INTRODUCTION

Economic theory and the global environment

Graciela Chichilnisky

Modern economic theory came to life in the middle of the twentieth century, providing the intellectual foundations for an unprecedented period of industrial expansion and globalization since World War II. Coupled with population growth, the successful trajectory of industrial society in the twentieth century led to a voracious use of natural resources and global environmental concerns in the twenty-first century. It is uncontested that, for the first time in recorded history, humans dominate the planet. We are changing the planet's atmosphere, its bodies of water, and the complex web of species that makes life on earth. This radical change in circumstances led to rethinking of the foundations of human organization and, in particular, the industrial economy and the economic theory behind it. The rethinking is underway. *Sustainable economics* emerged in 1992 at the UN Earth Summit in Rio de Janeiro, anchored in the concept of Basic Needs that was voted by 150 nations as a cornerstone of efforts to redefine economic development[1]. The formal theory of sustainable development was introduced in Chichilnisky (1997, 2000). In essence sustainable development seeks to meet the basic needs of the present without depriving the future from meeting its basic needs.

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[1] Introduced in Chichilnisky (1976, 1977a,b), Herrera, Chichilnisky et al. (1974).

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This emphasis on the future is new, since until now we have always put the present first. It took some time for the concept of sustainable development to catch on, but it is now a world-wide economic objective that challenges the premises of industrial society and is precipitating its transformation in the twenty-first century. As evidence of this transformation, last year a newly created leading group of 20 nations, the G-20, officially advocated the need for change in economic thinking and recognized in a public declaration the world's aspirations for a new form of economics, sustainable development.[2] Sustainable economics is now a frequently embraced objective, but the challenge is to develop this concept and bring it into the body of economic theory with the clarity and solid foundations that were achieved by neoclassical economic thinking last century.[3] This Special Issue of Economic Theory and the Global Environment offers a selected view of the transition to a new economic theory that attempts to redefine economics as an integral part the natural universe.

Tjalling Koopmans, the founder of neoclassical economics, wrote that economics is about the production and efficient distribution of resources. This simple but profound definition of economics remains true today, as resource scarcity becomes a central issue around the world. Almost paradoxically, however, in his own foundational work on consumer behavior, Koopmans introduced an *impatience axiom* to explain economic decisions over time. This axiom explains how consumers choose and how they trade: discounting the future. This elegant and powerful work leads to a theory of economic growth that is largely insensitive to future generations (Chichilnisky 1997b, 2000). Koopman's theory led also to a concept of markets that we now recognize can ignore the limits and value of the earth's resources (Chichilnisky 1997b, 2000). The first four articles in this Special Issue address these important issues. They analyze how can economic choices be simultaneously fair to the needs of the present and of the future—the very essence of sustainable development—and do so by direct comparison with Koopman's axioms for choice over time. Some of these articles explore a planner's choice over time, and others explore markets where different traders have different choices. In all cases, however, the issues they address are the same: what is sustainable development? Are free markets the enemies of the environment?

In *Intergenerational equity, efficiency, and constructability*, Luc Lauwers (2011) examines economic decisions over time based on the requirement of equity between the generations. His goal is to analyze ways to overcome the bias of the *impatience axiom* and the fixed discount factor that it implies. The article examines and compares the overtaking criteria and Chichilnisky's criteria that take the short and the long run into account and shows that both criteria are able to resolve intergenerational conflicts. The article then focuses on a fundamental ambiguity that arises in

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[2] The G-20 Meeting took place in Pittsburgh, USA, 24–25 September 2009. The G-20 Leaders' Statement can be found in http://www.pittsburghsummit.gov/mediacenter/129639.htm. Here are relevant quotes from the Leaders' Statement: "As we commit to implement a new, sustainable growth model, we should encourage work on measurement methods so as to better take into account the social and environmental dimensions of economic development" and "Modernizing the international financial institutions and global development architecture is essential to our efforts to promote global financial stability, foster sustainable development, and lift the lives of the poorest". These statements substantiate the extent to which sustainable development has become a mainstream international priority.

[3] Solow (1992), Chichilnisky (1996).

both cases. The overtaking criteria, the author observes, is highly incomplete. In order to resolve this incompleteness, stronger anonymity (or equity) axioms are developed, but the author shows that a maximal anonymity axiom compatible with Pareto is non-constructible; 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 (Chichilnisky 1997b, 2000). Here, the long run is captured by a finitely additive measure. Such a measure, however, is a non-constructible object. Lauwers' article exhibits a fundamental ambiguity that arises in sustainable development, an ambiguity that may be considered suitable since we are dealing with choices about the long-run future—for example choices about which species would survive—which are ambiguous in nature. In any case, it is important to observe that the same ambiguity has existed in economics for a long time, since Adam Smith in fact. The second welfare theorem of economics—where an optimal allocation is always identified as a market solution—requires the Hahn-Banach theorem, which has the same lack of constructability feature as it is related to the Axiom of Choice (Chichilnisky 2011, this issue).

Charles Figuieres and Tidball's (2011) article *Sustainable Exploitation of a Natural Resource: A Satisfying Use of Chichilnisky's Criterion* examines the same issue as Lauwers, but from a different perspective. They find that the Chichilnisky's criterion for sustainability 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 (no-dictatorship of the present and no-dictatorship of the future). But this criterion 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 introduced by Beltratti, Chichilnisky, and Heal (1995). 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 some intermediate and infinitely distant generations.

Sustainable Recursive Social Welfare Functions is the third article on the topic of sustainable development. Geir Asheim, Tapan Mitra, and Bertil Tungodden (2011) explore another way of resolving the bias that impatience introduces between the present and the future. They observe that Koopmans' axiomatization of discounted utilitarianism is based on seemingly compelling conditions, yet the ensuing criteria lead 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". The analysis singles out one of Koopmans' original separability conditions (his Postulate 3a), here called "Independent Present", as particularly questionable from an ethical perspective.

The last article on the topic of sustainable development is *Sustainable Markets with Short Sales* Graciela Chichilnisky (2011). This article takes the matter one step

further and, rather than optimizing a single criterion, it deals with the objectives of several traders within sustainable markets, namely markets that meet the needs of the present without depriving the future from meeting its own needs. The article starts with the observation that market objectives can conflict with long-term goals. Behind the conflict is, once again, the impatience axiom introduced in T. Koopmans' seminal axioms of economics over time. The conflict is resolved in this article by introducing a new concept, *sustainable markets*. Sustainable markets differ from Arrow-Debreu markets in that traders have *sustainable preferences*, and no bounds on short sales. Sustainable preferences were introduced in Chichilnisky (1996) offering an alternative to Koopmans' foundational axioms of choice over time as they are sensitive to the basic needs of the present without sacrificing the needs of future generations. They embody the essence of sustainable development. Based on earlier work by Geoff Heal and the author, the current article shows that *limited arbitrage* is a necessary and sufficient condition for the existence of a sustainable market equilibrium where the invisible hand delivers sustainable as well as efficient solutions. By choice, traders take bounded positions with respect to each other. Prices have a new role in sustainable markets: they reflect both the value of instantaneous consumption and the value of the long-run future. The latter are suitably ambiguous values, as they are connected to the independence of the *axiom of choice* that is at the foundations of mathematics as shown by Godel (1940), an observation that matches the results of Lauwers' article in this special issue (Lauwers 2011, this issue).

Externalities are a central issue in twenty-first century economics, since the connectivity between individuals and their economies is greatly enhanced by globalization, as is the extent to which environmental commodities such as a clean atmosphere are *public goods* rather than the private goods that make up the body of neoclassical economics. Externalities imply intrinsic connections between individuals' consumption, for example when individual consumption produces pollution that affects others' welfare, while public goods represent a limiting case where consumption is not excludable in the sense that the goods are in principle available to all in the same quantity for example national defense, law and order, and knowledge. In an era of globalization, human links are increasingly strong and economics is increasingly concerned with private goods that produce externalities—unlike standard private goods that do not—and with public rather than private goods which each trader chooses independently from others. A typical example of a global public good—or public bad—is the atmospheric concentration of CO_2 that is the same the world over for physical reasons. CO_2 concentration cannot be chosen independently by the nations or the peoples of the world. Another example of a global public good is the sea level that is the same the world over.

Several articles in this volume deal with the increasing importance of externalities and public goods in twenty-first century economics. In the article *Detrimental Externalities, Pollution Rights, and the "Coase Theorem"* by John S. Chipman and Guoqiang Tian (2011), an article that builds on Chipman (1998), the authors analyze a simple model formulated by Hurwicz (1995) of two agents—a polluter and a pollutee. There are 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. There is also a government that issues legal rights—

property rights—to the two agents to emit a certain amount of pollution, which can be bought and sold with money. 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", so-called by 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) obtained by Edgeworth (1891), 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. This article provides an exposition of the problem, raises some questions about this result, and provides an alternative necessary and sufficient condition.

A different but closely related approach to the issue of externalities appears in the article *Global Warming and Economic Externalities* by Armon Rezai, Duncan K. Foley, and Lance Taylor (2011). The authors observe that given the scientific evidence that human emissions of greenhouse gases (GHG) contribute to global warming and have real economic consequences through climate change, and the fact that until recently there has been neither a market price for GHG emissions (the carbon market of the Kyoto Protocol created by the author Chichilnisky (1996), Chichilnisky and Sheeran (2009), now provides a market price for carbon) nor alternate institutions to impose limits on emissions (The Kyoto Protocol does), one can regard GHG emissions as an uncorrected negative externality. Economic equilibrium paths in the presence of such an uncorrected externality, they argue, are inefficient; as a consequence, there is no real economic opportunity cost to correcting this externality by mitigating global warming. Mitigation investment using resources diverted from conventional investments can raise the economic well-being of both current and future generations. They observe 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. The authors calibrate a simple Keynes-Ramsey growth model to illustrate the significant potential Pareto-improvement from mitigation investment, and to explain the equilibrium concept appropriate to modeling an uncorrected negative externality.

Externalities and public goods raise concerns about the extent to which public policy with respect to public goods must be global—or whether they can be local. This is the focus of Elinor Ostrom's (2011) article *Nested Externalities and Polycentric Institutions: Must We Wait for Global Solutions to Climate Change Before Taking Actions at Other Scales?* The author explores the issue of what are appropriate policies for global environmental problems such as climate change. She observes that the 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. A global policy is frequently posited as the *only* strategy needed. She suggests 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. In her view, 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.

Externalities are also the topic of the article by Larry Karp and Jiangfeng Zhang (2011) who analyze policies to redress externalities from a policy perspective. They revisit the classic choice between regulation by taxes or by quantities in their article *The Taxes Versus Quantities for a Stock Pollutant with Endogenous Abatement Costs and Asymmetric Information.* The authors compare emissions taxes and quotas when a strategic regulator and nonstrategic firms have asymmetric information about abatement costs, and all agents use Markov Perfect decision rules. Firms make investment decisions that affect their future abatement costs. They show that, 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, they argue, has not previously been recognized. For a special functional form (linear-quadratic) both policies are constrained efficient. Using numerical methods, the authors find that a tax has some advantages in this case.

Another approach to the global public good issue is in the article by Prajit Dutta and Roy Radner (2011): *Capital Growth in a Global Warming Model: Will China and India Sign a Climate Treaty?* The authors observe that global warming—a global public bad par excellence—is now recognized as a significant threat to sustainable development on an international scale (Stern 2007). 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 this paper is to examine the differential incentives of countries on different trajectories of capital growth. A benchmark dynamic game to study global warming, introduced earlier by Dutta & Radner, is generalized to allow for exogenous capital accumulation. It is shown that the presence of capital exacerbates the "tragedy of the commons". Furthermore, they argue that 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* results. However, they show that 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. This also happens to be the approach that was followed in practice by the United Nations Framework Convention for Climate Change, and its carbon market that was designed and introduced by this author in 1997 (Chichilnisky 1996 and Chichilnisky and Sheeran 2009). The Kyoto Protocol carbon market is now trading $200 billion/year in the EU Emissions Trading System (EUETS), and its Clean Development Mechanism has already transferred about $40 billion to China and India for clean technology projects since 2005 when the Kyoto Protocol became international law according to The World Bank annual report on Status and Trends of the Carbon Market, 2005–2010 (The World Bank 2005–2010).

The topic of global public goods and international climate negotiations is analyzed also by the article *Unspoken Ethical Issues in the Climate Affair: Insights from a Theoretical Analysis of Negotiation Mandates* by Franck Lecocq and Jean-Charles Hourcade (2011). Taking climate change as an example, this article provides new insights on the linkages between the optimal provision of a long-term public good and the optimal distribution of the associated abatement expenditures within and across generations. To do so, they write the Bowen-Lindhal-Samuel-

son (BLS) conditions for the optimal provision of the public good in a world divided into N countries, with two periods, present and future, and determine simultaneously the optimal response in the first and second period for a given rate of pure time preference. They observe that the optimal Negishi weights at the second period cannot be determined unambiguously, even under a "no redistribution constraint" within each generation, because the weights depend on future incomes. This highlights two often-overlooked ethical dimensions behind the policy debate about how to correct the market failures causing global warming: (i) Do rich countries agree on deals that 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 (status quo)? 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)? Studying them under the resulting four pairs of Negishi weights the authors find first period to solutions in which marginal abatement mandates are allocated in decreasing function of income. This means that once again—as was done in the Kyoto Protocol, its carbon market and Clean Development Mechanism (Chichilnisky and Sheeran 2009)—efficient solutions require favoring the welfare of the least developing nations. Each mandate leads to a different allocation of expenditures at the second period and to different optimal levels of abatement at both the first and second period. The authors show why only one these four mandates defines a space for viable compromises in the international negotiations.

The next article in this issue covers a topic that has been frequently debated in the global negotiations: *Carbon Leakages: A General Equilibrium View* by Jean-Marc Burniaux and Joaquim Oliveira Martins (2011) explores the effectiveness of unilateral action to curb carbon emissions that can be dismissed because of possible "carbon leakages". This refers to the possibility of a rise of emissions in non-participating countries after the participating countries have imposed emission limits in their own territories. The article offers a general equilibrium (GE) exploration of the key mechanisms and factors underlying the size of carbon leakages. The authors developed 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 was 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. The authors confirm the results obtained theoretically by using large computable GE models and show that, for a wide range of parameters' values, carbon leakages appear to be small. A similar conclusion was reached in the global climate negotiations but more understanding of this phenomenon could be very helpful to understand "self enforcing" global mechanisms to deal with the global public good aspects of climate change.

"*Walrasian prices in markets with tradable rights*" by Carlos Herves-Beloso, Francisco Martinez and Jorge Rivera (2011), is about a Nash equilibrium of a game in which limits are placed on *private goods with externalities*, which are generally quite different from *public goods*. For example the Sulphur Dioxide (SO2) market

that is traded in the Chicago Board of Trade for 20 years, trades rights to emit SO2, which are private goods with externalities and not public goods because SO2 concentrations in air differ from one city to the next. Instead in the case of a public good like CO_2 concentration in the atmosphere, everyone is exposed to the same concentration. The difference between public goods and private goods with externalities is important, since markets with privately produced public goods link efficiency with equity, a property that is not present in markets with private goods. The so-called "Coase theorem" that postulates no connection between efficient market solutions with externalities and the distribution of initial rights does not work with public goods, see Chichilnisky and Heal (1994, 2000) and on a related issue see Chipman's article in this volume (Chipman and Tian 2011). The first results on markets with tradable rights on privately produced public goods are in Chichilnisky (1993), see Chichilnisky and Heal (1994, 2000) Chichilnisky, Heal and Starrett (2000) in Chichilnisky and Heal (2000). It is useful to clarify that the results of the Herves Beloso et al article are not relevant to the carbon market of the UNFCCC Kyoto Protocol, which is international law since 2005 created by the author (Chichilnisky 1996; Chichilnisky and Sheeran 2009) despite what the article states. This is because the carbon concentration of the atmosphere is a global public good 'par excellence' as CO_2 mixes uniformly and stably in the planet's atmosphere and everybody is exposed to the same CO_2 concentration. Their article is, instead, about private goods with externalities.

In summary, this special issue deals with two central topics of economics that are increasingly pressing in the highly globalized and connected global economy of the twenty-first century. One is the extent to which the present generation has the future of humankind in its hands, and the ethical responsibilities that this implies. This leads to observations about consumer behavior that show more concern for the future than Koopman's classic impatience axiom would anticipate. This is evident in empirical observations of bonds prices in financial markets, through the pricing of long-term bonds (Chichilnisky 1997b, 2000), and certainly in the global climate negotiations that address the future of our children and grandchildren at least as much as our own. The economics of the twenty-first century give a more important role to the future and this opens up a number of challenges for economic theory. Sustainable preferences and sustainable markets are needed to meet these challenges, and the first four articles in this special issue address the theoretical foundations of this critical issue. The second topic in this special issue is the increasing importance of externalities and public goods in an increasingly interconnected world.

Together the collection is a microcosm of the evolution of economic theory in the twenty-first century, emerging from the compelling need to understand a new world economy as well as the global environmental challenges that it faces. It could be said that the role of economics is now to focus somewhat less on profits and more on the long-run survival of our species.

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