that are impossible to predict (some would say "disruptive").

One can here differentiate between human discovery and human creation: in the first instance what already exists is discovered (a resource, information, or law of nature) and in the second something that does not exist naturally is created by a human creative act of problem solving and reduced to practice. However, in the medieval Europe the Latin "invenire" (invention) was the word used for discovery of for example an iron ore. The meaning of "invenire" was accidental discovery (such as in a random process) where as "ars" (art) was used to connote derived technological know-how (such as in a purpose driven process).[12] "Ars" would thus be the process to extract the iron, like pumps to pump out the water. Thus, an inventor would be honored for new inventions that surpassed the state of the art (a new solution was "discovered"). The difference is that the iron ore was there all the time where as the pump was a solution created by a human idea. Similarly, institutions are human creations (even if we only over time discover which rules work and which don't), of which the patent system is thus one (economically important) example. The creative process is thus more of an individual and sociological process (with claims on intellectual property assets) whereas discovery more of an economic

systems follow this principle of temporal exclusive rights in exchange for public disclosure. In fact this was the principle introduced in the firs patent system in Venice in 1474 in an apparent attempt to *import*, i.e. trade, productivity enhancing inventions useful for the early manufacture economy. A 7 year exclusive right was issued in exchange for disclosure. The explicit underlying principle in the law was 'honoring the inventor'. This principle appears to have been lost in economic analysis and much of the discussion on patents. This is most notably commented by Plant (1934, p. 51)"Expedients such as licenses of rights, nevertheless, cannot repair the *lack of theoretical principle* behind the whole patent system." (Italics added). However, viewing the patent system as a *trade* system introduces the most fundamental economic principle, that of exchange.

[12] See (Kaufer 1989, p. 2) for a discussion on the origins of the word invention and patent.

one (with claims to a physical asset). The distinction between the human idea on using nature, and nature it self, runs deep in the patent system from the time it was construed, making the distinction of state of the art as a sociological (invention) process and state of nature a random (discovery) process quite meaningful. This discussion on discovery and creativity needs to be further elaborated on elsewhere but is mentioned here simply to give some historic perspective of the economic thought related to inventions and patents.

Firms often choose to keep inventions as trade secrets using them on their own, timing patenting or racing to patents depending on market dynamics. Firms may hide what is in pipeline for a trading partner to reveal it later (hold-up), or sell to a potential competitor (hold-up/hold-out), or someone who can become a competitor, changing the potential value for the buyer. Or firms may simply be withholding ideas for cost reasons, timing of investments, depreciation of assets, etc. The value is hard to estimate for most technologies, or combination of technologies, making choices between technologies difficult.[13]

An inventor firm typically does not reveal everything invented, has technology in pipeline, thus may keep more valuable technology for later, can hardly know everything that is in the heads of all employees, or what further ameliorations or related inventions may be made in the near or distant future. These characteristics and others of inventing, here characterized as uncertainties, appear to make mechanisms of exchange of ideas more difficult than for products and services.

By disclosing the inventions, the state-of-the-art is revealed and future inventions then build on technology closer to the state-of-the-art, thus *increasing* competition in development of technical ideas. By granting *tradable* rights on these state-of-the-art ideas, more exchange in ideas can take place between actors, each benefitting from the specialized knowledge of the other.

Fundamentally, these characteristic of exchange in technology between firms, based on the patent system, makes it *genuinely uncertain*. In markets, agents have to choose rationally between alternatives based on price. (See for example (Coase 1990, p. 80)). But how can you choose rationally when the value (and thus price) is uncertain (no distribution can be assessed) and the actions of the trading parties are uncertain (not known to anyone)?

The patent system therefore appears to create a particular economic structure (organization) when coordination of inventive activities moves from *within* a firm (hierarchy) to a *between* firms in a market with prices. A well functioning of this coordination would thus enable growth in technology, the basis of economic development. Today the trade in ideas, using the patent system to license technology, is estimated to the order of a trillion US dollars or more. If one would include

[13] About 2 % of all patents are used in products and services (Source: EPO). This does not mean that 98 % are economically useless. They are used as a strategy to exclude competition to get "too close" to a "core" technology (creating a larger technology area of claims), a pipeline of technology to be used later, trade (licensing, cross-licensing) or other strategies companies use or can invent.

cross-licensing, FRAND agreements on standards the value of such exchange in technology based on the patent system would probably be at least 5–7 times higher.

To deal with situations under *risk*, one clearly needs *information*, and preferably symmetric information to have markets with rational prices. However, under *uncertainty*, one needs *trust* in each others actions, to make rational decisions. The first problem clearly falls into the category of economics where as the latter is a sociological one. Exchange in ideas using the patent system thus requires the firms to solve the trust problem prior to exchange. To investigate what firms *do*–and *why* they do it–to actually overcome this uncertainty, and create trust in each others actions, in this global and documented trade, has been the purpose of this project.

The Study

The study was organized as a set of in-depth interviews with the heads of, and sometimes teams of, patent policy and licensing departments of mainly global firms exchanging rights on *patent protected* technology. Thirteen firms of which 10 were among the major patent licensing and patenting active firms in the world, participated in the study (all under request of anonymity).[14] One firm declined but gave such interesting reasons they are listed among the 14 firms interviewed. Most representatives where senior patent licensing professionals, having spent most of their career in the field, sometimes 20–30 years, and with a range of companies. Since there are alternative mechanisms to patents for sharing ideas, one "open source" network was interviewed (who also has patents). However, the focus of the study was firms using patents as the basis for *exchange*.

The selection was made with the criteria of: (i) patent licensing (trading) active firms (both producing firms and non-producing, intermediary trading, firms), (ii) industries where licensing is particularly active; industries with *high interoperability*, or component based industries and, (iii) preferably large firms (which trade with both large and small firms and therefore have experience in the most diverse range of strategies. Studying the large firms would thereby reveal strategies used together with small firms as well as large firms). Industries with low interoperability were approached (oil), but there was no interest to participate in the study as "they did not share technology" as one firm put it, which appears to be an interesting finding in itself.[15] The importance was to investigate the *broadest possible set of strategies*, and

[14] Names of firms participating have consequently been removed. However, identification by number is used in tables, etc, to relate a firm to a certain industry, and other possibly useful characteristics to relate the observed *behavior* to a unique entity.

[15] It is now a well-known fact that the oil industry does not share safety standards or technology internationally possibly to a lower extent than within other industries, which became clear during the BP/Halliburton catastrophe. After the disaster, there was some increase in security cooperation forced on the companies by governments, if I am correctly informed (http://www.ogp.org.uk/

Table 8.1 Firms interviewed

	Short case study				Primary business		
Firm ID	Region	Technology (industry with high interoperability)	Patent portfolio	Patenting	Licensing	Producing	Services
1	US	IT	> 10,000	x	x	x	x
2	US	Software	> 10,000	x	x		x
3	EU	Software	> 1,000	x			x
8	US	Software	> 10,000	x	x	x	
4	EU	Telecom	> 10,000	x	x		
10	EU	Telecom	> 10,000	x		x	
7	US	Telecom & IP	> 10,000	x	x	x	
5	JP	Consumer electronics	> 10,000	x		x	
9	TW	Consumer electronics	> 1,000	x		x	
6	US	IP	> 10,000	x	x		
12	US	IP	> 10,000		x		
13	US	IP	> 10,000	x	x		
14	US	IP	> 1,000		x		
11	EU	Oil (shorter discussion)	> 1,000	x		x	

large firms typically face those challenges in all fields, not only in patent licensing. A specialized intermediary firm was also included as was an "open source" firm, to capture these roles better. Some firms were new to this exchange whereas others were well seasoned. This was done to capture as much of the dynamics of the global patent licensing system as possible. By this selection, *basic* strategies could be discovered and documented, useful for sustained business models, not just special one-off cases, but hopefully the more general cases. This generality would then be used to formulate testable hypothesis of the behavioral properties of creating trust in each others actions, suitable for further experimental analysis.[16] Table 8.1 lists the firms by number in the study, industry, patent portfolio and market presence.

The interviews where conducted with as open questions as possible, to allow the firms to express *their* strategies (not wanting to impose a rationality of our own). Two basic questions were asked: *What* do you *do* when licensing patents? (process, contracts used, technical issues, policies, determination of fees and fee structure, etc); and, *Why* do you license patents the way you do? (strategic considerations,

global-insight/international-standards). These industries appear to be similar to the telecom industries before de-regulation. There was a gentlemen's agreement that technology was developed for the local operators. After deregulation, a global competition in technology started. The latest Apple-Samsung court case can be seen as an example of that.

[16] An economic experiment has been carried out as a result of this study and is reported elsewhere.

business model, industry, dynamics, etc). A third question was directed towards the role of *trust* in licensing and how they went about creating that trust in each others actions (which was asked as a hypothesis).

Most respondents gave very elaborate answers, resulting in page after page of interview material, as they laid out how they approached the licensing issues, their business processes and the role of trust, if any. After a number of interviews, common themes developed (were discovered) and additional questions were asked, testing some hypotheses. These questions were in particular related to practices on types of contracts used and contract changes over time (institutional learning on contract development), procedures to secure non-infringement (search costs), the view of contracts as "insurance" against loss of market access (see Ullberg (2012)) and being sued, and other similar institutional, contract, and management – governance issues.

There were also, towards the end when most data had been collected, seemingly conflicting visions about where exchange in technology *is* going or *aught* to be going. This was in particular the case between "open source" approaches to cooperation and patent rights approaches, both however using patent rights, but in quite different business models. As there is much research on open source schemes (for example work by Schweik and English (2012) based on Ostrom (1990, 2010), the main focus was how that "open source" strategy interacts with strategies of cooperation *with* property rights.

Some firms were interviewed once over the phone and others with sometimes several follow-up interviews and on site visit for in depth discussions with the whole team of IP professionals. In total about 40 interviews with 13 firms (and 1 decline) where carried out representing different expertise as the firms saw fit to organize their activities. The people interviewed worked with patenting, patent licensing contracts, financial valuation of portfolios, royalty audits, representing open source movements, organizational learning, litigation, acquisitions, patent sales, etc. representing a very broad set of skills one would expect in global exchange in ideas based on patents.

As firms required anonymity and that data be presented in summary form, information that could reveal the identity of a firm is intentionally general. However, specific comments are used in the text to represent views, in a non-firm specific language.

Business Models Supported by Strategies and Messages

> An ideology of honesty means that people choose to play the game of trade rather than steal, although property crimes may well pay the rational lawbreaker. (D. North 1981)[17]

Business Models

The study recognizes that there are different business models used by firms, or economic organization with respect to *patented technology*. The business models–the way firms operate as they compete for clients, structure their transactions, and earn their profit–are used to characterize the economic environment of the firms investigated. These are induced by property rights on technical ideas and contracts, communication rights, association rights, anti-trust regulations, national differences in these laws and cultural differences in cooperation, etc. i.e., the economic environment and institutions. Different models are simultaneously used, by different or the same firms and represent fundamental (business) strategic choices of firms.[18] The models go beyond traditional economic analysis of hierarchy or market coordination of activities. Four business models describe the environment for the purpose of this investigation.

1. Hierarchies (vertically integrated with respect to invention and innovation activities)
2. Networks (voluntary organizational cooperation between firms, including joint-ventures, loosely couples networks, open source networks (software))
3. Transactions (cooperation through tradable contracts)
4. Rent seeking (based on profit incentives created and de facto endorsed by the impersonal exchange system of property rights and court enforcement practices)

Firms operating in a *hierarchy* are firms that both invent new technology and innovate new products and services within the same hierarchy (firm). This is the analysis most economists use such as Schumpeter, and the approach in Arrow (1962). This represents a *personal* exchange mechanism between people within departments of a single firm hierarchy. What is exchanged *between* firms in this model, is information on the state of the art, shared through the patented technology, through the patent disclosures (not all technology is patented though and much remains trade secrets). However, this creates a competition in technology closer to the state of the art than without patenting; some technology that would have been trade secrets is patented.

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[17] North (1981) referenced in Smith (2004, p. 69).

[18] For a discussion of business models and risk see Ullberg et al. (2002), where the choice of business model is based on how management of risk and uncertainty has developed in the economic system during the last 100–150 years.

Firms operating in a *network* are similar to the hierarchy. Here it is common to share technology, know-how including patented technology. Patent pools are created to manage common patent holdings and other mechanisms like royalty free licensing. The network aims at creating a common product or service with common, shared, resources and can thus be seen as a loosely held firm (creating access to "common" assets). Therefore the hierarchy and networks are here treated as hierarchy as the coordination is still very personal and long-term.

Firms operating in a *market* are firms that contract patents through transfer or licensing, cross-licensing agreements. These could be for all patents in a portfolio, some selection of patents, limited to a certain field of use (products, services) or geography (markets), made possible by specific claims and validation states. These contracts are more impersonal in nature, and these agreements can be strategic or for marginal gains.

The fourth category is firms that, as a business model, extract rents by *systematically abusing* the patent and court systems. These are firms, who threaten to sue on the basis of possible infringement of patents, but the economic value of the patent has typically low merits – or even validity, but the court costs are prohibitive to clear these allegations. They are able to extract rents by forcing on patent licensing agreements, even if the patents are economically poor but it is cheaper to accept a license than go to court. This abuse is thus motivated by rules that give incentives created by the patent systems and court systems and not focused on economic value. Such rules are not incentive compatible with some social measure like Pareto optimality (Fig. 8.1).

In the following analysis we will now use the presented economic systems approach, business models (economic structure) and their different (observed) strategies to understand what firms do to create trust in each others actions through formal (and informal) messages.

Strategies and Messages that Create Trust

To analyze the interaction between firms exchanging technology using the patent system, the microeconomic system analysis described by Smith (1982, pp. 924–927) and others is used. Agents interact through language made up of agent specific (formal) messages to produce economic outcomes. Here the method is expanded to include messages that aim at creating trust in each others actions, to capture the process by which agents arrive at reducing uncertainty, making exchange (messages) possible. The agents' formal or informal *property rights in communication* (what messages can be sent – and not sent – by an individual agent) are then defined by the institution, structuring the language. The way firms have arrived at the messages and strategies is considered an institutional learning process that has developed over time with input from many sources. We are now ready to summarize the strategies and messages.

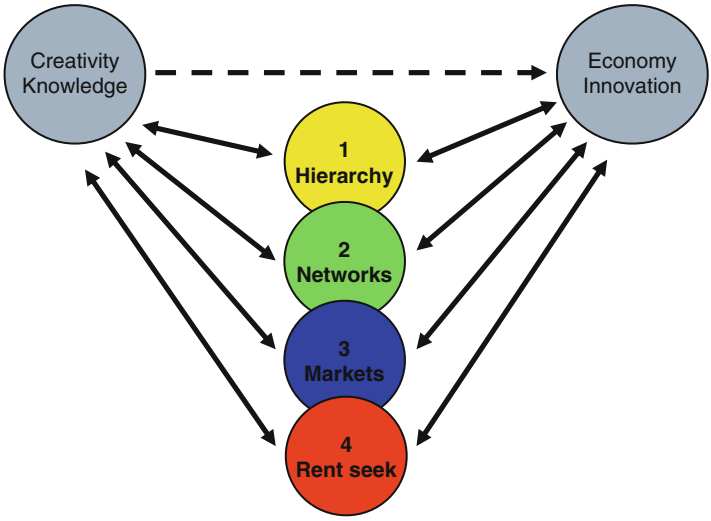

Fig. 8.1 Business models used to coordinate invention and innovation

Four Strategies of Self-Restraint: The Language of Trust

> Opportunism in all relational contracting and exchange across time is a cost, not a benefit, in achieving long-term value from trade. (Vernon Smith 2004)[19]

The interviewed companies and their trading partners fall into one or all of the business models: hierarchy, networks, transactions or rent seeking (the last only as trading partners to interviewed firms). Some are specialized in one business model whereas others operate in several models at the same time. What is characteristic is that firms in more competitive industries tend to cooperate more on technology, thus moving away from hierarchy (and networks) towards a market approach.[20] As the selected industries have high interoperability, exchange in technology based on patents would be expected but still their strategies differ considerably, even within the same product and service industry. Firms clearly choose their competitive strategy to promote value for customers and other stakeholders, not necessarily resulting in socially preferably outcomes.[21]

[19] V. Smith in Human nature: an economic perspective (Smith 2004, p. 69).

[20] In the industry which declined to participate in the study, the oil industry, almost no technical cooperation between companies occurred, and instead they develop their own technology in a hierarchy structure. This used to be the case for most industries 100 years ago (invention and innovation in the same firm), like in most economic analysis, but during the last century industry after industry have changed to a more cooperative mode – starting with networks – using the patent system at the heart of their coordinating mechanism.

[21] This is thus the daunting task of economic system development: to create incentive compatible rules. This must require some external input to the economic system.

The technology exchange strategies based on the patent system appears integrated in the firms' overall corporate strategies, but to a varied degrees. The competence on managing intellectual property rights (IP) is entering the executive decision making and board rooms, and many firms have turned trade in IP into a business or profit center. However, the tools used (databases, contracts, procedures) are mostly in-house creations, and some use expert firms. Competences come nearly exclusively from the legal side of patenting and, in some (pioneering) cases also from the financial or management consulting industry, or consumer (market) surveys in attempts to provide an economic basis to value patent portfolios in negotiations.

The firms organizing their business along the four business models – or combinations thereof – used four identified and distinct strategies to create trust in each others actions. These four strategies used by the patent licensing active firms in the study are:

1. *Staying clear* (of each others core technology areas)
2. *Strategic alignment* (cooperating transparently for a 3–5 year period)
3. *Marginal transactions* (trading high value patents as needed)
4. *Systemic abuse* (asserting low value patents with threat of high court cost)

Some initial observations will be made in section "Some Initial Observations on Dynamics", and the strategies will be explained in section "The Four Strategies Explained". The relation between the choices of business models and strategies is shown in Table 8.2. Institutional development is needed to enable business strategies that are more cooperative. The table shows also the strength of hierarchies, as they basically operate across the board, and thus have fall back positions if more cooperative models do not work. The (x) notation of systemic abuse means that this is not the core strategy but takes place as part of these models as well. As we will see in the next sections trust would be expected to be created by the use of different *mechanisms*. The firms thus implement their strategy–or create their strategy space–in one of the business models. Large firms tend, quite naturally, to choose models with greater strategy space.

Table 8.2 Business models and strategy to create trust in each others actions

	Strategy			
Business model	1. Staying clear	2. Strategic alignment	3. Marginal transactions	4. Systemic abuse
Hierarchy	x	x	x	(x)
Network		x	x	(x)
Transactions			x	(x)
Rent seeking				x

Some Initial Observations on Dynamics

These observations are probably quite obvious to any practitioner in the field, but documented here to give some short facts to the discussion on information and trust.

Change of International Property Rights Regime on Ideas Changed Business Models

The change in business model was given as a primary reason for the expansion of patent licensing during the last 100 years. From the mid-nineteenth century firms have moved from being motivated by *exclusion* of others, i.e. a hierarchy approach to invention and innovation, to be motivated by *exchange* through diverse manners of licensing, potentially benefitting from the best technology globally. This change may be attributed to the simultaneous decline of (royal/state) monopoly privileges and rise of merit based intellectual property rights.

The specialization between invention and innovation has opened a market in inventions, enabled by the global expansion of the patent system property right regime,[22] leading to this *structural* change in the economic system. This causality is key to the proposed thesis on the patent system as a *trade system* studied and tested in my (2012) book. This observation of change in business model may thus be that the patent system contributed to such a structural change, by a change of property rights regime, shifting the incentives to invest in technology to a more aggressive R&D policy as competition increased, thus slowly shifting the structure to coordination through markets, not hierarchy. The strategy then shifts, by necessity, towards creating trust in each others actions as firms exchange rights to use technology using the patent system. A market is established, creating need for intermediaries as "market makers". Trust has thus to move from a personal (hierarchical) to an impersonal (market) institutional trust. This more open selection process of technology would base new ideas closer to the real state of the art (as some trade secrets will be disclosed which otherwise would have been kept in a hierarchy without possibility of exchange in a less competitive economy).

[22] The patent system expanded rapidly internationally during the nineteenth century, after much discussion, culminating with the Paris convention in 1883, which was the first international patent convention. It was based on two principles: priority year and national treatment. These principles are still the guiding principles for patent cooperation in the world and the Paris convention is the only "international" patent system. Since 1994, with the TRIPS agreement by WTO, an almost global agenda has been attempted.

Institutionalized Learning in Non-standard Contracts: A Sociological Process

An observation on such cooperation through exchange was that almost all contracts used were *non-standard* contracts. The contracts used had developed over time to fix problems in the past (institutional learning). The more successful firms commented that the most important factor of success (i.e. profit) in patent licensing lies in institutionalizing a *learning process* of contract writing, getting feedback from the transactions, figure out a solution to the problems encountered and then systematically put that solution in the language of the contract to be used in the next transaction. This suggests that the institutional, or at least contractual, development is a process driven not only by legal or economic rationale, but by a *sociological* process, taking into account what trading firms actually do: based on experience of behavioral properties of contract clauses. This observation has similarities with the incomplete contract theory of Hart and Moore (1988) and Hart (1988). The companies having this internal process all had a much broader and nuanced approach of contracting in their industry. All contracts were strictly private information; however one firm shared a contract as an example.

Timing of Licensing

Firms being a licensor typically also try to negotiate a license when the uncertainty of the value of the technology is the highest, i.e. as early on as possible after the invention process, which would keep the *prices* down. The hope being that innovations using the technology would be possibly more profitable, if the technology was adapted and successful.

Adoption of Technology Through a Market

A fundamental concern of the top patenting and patent licensing companies was that the technology licensed aught to be adopted for long-term product or services use. The agreements also have to be designed in such a way that firms are willing to pay for it, the alternative is another technology or own technology. This clearly bears witness of a competitive market in patented technology. The "temporary monopoly on product" treatment of the patent system by economic theory therefore appears to be lacking this fundamental competitive use of patents.[23]

[23] This is a point to which I wish to develop further elsewhere. We are here talking about exchange in new, unique and industrially useful technology, not the products or services in which the technology may or may not be uses later on. This is thus a *producer* market in technical ideas, not a consumer market in products and services. Economic theory appears to treat the patent as a product or service commodity, but what is protected is a technology possibly useful in multiple products and services.

Here several of the most experienced firms advocate for a strategy of *industry adoption* of a technology, rather than pricing on the margin in one relation, the immediate value for the licensor. The licensor can thus be seen as *investing* in the licensee (given the cost schedule), in order for them to adopt a technology that may be profitable in the product/services developed for the *licensees* markets (there is a risk sharing element). Such a problem may be considered a principal-agent problem. However, the collaboration aims to get adoption for a certain technology which may become profitable for the licensor (the principal) if their technology would be used by the licensee (the agent), and in that case would generate a royalty stream down the road. There is thus collaboration between the inventor and innovator of specialized knowledge.

Here we see that the competitive equilibrium according to Muth does not hold, at least not on the margin, nor Nash, which calls for information symmetry, but there is another solution concept expressed here where self-restraint plays a key role.

This observation is the same as to say that they show a measure of *self-restraint* in the negotiation, regarding access and price of the patented technology, in order to allow for an exchange to take place where gains could be *realizable*. This action was observed among most patent active companies as a *policy*, thus indicating a realizable and *sustainable* approach, a business of exchange.[24]

No Trust: In the Positive Personal or Impersonal Sense

All firms expressed clearly that they did *not* place *any* personal, institutional or calculative[25] trust in each others actions, in the sense that firms would do what was beneficial for the other firm out of some good will. They did not expose themselves to this "pure trust", in the sense that they counted on that the other firm would act in their own interest (or they would act in the other firm's interest). However, the key finding was that they *do* put trust in each others actions *not* to do certain harm such as sue, hold-up, act opportunistic, etc.

[24] It is well known that licensing is a trillion dollar business today, but the point here is to begin to frame the observations as input to economic theory. As it appears at this stage, there is no concept that includes how firms manage this uncertainty. That is the reason why some of the process is described at some schematic level.

[25] Williamson (1993) concludes that the word "trust" aught to be used only in "personal trust". Institutional trust is really calculative trust. However, here trust is used in the sense of trust in each others actions, which can be both positive (that firms will reciprocate out of good will) or negatively (that firms will not do certain harmful actions).

The Four Strategies Explained

The four strategies will now be explained emphasizing the observed common theme of *informally of formally contracted self-restraint* and the messages sent with apparent purpose to create trust in each others actions.

1. *Staying clear* means that firms engaging in both inventive and innovating activities in the same hierarchy, stayed clear of each others' core competitive technology areas (in terms of patented technology). Firms thus specialize in key technology areas, creating a certain exclusive technology areas which they mastered better than others, through patent portfolio buildups. They create trust in each others actions – not to come too close to the other firms core technology areas – by using the patent system to protect proprietary technology areas (not simply single patents, which typically cover smaller areas) and by trying to invalidate competitors' patents through administrative and legal procedures that are "too close", making the point that it will be expensive to get too close to their technology area. The *message* sent is thus through the patent system procedures by often being extremely active and "on top of" any technology (application or patent) that may be perceived as "too close". (To gain an upper hand on information on competitor's possible direction of future technology, they frequently attend technology meetings, conferences etc. to search for possible research that formulates technical *problems* which indicate future areas of patenting.)

Also, as patents are hard to clearly specify, a large number of patents *increase* uncertainty in the rationale of getting too close, as a litigant may be countersued by the defendant.[26] Such response is mutual, resulting in very large patent portfolios as a *patenting* strategy, with many opportunities for suing *each other*, creating an economic environment where no-one can really come out better off if suing. This appears to be similar to a mutually assured destruction (MAD) strategy, and in fact the firms talked about this strategy using those words. This policy thus makes parties staying clear of each others' key technology fields, and one creates a trust in each others *actions* that they will not come close, not sue, not harm but "stay clear".

The mechanism of creating trust in each others actions, that they will not be sued or infringed, etc, is thus achieved by *mutually enforceable self-restraint*. Parties trust that they will not be systematically infringed, thus can make rational decisions (choices) on investing in research and development resulting in new patentable inventions and product and service innovation, by relying on their mutual retaliatory capacity.

The patent system plays a key role in coordinating these activities both through disclosure (everyone knows which fields the others find important), which is used to signal but also increase risk and uncertainty by confusing ("hiding" information of strategic initiatives using patent classification system innovatively, and other

[26] Famous cases involve many global firms in particular in non-component based industries, and where competition is limited.

mechanisms, leading to deferred publication, where possible, hiding *ownership* where possible.).

No formal contracts are made. Instead, the value of the in-house patented technology is essentially cleared in the product and service markets where their respective patents are used. Strategies like corona patents (patenting possible product and process ameliorations around a core technology) attempt to end such a competitive position once the core patents run out.

Market access for products and services are attempted to be assured by making sure no-one comes too close to the competitive technology.

Maximizing *uncertainty* in what is being invented and patented and maximizing *certainty* in patented core technology (creating assets) – "what we want are patents like tigers!" – is the solution in this strategy. Such strategy can only be used by very large firms, and even they cannot afford a "patent everything policy" having a patent department budget, limiting the value of a strategy of creating uncertainty in favor of certainty. These firms repeatedly call for quality patents, not volume patents (which thus reduces the overall cost of patenting).

Trust is thus created by mutually assured destruction (costly legal battles) giving incentives to stay clear, maximizing uncertainty of actual patent portfolio technology protection which increases the probability that firms do infringe each other, and that some of the patents actually "bite". Large patent portfolios with these characteristics allow the parties to make rational decisions on investments in R&D, based on the patent system's signaling and excluding properties. Such "giants" put almost everyone else under their shadow of patent protection, increasing the uncertainty from gains in exchange for non-equal size parties, like SMEs, or new entrants (initially too small IP portfolios to pursue this strategy[27]).

2. *Strategically aligned* firms engage in cross licensing agreements for a period of time, typically 3–5 years, based on whole or parts of large patent portfolios. These contracts often have a *capture period* option, which means that all *new* patented technology during the duration of the contract will also be included (captured) in the agreement. New patented technology will not be withheld, nor will information be withheld about what is in pipeline, as they have cleared all extant *and future* patented technology in the contract, and expressed sharing of information. They are thus exchanging everything (or parts of everything or for a particular product and services market) with each other in order to have access to future technology, with much lowered uncertainty. This is almost the opposite strategy of "staying clear". These agreements can be limited to specified products or services, creating a "strategic alignment" in patented technology (*not* products and services!) between the firms during the period. The contracts can

[27] A publicly reported example here is of course Google's repeated attempts to buy patents to defend the open Android system. Public cases like the Rockstar consortium are a cooperative response from the telecom and software industry to this new business model of advertising which could price out the telecom services and software. The message was clear: Stay clear of our business model!

end without possibility to extend them, or have clauses of renegotiation of price to extend the access to technology, so called "guillotine contracts". They can also be valid for the life of the patent, thus guaranteeing that the technology can be used in extant products and services. These contracts result in net payments when parties are unequal in perceived patent portfolio strength.

Trust in each others action – that parties will not sue, harm, etc. – on extant or future patented technology is thus assured by clearing extant patents with cross-licensing and adding this special formal contract which takes away the possibility to sue for *future* patented technology. There is thus a mutual (or multi-lateral) contracted *self-restraint* on each others actions not to behave opportunistically with new patented technology. Neither party can "renegotiate" prices or have competitive bidding (hold-up) on new patents.

The *messages* sent in this process is a formal one "not to sue for new patented technology", creates trust in each others actions to that rational investment decisions can be made in R&D and product and service innovations. This strategy, to be effective, can be pursued by firms with large, but not necessarily very large portfolios, which could "clear" technology useful for a strategic period. The solution to trust is thus negotiated by a different mechanism, enforceable contracts, rather than enforceable property rights. (Trade moves from a product/services market to an *asset market* with personal/impersonal contracts, a market based on the patent rights).

If a breach of trust is done, with respect to use of patented technology in products or services not contracted (fields of use, or markets), or not reporting sales properly, annulment of contract, etc. there will not likely be any renewal or further business the next period thus moving to a "stay clear" strategy. That strategy may not be preferred.

3. *Marginal transaction* firms engage in more or less transactions on *high value* patents, often in the form of smaller or larger portfolios. The competitive value of technology is thus much more known in these cases, or believed to possibly have value for a direct application in innovative products and services. The purpose of this licensing is thus more directly related to an investment in innovations. These contracts are thus made to clear extant patented technology in new (or current) innovations. The contracts can be for the life of a patent or a specific time. Straight forwards licensing, cross licensing or other forms like standards licensing are different versions of these transactions. There is little or no strategic alignment here, with capture periods, and intermediary traders (who do not patent) can therefore be a source of patents in this exchange. However, information asymmetry plays an important role as truth revelation about holdings is important in pricing bundles of patents. Some of these contracts are highly standardized "tear off" license contracts that can be bought on the internet, for example regarding usage of some standards. A broad range of types of contracts are found but the common theme is that they all relate to extant patented technology with proven or anticipated value.

Trust in each others actions is here created by clearing specific patents listed in the contract for certain products and services and by the existence of formal and competent patent courts that penalize infringers based on value and proportionality.

Clarity of ownership is a key in this strategy. The trust is thus much more impersonal than in the other examples.

The *messages* sent are willingness to engage in contracts and filing law suits, if infringements are suspected outside of the contracted areas. If a breach of trust is made, then long court battles may be started, with the purpose of enforcing the patents. Parties thus restrain from infringing by a policy of honoring the inventor resulting in marginal transactions. These may result in a "staying clear" strategy if trust is breached but more commonly a license agreement often including penalty for infringement use at a multiple of the "typical" royalty rates as a penalty or other mechanisms to deterring infringements.

4. *Systemic abuse* firms engage in rent seeking using the patent courts, often trying to assert *low value* patents. These firms can be considered inventors, intermediary traders or innovators, and they seek out, often larger firms in large volume products and services markets, and assert their low value patents against a likely infringement. As court procedures are very costly, around $1–2 m/case, these firms then propose to settle out of court for a smaller sum against a license to use the technology. Since this is a cheaper way to clear the potential infringement, many firms settle. This is thus "Russian mafia like methods, paying protection money" as one large firm called it. However, recently this approach is also used against smaller businesses potentially infringing low value or patents that might be invalidated in a reexamination. The business model thus relies on high court costs, in particularly in the USA, where asymmetric costs can be imposed on the defendant by the so called *discovery* procedure, by which the defendant have to reveal private information to the courts, like emails, documents, etc, if there is a suspicion that infringement is made. This is a costly process. The European system with "looser pays", does not share the same problem as the courts evaluate the penalty based on value.[28] If the value is low, then the penalty is low, and also the probability to win a court case – which is not guaranteed – has to be taken into account by the litigant. This rule appears to put some checks and balances regarding enforcement based on value. The rent seeking firms may also come back with a second law suit shortly after the first, as information of ownership can more or less be legally hidden (shell-companies) and no updated registry exists. This is a clear system failure, where the incentives are not to enforce the economic value of a patented technology, but use court costs as means of some "extortion".

The response to this systemic abuse is to not license under threat of court costs but to go to court and pursue annulment of patents, showing the low value, thus somehow impose a more symmetric cost on the litigant, making the business model less profitable (or unprofitable, running these firms out of business). Such actions discipline the systemic abusers and teach them that if they want a license they should come with valuable technology and also full disclosure of other patents owned (information issue). Also in this case, we see that self-restraint when it comes to patent quality and value is a key in sustaining exchange and this strategy.

[28] Currently there is a discussion on the US to look into this problem of enforcing low value patents, hoping to halt such systemic abused, deemed inefficient to innovation.

In addition firms increasingly go to lawmakers and try to amend the court proceedings; lobbying legislators is something done to "correct" this systemic error. This topic is a complex issue and solutions proposed appear favor the hierarchical business model, which was used more 100 years ago than today, and less cooperation through markets. Such attempts thus appear to have the aim to create incentive compatible rules for the *firms'* strategies to operate and create trust. However, from an *economic* point, the incentives aught to be compatible with social gains, which is a much more challenging task. Strategies 2, 3 appear much more compatible than 4 in this respect.

Trust in each others actions is thus created by going head to head with the systemic abusers and basically try to make their business model unprofitable unless valuable technology is presented, either through repeated court battles or lobbying for better laws. In such a case the inventor's rights are honored.

The *messages* sent are thus following through with court proceedings, annulment procedures with the patent office and willingness to pay for valuable technology. This systemic abuse is not easy to counter as a small firm and appears need a change of incentives. The property rights on these *messages* aught to be changed to change the incentives to favor high value patents.

In all these cases the common *theme* appeared to be that self-restraint regarding litigation (enforcement), opportunistic behavior (hold-up) and time value of returns in the interest of the client (licensee), was informally or formally contracted. As noted, this was achieved through different mechanisms, used in the different strategies by the firms operating diverse business models. Messages, communicated using the mechanisms, were used to arrive at the outcome of a sustained state of trust in each others actions, together forming a language of trust. These messages can be seen as part of a process to achieve the intended outcome of trust in each others actions, a process that was different in each strategy. The property rights on communication of these messages are therefore important in an economic system based on inventions of new technology. If the contracted trust could *not* be sustained, a change of strategy towards less cooperation (hierarch) was made. Each strategy thus resulted in that trust was achieved in each others actions not to infringe or sue for business essential, extant or future patents, reducing the uncertainty in the value of the future cooperation to a level where *rational* investment decisions could be made in innovations to achieve realizable and sustainable gains from exchange in patented technology.

Of particular interest appears the contract with capture period option that was used to move closer to an asset market in ideas. The contractual arrangements (formal and informal) follow a pattern of initial steps in institutional arrangements towards more impersonal exchange in patented technology. The behavior, based on the messages, appear to cover assertion of residual ownership.

A second, economic, dimension was observed, search costs, and is developed further in the next section. These economic and sociological observations also appear to lend themselves to generalizations beyond patents such as international cooperation. Such possible generalizations are elaborated on in the last section.

Table 8.3 summarizes the strategies and messages used to create trust in each others actions motivated by subsequent gains from such exchange.

Table 8.3 Messages (language) used to create trust in each others actions by means of mutual (multilateral) self-restraint, as firms exchange patented technology under uncertainty

Strategy	Policy	# Message	Self-restraint mechanism
Stay clear	Mutually assured destruction	1. Build up massive patent portfolios in order to increase uncertainty in possible litigation situations, deterring others from suing and infringing as there is certain overlap on both sides.	Cost of litigation mutually prohibitive, enforcing property rights.
		2. If informal contract is breached then suing each other in court, which will deter further action.	
Strategic alignment	Honoring the inventor	3. Contract with capture period option, offering mutual access to any future technology during contract, and not being sued	Completely open sharing of everything (cannot hold-up or negotiate on each patents), enforcing contracts (and property rights)
		4. If formal contract is breached (in fields of use or after term expired) then suing each other in court, which will deter further action.	
		5. If infringements made then no extension of contract possible, i.e. "stay clear" strategy is option	
Marginal transactions	Honoring the inventor	6. Contract not to sue, on specific patents and fields of use	Court litigation based on penalty proportional to value of patented technology in product/ service markets
		7. If formal contract is breached (in fields of use or after term expired) then suing each other in court, which will deter further action.	
		8. If infringements made then no extension of contract possible, i.e. "stay clear" strategy is option	
Systemic abuse	Litigate to enforce, based on "cheap" low value patents	9. Threaten to litigate in order to agree on license under threat of high court costs	Massive court litigations by defendants to invalidate ligitants patents, imposing cost on litigant to make business model unprofitable
		10. If litigant comes back too often or only with low value patents, then defendant tries to anull patents through court proceedings, to run litigant out of business or change behavior	

When portfolios with thousands of patents are to be evaluated, in practice, only a few are valued making agreements often net-agreements. The big portfolios are reduced to a few discussion patents where value is clear. In courts also only a few patents (or claims) are dealt with, not whole portfolios. This makes it complicated to defend property rights with courts alone, resorting to additional mechanisms. Contracts of self-restraint are needed to honor the inventor, not to sue, to have a functioning trade in ideas. Trust in each others actions must complement trust in courts proceedings.

We can see these strategies as four steps in a progression from personal to impersonal trust through formal and informal contracts. The economic consequences of these contracts appear to be that the agents do not trade on the margin, but on some other longer-term value or capabilities. This is a testable hypothesis in an experimental environment, and a controlled laboratory experiment has been designed to investigate this. The mechanisms clearly point towards strategies moving away from separation and litigation to cooperation.

Comments on Some Observed Dynamics

Market Access: Implications of Patent Portfolio Size

From an institutional economic policy perspective the size of the portfolios needed to sustain the diverse strategies is interesting as this indicates the research and capital needed, i.e. the size and balance sheet of firms, to sustain trust in each others actions. Observations on portfolio size indicate that very different sizes are needed to reduce uncertainty in the strategies. Such a policy is thus an extension to the institutional constraints to reduce risk in transactions and exchange (the fundamental rational for institutions). Here an incentive for productive cooperation in the creative process is at heart, requiring reduction in uncertainty. In the case studied here, strategies requiring smaller patent portfolios would be necessary for broader inclusion of human ideas. Figure 8.2 shows the approximate relationship between patent portfolios sizes needed to adopt a certain strategy.

In this study, contractual agreements and search costs have been seen as decisive. It appears that institutional and tax policies that give incentives to move from strategy 1 and 4 to 2 or 3 are compatible with social goals of growth in productivity enhancing patented technology, making the selection process more demand driven, more internationally inclusive and more competitive.

An Economy of Scale of 1

This shows the challenge of socio-economic policy: To reach the individual inventor level. A key policy question then becomes whether individual inventors (or small teams of inventors) aught to be a topic of economic policy. That would definitely

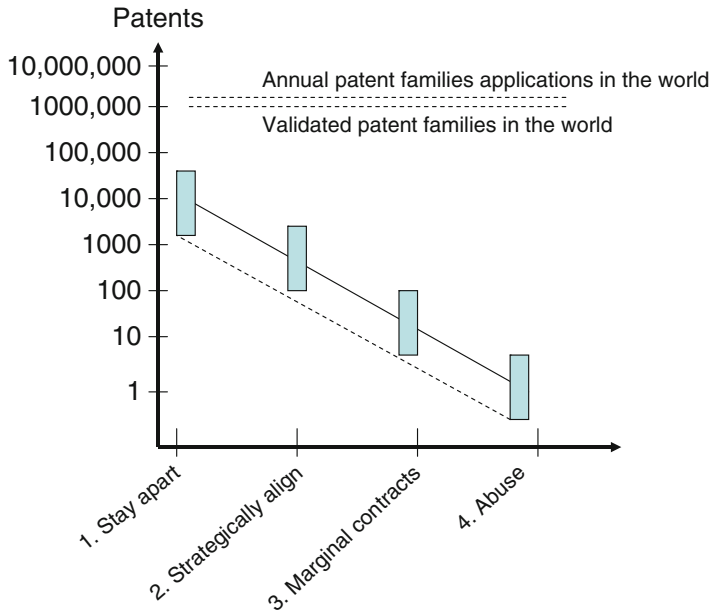

Fig. 8.2 Size of patent holdings to sustain strategy of trust

challenge 70 years or more of reliance on economies of scale economic policy, promoted by the industrial approach of mass production (and seen by politicians as the source of job creation). Perhaps thinking of economics in terms of the "second economic revolution" is more fruitful? That approach allows for a discussion on economic structure, not pre-determined by an "industrial" approach as the economic engine.[29] The proposition here is that integration of technology and science aught to be structured in a more productivity enhancing way through a selection process in a market (not an invention-innovation hierarchy) which started by the creation of the patent system in 1474 offering *tradable* patent rights (initially *importing* technology). The incentives aught therefore, it seems, be more compatible with producing protected productivity enhancing technology than "more of the same" products and services at "lower cost". A rebalancing of incentives towards inventive activity is needed, creating a more dynamic economic system. Higher cost may thus be better than lower cost (within some limits), as the creative process gets funding, increasing productivity through new technology, not only scale. A producer market in ideas appears to solve this problem, by separating inventions (technology selection process) and innovations (products, service selection process where EOS matters).

[29] One reason of challenging this approach is that today the economic system in the developed economies are about 60–80 % services, and even in developing countries services dominate.

This change towards one (1) can be seen in 3D printing, flexible manufacturing, innovation parks, past century's tech clubs, incubator and, maybe, also science parks (which can be seen as a first recognition of the need for more dynamism in the economic system).

Concentration of Inventive Resources

Such economic structure of inventor and innovator coordinating in a market would be the anti-thesis of Robinson (1977). A producer market thus creates competition between inventions that can be used in new innovations, and more-of-the-same-innovation, opening investment opportunities for the rational investor. Clearly the trust problem between inventors, traders and innovators is a key ingredient in such an economic system.

The economic structure (EOS) may have concentrated the inventive resources to very large firms, without strategies for exchange with moderate patent active firms. These smaller firms are typically startups, introducing new ideas. This means that barriers of entry of inventions may have been increasing, reducing the dynamics. Economic use of technology in a broader way, with specialized firms pursuing different applications of the same technology adding to the dynamics, of the economic system seems to distribute new technical ideas further than a structure of hierarchical inventor-innovator firms who largely focus on one application of the patented technology. Robinson (1977) lamented the crisis in the 1970s of the development of new products and services as large firms "monopolized" new technology. However without apparent discussion of economic structure, rather effects of concentration of capital in the hands of the few. More *internationally* tradable right – at the scale of 1 – may therefore be a fruitful source of further economic policy investigation.

Mutually Assured Self-Restraint

The conclusion of the study points at that all strategies appear to have at its core a formal or informal contractual agreement to "honor the inventor" on the one hand and refraining from opportunism on the other by mutual (or multilaterally: inventor, intermediary trader, innovator) self-restraint. One could say that the strategy space of mutually assured *self-restraint* (MAS) is broader than mutually assured *destruction* (MAD) and includes at least four strategies to achieve trust in each others actions. Implications of MAS appear to be that policy aught to facilitate enforcement of both tradable patent rights and contracts based on potential economic value. The enforcement of both ownership and transactions allows for uncertainty to be reduced so rational investment decisions (choices) can be made.

If self-restraint is not upheld, there are costly mechanisms to correct that. If institutional policy would be implemented in this area, a key focus would be for less costly mechanisms to be implemented (administrative patent procedures, patent quality, court cost). It is thus not only a "better" patent system (in terms of for

example quality) that is needed, but a better contract law and court proceedings that give useful property rights on *communication* (what messages can be sent and received) starting at the individual inventor level. The discussed messages represent elements of such an institutional development.

Search Costs

Search Costs and Impact on Strategy Choice

In addition to the sociological concept of self-restraint, an economic concept, *search costs*, was observed as being critical to the choice of strategies to create trust. This concept interacts with the ability to create trust in each others actions. The costs reported here expressed by basically all firms refer to:

A. Patent system:

1. finding prior art (a classification problem),
2. a digital divide issue (access to databases, internet, etc),
3. identifying legal validity, geographic validation and
4. ownership of patents (currently not updated)

B. Corporate law

5. indirect ownership (shell companies)
6. licenses of patents (private information)
7. discovery procedure costs (US)

C. International law

8. injunction procedures
9. international prior art searches

These and many other costs are key for the firm respecting others patents to simply *stay clear* of others patented technology. Today these costs are prohibitive for most companies if not even not all. It is thus virtually impossible to completely stay clear and not infringe. Such uncertainty works three ways: (i) the inventor may not be able to license technology (ii) the traders cannot trade as it is illegal to license invalid patents, and (iii) for innovators who cannot be certain of the value of the technology and its exclusive use or ownership, to mention some cases. These search costs creates a situation where infringements are inevitable and, together with expensive court procedures, limits the strategy space for cooperation though patents as described in the strategies.

In the study the conclusions appears to be that if search costs are high then strategies 2 and 3 are less likely. Thus high search costs favor strategy 1, “staying clear”, limiting gains from exchange in technology and strategy 4, “systemic abuse”, which use uncertainty of ownership, hiding information, etc to extort possible infringers.

Table 8.4 Search costs and strategy to create trust in each others actions

	Strategy			
Search costs	1. Staying clear	2. Strategic alignment	3. Marginal transactions	4. Systemic abuse
Low	(x)	x	x	(x)
High	x	(x)	(x)	x

x, indicates strong correlation; (x), weak correlation based on interviews

High search cost, an information, risk and cost problem, thus interacts with the strategies to create trust to reduce uncertainty. Search costs are therefore a key parameter in connecting the economic dimension of the problem to the sociological problem of trust. Table 8.4 shows the relationships discussed by the interviewed firms.

This division of the economic and the sociological problem is the basis of the *experimental investigation*, representing treatment variables of search cost and contract. High search costs facilitate the creation of a rent seeking business model, that of infringing and suing, which may result in that the value from the invention is reduced (by theft) from the inventor, resulting in less cooperative strategies from the inventor as the only possible response (choosing the hierarchy strategy). This reduces the potential growth of technology through exchange and, in addition, loss of signal for the direction of science, to support further inventions. The rational law breaker (thief) always chooses dominant strategies (Smith 2004, p. 69), which may be created through high search costs, in turn a possible policy issue. The loss of cooperation in the use of patented technology thus has impact on both the direction of patented technology and for the direction of science.

Discussion of Search Costs in Relation to Policy

One particular feature in the US patent system making search costs high was the possibility to *hide* ownership of patents through shell companies (ownership only has to be reported if above a certain threshold of ownership), and possibly other mechanisms. This was used systemically in the abuse strategy, to be able to keep private information on ownership, thus be able to sell a portfolio on slices and many times. This attempt to "bundle" patents does not allow the buyer to bid for "bundle" that he is interested in as a whole, and being unaware of whether technically related patents will end up with competitors, or more often, the abusing firm could come back and sell another set of patents right after. See under abuse strategy for resolution mechanism. Other mentioned costs are due to lack of registry for updated patent ownership registry (who owns what), patent license registry[30] (who has access to what, which is a strictly private business today).

[30] It is unclear whether a compulsory patent license registry would be in the interest of economic development. Incentives for voluntary publication of these licenses may be better. Forcing publication of licensing may result in less licensing, as they reveal strategic intents, like patent applications do. However, this topic is an issue of study and

Patent classifications is another area, which allows for systematic "hiding" of inventions by splitting up an invention in many patents under different classes (a common strategy of patent applicants), creates such search costs. The international patent classification system, base largely on the European patent classification system appears more helpful, as it has a clearer technology focus than the US patent classification, which does not have the same structure. A classification that better captures technology areas, and is followed by the patent offices, would help in making the patent claims more clearly connected to an inventive technology.

Patent quality was a recurring theme among the most active patenting firms as mentioned. One dimension of this it that too many patents without real technological merit are granted (this is a contentious issue). A rule of thumb among patent professionals[31] used to be to have a grant rate or 50 %. This rate varies a lot and was in the US above 90 % a decade ago. That resembles more a registration system than examination system. Many other countries have similar procedures (and some, at least in the past only had registration and validation took place through courts). There has however been a pushback in the USA[32] and the grant rates are now lower. The problem from a search cost perspective is that a lot of patents that should never have been granted is out there, and to stay clear from them, creates an "impossible" situation for companies using patents productively. These patents of low quality are also "feed" for systemic abuse firms to threaten to sue for possible infringement.

There are also other search costs involved such as access to patent information (databases), data collection and analysis of their use in products, validity data (which patents are upheld, where), company data, and internet, i.e. the digital economy's toolbox.

Economic Theory Consequences of Contracts and Search Costs

The main purpose of this study has been to investigate the strategies firms use to create trust in each others actions, in an economic-sociological environment of genuine uncertainty. The hope was to give input to economic theory regarding how to better handle uncertainty and risk, by first solving the sociological problem of uncertainty and then the problem of risk. Some possible consequences are here outlined.

The solution to the problem of uncertainty appears to be in contracts of multilateral self-restraints. This implies that, since the marginal value of future inventions cannot possibly be known, and that opportunistic behavior such as hold-up cannot

[31] Ref. to personal communication with the head of international relations at the Swedish patent office, a senior patent professional with 30 years in the patenting world.

[32] Why reference to the US? Many countries look at the US for guidance on patent office policy so what the US does matters internationally.

be excluded, contracting the exclusion of and enforcing such behavior, informal (personal) and formal (impersonal) contracts on patented technology, the contracted price cannot possibly be on the (genuinely uncertain) marginal value of the next invention. It has to be on some other value, in order for agents to make rational decisions (choices) regarding investments in further products and service innovations using the patented technology. Solving the sociological problem of trust implies that some patented technology would be overpriced and other underpriced ex ante, if evaluated in ex post situation.

This puts focus on three areas: residual ownership on technical ideas, contracts and market prices. The quality of patents, their disclosure, claims, and classification (i.e., their specification), is the key for ownership and the creation of an asset market in the first place. This means that specifications of the property rights (like their quality) need to be part of any contract. The contracts, which include implicit or explicit self-restraint giving their enforcement, would be priced, possibly, according to some long-term average value,[33] or, the risk appetite of buyers "betting" on that the sellers will invent more profitable technology in the future higher than the average. This creative process requires further investigation. Price discussions would thus include the (economic) effectiveness of the management of the uncertainty through self-restraining contracts and the search costs related to quality of assets in terms of ownership.

This suggests that economic structure depends on assets, self-restraining contracts in determining the value and thus market price. We posit that firms are thus organized along the lines of ability to solve this sociological problem of trust in each others actions, not simply residual ownership and transaction costs. Including these dimensions characterizing what firms do to manage genuine uncertainty, into a formal theory would be a next step.

In all these cases the discussion on market efficiency under risk (Arrow 1962) needs to be ameliorated for uncertainty.

If the findings in this study can be verified, such a discussion could be made along the lines of the four strategies:

1. Staying clear strategy – uncertainty in opportunistic and rent seeking behavior.
2. Capture period contract – allows uncertainty to be managed through contracts. This is not a marginal value.
3. Marginal contract – well seasoned technology with proven value can be traded at "value" or portfolio value.
4. Abuse – systemic failure (not market failure), that give incentives to hide information.

In such a discussion attention may include the *direction* the patented technology created and exchanged is taking in terms of its benefit for economic development.

[33] The best forecasting estimator is the relatively simple: forecasted value = long term trend (1-a) + last value*a. The long-term trend could be the average. Ref. to personal communication with Prof. Spyros Makridakis, INSEAD.

The derivate effect would be the *direction* science takes in terms of its benefit for technology for which there is a expressed (signaled) demand.

The economic consequences of these formal and informal contracts appear to be that the agents do not trade on the margin, but on some other value. That could possibly be average value or "betting" on a value higher than average given that incentives are in place to invent towards an expressed demand. This is a testable hypothesis in an experimental environment, and a controlled laboratory experiment has been designed to investigate this.

Proposed Experimental Investigation

An experimental investigation is proposed that build on earlier experiments on the study of performance and behavioral properties of markets in patents (Ullberg 2009, 2012). Here a choice of nine technologies is given to an inventor and two intermediary traders and eight innovators in two industries compete using an auction mechanism for a tradable two-part tariff contract on patented technology, as a security. The patent validity is variable (the property right ownership has a probability less than 100 %). The study will expand the *choices of contract* to the capture period contract (the inventor to invest and innovator uses the patented technology in three periods) and the marginal contract (the inventor invests once and the innovator uses it in three periods), *enforcement of contracts* (non-contract holders can infringe technology and holders can enforce by searching to find infringers and sue in court) and an economic environment of diverse *search costs*.

The experimental design is a 2×2 design with the two contract types and two levels of search cost (high and low) corresponding to an economic system of both management of uncertainty through contracts (asset and contract problem) and management of risk through search costs (institutional problem). The design thus lends itself to first investigation of prices given both uncertainty and risk. Previous experimental results indicate that the model has pretty good parallel behavioral properties, promising to lend it self to further study of institutional performance, of contracts/enforcement and search costs. This experiment is reported elsewhere.

Implications for Other Fields

The strategies appear to have some generality for other areas outside creating trust in exchange of patented technology. Several examples have been found of which a few are mentioned here: US-Russia relations, the first patent law and limiting state monopolies, and international institutional development.

The Limits of Partnership

In "The limits of partnership" (Stent 2014) explores the relationship between the US and Russia the last 20 years. The partnership is partly about innovation between US-Russia, thus a partnership that strikes at the heart of economic cooperation and development.

Trust in each others actions has gone through "four resets" since that Christmas day in 1991 when the Soviet Union disappeared (George H. W. Bush, Clinton, George W. Bush and Obama). The Russian explanation is that although "every Russian President has begun his term with high expectations for the relationship and every term ends in disappointment because the United States has disregarded Russia's interests." (Stent 2014, p. x)

If the findings reported here has bearing outside cooperation under uncertainty in exchange in patented technology, self-restraining contracts are needed and possibly an international commercial court. This may not be sufficient though but move in the direction of strengthened international institutional development may be needed as well, in today's multilateral world, where the two former super-powers now have to relate to a world of multiple "super-powers". See (Kissinger 1994) for a foresighted discussion of challenges for the USA in finding a future role of USA in world diplomacy.

Stent comments that the central objective of Russia since 1992 ha been to "regain it status as a great power and be treated as an equal *by the United States*." (Stent 2014, p xi) This is firmly how the firms operate in the "stay apart" strategy, as they try to find means of cooperation, through *mutual* self-restraint. The fallback strategy has to guarantee the continued prospering of the own hierarchy, and that can only be assured by mutually assured destruction to create trust in each others actions, not to "invade" or compete in each others markets and stop competition on technology in those divided markets. A sustained, but economically less efficient non-cooperative strategy than strategic alliance, or marginal cooperation is achieved. "The US interest has been to prevent Russia from acting as a spoiler in areas where the US has vital interests" (Stent 2014, p. xi). Mutual self-restraint is a necessary step towards increased cooperation.

According to Stent, an American perception that a weak Russia I amenable to acquiescing to a U.S. agenda has created a visceral Russian determination not to be treated as the US's junior partner. This, again, is what is observed by partners in a stay-apart strategy, where weak or no contracts and institutions exist to enforce individual, weaker, firm's rights. The alternative to such a strategy would be a shift towards an international contractual and institutional development process, where each party competes on specialties in a multi-polar world, not on a mutually assured destruction. The strategies found here may therefore be helpful to explain the rationale of increased formalization of international collaboration.

First Patent Law

The first patent law: 1474, 19 March, is an example in it self of contracted self-restraint:

> There are men in this city, and also there come other persons every day from different places by reason of its greatness and goodness, who have most clever minds, capable of devising and inventing all kinds of ingenious contrivances. And should it be legislated that the works and contrivances invented by them could not be copied and made by others so that they are deprived of their honour, men of such kind would exert their minds, invent and make things that would be of no small utility and benefit to our State. Therefore, the decision has been made that, by authority of this Council, any person in this city who makes any new and ingenious contrivances not made heretofore in our Dominion, shall, as soon as it is perfected so that it can be used and exercised, give notice of the same to the office of our Provveditori di Comun, having been forbidden up to ten years to any other person in any territory and place of ours to make a contrivance in the form and resemblance of that one without the consent and license of the author. And if nevertheless someone should make it, the aforesaid author and inventor will have the liberty to cite him before any office of this city, which office will force the aforesaid infringer to pay him the sum of one hundred ducats and immediately destroy the contrivance. But our Government will be free, at its complete discretion, to take and use for its needs any of the said contrivances and instruments, with this condition, however, that no one other than the authors shall operate them.

The last sentence contacts self-restraint between the governments, thus limiting the previous royal monopolies granted to the friends of the king, creating some trust in the actions of the government, provided the courts would honor the law. The transition from personal to impersonal exchange thus goes through steps of contract and institutions to enforce contracts. Some research portray that "constitutionalizing patents" was a way limit monopoly rights handed out by kings, provide a way to impose self-restraint by governments (Nard and Morriss 2004). Royal privileged (political processes) are thus turned into administrative processes.

International Institutional Development

Base on the proposition of self-restraint, an increase international cooperation would benefit, in terms of institutional learning, by an external input to the nation states.

The question maybe more how to get there, i.e. institutional learning, than the need for enforcement of mutually self-restraining contracts. Experimenting is a key here, thus, regional and limited multi-party agreements could result in this learning. One could see the G7, G8, G77, etc as such attempts to bridge the bilateral agreements with international, multilateral, agreements such as UN, WTO, etc.

In this spirit, a more temporal contract could be introduced, allowing for strategic alignment between states for a time. That may advance the institutional learning faster than long-term commitments where rules may be difficult to change. You don't want to change the rules too easily either, as it is trust that is desired. A length

could be perhaps 15 years or 50 years or so (a rather long-term investment horizon for most firms). Hong-Kong with 99 years could be seen as such an example in international trade. This temporary institutional learning, would then lead to perpetual rules of markets.

Compare North on limited versus open access order (North 1990), where he argues for rule of law for the elite. Here we may see a similar process among nations, coordinated through international rules and laws. However, the process by which this institutional learning could take place, based on the finding here, may suggest that temporal international contracts and agreements, allowing strategic alignment to take place – and be tested – may be a way to develop this international cooperation, rather than the difficult process of multilateral negotiations, often with political concerns dominating other concerns in society.

A more experimental approach may be able to include business, civil society and governments (as a rule maker and enforcer), creating a separation and coordination between diverse interests to better represent the whole society (not only economic interest, or political ambitions, or religious concerns or other special interest groups). Such as system would lead to more competition, thus, incentives to learn.

Conclusions

We have discussed key aspects of what firms do to create trust in each others actions when exchanging uncertain current and future technology in patent markets (technically based on the patent systems). To resolve *risk,* information (an economic problem) is required to create a probability distribution of future events, but to resolve *uncertainty,* where information is not available, trust in each others actions is needed (a sociological problem). The economic treatment of risk in the literature is based much on the Arrow-Debreu security with markets on state of *nature* (in a broad sense). In markets in patents, state of *the art,* is traded which is far more uncertain than state of nature (which can be investigated by studying nature) as these are new, untested (mostly) technical solutions created by people (which involves uncertain human behavior and ideas). Different cooperative strategies were identified to resolve this uncertainty by the firms, depending on the business model, patent system strength and search costs (to stay clear of patent claims).

The attempt has been to separate the sociological problem from the economic problem to better understand the *process* by which uncertainty is managed (reduced) and governed in these cooperative environments. The cooperative strategies, four in total, all appear to be built on *informally and formally contracted self-restraint* among the trading partners (inventor, intermediary traders, innovators, financers[34]). The strategies identified are (1): "staying clear" of each others technology areas "clearing" technology indirectly in the product/service markets, (2): "strategic

[34] Financiers were not part of the interviewed firms but mentioned in the discussions as "trading partner".

alignment" with capture period contracts including future patented technology for a period, (3): "marginal transactions" of patents in use, thus market values are "known", and (4): "systemic abuse" where uncertainty of ownership of (mostly) low value patents is used to extort, backed by prohibitive cost of enforcement, avoiding a negotiation on (the low) value.

That contracted self-restraint creates trust in each others *actions* not to sue, hold-up or behave opportunistically, reducing uncertainty in the informal or formal relations making rational decisions for investments possible (where the strategies to create trust can be sustained). They create an economic system where sustained exchange can take place. The process of creating trust and *reducing* uncertainty in an economic system can thus be described by a selection of strategies moving from strategy 1 and 4 to strategy 2 and 3, where direct negotiation on the value of patented technology is possible (in 1 it is only indirect and in 4 it is the "cheaper" alternative to court costs). This selection is in turn dependant on the incentives to trade technology, i.e. realized gains from trade given that trust can be maintained to reduce uncertainty.

A series of *messages* were used by firms to create trust in each others actions, different for each strategy. These messages then form the *language of trust*. The messages appear to assure "freedom to act" in the innovation market by clearing the patented technology rights through different *mechanisms*: for strategy 1: mutually assured destruction (MAD), 2: mutually assured self-restraint (MAS) in various licensing agreements, 3: limit field of use (FOU), geographic markets (potentially in connection with standards) and 4: running systemic abuse firms out of business (SAB) by annulling low value patents (with patent offices) to dissuade litigation based on prohibitive court costs.

A possible next step would be to *develop* these mechanisms further to tie them closer to the strategies and messages. Such a study may help in enabling a more incentive compatible policy to move from strategies 1, 4 to 2, 3.

$$\text{Strategy} \rightarrow \text{Messages} \rightarrow \text{Mechanisms}$$

The choices of strategy appeared also to be directly impacted by "search costs" to clear any patent infringement. These cost include finding the rightful *owner* of a patent (currently no updated registry exists, shell-companies are used to intentionally hide ownership), finding patents that may *infringe* new inventions (classification issues, unclear disclosure and claims) and finding *overlaps* between portfolios, to give some examples. In essence this is an asymmetric information problem (an economic problem) that appeared to interact directly with the choice of strategy to create trust. These search cost require a systemic approach to the patent system, so that economic value will be the basis of negotiation, not overshadowed by diverse search costs. *Quality* of patents and public information on legal *ownership* are therefore key issues.

All strategies are thus not available to all firms, which cannot be efficient, as incentives to invest in new inventions are then reduced (at the discretion of some firms). Only the largest firms can get the access they want, and even they have issues

with systemic abuse. To send a MAD message one needs to invest in a very large portfolio (thousands or tens of thousands of patents). Only then can the uncertainty in claims be *high* enough that MAD is assured if core technology is infringed. To send a MAS message huge research portfolios are needed to leverage research capabilities as net-licensing fees may be too expensive. A FOU message, a contract and price negotiation is considerably less expensive, but these represent often technology in use not new technology, which drives future investments. To send a SAB message is relatively inexpensive but to *respond* to a SAB message is expensive and these firms often settle out of court.

The messages thus appears to first assure *ownership* of technology invested in to exclude (use them in own innovations) or trade, and then assure *terms of trade* (contracting a diverse range of licenses, cross-licenses of portfolios, parts of portfolios or individual patents). In the end the messages serve to assure self-restraint that the parties will not sue, nor hold-up or behave in an opportunistic way in pricing new technology. Those costs clearly depend on a culture of "honoring the inventor". Incentive compatible decisions in patent markets are thus not on the margin, but on a more long-term relation of trust in each others actions. The hope is, as a next step, to integrate trust in economic theory, based on the sociological process to manage uncertainty through informal and formal contracts.

Enabling increased selection of strategy 2 and 3 will likely create a more dynamic economic system with less (concentration of) ownership of technology in hierarchies, as incentives to invest in new technology and trade it are likely higher. A more competitive technology producer market likely leads to a higher growth rate in economically useful technology (i.e., increased productivity) due to increased demand side knowledge revealed in the bidding process of prices, thus potentially higher growth in the economic system.

It also appears that these four strategies also may have merit in more general applications such as international relations and international institutional development where attempts are made to forge a more cooperative world between nation states, as well as in sports, family, and other sociological problems where trust in each others actions is a key element.

In summary institutional and taxation policy, as well as further economic theory development, aught to be informed of these strategies and messages to solve the sociological problem of trust in a way that gives (i) incentives to move from strategy 1 and 4 towards 2 and 3, where exchange between firms takes place, and thus increased specialization and learning, (ii) accessibility to these strategies (including their cost) giving property rights of communication in the language of trust down to the *individual* inventor, changing the incentives to a much more global, and sustainable, inclusion of exchange in patented technology. A policy initiative also aught to lower search costs further enabling choices of more cooperative strategies.

Such trusted cooperation would thus give incentives for a *direction* of development of new patented technology towards more economically useful technology, and by its derivate, the direction of science, to support further creativity and exchange of human ideas in a trusted socio-economic system.

Finally, such strategies can enable exchange in technology North-South, integrating future technology developed elsewhere in a single, integrated, market in ideas, possibly advancing technology towards higher (sustained) growth, enabled by a common language of trust.

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Chapter 9
Data-Intensive Computing and the Future of Research

Åke Edlund

Abstract Massive data sets are being produced in industry and academia of today. Scientists are probing extreme phenomena in scientific fields with mature theories like astrophysics and particle physics. At the same time we see increasingly exploratory research areas evolve, mining large data sets to find new phenomena and patterns. In industry, but also very much in academia, there are huge efforts in making meaning of human activity on the Internet, and as if these data sets were not enough, sensor networks 'sensing everything everywhere' is evolving. Information advantage, be it in business or academia, is crucial in today's global competition, and that is why there is so much interest in data and the technologies handling the data. What is new in the discussions about data and its underlying value is the increasing rate in the production of information, and how companies and academia are cross-fertilizing the information flows to produce even more information. Internet, Cloud Computing, 'Big Data', Internet of Things – it is easy to get lost in the technical discussions forgetting what it is all about: information, how to gather it, how to manage it, and how to make timely and informed decisions based on what we find. During the last decade much of the discussions have been centered on the effects of the cloud computing paradigm shift, but that is only the latest technological achievements in the overall effort of producing and analyzing information. In this chapter we look into the characteristics and evolution of information technology, discussing in more detail the latest paradigm shifts, and the new challenges and opportunities facing the companies and scientists. In the end of the chapter we include a list of suggested research topics in this area.

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Software Industry Characteristics and Its Paradigm Shifts

Since the move into computing, the evolution of Science is closely intertwined with software industry, adopting to its changes but also directly affecting the software industry itself. Below we briefly look at the characteristics of software industry and how, and why, it is evolving at an accelerated pace.

The Power of Exponential Changes

Exponential improvements in computer hardware over the last decades have propelled the software industry with wide implications in all information centric areas. Computers are able to perform ever increasingly number of operations per second, doubling in every 18 months for the same cost unit (Moore's law), and in parallel storage capabilities are improving, even if not at the same speed. To further illustrate the exponential changes, we have added the picture below showing the, even higher, increase of capabilities from the area of genome sequencing. The left picture gives the reader a hint of the upcoming data flood from the Life Sciences area, both from industry as from academic research. The right picture shows the data explosion following the change. Just to clarify: sequencing a genome cost years of work and hundreds of MUSD in the beginning of the century. Now the cost is down to below 1,000 USD (www.utsandiego.com/news/2014/Jan/14/illumina-thousand-dollar-genome; Haussler; Haussler et al. 2012), and sequencing time to minutes (Figs. 9.1 and 9.2).

In addition to this technological evolution, we have seen the rollout of high-speed network connections and an enormous increase of Internet users. We have also seen the change in how users connect to the Internet: The selected means of accessing the services from Internet has moved the market from PCs to handheld

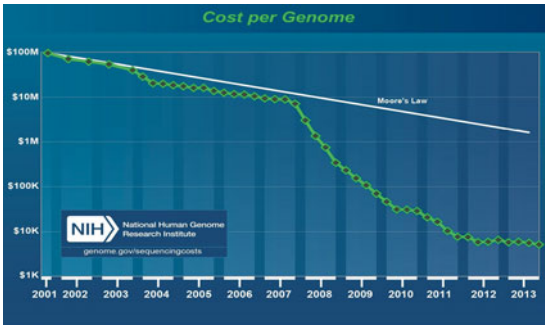

Fig. 9.1 (www.genome.gov/sequencingcosts)

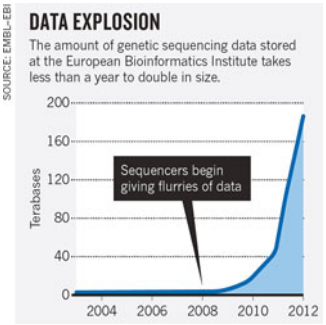

Fig. 9.2 (EMBL-EBI)

devices, with implications on networks, businesses in general and in challenging the earlier Windows-Intel dominance: the users of handheld clients need different solutions both in terms of software as in technological architecture. We also see how developing countries 'leap frog' over the old wired investments and move straight to the mobile Internet business models.

In parallel with the technological changes, its users are adopting to the new services. This change in user's behavior, e.g. in accepting payments over the Internet, enables new business models to emerge. Cloud computing, discussed more in depth later in this chapter, relies heavily on these changes in user behavior. Trust is a key component in this user behavior. It took years for the industry to earn its customers' trust. But trust is lost faster than it is earned.

Adopting to this change in user behavior and technology a new set of dominant companies that didn't even exist two decades ago have evolved, challenging the older giants. So, what is the main difference between the old way (before Internet) of doing business to todays? The short answer is that the new dominant companies are fully information focused, they deliver services over the Internet, and they have been collecting information from start, both to be able to improve their own services as well as creating new services based on the enormous amount of data they have about the Internet. In short, one of Google's main ideas is to "download the Internet and rank it". This is the way they order their data for us to be able to use e.g. Google search. But, they also store what we search for, what we click on, and from where we did this. Based on this information Google analyze their data, combines the data sets to create new, improved, services to its user. Other examples are the media streaming companies, who are very active in building recommendation systems on music and films to help improving their user's experience. At the same time they gather geographical and behavior information to adjust their underlying delivery technology – again to improve their user's experience, but also to lower their own cost.

The more advanced data analysis the companies can manage, the better they will cope with competition. This is 'Big Data', and, yes, the data the larger companies are analyzing is big in volume, as in velocity (how much it increases over time) and variety (very different sources with high variation in quality). But is this only for larger companies? No. Any company who deliver services over the Internet have large amount of user and usage data, data that hides pattern and insights on how to improve – how to compete.

Software Industry Characteristics and Its Paradigm Shifts

> Unlike hardware, software is expected to grow and evolve over time. Whereas hardware designs must be declared finished before they can be manufactured and shipped, initial software designs can easily be shipped and later upgraded over time. Basically, the cost of upgrade in the field is astronomical for hardware and affordable for software. (Patterson and Fox 2012)

The software industry is one of the most rapidly changing areas in the economy, and the software industry today is affecting most areas using information in any format. Cloud computing is the latest big change, affecting the way we produce and consume software products and services. This change is most likely greater than the introduction of Internet. The cloud market is global and it is all about services consumed over the Internet directly by customers.

Before going any further in the discussion, let's look at some numbers on why software is a very important part of industry, taking Sweden (Report from Swedish software organization Swedsoft) as an example: At Ericsson 80 % of their investments in R&D are software related – a total of 3 billion USD every year. Maybe more surprising, are the numbers from the car industry indicating that 25–35 % of the value of a car is in its software. Thirty years ago this number was 1 %. Seventy percent of the innovation built into Swedish trucks today comes from software developed in-house. Even industries closer to hardware rely heavily on software in maintaining a high productivity and competitiveness on the global market.

Software Industry Is in Constant Change

While Internet created a new way of communicating data between users and companies, Cloud Computing paves the way for a service based economy – where customers consume services – not just data – online. Instead of buying, installing and managing programs on your computer to handle your business, you go online to manage and use all your services. There is no need to handle versions of software, security patches and hardware. All you need is an Internet connection and a device

to access your services. As a reflection of this change, and as mentioned earlier, we are now moving into the 'post PC era', where smart clients (mobiles, tablets) are good enough to solve many of our daily needs.

Factors explaining this rapid development in the software industry can be found in the fundamentals of software itself: new software development is based on old – successful – software development. That is: the longer this field evolves, the more it is building tools to create new software, solving more complex problems in a shorter time. This is true for all fields, but in software the change is very rapid, as is the uptake and the inheritance (and copying) of previous results. Another fundamental characteristic of software is how easily the resulting product – the software – is duplicated and distributed. Compared to classic industry products, for example cars, software evolves and spreads considerably faster. Moreover, as was mentioned in the introductory quote "the cost of upgrade in the field is astronomical for hardware and affordable for software", further emphasizes the differences between hardware and software. Due to this feature, i.e. that software is undergoing constant change and continuous updates; software products can have very long life times (Patterson and Fox 2012).

With this in mind it comes as no surprise that we, again, face a large transition in software industry, an industry where paradigm shifts seems to appear with a regularity of once every decade.

The exponential growth in the underlying capabilities of the hardware delivering the software based applications have taken us from local computers, available only for a few national institutions, to personal mobile handheld clients accessing services where ever we go: Internet connects us, the Cloud deliver the services, and now we increase our gathering and analysis of the data surrounding us. This, latest, step is named 'Big Data' and is as disparate as 'Cloud computing' was still in 2007, and, as in the advent of Cloud computing, many consider it as no change but just something we have been doing all the time. And, yes, analyzing large data sets to gain competitive advantage is not new to larger corporations. What is new is the amount of available data and the increased capabilities to analyze the data. As described above, software industry builds on the shoulders of earlier achievements. A comparison to illustrate this: Old software licensing model, customer buys software to be used locally. The selling company receives information during the purchase and when the customer downloads updates of the software. Companies who are information centric and deliver their services over the Internet receive a flow of user information for the full duration of the usage of the service. For example, the software-as-a-service company immediately sees when the usage of the service drops – a signal that the customer might be unsatisfied with the service. This applies also to smaller companies, e.g. game developing companies who analyze in detail the usage of their games, looking for improvements to e.g. avoid making too hard (or too easy) steps in the games. This latter illustration is a good example of analyzing the company's internal data as well as public Internet data, where they look for increase in usage of 'cracking' solutions – where the game players got stuck and look for tricks to get passed the game steps.

Making Meaning Out of Massive Data: Inference Challenges

In earlier sections we discussed the characteristics of software industry. This was needed to understand why we see yet a new change in this area, just as we start to adapt to the latest paradigm shift. We write 'Big Data' of two reasons. Firstly, 'Big Data' is a very vague description of a huge area, an area that doesn't easily describe itself in just two words. Secondly, what is 'Big' in 'Data'? Learning from recent history: in the beginning of Cloud computing there were numerous definitions of cloud computing. After the overview report (Armbrust et al. 2009) the area cleared up, followed by the definitions NIST (US National Institute of Standards and Technology) and EU (2012) realizing that the meaning of the words 'Cloud computing' should be divided in some key concepts together with user dependent views. In [Michael Jordan] efforts are put into identifying the challenges in a scalable way, defining the fundamental questions regardless of what we consider 'big' today. Remember when 1 GB was huge? Not anymore.

The Long Tail of Science
Collectively "long tail" science is generating a lot of data, estimated at over 1PB per year and it is growing fast. 80-20 rule: 20 % users generate 80 % data but not necessarily 80 % knowledge. (Gannon).

Inference of Massive Data

Extracting inference out of massive data sets is challenging, creating a demand of very special combination of knowledge: understanding of the underlying data, combined with computer skills and rigorous mathematical and statistical background (Fig. 9.3).

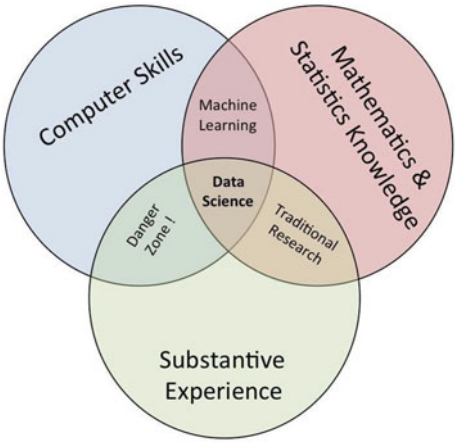

Fig. 9.3 (http://drewconway.com/zia/2013/3/26/the-data-science-venn-diagram)

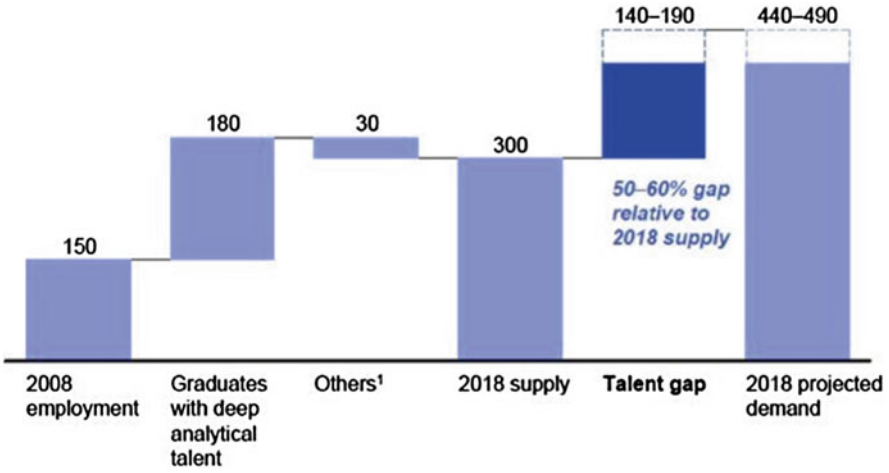

Fig. 9.4 (www.mckinsey.com/mgi/publications/big_data/index.asp)

Failing on one of these capabilities result in increased risk of mistakes, in risk of misleading conclusions. "There will be a shortage of talent necessary for organizations to take advantage of big data. By 2018, the United States alone could face a shortage of 140,000 to 190,000 people with deep analytical skills as well as 1.5 million managers and analysts with the know-how to use the analysis of big data to make effective decisions. Informatics aimed at 1.5 million jobs. Computer Science covers the 140,000 to 190,000" (www.mckinsey.com/mgi/publications/big_data/index.asp) (Fig. 9.4).

Challenges: Separating Knowledge and Misleading Information

A major challenge in analyzing massive data forces us to add even more workload: adding analyses of the error bars, the confidence interval, to the overall analysis. The challenge lies in parallelizing the error estimation, an area still in its infancy much as a result of its inherent complexity combined with the massive size of the underlying data. Or as Michael I Jordan (Frontiers in Massive Data Analysis report) describes it: "There is a need of statistical principles (that scale) to justify the inferential leap from data to knowledge. It is always possible to turn data into something resembling knowledge but which actually is not. And it can be quite difficult to know that this have happened".

Data Exploration: Not So Easy

Exploring these massive data sets to infer knowledge is a demanding task also with today's data-intensive technologies. In parallel with the increased performance of base technologies, mathematical algorithms are evolving with a multitude of challenges in developing traditional statistical methods. Machine learning, a sub discipline of statistics, gives the analysts novel approaches to classify and identify patters in the underlying, massive, data sets. Still, with all these improvements in methods and infrastructure, the massive data sets creates challenges to the user, also in the choices on how much information she should ask for. It is easy to become greedy with such wealth of information.

Not knowing the underlying laws of large datasets puts the user at risk of misleading conclusions. The problem arises when the user adds more features to be studied, increasing the possible correlations exponentially. Adding more features to the models increase the risk of 'perfect matching' of features that only share probability distributions – not having anything else in common. We find inference, that doesn't have bearing in reality, and the bad news is: we won't even understand, neither notice, the mistake.

Time Aspect of Inference

As mentioned above there is a risk of becoming greedy when dealing with large datasets. Adding too many features into the equation is not the only sign of greed here: what if I can get the conclusions, the recommendations, from the data sets faster? Faster than anyone else? We see an increasing interest in data analytics in near real-time, going from reporting to operations. Moving the data analysis from batch processing, longer analyzing time spans, towards analyzing near-time to real-time processing of information increase the challenges we already discussed. If we try to analyze streaming data we have a shorter time window to do the actual analysis, limiting us further. If you have the required knowledge in statistics you will adapt the questions you pose to such data.

Data Discovery and the Internationalization of Science

Science does not evolve in paradigm shifts as frequently as software industry; still we see three clear changes in Science in the history (see The fourth paradigm: Data-intensive scientific discovery). In the very beginning science was an empirical discipline, describing natural phenomena. Over time, based on the patterns we identified, we started to build theories describing many of the phenomena, using models and generalizations. This was the first paradigm shift, expanding from empirical to theoretical science. In the last few decades we have increasingly used

computers to simulate complex phenomena where analytical solutions of the theoretical models have been too, often impossible, to handle. This was the second paradigm shift in Science, adding computers to the chain of scientific work, from empirical studies to theoretical models to be translated to computers for massive simulations to further extend the reach of Science. As a result of this 'coupling' with computers and Science, these to areas are now evolving in symbiosis.

Massive data is not only generated from social interactions on the Internet and other web based information, but as much about data generated and analyzed in natural sciences, economy to humanities. Here the scientists are seeing a 4th paradigm in Science itself – the data exploration era.

Now we see a fourth paradigm shift in Science (The fourth paradigm: Data-intensive scientific discovery), data exploration, where the scientists analyze massive data sets from simulations and experiments to infer new knowledge or verify theories. The world of science has changed, where the new model is for the data to be captured by instruments or generated by simulations before being processed by software and for the resulting information or knowledge to be stored in computers. Scientists only get to look at their data fairly late in this pipeline. The techniques and technologies for such data-intensive science are so different that it is worth distinguishing data-intensive science from computational science as a new, *fourth paradigm* for scientific exploration (The fourth paradigm: Data-intensive scientific discovery), often named as eScience.

Looking at the various scientific areas we see the evolution of two branches of every discipline. For example (The fourth paradigm: Data-intensive scientific discovery), if you look at ecology, there is now both computational ecology, which is to do with simulating ecologies, and eco-informatics, which is to do with collecting and analyzing ecological information. Similarly, there is bioinformatics, which collects and analyzes information from many different experiments, and there is computational biology, which simulates how biological systems work and the metabolic pathways or the behavior of a cell or the way a protein is built.

Geoffrey Fox (Hey et al. 2012) has described this change in Science in the following "Big Data Ecosystem in One Sentence"

Use Clouds running Data Analytics processing Big Data to solve problems in X-Informatics (or e-X)

X = Astronomy, Biology, Biomedicine, Business, Chemistry, Crisis, Energy, Environment, Finance, Health, Intelligence, Lifestyle, Marketing, Medicine, Pathology, Policy, Radar, Security, Sensor, Social, Sustainability, Wealth and Wellness with more fields (physics) defined implicitly Spans Industry and Science (research)

With respect to internationalization of Science, eScience is taking one step further from earlier, highly international, environments. Data from large experimental devices, e.g. telescopes and particle accelerators like the CERN Large Hadron Collider (LHC), is distributed to scientists world-wide to study. Sometimes this comes as a necessity, due to the data sizes (like in the LHC case), where the data

need to be analyzed over a large number of collaborating scientists. CERN LHC is in itself a good example of international collaboration, where countries goes together to build a experiment too expensive for any single country, then sharing the data for remote analysis. It is also a good example of massive data exploration. Finding the 'needle in the haystack', the Higgs Boson, was just the beginning.

Since its move into computing many science areas are taking advantage of the paradigm shifts in software industry and is often one of the contributors, e.g. in the designing of the world-wide-web. Cloud computing, briefly mentioned above, is embraced by the science community creating new scientific services simplifying the daily work of the researchers. As seen from the Geoffrey Fox quote above, the examples are many where researchers reach out to cloud resources for increasingly larger computational challenges. Platforms for sharing and further developing workflows and data are today common practice in many disciplines, e.g. within the Galaxy community (galaxyproject.org). In the same way as enterprises, especially early stage companies, adapt to web based collaboration and communication, researchers are getting increasingly used to the same tools, e.g. using various web based project collaboration tools and code sharing like github. Today's researcher gets far without having to buy and manage hardware. For data scientists, the following section is possibly the largest change so far.

Data Analysis: As a Service

One of today's barriers to a successful data analysis environment, where the scientist can focus on the analysis on his data, is the management of the underlying infrastructure and workflows. Even if the emerging cloud technologies are simplifying the management of the infrastructure and development of the services needed, it is still a complex and demanding task. Infrastructure-as-a-Service (IaaS) gives the user elastic and cost efficient usage of the infrastructure (compute, network and data storage), while Platform-as-a-Service (PaaS) gives the user tools to develop the final services to be used. So, even if IaaS and PaaS are simplifying the basic infrastructure and development, the data analytics stacks needed (consisting of many layers and complex workflows) creates an overall complex environment for the data analyst to handle.

A number of companies are providing services to simplify the deployment and handling of these data analysis environment, from software distribution companies to larger cloud providers. Still much of the work remains for the user, and in addition the data analytics workflows themselves are often combinations of many different services (e.g. streaming, batch, graph data analysis, machine learning algorithms) with need of reloading of data. There is a need of a unifying data analytics stack and one of the most promising is the Berkeley Data Analytics Stack (BDAS) based on the Apache Spark (Zaharia 2014). In BDAS the services all use the same underlying data abstraction enabling the user to write complex analysis within one unified workflow.

The final step, in the simplification of the data analyst's work, was recently taken by one of the founding companies behind the BDAS, in *delivering the whole data analytics stack as a service, including the underlying infrastructure needed* (http://databricks.com/cloud/). By this the user now can manage and analyze his data from a browser, with a minimum need of management of the underlying infrastructure.

The implications of this new move, to a Data-Analysis-as-a-Service, are many. The amount of researcher that will now be able to do more analysis will increase dramatically. The analysts will be able to use more advanced workflows, and handle larger amount of data.

The challenge lies, as before with IaaS, the concerns with respect to data privacy: the above-mentioned Data-Analysis-as-a-Service relies on cloud providers, and at this stage only US-based, starting with Amazon – later Google and Microsoft.

Research Topic Data-Analysis-as-a-Service, as provided in (http://databricks.com/cloud/)*, gives researchers a considerably improved environment for their work. It also enables a larger set of researchers to do more science than before. Will this be a competitive advantage for the US-based researchers? Will non-US researchers be limited by their government in how much they may use the US-based infrastructures behind the Data-Analysis-as-a-Service? What will the implications be, and will this lead to a push on non-US-based infrastructure providers to evolve?*

Concluding Summary: Data Discovery and the Internationalization of Science

The academic community is increasingly making use of the same software technologies as industry. In many areas researchers in academia are early adopter of the new technologies and often part of its development. We have seen this during the introduction of Internet, where e.g. the development and specifications by Tim Berners-Lee of HTML were made due to needs of researchers at CERN. The adoption of cloud technologies by academia is well described in the XSEDE report (2013) presenting data (2012–2013) from 80 cloud users (world-wide) and their experiences. In the era of massive data analysis ('Big Data') we see an increasing contribution to the open source with novel data analytics stacks (e.g. The Berkeley Data Analytics Stack, partially hosted under Apache), and with new services emerging (as described in the section "Data Analysis: As a Service" section above).

The dependencies on the novel technologies are much the same in academic research as in industry. For example academic research is sensitive to security issues and levels of trust much in the same level as companies, especially in the areas where sensitive personal data might be affected. In Life Sciences there are limitations on how much researchers are allowed to use public clouds.

One research topic in this area is to study *how fragile current business models are, including academic users? What are the effects of losing trust in e.g. US based companies due to the news regarding NSA and personal information? What is the*

geographical and political distribution of these effects? How does it affect current public vs private cloud computing services? See e.g. "How the NSA Almost Killed the Internet" (Wired, Jan. 2014)

As was described in this chapter, handing massive data is challenging. To be able to extract knowledge out of the data, maintaining a rigorous measure of the error rate of the hypothesis made out of the data, calls for expertise in multiple disciplines. One possible research topic could be to further study the following question:

Are we getting more informed or are we just increasing the amount of misleading 'statistical' advice? How well are the analysis performed, are we sacrificing error estimates calculations for more complex analysis – or put differently, how do we strike the balance of how much we try to analyze with solid statistical handling of the information? It is hard to handle massive data, even harder if we want to have estimates of the error in our results.

Worth noting in this are is that we didn't even mention the other challenges in managing massive data sets: how to handle the increasing inflow of data, how to clean the data, how to store (and decide what to not store). Another main topic to address is the value of the analysis put in perspective of the management cost of the data handling. This is related to the question of competitive advantage in analyzing existing data and the risk in not analyzing.

Relevant to all above is the question of available persons with the right knowledge, a research topic in its own right:

If the demand is higher than the available resources, how is the market evolving for data analysts? How are the companies and nations competing for the persons with data analysis profiles – and how are data analysis companies evolving to create businesses in this gap?

One more area to study arises when considering the following studies from an academic viewpoint: "Computing is being transformed, new companies are emerging. Many organizations that have Big Data don't have the ability to process Big Data." from the Best Practices in Big Data Storage report, Tabor Communications Custom Publishing Group.

From the report "From Value to Vision: Reimagining the Possible with Data Analytics, What makes companies that are great at analytics different from everyone else" by MIT Sloan Management Review and SAS Institute (www.sas.com/content/dam/SAS/en_us/doc/whitepaper2/reimagining-possible-data-analytics-106272.pdf) we see an increase in number of companies that see business analytics as a competitive advantage, rising from 37 % in USA in 2010 to 67 % in 2013. In the report they also estimate the number of innovative companies (in making use of business analytics) to 11 % while 29 % still remain 'analytically challenged, where the available data is more of a burden than an asset (Figs. 9.5 and 9.6).

Research Topic A similar study of the academic researchers would be very interesting, knowing that not all are early adopter of new technology.

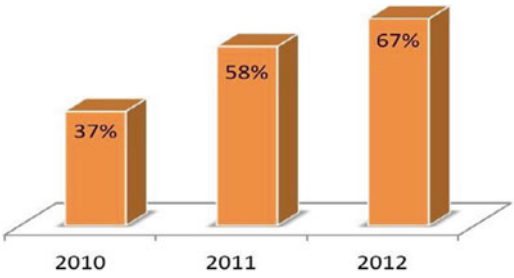

Fig. 9.5 (www.sas.com/content/dam/SAS/en_us/doc/whitepaper2/reimagining-possible-data-analytics-106272.pdf)

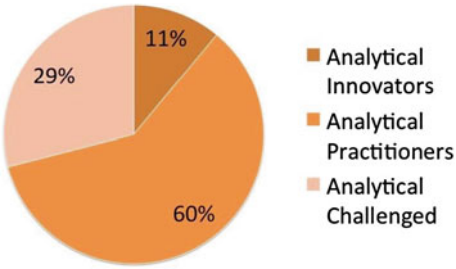

Fig. 9.6 (www.sas.com/content/dam/SAS/en_us/doc/whitepaper2/reimagining-possible-data-analytics-106272.pdf)

We end this discussion chapter with a positive note from the central report *Frontiers in Massive Data Analysis* (Frontiers in Massive Data Analysis report) "The hope is that if massive data could be exploited effectively, science would extend its reach, and technology would become more adaptive, personalized and robust". Challenges aside, there is considerable value to find in the data deluge we are now experiencing – in all information centric research areas, i.e. basically all science.

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Chapter 10
Exploring Network Behavior Using Cluster Analysis

Rong Rong and Daniel Houser

Abstract Innovation increasingly does occur in network environments. Identifying the important players in the innovative process, namely "the innovators", is key to understanding the process of innovation. Doing this requires flexible analysis tools tailored to work well with complex datasets generated within such environments. One such tool, cluster analysis, organizes a large data set into discrete groups based on patterns of similarity. It can be used to discover data patterns in networks without requiring strong ex ante assumptions about the properties of either the data generating process or the environment. This paper reviews key procedures and algorithms related to cluster analysis. Further, it demonstrates how to choose among these methods to identify the characteristics of players in a network experiment where innovation emerges endogenously.

JEL Classification C46, C81

Introduction

Innovation often occurs in networked environments. A player in these networks may play the role of either "innovator" or "follower". To identify the characteristics of players is a crucial first step towards understanding the process of innovation and economic growth. More generally, researchers in social science often need to classify individual behavior data into meaningful groups so that we can better describe the differences and similarities among individuals.

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When natural features, such as gender, age or income, are obviously driving the change of the variable of interest (in our case the level of innovation) then one can form hypotheses regarding the nature of differences between groups and, subsequently, use statistical methods such as regression analysis to validate or reject these hypotheses. Unfortunately, such a priori interpretations of data are not always available. An advantage to cluster analysis is that it does not require strong ex ante assumptions about the data generating process. As a numerical method for classification, cluster analysis allocates large and complicated datasets into discrete groups.

As early as the 1920s, psychologists were interested in the composition of ability. Some claimed all ability could be explained using two factors (Spearman 1904), others argued that there were more divisions, such as verbal, arithmetic, memory and spatial. Left unanswered were the number of low-level abilities and the way they relate to each other. This question inspired Robert Tryon to develop the first cluster analysis algorithm, then leading to the development of the first cluster analysis software BC TRY in the 1960s (Tryon 1932, 1935; Tryon and Bailey 1966).

Since then, numerous mathematical algorithms have been proposed to improve the performance of clustering (Everitt et al. 2011). Due to its simplicity and wide applicability, cluster analysis has been commonly used for data analysis in fields ranging from astronomy (Rosenburg 1910; Babu and Feigelson 1997 for a review), biology (Kerr and Chirchill 2001; Witten and Tibshirani 2010), psychology (Johnson 1967; Farmer et al. 1983; Borgen and Barnett 1987; Hay et al. 1996) and anthropology (Clarke 1968; Sutton and Reinhard 1995), marketing (see Punj and Stewart 1983 for a review), to increasingly in economics (Fisher 1969; Hirschberg et al. 1991; El-Gamal and Grether 1995; Slater and Zwirlein 1996; Houser et al. 2004; Yamamori et al. 2008; Adomavicius et al. 2012).

Walter Fisher was the first economist to systematically study the problem of classification. In his 1969 book *Clustering and Aggregation in Economics*, he foretold the increasing complexity of quantification in social variables and stressed "the need for systematic and scientific simplification" of social science data through clustering.[1] The discussion regarding the methods of clustering disappeared in economics for a long time after Fisher's book was published. In 1960s and 1970s, the fields that saw new developments and applications using clustering methods were largely psychology and anthropology.

El-Gamal and Grether (1995) revived economists' interest in uncovering behavioral strategies from complex data. They developed a pseudo-Bayesian approach to classify behavioral strategies used by individuals in games. The method is loosely related to finite mixture density clustering. Houser et al. (2004) developed a related method in which the nature and the number of decision rules are determined simultaneously.

Substantial time elapsed from Fisher's original work to the time empirical economists began to apply cluster analysis to real-world datasets. Among the few studies

[1] The methods reviewed in Fisher (1969) is somewhat different from the cluster analysis defined by its current literature. The author did relate these clustering and aggregation methods to the general literature of cluster analysis.

that implement cluster analysis, a variety of topics are included. Hieschberg et al. (1991) identify clusters for welfare measures across countries using multiple hierarchical agglomerative clustering methods. Slater and Zwirlein (1996) adopt a slightly different hierarchical method using Ward's minimum variance as clustering criteria.[2] They allocated 303 S&P 400 companies into eight distinct groups in which some were classified as "stable maintainers" and others "leveraged strategists".

Recently, a few experimental economists started to use cluster analysis to identify behavioral patterns among subjects. DeRubeis et al. (2007) investigates the difference on the transmission pattern of sexually transmitted disease. The authors clustered individuals based on their demographic and clinical characteristics and separated the social network analysis for each cluster. Yamamori et al. (2008) found three types of dictators in a modified dictator game with communication using Ward's minimum variance hierarchical clustering. Adomavicius et al. (2012) found that bidders in their auction experiment could be categorized into three behavioral groups using k-means clustering.

Given the level of complexity of innovative behavior in networks and the absence of pre-specified hypothesis on players' characteristics in these networks, it is natural to extend the use of cluster analysis to this context. The goal of this paper is to (1) review cluster analysis methods that are straightforward and easily implementable and (2) provide a concrete example of implementing this technique in a network dataset where we identify the "innovators" without pre-specifying their characteristics. Two key questions must be answered before implementing any clustering procedure[3]: which method should be used for the clustering analysis; and which method should be used to discover the number of clusters in the data. As these two decisions are made separately, we review them in separate section of the paper.

In section "Measures Used in Clustering", we begin with a discussion of various clustering criteria and how they are used to find clusters in one's data. Since finding exact solutions in cluster analysis can be extremely computationally burdensome, semi-optimal clustering algorithms, such as k-means and k-median algorithms, are discussed. Section "Clustering Procedure: K-Means and K-Median Clustering" reviews procedures for cluster analysis and discusses different methods used for each procedure. In addition to the choice of clustering methods, one also needs to choose how to determine the "correct" number of clusters. Section "Methods for Choosing the Number of Clusters" reviews two common approaches for this, the Silhouette width and the Calinski-Harabatz index. Section "Analyzing Network Data Using Cluster Analysis: An Example" introduces an example relevant to the study of innovation in networks and provides a sample analysis using data from a laboratory experiment related to innovation. The final section concludes.

[2] The difference and relations between cluster method and cluster criteria will be detailed in section "Measures Used in Clustering".

[3] An exception arises when one uses finite mixed density approaches for cluster analysis. In this case both questions are answered at the same time.

Measures Used in Clustering

With optimization cluster analysis one develops indices and criteria to know in a mathematically precise way how "close" or far apart objects are to each other. There are many schools of thought regarding clustering.

One method adopts a bottom-up approach where the closest two objects are grouped first and then a third objects that are closest to the two[4] are added, so on and so forth. This method gradually forms a tree-like cluster result which gives its name "Hierarchical clustering". The hierarchical cluster analysis has a natural implication in taxonomy where objects bear similarity at different levels and join groups that are not necessarily horizontally comparable. An example is the classification of plants where genus, family and variety are groups formed at different levels of similarity. However, when studying clusters in social science data, researchers are often interested in parallel group structures that contain the entire dataset. This specific goal is achieved with another clustering method, optimization clustering.

The goal of optimization clustering is to allocate optimally all objects into a few groups[5] so that the aggregate distance within a group is small and the distance between groups is large. As this method provides a way to place individuals into flexible decision rule categories, and is straightforward and easily applicable to almost all behavioral datasets, we believe that the method bears relevance to the current discussion.

We introduce optimization clustering by describing each step of the clustering procedure. It starts with distance measures which calculate how close and far apart an object (or a group) is from another object (or another group). Built on the distance measures, we then discuss a variety of (dis-)similarity indices developed to aggregate these distance measures for any particular group. Different similarity indices are then combined to become the goal of the maximization (or minimization) problem. We introduce these goals (also known as optimization criteria) one by one. Finally, we demonstrate how clustering algorithms, like k-means and k-median, provide quasi-optimal solutions for the computationally impossible clustering problems.

Distance Measures

The starting point of many clustering investigations is an $n \times p$ multivariate matrix X with n observations each of which are described with p distinct characteristics. For behavioral datasets, this can be interpreted as a matrix of n individuals with each individual having p descriptive variables, such as gender, age, choices, etc.

[4] Depending on the sub-school of thought, the similarity of an object to a group of objects could be evaluated by the distance of the object from the mean, the centroid, or the farthest or the closest object of the group.

[5] The number of groups is a choice variable for the researchers. Methods to choose the number of groups are discussed in section "Clustering Procedure: K-Means and K-Median Clustering".

Table 10.1 Counts of matches and mismatches for two individual *i* and *j*

		Individual *j*		
		1	0	Total
Individual *i*	1	*a*	*b*	$a+b$
	0	*c*	*d*	$c+d$
	Total	$a+c$	$b+d$	$p=a+b+c+d$

A variety of distance measures have been proposed to measure quantitatively the distance between objects from a set of categorical or continuous observations (see, e.g., Jajuga et al. 2003). Categorical data are usually measured in terms of similarity, while continuous data are commonly measured in dissimilarity (or distance). These two types of measures are mostly interchangeable as they carry the same amount of information regarding distance.

When individual measures are binary, one may use the Matching Coefficient or Jaccard Coefficient as a distance measure. For each pair of individuals, the above table counts the matches and mismatches in the p variables (Table 10.1).

The Matching Coefficient approach simply calculates the ratio of one-one and zero-zero matches over the total number of characteristics p.

$$s_{ij} = (a+d)/(a+b+c+d) \tag{10.1}$$

Alternatively, the Jaccard Coefficient ignores the zero-zero matches when calculating the similarity. Therefore, the Jaccard Coefficient is:

$$s_{ij} = a/(a+b+c) \tag{10.2}$$

This is particularly useful when the absence of a large number of attributes may not necessarily lead to a high degree of similarity. For example, in biology, lacking similar attributes when comparing certain plants with certain insects does not lead to a high degree of similarity between them. Therefore, the principle to choose between the above two coefficients depends on the characteristics of the variables. When co-absence is considered informative, one may use the Matching Coefficient, otherwise the Jaccard Coefficient should be used.[6]

When each variable has more than two categories, the similarity measure s_{ijk} is constructed for each variable: when two individual i and j are the same on the kth variable, s_{ijk} equals one, and is zero otherwise. The measure is then averaged over all p variables. The over-all similarity measure between individual i and j is calculated as:

[6] Similar coefficients have been proposed by Rogers and Tanimoto (1960), Sneath and Sokal (1973) and Gower and Legendre (1986). Their proposed coefficients vary the weight on the mismatches.

$$s_{ij} = \frac{1}{p}\sum_{k=1}^{p} s_{ijk} \tag{10.3}$$

Alternatively, one can also divide multiple categories into two subsets, then convert the original data into binary datasets and finally apply the Matching Coefficient or Jaccard Coefficient approach as in Eqs. 10.2 and 10.3. However, whether it is proper to divide categories into two subsets may depend on the specific dataset and the research question one wishes to address.

When each individual has their characteristics measured as a continuous variable, distance between two individuals i and j are typically quantified by a dissimilarity index d_{ij}. A variety of dissimilarity measures are proposed, among which Euclidean distance is the most commonly used one:

$$d_{ij} = \left[\sum_{k=1}^{p}\left(x_{ik} - x_{jk}\right)^2\right]^{1/2} \tag{10.4}$$

where x_{ik} and x_{jk} are, respectively, the kth variable value of the p-dimensional observations for individual i and j. This distance measure has the appealing property that the d_{ij} can be interpreted as physical distances between two p-dimensional points $x_i = (x_{i1}, x_{i2} \ldots x_{ip})$ and $x_j = (x_{j1}, x_{j2} \ldots x_{jp})$ in Euclidean space. Alternatively, city block distance measures the dissimilarity of individuals on a rectilinear configuration.[7]

$$d_{ij} = \sum_{k=1}^{p}\left|x_{ik} - x_{jk}\right| \tag{10.5}$$

Where x_{ik} and x_{jk} are defined in the same manner as it is in Euclidean distance. Both of the above two measures are special cases of the general Minkowski distance with $r = 2$ and $r = 1$ respectively:

$$d_{ij} = \left(\sum_{k=1}^{p}\left|x_{ik} - x_{jk}\right|^r\right)^{1/r} \quad (r \geq 1) \tag{10.6}$$

In some cases, the data may contain both categorical and continuous variables. It is possible to construct a single measure by combining distance measures either with or without certain weighting function.

Notice that even though the distance measures mentioned above for categorical data are measuring distance in similarity while those for continuous data is in dissimilarity, in most cases, these two measure are interchangeable using the following formula[8]:

[7] It is also known as the Manhattan distance or taxicab distance as it is measures the travelling distance between two points on the street when city blocks are organized chess-board style.

[8] Gower (1966) showed that if a similarity matrix S, with element s_{ij}, is nonnegative definite, then the matrix D, with elements d_{ij} defined by Eq. 10.5 is Euclidean.

$$d_{ij} = \sqrt{1 - s_{ij}} \tag{10.7}$$

In the following discussion, we assume the distance is measured in, or has been converted to, dissimilarity.

Dissimilarity Index

Whichever distance measure one may choose, one can form the dissimilarity matrix D by stacking the distance between all pairs of objects. In behavioral datasets, therefore, each row or column of a dissimilarity matrix corresponds to an individual. Each entry reflects a quantitative measure of dissimilarity between a particular pair of objects.

An informative clustering should include groups such that the distance between objects in the same group is small, while the distance between groups is large. Based on this simple principle, a variety of so-called "dissimilarity indices" (formed by taking combinations of distance measures) have been suggested.

With d_{lv}^{qk} defined as the dissimilarity between the lth object in the qth group and the vth object in the kth group, the following equations gives a simple example of an index that measures heterogeneity within group m:

$$h_1(m) = \sum_{l=1}^{n_m} \sum_{v=1, v\neq l}^{n_m} \left(d_{lv}^{mm}\right)^2 \tag{10.8}$$

Intuitively, this index is the sum of squared dissimilarities between two objects that belong to the same group m.

Another commonly used similar index measures the sum of squared dissimilarities between an object in a cluster group m and the mean of objects in group m. It is also known as the trace of within-group dispersion matrix.[9] This index comprises the foundation for the k-means clustering algorithm which we will discuss later.

$$h_2(m) = \frac{1}{2n_m} \sum_{l=1}^{n_m} \sum_{v=1}^{n_m} \left(d_{lv}^{mm}\right)^2 \tag{10.9}$$

The final index we note here uses the smallest sum of distances to quantify dissimilarity of a group:

$$h_3(m) = \min_{v=1,\ldots n_m} \left[\sum_{l=1}^{n_m} d_{lv}^{\mathrm{mm}} \right] \tag{10.10}$$

[9] The dispersion matrix is derived from multivariate matrix X directly without constructing the dissimilarity matrix D. These two methods are mathematically equivalent, hence we omit the discussion of the other method.

where a reference object v is connected with all other objects in the group m to form a star, which then determines the sum of distance of the group. Since the smallest sum of distance is achieved when the reference object v is at the center of the group, the index is often referred to as the "star index". $h_3(m)$ index is used in the k-median algorithm.

All three indices mentioned above measure the dissimilarity within the group m and ignore the information about the distance between group m and other groups. Separation indices are designed to capture this information. One commonly used separation index takes form $h_1(m)$ but now instead of summing over within group distance, the distance $d_{ml,kv}$ captures the dissimilarity between the object l from group m and the object v from a different group k.

$$h_4(m) = \sum_{l=1}^{n_m} \sum_{k \neq m} \sum_{v=1}^{n_k} \left(d_{lv}^{mk}\right)^2 \tag{10.11}$$

As separation indices are mostly capturing the same information as in dissimilarity indices[10] and that the current computer algorithms tend to use the latter, we will refer readers who are interested in other separation indices to Everitt et al. (2010).

Clustering Criteria

Having chosen an index to represent a group's dissimilarity, clustering criteria can be defined by aggregating these group measures over all groups. The aggregation can be defined as the sum of dissimilarity over all groups as in $c_1(n, g)$, or as the maximum or minimum dissimilarity among groups as in $c_2(n, g)$ or $c_3(n, g)$ below:

$$c_1(n,g) = \sum_{m=1}^{g} h(m) \tag{10.12}$$

$$c_2(n,g) = \max_{m=1,\ldots g} \left[\mathrm{h(m)}\right] \tag{10.13}$$

$$c_3(n,g) = \min_{m=1,\ldots g} \left[\mathrm{h(m)}\right] \tag{10.14}$$

One of the most commonly used clustering criteria combines $c_1(n, g)$ with dissimilarity index $h_2(m)$ to represent the total sum of within group dissimilarity. The criterion can also be shown equivalent to the within-group sum-of-squares criteria derived directly from the $n \times p$ multivariate matrix X.

[10] Roughly speaking, the sum of squared distance of the sample comprises two parts: the within group sum of squares and the between group sum of squares. Since the total sum of squared distance is constant, minimizing within group sum of squares, the dissimilarity index mentioned earlier, is equivalent to maximizing the between group sum of squares, the separation index.

$$c_1^*(n,g) = \sum_{m=1}^{g} h_2(m) = \sum_{m=1}^{g}\sum_{l=1}^{n_m} \left(d_l^{m\bar{m}}\right)^2 = \sum_{m=1}^{g}\sum_{l=1}^{n_m} \left(x_l^m - \bar{x}^m\right)' \left(x_l^m - \bar{x}^m\right) \quad (10.15)$$

Intuitively, when the above $c_1^*(n, g)$ clustering criterion is minimized, agents put into the same cluster share descriptive variables most similar to each other as compared to when they are allocated based on any other alternative clustering outcome.

There are a few features of the above clustering criterion of which any user should be aware. First, the method is scale dependent. For data that contains variables measured on different scales, one may reach different solutions from the same raw data standardized in different manners. Second, this clustering criterion imposes a "spherical" structure on the clusters and is unlikely to find clusters of other shapes, for example, agents that are separated into a few layers. Other clustering criteria exist to circumvent these two features.[11] However, any clustering approach has its advantages and disadvantages, and one must evaluate approaches within the context of particular applications.

Clustering Procedure: K-Means and K-Median Clustering

Ideally, one would consider all combinations of objects and choose the one that yields the lowest dissimilarity index within each group.[12] However, when the number of objects is large, it becomes infeasible to do this. Indeed, Liu (1968) provides the exact number of possible partitions one must consider in order to cluster n objects into g groups:

$$N(n,g) = \frac{1}{g!}\sum_{m=1}^{g}(-1)^{g-m}\binom{g}{m}m^n \quad (10.16)$$

That is, in order to partition 100 network agents into 5 groups, the number of possible combinations to examine is about 6.6×10^{67}. The task becomes impossible even with modern computational power when the population under analysis comprises hundreds, if not thousands, of agents. This excessive computational burden has led scholars to develop numerical search algorithms to approximate clustering solutions. Here we review the two most commonly used numerical algorithms, k-means and k-median, both of which involve iterative updating processes for partitions and group centroids.

[11] Attempts to create clustering criteria less restrictive regarding the cluster's shape include Scott and Symons(1971), Symons(1981), Murtagh and Raftery(1984), Banfield and Raftery(1993) and Celeux and Govaert(1995).

[12] Indices that measure the separation between groups are also used in many other methods. We refer interested readers to Everrit et al. (2011).

- **K-means Algorithm:**

As stated in its name, the k-means algorithms emphasize the mean of the clusters. Generally speaking, all k-means algorithms involve iterative updates of clusters by simultaneously relocating objects into the cluster whose ***mean*** is closest and then recalculating cluster means. Particularly, all k-means algorithms contain the following four steps:

1. g initial seeds are defined for each cluster by a p-dimensional vector, $\tilde{x}^m = (\tilde{x}_1^m, \tilde{x}_2^m, \ldots, \tilde{x}_p^m)$ where $\tilde{x}_k^m$ stands for the kth characteristic of the initial seed of cluster m. The squared Euclidean distance between the ith object and the initial seed of cluster m is simply calculated as:

$$d^2_{i\tilde{x}^m} = \sum_{k=1}^{p} \left(x_{ik} - \tilde{x}_k^m \right)^2 \tag{10.17}$$

   By comparing the result of Eq. 10.17 for an object with each initial seed (there are g of them), we allocate the object to the cluster where the result is minimized.

2. After all objects have been allocated to one cluster or another, the mean of the cluster is obtained by taking average over all objects that falls into each cluster. This is done for each dimension of the p characteristics:

$$\bar{x}^m = \left(\bar{x}_1^m, \bar{x}_2^m, \ldots, \bar{x}_p^m \right) \tag{10.18}$$

   The above mean of clusters $\bar{x}^m$ can then replace the initial seeds $\tilde{x}^m$ and be used to calculate the squared distance between each object and each cluster centroid as in Eq. 10.17. Objects are again moved to the cluster which yields the lowest squared distance measure.

3. The step (2) is repeated. For each repetition, the old cluster mean is replaced by the one calculated from the latest membership. The process repeats until no objects change membership.

Although all k-means algorithms attempt to minimize within-group sum of squared deviations from (group) mean, they may differ from each other in details. Depending on the specific dataset used, these differences may have substantial impact on the clustering results.[13] Here we trace a few important differences of these most popular algorithms.

First, the methods of initialization affect the final clustering results. The simplest suggestion, currently used in SPSS, chooses g random data points as initial cluster seeds (MacQueen 1967). A slightly different method randomly partition all data points into g mutually exclusive groups and use the group mean as initial seeds

[13] We have found substantial differences in K-means clustering results produced by the standard packages in Stata, R and Matlab. We traced it to differences in the specific numerical algorithms used by each package.

(Steinley 2003). These two methods both rely on the random process, therefore may yield a different clustering result each time the algorithm is performed.

Various deterministic methods also exist. Astrahan (1970) suggest a two parameter method as follows: before initialization, two distance d1 and d2 are specified. Then for each data point, a density index is calculated as the number of objects that are less or equal to d1 distance away from the object. The object that yields the highest density is selected as the first seed. Objects that are within the distance of d2 to the first seed are removed from the consideration. A second seed is selected if it has the highest density among the remaining objects. The objects that are within distance d2 to the second seeds are removed. The process continues until all g seeds are determined. A similar process was suggested by Ball and Hall (1965) and implemented in the PROC FASTCLUS procedure in SAS. Although other types of random or deterministic processes exist (see Milligan 1980 and Bradley and Fayyad 1998 for examples), Steinley (2003) suggest that the most robust method that outperform most of the arbitrary initialization rules is to use multiple random restarts (in order of thousands) and pick the one result that gives the smallest clustering criteria value. *Kmeans* package in R allow the user to specify the number of restart.

Second, to further minimize the squared distance as in Eq. 10.17, some algorithm suggests to introduce an additional stage of single-object reallocation process after the group reallocation has been settled (Späth 1980; Hartigan and Wong 1979). Specifically, after performing the standard iterative process (1)–(3) mentioned above, if there is an object in cluster m such that

$$\frac{n_m}{n_m - 1}\left(d_i^{m\bar{m}}\right)^2 > \frac{n_{m'}}{n_{m'} - 1}\left(d_i^{m\bar{m}'}\right)^2 \tag{10.19}$$

The object *i* should be moved from cluster *m* to cluster *m'* and the squared distance (as in Eq. (10.17)) is reduced. The objects will be checked and moved if necessary one after another until no further improvement can be achieved by this process.[14]

- **K-median Algorithm:**

In more recent years, the k-median algorithm has received increasing attention (Kaufman and Rousseeuw 1990; Späth 1980; Hansen and Jaumard 1997; Kohn et al. 2010). This algorithm relocates an object to a group whose ***median*** is the closest to it according to certain distance measure. Numerically, the specific clustering procedure proceeds like k-means except that the clustering criteria in Eq. 10.15 is replaced by

$$c_2^*(n,g) = \sum_{m=1}^{g}\sum_{l=1}^{n_m}\left|\left(x_l^m - \breve{x}^m\right)\right| \tag{10.20}$$

[14] The *kmeans* package in Matlab and R adopt this two-phase iterative algorithm.

Where $\tilde{x}^m$ refers to the median vector of the *mth* cluster. The original idea of using median instead of mean is to reduce the influence of outliers. However, Garcia-Escudero and Gordaliza (1999) pointed out that k-median method can also be as affected by outliers as k-means since the "joint" selection of two medians are unlikely to be as robust in terms of centralization as when only one random variable is involved.

Variations of k-median algorithm also exist in terms of how initial seeds are selected and how objects are swapped between clusters. PAM (Partitioning Around Medoids), developed by Kaufman and Rousseeuw (1990) and implemented in the *pam* package of R language, is one of the most popular one. The algorithm sets the objective function as the sum of distance between each object and its nearest medoid. The initial seeds in PAM are chosen by a greedy built phase[15] where the seed is added one after another and only the one that brings the largest improvement on the objective function will be selected.

Once the built phase completes, a multi-iteration swapping stage begins. For each iteration, a medoid object i and a non-medoid object j will be selected that brings the largest improvement on the objective function if i and j are switched. The iterations continue until no improvement is possible. Since in both built phase and swapping phase, there are many pairs of objects to go through to find the largest improvement, the original PAM algorithm is very time consuming with large dataset and increasing number of clusters.[16]

Methods for Choosing the Number of Clusters

Independent of the choice of clustering criteria and algorithms introduced above, one also needs to choose the method to determine the number of clusters. The past literature has recommended many methods that are algorithmic, graphical or formulaic. All of these methods are based on some logical heuristics. To judge which method is better at recovering the number of clusters, Milligan and Cooper (1985) conducted a Monte Carlo analysis to compare 30 of the most popular ones and concluded that the top performer is the one suggested by Calinski and Harabasz (1974)

[15] In programming, greedy algorithms refer to the ones that are based on heuristics who find locally optimal choice.

[16] The same authors also developed a similar but less deterministic method CLARA (Clustering LARge Applications), implemented in R language. This method could reduce the computing time significantly when a dataset is large. Meanwhile, STATA implements its *cluster kmedians* command in a similar way as in the basic k median algorithm as described at the beginning of this subsection.

(which we denote by C-H).[17] Another popular method readily available in many commercial packages is Silhouette Width. The output of this method includes a visualization giving direct clue on the performance of clustering under different numbers of clusters. We review Silhouette Width in this paper as well.

C-H Index

C-H (1974) suggested that the optimal number of clusters, g*, should maximize the following value C(g):

$$C(g) = \frac{trace(B)}{g-1} / \frac{trace(W)}{n-g} \tag{10.21}$$

where

$$B = \sum_{m=1}^{g} n_m \left(\bar{x}^m - \bar{x}\right)\left(\bar{x}^m - \bar{x}\right)' \tag{10.22}$$

representing the between-group dispersion matrix, and

$$W = \sum_{m=1}^{g}\sum_{l=1}^{n_m}\left(x_l^m - \bar{x}^m\right)\left(x_l^m - \bar{x}^m\right)' \tag{10.23}$$

representing the within-group dispersion matrix, both of which derive from the original multivariate matrix X.

Silhouette Width

The Silhouette Width index is first mentioned in Rousseeuw(1987). His paper argues that due to the absence of visualization for the quality of cluster, it is hard to tell whether an object is well-classified or misclassified. He then proposed the index and the plot of Silhouette Width to visualize the quality of cluster. Interestingly, the Silhouette Width Index has become increasingly popular as a way to choose the number of clusters and has been adopted by most commercial packages along with the Calinki-Harabatz Index we introduced above.

[17] Another successful technique developed by Duda and Hart (1973) works with hierarchical cluster methods. The network data do not fit these types of cluster analysis.

For a given clustering result, the Silhouette width indices, denoted by s(i), are calculated for each object i=1,2,…,n, which are then combined into a Silhouette plot. Individual silhouette width s(i) is defined as:

$$s(i)=\frac{\min\limits_{C\neq M(i)}\frac{1}{n_C}\sum\limits_{\substack{k\notin M(i)\\ k\in C}} d(i,k)-\frac{1}{n_{M(i)}}\sum\limits_{\substack{j\in M(i)\\ j\neq i}} d(i,j)}{\max\left[\frac{1}{n_{M(i)}}\sum\limits_{\substack{j\in M(i)\\ j\neq i}} d(i,j),\ \min\limits_{C\neq M(i)}\frac{1}{n_C}\sum\limits_{\substack{k\notin M(i)\\ k\in C}} d(i,k)\right]} \tag{10.24}$$

where M(i) refers to the cluster that contains object i, $n_{M(i)}$ refers to the number of objects in cluster M(i) and C refers to any cluster other than M(i).

The first term in the numerator refers to the minimum average distance of an object to all members of another cluster. It calculates the average distance from i to all members of an arbitrary cluster C. After the average distance is calculated for all arbitrary clusters, the closest cluster (in terms of distance to object i) is used.

The second term in the numerator refers to the within cluster average distance for object i. The term simply calculates the distance between object i and each other object in the same cluster and then takes an average. The denominator is the maximum of the two terms that appear in the numerator.

From the above formula, it is easy to see that s(i) would increase as object i is closer to other objects in the same group and farther away from objects in other groups. However, more characteristics of the index are revealed by evaluating s(i) under three different conditions.

First, note that if $\frac{1}{n_m}\sum\limits_{\substack{j\in m(i)\\ j\neq i}} d(i,j)<\min\limits_{c\neq m(i)}\frac{1}{n_c}\sum\limits_{\substack{k\notin m(i)\\ k\in m(c)}} d(i,k)$, then s(i) can be simplified as $1-\frac{\frac{1}{n_m}\sum\limits_{\substack{j\in m(i)\\ j\neq i}} d(i,j)}{\min\limits_{c\neq m(i)}\frac{1}{n_c}\sum\limits_{\substack{k\notin m(i)\\ k\in m(c)}} d(i,k)}$. That is s(i) is always positive and approaches 1 as the measure of within dissimilarity (the numerator) is much smaller than the measure of the smallest between dissimilarity (the denominator).

Similarly, consider the opposite case where $\frac{1}{n_m}\sum\limits_{\substack{j\in m(i)\\ j\neq i}} d(i,j)>\min\limits_{c\neq m(i)}\frac{1}{n_c}\sum\limits_{\substack{k\notin m(i)\\ k\in m(c)}} d(i,k)$. Under this condition, s(i) can be simplified as $\frac{\min\limits_{c\neq m(i)}\frac{1}{n_c}\sum\limits_{\substack{k\notin m(i)\\ k\in m(c)}} d(i,k)}{\frac{1}{n_m}\sum\limits_{\substack{j\in m(i)\\ j\neq i}} d(i,j)}-1$, which is

always a negative number and approaches −1 if within dissimilarity is large and the between dissimilarity if small. That is to say that the silhouette width index defined as in Rousseeuw(1987) is an index between −1 and 1 with a higher positive number indicating a better clustering quality.

In practice, one should choose the number of clusters that maximizes the average Silhouette Width across all objects.

Analyzing Network Data Using Cluster Analysis: An Example

The Dataset

To demonstrate the usefulness of cluster analysis in studying innovation in networks, we borrow the data from an experimental study that looked at individual behavior in a networked innovation game (Rong and Houser 2012). The study contains the repeated choice data from 160 subjects. Each subject is involved in a decision making game where they can earn money by either choosing to pay a high cost to provide a public good (representing costly but beneficial innovation) or choosing to pay a low cost to link to others who provide the public good (representing the follower or free-rider). Therefore, for each subject and each period, the dataset contains the contribution decision (1 if contributing to public goods, 0 if not contributing to public goods) and the linking decision (1 if linked to others, 0 if not linked to others) for each subject.

There are several treatments designed to mimic different market institutions which arguably could affect the level of innovation. The authors found significant difference between each institution. However, it is interesting to understand how each institution works to generate the difference in innovation. This is a task in which cluster analysis can play an important role. We use the dataset from that study to demonstrate how to use cluster analysis in this context and what level of new knowledge can be obtained from this exercise.

Our analysis proceeds in two steps. First, we estimate for each individual the parameters that characterize the way they make decisions given the information they have during their decision time. Then, we use cluster analysis to group similar individuals according to how their decision depends on the information they have. We call this dependence "decision rules". In particular, we run a linear regression for each individual with the repeated decisions on contributing to public goods (or not) as a binary dependent variable. We regress this contribution decision on a constant, a dummy for whether investing is rational and a "history index" characterizing the subjects contribution behavior in the previous two rounds (see also Kurzban and Houser 2005). After this analysis, individuals are characterized by the three estimated coefficients from their regression results. We have 142 subjects in our sample.[18]

[18] We drop 18 subjects in this process, as there is zero variation in their dependent variables therefore we cannot estimate the coefficient for those subject using regression analysis.

In the second step, we implement the k-means algorithm to cluster these estimates into groups of behavioral rules.

The purpose of this analysis is to draw inferences about the behavioral rules of individuals in various treatments. We found that the difference in treatment design leads to different behavior rule usage. Note that our maintained assumption is that behavioral rules in all treatments are formed using elements from a menu of information that are finite and identical (in this case, decisions could be either "rationality dependent", "history dependent" or "constant level determined"), but that different treatments lead to rules that differ at the level of usage on each of this information. Without ex ante knowledge of what kind of weights people may put on each piece of information, we use cluster analysis to detect them. Cluster analysis allows us to explore behaviors among individuals without the need to pre-define the nature or number of possible rules (see also Houser et al. 2004).

Behavioral Rule Parameters

The independent variables we include in our regressions are meant to capture a person's: (i) base rate willingness to contribute to public goods (captured by the regression's constant); (ii) consistency with individual rationality (captured by the a dummy variable that takes value one if it is optimal to contribute); and (iii) propensity to form a "habit" of choice in the sense that they do what they did before (captured by the variable indicating the lagged decisions for the past 2 rounds). Equation 10.25 specifies our regression equations for contribution decision:

$$contribution_{i,t} = \beta_1 * rational^{p}_{i,t} + \beta_2 * \sum_{s=1}^{2} contribution_{i,t-s} + \beta_3 + \varepsilon_{i,t}$$

where

$$rational^{p}_{i,t} = \begin{cases} 1, \text{if it is optimal from subject i to contribute} \\ \text{to public goods at round t} \\ \quad \text{according to individual rationality criteria} \\ 0, \text{otherwise} \end{cases} \tag{10.25}$$

$$contribution_{i,t-s} = \begin{cases} 1, \text{if subject i contributed to the public} \\ \text{goods in round t} - \text{s} \\ 0, \text{otherwise} \end{cases}$$

The above regressions are repeated for each individual. Each individual's estimates can be represented by a point in 3-space (See Appendix 1).

K-Means Clustering

We implement our k-means cluster analysis, as well as cluster number selection, using R. Based on the C-H index, we find three clusters in contribution decisions (See Appendix 2).

The three panels of Fig. 10.1 are the three 2-space projections of the estimates $\{\beta_1, \beta_2, \beta_3\}$ from regression on contribution decisions (Eq. 10.25) into corresponding 2-space. Each point represents an individual's estimates from his/her contribution decisions regression. Points with the same marker belong to the same cluster.

It is clear from visual inspection that our clusters are well-separated. To provide statistical evidence on the strength of this separation, we analyze the separation along each independent variable's axis. Mann-Whitney tests find significant differences between all pairs of clusters in each axis ($p < 0.001$), with the exception of the constants in the triangle and round clusters.

Not only are the clusters clearly separated, the location of the clusters also carries meaningful interpretation in our sample. Table 10.2 provides the mean estimate for each independent variable and for each cluster, and also reports whether that mean is significantly different from zero.

Based on the results from Table 10.2, we summarize the characteristics of the three clusters that define the three behavioral rules used by our subjects. Note that the decision rules below are not pre-specified. It is generated as a result of clustering.

1. We define the cluster indicated with round markers as the "Rational" type. People that belong to this cluster are guided by the rationality of the current opportunity to contribute. They focus less on their past choices, and their base rate of investing is near zero.
2. We define the cluster indicated by triangle markers as the "Habit" type. Subjects in this cluster are guided by rationality, but relatively less than the Rational type. Instead, their current decisions follow closely their past decisions.
3. We define the cluster indicated by square markers as the "Dogmatic" type. We find that these subjects have the highest base rate of investing among all three types.

The clear separation of the three types of individuals in this experiment shows that innovation is not generated for the same reason for all people. Some people develop new ideas because it is optimal for them to do so. Some people innovate for the reason that they have done that before. The rest of the innovators choose to do so without concern for individual payoffs or their personal history. They are the dogmatic innovator.

Which types of innovators drive innovation in society and how can we promote their existence? These questions can be addressed by investigating how institutional characteristics in our various treatments affect the types of behavioral rules subjects use.

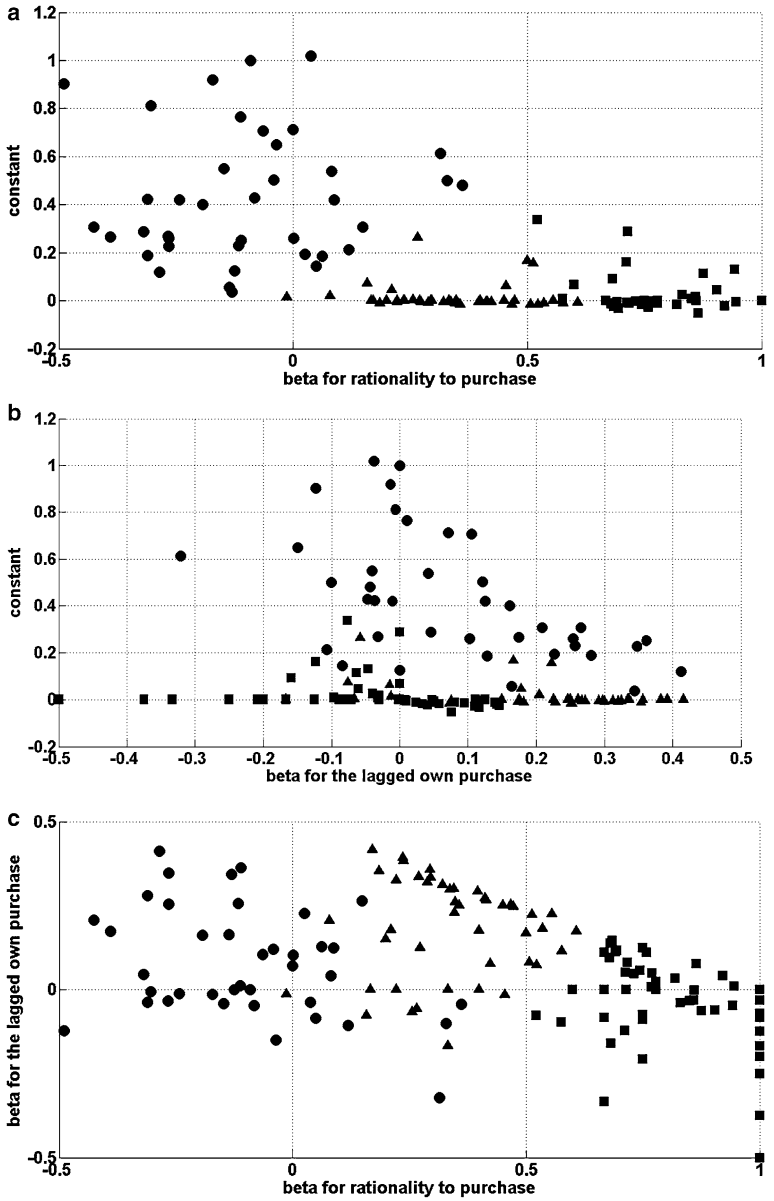


Fig. 10.1 Projections of estimates from contribution decision

Table 10.2 The mean of estimates from regression on contribution decision

	Square cluster	Triangle cluster	Round cluster
Rational to contribute	0.8190	0.3411	–0.0978
	(0.0000)	(0.0000)	(0.0054)
Lagged choice	–0.0408	0.1745	0.0782
	(0.1480)	(0.0000)	(0.0120)
Base rate(constant)	0.0175	0.0137	0.4279
	(0.2589)	(0.7066)	(0.0000)
Number of subjects	57	46	39

Note: *p*-value from Wilcoxon signed-rank test in parentheses

The level of innovation is lowest at the two treatments where subjects can make unconstrained choice.[19] This low level of innovation coincides with a concentration of Dogmatic type subjects (41.38 % and 90 % respectively) in both treatments. That is to say, having a concentration of players using the Dogmatic rule is not conducive to innovation. The unconstrained choice treatments may be unhelpful in generating innovation.

On the contrary, for the other two treatments that feature constrained choice sets, the data include relatively high levels of innovation. In those two "successful" treatments, the large majority of subjects (92 %) choose to behave rationally or follow a habit (88.89 %). We found zero dogmatic innovators in these two treatments.

In the last treatment where a medium level of innovation is observed, it is also the case that no subject belongs to the Dogmatic type.

The knowledge gained from cluster analysis provides a clear picture on which treatment design generates the most innovation and the reasons why that has happened: the behavioral rules shift away from the dogmatic innovator. This finding is not available in the absence of clustering results and it would seem very difficult to come up with it as an ex-ante hypothesis. For these reasons, this example well-demonstrates the value of cluster analysis in the study of large and complex datasets.

Summary

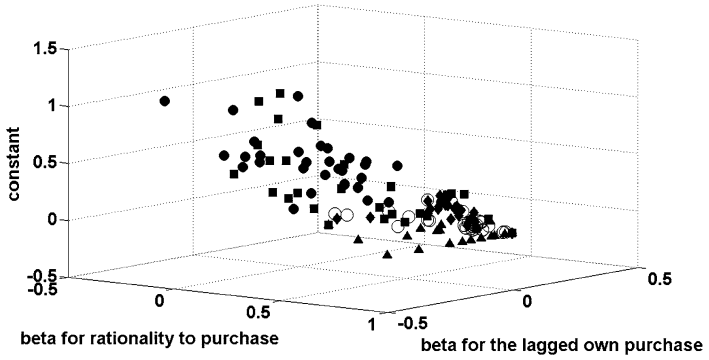
Cluster analysis is an intuitive method to analyze complicated data sets. Without making strong assumptions regarding the data generating process, the method divides observations into discrete groups based on patterns of similarity. We reviewed key features of cluster analysis in this paper. First, we reviewed several distance measures appropriate for different types of measures (binary, categorical or

[19] The detail of the treatment design is of less importance to this study. We suggest the interested readers to find detailed description of the experiment in Rong and Houser (2012).

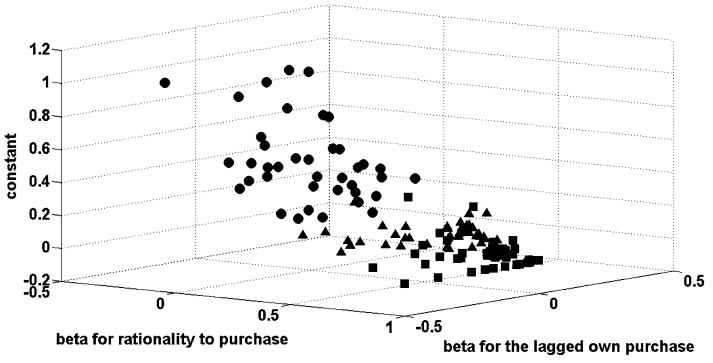
continuous). We then illustrated how distance measures can be combined into dissimilarity matrices and how these matrices are further used in forming clustering criteria. We also discussed the detail of two popular algorithms: k-means and k-median. Finally, we reviewed two indices, Calinski-Harabatz Index and Average Silhouette Width, used to discover the number of clusters in the data. We offered an example of this approach using experimental network data, and argued that individual decisions made in a network environment are often generated by complex behavioral rules that can be difficult to specify a priori. Such environments may particularly benefit from clustering methods.

Appendix 1. 3-Space Plot for Individuals' Estimates by Treatment

Note: Different markers represent different treatments, ■ – Seq_B; ▲ – Seq_L; ● – Sim_B; ♦ – Sim_L; ○ – Sim_L_NoRFR



Appendix 2. 3-Space Plot for Individuals' Estimates by Cluster



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