The Economics of the Global Environment—Catastrophic Risks in Theory and Practice

Graciela Chichilnisky and Armon Rezai

1 Introduction

The world economy is changing fundamentally and irrevocably in front of our eyes. There is no disputing the fact. Yet the evolution of economics as a science does not match the sea of change we observe in the real world. This book attempts to address this somewhat remarkable and risky gap. It offers a collection of essays by leading economists who offer their vision on new foundations of economics, on experimental research testing the new theory and on its use in path breaking global policy. Some of the essays have been presented at the AFOSR workshop on Catastrophic Risk at SRI, Menlo Park, California, on May 31 and June 1, 2012, organized and sponsored by the Columbia Consortium for Risk Management at Columbia University.[1]

Global economic change is unfolding as we write this book. In December 2015, 200 hundred nations met in the most important climate change negotiations in decades, the Paris Convention of the Parties COP 21, to decide on the fate of the practical consequences of the world's single international agreement to achieve needed reductions of

[1] www.columbiariskmanagement.net.

G. Chichilnisky (✉)
Departments of Economics and Mathematical Statistics, Columbia University, 335 Riverside Drive, New York, NY 10027, USA
e-mail: gc9@columbia.edu

A. Rezai
Department of Socio-Economics, WU—Vienna University of Economics and Business, Welthandelsplatz 1, 1020 Vienna, Austria
e-mail: arezai@wu.ac.at

A. Rezai
IIASA, Schlossplatz 1, 2361 Laxenburg, Austria

A. Rezai
Vienna Institute for International Studies, Rahlgasse 3, 1060 Vienna, Austria

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carbon in the atmosphere—the Kyoto Protocol and its path breaking Carbon Market. The debate centers on who should reduce carbon emissions—the poor or the rich nations of the world. Poor nations have been an unexpected engine of the growth of the world economy since 2000, and the G-20 was created as the first leading group of nations to include poor countries, the BRIC nations. The BRICS Bank they created can compete with the Bretton Woods' institutions such as the IMF and the World Bank that were created by the rich nations in 1945, at the end of WWII. These are the first global financial institutions in the world economy, largely responsible for an extraordinary period of success and globalization of capitalism, and a sea of change we observe today. The force of globalization since WWII led to a 300 % growth of the international economy over and above national growth, and joined all nations at the hip. At the same time the successful internationalization of capitalism led to the largest consumption and overexploitation of extractive resources the world ever saw. Minerals, metals, fuels, soil, and even the oceans that are 70 % of the planet's surface are disappearing in front of our eyes. The catastrophic risk of climate change from the overuse of fossil fuels is only matched by an equally catastrophic risk of biodiversity destruction and the vast and wasteful overexploitation the oceans. We know we have created the 6th largest destruction of life in the planet in the entire 4.5 billion history. We also know that the global environment is the trump card for the success or the demise of human societies. This is one of the key areas where economic science and economic reality are seriously out of step. And this is why the book is about the global environment and the catastrophic risks we face.

2 Part I. Catastrophic Risk in Economic Theory

The first part of the book goes to the foundations of economics and decision theory and expands existing theory to include rare events that are catastrophic and yet often neglected by existing theory. The articles introduce new breakthrough axioms, theorems that characterize the new probabilities that they characterizes and new criteria of optimality, updating the definition of probabilistic inference and formalizing sustainable preferences and behavior.

Peter Hammond's piece **Catastrophic Risk, Rare Events, and Black Swans: Toward an Alternative Synthesis** follows a series of articles (Chichilnisky 1996a, 2000, 2009, 2010) that set out an integrated decision theory intended to capture special properties of catastrophic risk, rare events, and black swans. Here these three are treated as separate extensions of orthodox decision theory. Precursors discussed include: (i) following Jones-Lee (1974), undefined willingness to pay in the case of catastrophic risk; (ii) following Hammond (1994) and others, rare events with infinitesimal probabilities. The author sketches a theory where enlivened decision trees can represent a dynamic process involving successive unforeseeable "true black swan" events and argues that a different integrated theory, yet to be developed, could perhaps include all these three features.

In **Preference Representations for Catastrophic Risk Analysis**, Richard E. Ericson and Jamie B. Kruse survey behavioral models of preference relations

applicable for analysis of decisions in the face of catastrophic risk. The authors characterizes catastrophic risk and the implications of various representations are explored in simple, illustrative examples. They present an argument for the applicability of "variational preferences" for the analysis of behavior and decision making in the face of catastrophic risk. Louis Narens article provides a different formalization of risk. Almost all models of decision making assume an underlying Boolean space of events. This gives a logical structure to events that matches the structure of propositions of classical logic. In his article **Modeling Decisions Involving Ambiguous, Vague, or Rare Events** Narens takes a different approach, employing events that form a topology instead of a Boolean algebra. This allows for new modeling concepts for judgmental heuristics, rare events, and the influence of context on decisions.

Like Narens', Jun Zhang's article **Modeling Uncertainty, Context and Information Fusion via Lattice-Based Probability** investigates mathematical foundations for probabilistic inference, uncertainty representation, and information from disparate information sources. Probability measures are defined on an event space that is modeled as a bounded distributive lattice, including Boolean lattice as a special case, and standard probability theory is axiomatized. Following Narens (2009, 2011), Zhang invokes the relative pseudo-complementation operator on a distributed lattice, leading to Heyting algebra of event space that underlies intuitionistic logic. He considers basic probability assignment on a finite distributive lattice, leading to lower probability (belief function) and upper probability (plausibility function) on such lattices. Making use of the fact that topology on a set, that is, the collection of all open sets, forms a distributive lattice, pseudo-complementation can be addressed through the closure operation under an arbitrary topology introduced on the event space. He models contextual information for uncertainty as prescribing a topology on the event space. The totality of all topologies on an event space form a bounded complete lattice, ordered by coarse-grading, with the discrete topology as the top element (the finest/largest topology), and the indiscrete topology (consisting of only two elements, the null set and the full set) as the bottom element, the coarsest/smallest topology. By identifying topology with context, it provides a principle for defining "focal elements" (on open sets of the topology) combining them across different contexts in the lattice of topologies, more general than do current theories such as Dempster-Shafer belief function and Zadeh's fuzzy probability.

In **The foundations of uncertainty with black swans**, Chichilnisky extends the foundation of probability to include samples with rare events that are potentially catastrophic, called black swans. Examples are market crashes, catastrophic climate change, and species extinction. Such events are generally treated as ''outliers'' and disregarded. She proposes a new axiomatization of probability requiring equal treatment of rare and of frequent events—the Swan Axiom—and then characterizes all the probabilities that the axioms imply. These are new probabilities are neither finitely additive nor countably additive measures but rather a combination of both. They exclude countably additive probabilities as in De Groot (1970) and Arrow (1971) and Savage's (1954) finitely additive measures. The probabilities that satisfy the new axioms are standard distributions when the sample has no black swans,

so the axioms are an extension of standard theory. The finitely additive part assigns however more weight to rare events than do standard distributions and in that sense explains the persistent observation of ''power laws'' and ''heavy tails'' that eludes classic theory. The axioms and the representation theorems extend earlier work by the author (Chichilnisky 1996a, 2000, 2002, 2009) to encompass and extend the foundation of probability (Villegas 1964; Dubins and Savage 1965; Dubins 1975; De Groot 1970; Purves and Sudderth 1976) and the theory of choice under uncertainty of Arrow (1971).

The Topology of Change seeks to overcome a bias in standard probability theory, which treats rare events as 'outliers' that are often disregarded and underestimated. The author argues that in a moment of change rare events can become frequent and frequent events rare. Chichilnisky therefore postulates new axioms for probability theory that require a balanced treatment for rare and frequent events, based on what she calls "the topology of change". The axioms extend the foundation of probability to integrate rare but potentially catastrophic events or black swans: such as natural hazards, market crashes, catastrophic climate change and major episodes of species extinction. New results presented in this article include a characterization of a family of purely finitely additive measures that are—somewhat surprisingly—absolutely continuous with respect to the Lebesgue measure. This is a new development from an earlier characterization of all the probabilities measures implied by the new axioms as a combination of purely finitely additive and countably additive measures that was first established in Chichilnisky (2000, 2002, 2009). The results are contrasted to the work of Kolmogorov (1933), De Groot (1970), Arrow (1971), Savage (1954), and Von Neumann and Morgernstern (1944).

In **Sustainable markets with short sales** Chichilnisky argues that market objectives may conflict with long-term goals, and that behind the conflict is the impatience axiom introduced by Koopmans to describe choices over time. The conflict is resolved here by introducing a new concept, "sustainable markets". These differ from Arrow-Debreu markets in that traders have sustainable preferences and have no bounds on short sales. Sustainable preferences were defined by Chichilnisky as preferences that are sensitive to the basic needs of the present without sacrificing the needs of future generations and embody the essence of sustainable development (Chichilnisky 1996b). In her theorems 1 and 2 Chichilnisky shows that limited arbitrage is a necessary and sufficient condition describing diversity and ensures the existence of a sustainable market equilibrium where the invisible hand delivers sustainable as well as efficient solutions (Chichilnisky 1995; Chichilnisky and Heal 1997). In sustainable markets prices have a new role: they reflect both the value of instantaneous consumption and the value of the long-run future. The latter are connected to the independence of the axiom of choice at the foundations of mathematics (Gödel 1940).

3 Part II. Ethical and Welfare Considerations

The second part of the book covers new fundamental thinking on the ethical and welfare considerations that should guide us when our actions today irrevocably change the future, and in particular the welfare of new generations that are yet to come. The problem requires a rewriting of neoclassical thinking that is dominated by the excellent work of Tjallings Koopmans in the 1960s who wrote when the pressing global environmental issues we face today were still to be understood (Koopmans 1960). He defined the neoclassical theory of economic choice based on "impatience," an axiom that he created which exponentially discounts the future by requiring fixes rates of discount from 1 year to the next and forever, thus obliterating the long term future implications from our actions today. This section seeks practical new axioms to replace Koopman's and criteria of optimality that define a sustainable economy. These authors and their articles are creative, polemic, theoretic and practical.

Geir Asheim, Tapan Mitra, and Bertil Tungodden ask what ethical criteria should be adopted when managing the global environment. In **Sustainable recursive social welfare functions** they study ethical criteria for intergenerational justice when faced with the task of managing the global environment. They argue that Koopmans' axiomatization of discounted utilitarianism is based on seemingly compelling conditions, yet this criterion leads to hard-to-justify outcomes. Their analysis considers a class of sustainable recursive social welfare functions within Koopmans' general framework. This class is axiomatized by means of a weak equity condition ("Hammond Equity for the Future") and general existence is established. Any member of the class satisfies the key axioms of Chichilnisky's "sustainable preferences" (Chichilnisky 1996b). The analysis singles out one of Koopmans' original separability conditions (his Postulate 3′a), that they call "Independent Present", as particularly questionable from an ethical perspective.

In **Intergenerational equity, efficiency, and constructability**, Luc Lauwers addresses global environmental issue such as biodiversity conservation or climate change, and argues that they are in reality long-term issues that are not properly taken into account with traditional models that incorporate the impatience axiom, which is manifested in fixed discount factors and in the use of present discounted utility criteria. When both the short and the very long run are important, he argues that one can appeal to overtaking criteria and Chichilnisky criteria. Unfortunately, overtaking criteria are highly incomplete. In order to decrease this incompleteness, stronger anonymity (or equity) axioms were developed. The author shows that a maximal anonymity axiom compatible with Pareto is a non-constructible object; its existence relies on the Axiom of Choice. The Chichilnisky criterion is based upon two axioms: non-dictatorship of the present and non-dictatorship of the future. Here, the very long run is captured by a finitely additive measure. Such a measure is a non-constructible object and has therefore no explicit description.

In **Sustainable exploitation of a natural resource: a satisfying use of Chichilnisky's criterion** Charles Figuières and Mabel Tidball analyze Chichilnisky's criterion for sustainability and argue that it has the merit to be, so far, the unique explicit, complete and continuous social welfare criterion that combines successfully the requirement of efficiency with an instrumental notion of intergenerational equity (Chichilnisky requires no dictatorship of the present and no dictatorship of the future). But they argue that it has one drawback: when applied in the context of renewable resources, and with a constant discount factor, there exists no exploitation path that maximizes this criterion. The present article suggests a way to cope with this problem. The idea is to restrict attention to the set of convex combinations between the optimal discounted utilitarian program and the stationary program leading to the green golden rule. It is shown that an optimal path in this set exists under rather weak sufficient conditions on the fundamentals of the problem. Some ethical properties of this approach are also discussed. In some cases, it turns out that the restricted solution implies no loss of efficiency and benefits intermediate and infinitely distant generations.

Finally Luc Lauwers studies **t**he history of the axiomatic approach to the ranking of infinite streams that starts with Koopmans' (1960) characterization of the discounted utilitarian rule. In **The axiomatic approach to the ranking of infinite streams** the author argues that **t**his rule, however, while it meets Chichilnisky's axiom of dictatorship of the present it sets asides future generations. Recently, Lauwers (2010) and Zame (2007) uncovered the impossibility to combine in a constructible way the requirements of equal treatment, sensitivity, and completeness. This contribution presents and discusses different axioms proposed to guide the ranking of infinite streams and the criteria they imply. The literature covered in this overview definitely points towards a set of meaningful alternatives to discounted utilitarianism.

4 Part III. The Environment in a Global Context

Thinking about policy in a context of global change is a challenging task. In one of her last articles, Elinor Ostrom's **Nested externalities and polycentric institutions: must we wait for global solutions to climate change before taking actions at other scales?** argues that **t**he literature on global climate change has largely ignored the small but positive steps that many public and private actors are taking to reduce greenhouse gas emissions. She says that a global policy is frequently posited as the *only* strategy needed. The author argues that it is important to balance the major attention on global solutions as the only strategy for coping with climate change. Positive actions are underway at multiple, smaller scales to start the process of climate change mitigation, and researchers need to understand the strength of polycentric systems where enterprises at multiple levels may complement each other. Building a global regime is a necessity, but encouraging the emergence of a

polycentric system starts the process of reducing greenhouse gas emissions and acts as a spur to international regimes to do their part.

In **Capital growth in a global warming model: will China and India sign a climate treaty?** Prajit Dutta and Roy Radner point out that global warming is now recognized as a significant threat to sustainable development on an international scale. They argue that one of the key challenges in mounting a global response to it is the seeming unwillingness of the fastest growing economies such as China and India to sign a treaty that limits their emissions. The aim of their paper is to examine the differential incentives of countries on different trajectories of capital growth. A benchmark dynamic game to study global warming, introduced in Dutta and Radner (2009), is generalized to allow for exogenous capital accumulation. It is shown that the presence of capital exacerbates the "tragedy of the common". Furthermore, even with high discount factors, the threat of reverting to the inefficient "tragedy" equilibrium is not sufficient to deter the emissions growth of the fastest growing economies—in contrast to standard folk theorem like results. However, foreign aid can help. If the slower growth economies—like the United States and Western Europe—are willing to make transfers to China and India, then the latter can be incentivized to cut emissions. Such an outcome is Pareto improving for both slower and faster growth economies.

The ethical foundations of climate change policy are also the topic of Franck Lecocq and Jean-Charles Hourcade's article **Unspoken ethical issues in the climate affair: Insights from a theoretical analysis of negotiation mandates**. Taking climate change as an example, their article provides new insights on the optimal provision of a long-term public good within and across generations. They consider the Bowen–Lindhal–Samuelson (BLS) conditions for the optimal provision of the public good in a world divided into N countries, with two periods, present and future, and we simultaneously determine the optimal response in the first and second periods for a given rate of pure time preference. However, the Negishi weights at second period cannot be determined unambiguously, even under a "no redistribution constraint" within each generation, because they depend on non-observable future incomes; and thus on the answers to two often-overlooked ethical questions: (i) Do rich countries agree on deals which recognize that developing countries may catch up with developed countries in the long run, or do they use their negotiating powers to preserve the current balance of power? And (ii) does each country consider only the welfare of its own future citizens (dynastic solidarity) or does it extend its concern to all future human beings (universal solidarity)? Answers to (i) and (ii)—critical in the debate about how to correct the market failures causing global warming—define four sets of Negishi weights and intertemporal welfare functions, which we interpret as four mandates that countries could give to the Chair of an international negotiation on climate change to find an optimal solution. Leqcocq and Hourcade find that in all mandates, public good provision expenditures are decreasing functions of income at first period. But each mandate leads to a different allocation of expenditures at second period and to different optimal levels of public good provision at both first and second periods. Finally, they show that only one of these four mandates defines a space for viable

compromises. The effectiveness of international climate policy to curb carbon emissions has also been challenged because of possible "carbon leakages", which refers to the rise of emissions in non-participating countries.

In **Carbon leakages: a general equilibrium view** Jean-Marc Burniaux and Joaquim Oliveira offers a general equilibrium (GE) exploration of the key mechanisms and factors underlying the size of such carbon leakages. They develop a two-region, two-goods simplified GE framework, incorporating three types of fossil fuels (coal, oil and low-carbon energy), international trade and capital mobility. The model is designed to make tractable extensive multidimensional sensitivity analysis. The results suggest that the coal supply elasticity plays a critical role, while substitution elasticities between traded goods and international capital mobility appear relatively less influential. The shape of the production function also matters for the size of the leakages. Confirming the results obtained with large computable GE models, for a wide range of parameters' values, overall carbon leakages appear to be small. Therefore, the argument that unilateral carbon abatement action taken by a large group of countries (such as the Annex 1 group) is flawed by significant carbon leakages is not supported by Burniaux and Oliveira's sensitivity analysis. The likelihood of small leakage effects strengthens the call for the formation of a worldwide coalition to stabilize atmospheric carbon levels and halt climate change.

5 Part IV. The Case of Climate Change

The issue of climate change is the most pressing global policy issue today. For decades the world economy has been on an unsustainable trajectory with worldwide carbon emissions projected to increase beyond the mid of this century. The chapters of this section discuss the case of climate change from various points of view: natural science, social choice theory, and welfare economics. The IPCC (2014) recently projected that, due to years of inaction, reductions of carbon emissions are not enough anymore. The removal of carbon from the atmosphere is now needed in order to avert catastrophic climate change and has become a critical issue in climate policy. Peter Eisenberger tackles the issue in the article **Chaos Control—Climate Stabilization by Closing the Global Carbon Cycle**. The central idea behind the control of chaotic systems is that the same feedbacks that destabilize a complex system producing chaotic dynamics can be used to relatively easily stabilize it, drawing on an idea developed by Chichilnisky earlier. While many argue that the carbon cycle feedbacks are destabilizing the climate, Eisenberger argues that those same feedbacks can be used to stabilize the climate. The controlling variable is the amount of CO_2 in the atmosphere and the control strategy is to close the global carbon cycle of our planet, including human and planetary components, so the ambient concentration is fixed. The stabilization using CO_2 capture from or release to the atmosphere requires less energy per year than the amount used to stabilize the climate in our buildings and for less cost than 1 % of the global GDP. What is more, closing the carbon cycle by using carbon from the air and combining it with

hydrogen from water to produce a new energy sources and thus removing the current negative feedback between our energy use and the planet, can enable us to use as much energy as we need for economic growth and well-being. Chaos control of our climate transforms the threat of climate change into an opportunity for our species and our planet to flourish in the Anthropocene era.

According to Norman Schofield, the enlightenment period was a philosophical project to construct a rational society without the need for a supreme being. It opened the way for the creation of market democracy and rapid economic growth. At the same time economic growth is the underlying cause of climate change, and we have become aware that this may destroy our civilization. In **Climate Change and Social Choice Theory** Schofield argues that the principal underpinning of the enlightenment project is the general equilibrium theorem (GET) of Arrow and Debreu (1954), asserting the existence of a Pareto optimal price equilibrium. Arrow's work in social choice can be interpreted as an attempt to construct a more general social equilibrium theorem. His article surveys recent results in social choice which suggests that chaos rather than equilibrium is generic. He also considers models of belief aggregation similar to Condorcet's Jury theorem and mentions Penn's Theorem on the existence of a belief equilibrium. However, Schofield argues that a belief equilibrium with regard to the appropriate response to climate change depends on the creation of a fundamental social principle of "guardianship of our planetary home." Schofield suggests that this will involve conflict between entrenched economic interests and ordinary people, as the effects of climate change make themselves felt in many countries.

Larry Karp's article studies the policy implications of standard economic theory in **Discounting and the evaluation of climate policy.** His essay discusses the relation between utility discounting and climate policy, returning to the problem of Koopmans' impatience axiom. Karp uses simple cost-benefit analysis to show that the planner's willingness to pay for the elimination of a climate event is greater, but less sensitive to discounting, when the event is random instead of deterministic. Examples in an optimizing setting show that policy may be less sensitive to discounting the more nonlinear is the underlying model. He then explains why, in general, there should be no presumption that the risk of catastrophe swamps discounting in the assessment of climate policy and concludes by pointing out that intertemporal transfers between the same agent at different points in their life, and transfers between different agents at different points in time, are qualitatively different, and should not be assessed using the same discount rate.

In **Global warming and economic externalities** Armon Rezai, Duncan Foley, and Lance Taylor return to the problem of the open carbon cycle and argue that despite important and worldwide policy efforts such as the Kyoto Protocol, the emission of greenhouse gases (GHG) remains a large negative externality. Rezai et al. point out that economic equilibrium paths in the presence of such an uncorrected externality are inefficient and that, as a consequence, there is no real economic opportunity cost to correcting this externality by mitigating global warming. The conclusion is that mitigation investment using resources diverted from conventional investments can be Pareto improving for present and future

generations in the sense of raising the economic well-being of both current and future generations. The authors argue that the economic literature on GHG emissions misleadingly focuses attention on the intergenerational equity aspects of mitigation by using a hybrid constrained optimal path as the "business-as-usual" benchmark. In a simple, calibrated Keynes-Ramsey growth model they then illustrate the significant potential Pareto improvement from mitigation investment and the equilibrium concept appropriate to modeling an uncorrected negative externality.

6 Part V. Economic Policy and Regulation

Having discussed the foundations of catastrophic risks in economic theory, articles in this section discuss the implications for economic policy particularly with respect to the risks posed by climate change. The article **Detrimental externalities, pollution rights, and the "Coase theorem"** by John Chipman and Guoqiang Tian revisits the old question of taxes vs. quotas. Extending Chipman (1998), they analyze a simple model formulated by Hurwicz (1995) of two agents—a polluter and a pollutee—and two commodities—"money" (standing for an exchangeable private good desired by both agents) and "pollution" (a public commodity desired by the polluter but undesired by the pollutee). A government issues legal rights to the two agents to emit a certain amount of pollution, which can be bought and sold with money and it is assumed that both agents act as price-takers in the market for pollution rights, so that competitive equilibrium is possible. The "Coase theorem" (Stigler 1966) asserts that the equilibrium amount of pollution is independent of the allocation of pollution rights. A sufficient condition for this was in another context already obtained by Edgeworth (1925), namely that preferences of the two agents be "parallel" in the money commodity, whose marginal utility is constant. Hurwicz (1995) argued that this parallelism is also necessary and Chipman and Guoqiang critically discuss these results and provide an alternative set of necessary and sufficient conditions.

Larry Karp and Jiangfeng Zhang also discuss the emissions taxes or quotas choice in a setting where a (strategic) regulator and (non-strategic) firms have asymmetric information about abatement costs, and all agents use Markov perfect decision rules. In **Taxes versus quantities for a stock pollutant with endogenous abatement costs and asymmetric information** firms make investment decisions that affect their future abatement costs. For general functional forms, firms' investment policy is information-constrained efficient when the regulator uses a quota, but not when the regulator uses an emissions tax. This advantage of quotas over emissions taxes has not previously been recognized. For a special functional form (linear–quadratic) both policies are constrained efficient. Using numerical methods, Karp and Zhang find that there is no simple answer to the question of which instrument to use.

In **Walrasian prices in markets with tradable rights** Carlos Hervés-Beloso, Francisco Martínez, and Jorge Rivera consider an exchange economy where there is an external restriction for the consumption of goods. This restriction is defined by both, a cap on consumption of certain commodities and the requirement of an amount of rights for the consumption of these commodities. The caps for consumption are imposed exogenously due to the negative effects that the consumption may produce. The consumption rights or licenses are distributed among the agents. This fact leads to the possibility of establishing license markets. These licenses do not participate in agents' preferences, however, the individual's budgetary constraint may be modified, leading to a reassignment of resources. The authors' aim is to show the existence of a Walrasian equilibrium price system linking tradable rights prices with commodity prices.

7 Part VI. Catastrophic Risk in Economic Practice

Catastrophic risks have far-reaching implications for existing economic approaches and will force significant reconsideration of the fundamental assumptions. The chapters of this section present empirical and experimental evidence for this pressing necessity. In **Exploring the role of emotions in decisions involving catastrophic risks: Lessons from a double investigation** Olivier Chanel, Graciela Chichilnisky, Sébastien Massoni, and Jean-Christophe Vergnaud report on experimental results about how natural disasters due to climate change (like floods, hurricanes, heat waves or droughts) combine a risk of large losses and a low probability of occurrence, and require decisions to be made in highly uncertain universes. They highlight the inability of standard decision under uncertainty models to provide rankings when some outcomes are catastrophic impedes rational (public) decision-making. This paper examines the role of emotions in individuals' choices among alternatives involving catastrophic events, either in real life (flooding) or artificial (laboratory experiment) situations. The author report a survey on 599 respondents aimed at determining how people exposed to different levels of flood risk form beliefs and make decisions under uncertainty before and after emotion-generating events. Data on their emotions, the emotions they expect to experience, their personality and psychological determinants, their symptoms before and after emotion-generating events are collected and analyzed. In parallel with this survey, experimental protocols replicate the emotional experience of a catastrophe and measure its impact on behavior and formation of beliefs. Emotions are induced by framing effects and measured through a self-declared worry scale. The authors collect behavioral data (insurance choice, subjective beliefs, performance) and measure how they are affected by the emotions felt during the decision-making. These protocols test some assumptions in the survey using experimental paradigms from psychophysics that allow us to control the sources of uncertainty experienced by the subjects. The results reported confirm that emotions connected with the nature of the risk can significantly affect desire to reduce it. The survey provides

valuable material for comparative analysis, revealing how actual experience of an anticipated event affects decisions. The experiments show that emotions affect the decision-making process and the forming of probabilistic beliefs.

In **How the change of risk announcement on catastrophic disaster affects property prices** Hayato Nakanishi presents evidence of the benefits of expected utility that is sensitive to rare events. Specifically, he estimate the treatment effect of reports on rare catastrophic tsunamis by using a land price hedonic approach. To identify this effect, he employs a difference in differences (DD) design. Ordinal expected utility predicts no effect since the probability of catastrophic events is sufficiently small to be ignored. The estimation results, however, reveal a significant effect. Just the results of Chanel et al., this implies that ordinal expected utility derived from objective risk distribution may be insufficient for the study of the economic implications of rare catastrophic events.

Finally in **Modeling US stock market volatility-return dependence using conditional Copula and quantile regression** Temisan Agbeyegbe examines the return-volatility relationship for some indices reported on exchanges in the United States of America. He utilizes both linear quantile regression and copula quantile regression to evaluate the asymmetric volatility-return relationship between changes in the volatility index (VXD, VIX, VXO and VXN) and the corresponding stock index return series (DJIA, S&P 500, the S&P 100 and NASDAQ), as the quantile copula models allow for inference at different quantiles of interest. Agbeyegbe finds, first, that the relationship between stock return and implied volatility depends on the quartile at which the relationship is being investigated. Second, he obtains results similar to those reported for European exchanges showing the existence of an inverted U-shaped relationship between stock return and implied volatility. This result was obtained even after controlling for changes in volatility of return using a GARCH (1,1) filter.

In consonance with the Introduction to this volume and Peter Eisenberger's article, Alan Kirman argues in **Economic Crises: Natural or Unnatural Catastrophes?** that whilst models of the environment and particularly of the climate represent evolving complex systems with non-linear dynamics and complicated feedbacks, macroeconomic models have remained essentially in an equilibrium framework in which the only major changes that can occur are the result of exogenous shocks. Kirman explains why this has been the route taken by macroeconomists and in his article he suggests that the economy shares many of the features of the environment and that it should also be viewed as a complex system which is prone to experience major, sudden and sometimes catastrophic, changes. These changes are largely due to the endogenous evolution of the system and not only to outside influence. In the Anthropocene we have to take account of the co-evolution of two complex systems, the environment and the economy, and the economic models that have been proposed as "integrated" models do not capture the complexity of the economy nor of its interactions with the environment. According to Kirman, successfully doing this will provide a better explanation of the evolution of the economy but will also imply that economists have to be much more modest their claims.

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