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The Economics of Avoiding Dangerous Climate Change

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THE ECONOMICS OF AVOIDING DANGEROUS CLIMATE CHANGE

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Abstract

The problem of avoiding dangerous climate change requires analysis from many disciplines. Mainstream economic thinking about the problem has shifted with the Stern Review from a single-discipline focus on cost-benefit analysis to a new inter-disciplinary and multi-disciplinary risk analysis, already evident in the IPCC Third Assessment Report. I argue that this shift is more evidence of the failure of the traditional, equilibrium approach in general to provide an adequate understanding of observed behaviour, either at the micro or macro scale. The economics of the Stern Review has been accepted by governments and the public as mainstream economic thinking on climate change, when in some critical respects it represents a radical departure from the traditional treatment. The conclusions regarding economic policy for climate change have shifted from "do little, later" to "take strong action urgently, before it is too late".

This editorial sets out four issues of critical importance to the new conclusions about avoiding dangerous climate change, each of which have been either ignored by the traditional literature or treated in a misleading way that discounts the insights from other disciplines: the complexity of the global energy-economy system (including the poverty and sustainability aspects of development), the ethics of intergenerational equity, the understanding from engineering and history about path dependence and induced technological change, and finally the politics of climate policy. I argue that equilibrium economics fails to provide an adequate and coherent explanation of why human behaviour is leading to climate change (via economic choices and the use of the atmosphere as free waste waste disposal) with the aim of guiding climate policy. In contrast, the Stern Review considers traditional cost-benefit analysis as a marginal approach inappropriately applied to global climate change, which is a significant, multidisciplinary and systematic problem. This is one reason for the intemperate response from some traditional economists to the Stern Review. Their criticisms illustrate the sensitivity to the implied criticism of their methodologies and conclusions, when equilibrium economics underlies most text books of economics and journals of economic theory.

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[1] This Working Paper is a preview. The original publication will be available at www.springerlink.com.

1 Introduction

Since the early 1990s, it has been internationally recognized that one consequence of economic activity has been the accumulation of greenhouse gases and that this may lead to climate change. This already threatens development in poor countries that are most vulnerable to climate variability. If unchecked, it will threaten future generations with unknown but potentially catastrophic climate events, given the availability of fossil carbon at current prices relative to carbon-free alternatives, which could raise concentrations to levels not seen for millions of years. At the same time the costs of reducing the emissions have been agreed as negligible in relation to expected growth in incomes. Yet, after 17 years, global action has been limited and emissions have continued to grow. Indeed, the political recognition of the urgency of the problem has only become evident at a global scale since the publication of the Stern Review of the economics of climate change in 2006.

One reason for this delay has been the response by a clique of economists, dating from the publication of the first IPCC Report in 1990, to the concern and calls for action by the climate scientists. The response came in the form of the mis-application of a tool developed by equilibrium economists for prescriptive public policy: the cost-benefit analysis. This editorial addresses the question of how and why the focus of the *economics* of climate change has shifted from the single-discipline cost-benefit analysis, as in the IPCC Second Assessment Report in 1995, to the multi-disciplinary uncertainty analyses in the subsequent IPCC Reports of 2001 and 2007 and the radically different policy prescriptions of the 2006 Stern Review.

The application of traditional cost-benefit analysis has yielded, with some exceptions, policy prescriptions of insignificant carbon taxes and delayed action until more information is available on the problem and more R&D has been done to lower the costs of any response. The new mainstream uncertainty analysis, in contrast, suggests that a political global decision needs to be taken urgently on targets to avoid dangerous climate change and that cost-effective and equitable policies and measures should be implemented strongly without delay to accelerate progress towards a complete decarbonisation of the world economy.

Defining dangerous in this context is a social and political task. Implicitly some progress has been made with the European governments' 2˚C target for average long-term global temperatures above pre-industrial levels, the G8's 50% reduction in global GHG emissions below 1990 levels by 2050 as agreed by the meeting in Heiligendamm, Germany, June 2007, and the "deep cuts" of the UNFCCC Bali Action Plan of December 2007. The AR4 WG3 Summary for Policymakers gives an indication of just how deep the cuts will have to be. It presents six scenarios from the literature on the scale of action required. For a chance less than 50:50 that the target will be met, the scenarios suggest that global CO_2 emissions will have to be between 50% to 85% below 2000 levels by 2050, and becoming negative (through sequestration and storage) by 2070 and beyond. Therefore to be reasonably sure of avoiding dangerous climate change defined as a 2˚C rise or less, the world should be aiming for complete decarbonisation by 2050 or earlier, to be safer. All sectors in all countries should be aiming to stop emitting GHG into the atmosphere as soon as possible without excessive cost[2]. Without

[2] The carbon price associated with this target is not the topic of this paper, but it is of great interest. Without sufficient literature to assess such a price, it is necessary to extrapolate from the AR4 literature on less stringent targets (Barker *et al*, 2007, pp. 636, 648 and 659-661). A precautionary, provisional estimate for a global price for the 2˚C target appears to start in the range $US80 to $US100/t$CO_2$ by 2020 and earlier if possible, rising after 2020 and all in year 2000 prices.

urgent action, the risks of losing coral reefs and pristine tropical rainforests appear significant, e.g. for a rise above 1 to 3˚C, the AR4 WG2 Summary has "very high confidence" of widespread mortality of coral reefs.

In this editorial I argue that this shift in thinking is more evidence of the failure of equilibrium economics in general to provide an adequate and coherent explanation of observed behaviour, from the personal (micro) to the global (macro) scales, with the aim of guiding policy. Equilibrium economics underlies most textbooks of economics and journals of economic theory. It is theory largely unsupported by formal scientific observation and empirical data. Over the past 50 years, it has been increasingly recognised as dependent on false assumptions about human behaviour and physical systems, and as based on a rigid and ill-informed interpretation of utilitarian ethics. The continued use of the assumptions, most pertinently in the application of cost-benefit analysis and computable general equilibrium models for climate policy, strongly suggests that their only justification is that they are required for the mathematics and computation to be tractable. Any empirical support for the theory has been generally incoherent, *ad hoc* and rhetorical, with the most outstanding example the fact that the multi-sectoral equilibrium modelling of GHG mitigation policy over the century, which dominates the literature, is based typically on one year's data (and this is simply to calibrate the model to yield results of the right magnitude, rather than to provide empirical validation of the results).

In contrast, the Stern Review considers cost-benefit analysis as a marginal analysis inappropriately applied to a non-marginal multi-disciplinary systemic problem (p. 50). Both Stern (p. 163) and the IPCC Reports after 1995 take a multi-criteria approach rather than a narrowly monetary one and question cost-benefit analysis. This is one reason for the intemperate response from some traditional economists to the Stern Review[3]. The effect of the more general approach is to criticise, qualify, and generally undermine such equilibrium thinking in the assessment of the costs and benefits of climate change and its mitigation. This is not new[4]: government rejection of the cost-benefit valuation of human lives goes back to the IPCC Second Assessment Report. What is new is that the economics of the Stern Review has been accepted by governments and the public as mainstream and consensus economic thinking, when in critical respects it represents a radical departure from a traditional deterministic treatment and its messages for economic policy.

This editorial takes an interdisciplinary approach to the economics of dangerous climate change, contrasting the cost-benefit analysis (CBA) with the new economics of risk that acknowledges and respects the insights and analysis from other disciplines, namely the other social sciences, climate and geographical sciences, ethics, history, engineering as well as

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[3] Tol and Yohe (2007, p. 233-4) accuse Stern of "substandard analysis" and "dubious economics"; Nordhaus claims that Stern is "political" (2007a, p. 5) and the discount rates used are "extreme" (p. 6); Dasgupta (2007, p. 7) accuses Stern of choosing parameter values so "that they yield desired answers." Such charges are perhaps more appropriately made against neoclassical economics as in (Mirowski, 1989, 2002; Barker, 1996b, 1998; Nelson, 2001; DeCanio, 2003; Ackerman and Nadal, 2004; Foley, 2006; Nelson, 2006; Beinhocker, 2006). The charges also contrast with the praise by leading mainstream economists and Nobel Laureates quoted in the Review, such as Mirrlees, Sen, Stiglitz, and Solow, and support after publication from Arrow, DeLong and Deaton among others. There are far too many references to include in the space permitted, so I have only included examples of the mainstream literature and the last or later references in the new literature.

[4] Previous academic critiques of the optimizing (Barker, 1996) and discounting (Hasselmann, 1999) approaches of traditional cost-benefit analysis have had no discernible effect on the methodology or conclusions.

complexity and evolutionary theory[5]. This editorial introduces the other papers in this issue on the economics of climate change following the publications in 2006 of the Stern Review, and in 2007 of the critiques of the Review and the IPCC Fourth Assessment Report (AR4). The paper by Quiggin consolidates the arguments relating to Stern's use of the discount rate, claimed to be the main reason for differences between the conclusions of Stern "take strong action urgently" and those of the critics. The paper by Jaeger, Schellnhuber and Brovkin promotes the case of other values than purely economic ones in social choices for the future climate system. The paper by Hasselmann and Barker proposes a new international body to develop data and modelling for mitigation policies to avoid dangerous climate change, based on risk analysis and a systematic treatment of global energy-environment-economy time-series data.

This editorial sets out four issues of critical importance to climate policy, each of which have been either ignored by traditional economic modelling of the problem, or treated in a misleading way that discounts the insights from heterodox economics and other disciplines.

1) The global economy, with its use of energy and emissions of GHGs, is a complex, non-linear dynamic system with technological change inherent in economic growth. Climate effects and responses to climate policy are potentially non-marginal changes to the system in the context of strong uncertainty.
2) The problem of intergeneration equity from climate change and mitigation is primarily an ethical one, and should be informed by moral philosophy rather than economics in isolation. Traditional economic models adopt an extreme form of utilitarianism, with a questionable choice and use of discount rates, ignoring the philosophical literature and the concept of justice.
3) Engineering and history inform GHG mitigation policy through studies of the production processes involving the supply and demand of energy, in particular the technical possibilities of accelerated decarbonisation of the energy system. Economic history is critical in understanding the relationship between mitigation policies, economic development and technological change because the time scales are long in relation to the life-times of most energy-using capital, so that the technologies involved can respond to carbon-price signals over the policy period. Traditional models assume continuity and path independence.
4) The politics of mitigation implies unstable alliances and trade-offs between governments and political parties. By the use of the social welfare function (required for the calculus), traditional economists simplify social choices and pre-empt political negotiation, claiming an optimality for their subjective assumptions and market interpretations.

This is an ambitious agenda and the issues can only be summarised, relying on the underlying literature. The implications for new economic thinking are often unclear, provisional and tentative in the face of the certainties of some cherished traditional beliefs. This editorial covers the issues one by one, but first the economics needs to be further explained and the Stern Review and IPCC Reports interpreted in the light of the shift in economic thinking.

2 "Traditional" and "new" economics approach to climate change

[5] Other disciplines are just as important, including the humanities, but I am restricting the discussion to a few issues. In particular, I do not consider in any depth the analysis of development, which is crucial for adaptation to climate change.

Understanding and solving the climate problem requires the synthesis and co-development of many disciplines with different traditions and links between them. Economics is relevant because it explains why human behaviour might lead to climate change (via economic choices and the use of the atmosphere for free waste disposal) and it provides systematic methods for assessing (and monetizing) costs and benefits of different activities and policies. However, it is important to distinguish between a general definition of economics[6] and the particular approach used (pre-Stern) in most of the literature on the economics of climate change. Following Beinhocker (2006) and Maréchal (2007) I shall call this particular approach "traditional" economics defined as

> "… the set of concepts and theories articulated in ... textbooks. It also includes concepts and theories that peer-reviewed surveys claim, or assume, that the field generally agrees on." (Beinhocker, 2006, p. 24)[7].

This traditional economics is epitomized by Samuelson's *Economics*, now co-authored by Nordhaus[8], and based on the neoclassical mathematical synthesis promoted by Samuelson that came to dominate mainstream economics thinking in the late 20thC. I shall contrast the traditional economics with a "new" economics, as in the title of Boulding's 1992 book, including complexity, evolutionary and Post Keynesian theory and emphasising institutions, non-linear dynamics, and deep uncertainty.

Neoclassical economics is defined as being characterized by an emphasis on rationality, via the use of utility maximization, an emphasis on equilibrium, and by neglect of strong kinds of uncertainty, particularly of fundamental uncertainty (Dequech, 2008, p. 290). The traditional economic approach to modelling climate change has been almost exclusively and narrowly neoclassical, adopting a version of expected utility theory with human welfare usually

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[6] Economics is the study of social activity undertaken with its primary purpose the expectation of reward, which usually involves money, the motivations of such activity and its consequences both good and bad, e.g. for equity and the environment. In contrast the neoclassical economist Robbins (1932) defined economics as "the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses" (p. 16), asserting that economics is a value-free science.

[7] It has become debatable whether neoclassical equilibrium economics is mainstream anymore (Dequech, 2007). This paper argues that Stern has shifted the mainstream away from the traditional neoclassical approach to climate-change economics. See (Maréchal, 2007) for a supporting view. For a more general view see (Hodgson, 2007). Prominent economists are acknowledging that for macroeconomic growth "The right way to think about this complex set of issues is not clear, but it is clear that the competitive paradigm cannot be fully appropriate." (DeLong and Summers, 2001). Arrow (2007) accepts the Stern estimates of costs and benefits, quoting the range of GDP mitigation costs (3.4 to -3.9%) from the meta-analysis in (Barker et al, 2006). Akerlof (2007), the 2007 President of the American Economic Association, exposes the weaknesses of neoclassical macroeconomics and suggests that early Keynesian macroeconomic theory has more explanatory power. Deaton (2007), the 2008 President of the AEA, supports the Stern treatment of discount rates: "Whatever it is that is generating market behaviour, it is not the outcome of an infinitely lived and infinitely far-sighted representative agent whose market and moral behaviours are perfectly aligned, and who we can use as some sort of infallible guide to our own decisions and policies." (p. 4)

[8] Samuelson and Nordhaus (2001) is the 17th edition of a textbook originally published by Samuelson in 1948. Yohe, another contributor to the traditional literature, has published a study guide to this textbook (1989). Nordhaus is taken as the exemplar in this editorial (rather than a straw neoclassical man) because of his economics, methods and distinction in the field. He provides full details of equations, exposing all his assumptions. His approach is followed by many others and his models are widely used for climate policy analyses. It is characteristic of his work, and of his school, that qualifications to the economics or results (e.g. extreme events, recycling of carbon tax revenues or induced technological change) are introduced independently, but subsequently there is usually a reversion to the core model even when the qualifications produce radical effects on the results (Nordhaus, 1993, 2007b). Other problematic features one would expect in a CBA, e.g. environmental co-benefits of GHG mitigation, are ignored. Eventually, if the qualification becomes mainstream, it is accommodated in the model or analysis (Mirowski, 1989, 2002)

translating into private market consumption per head in the applied models. The theory is applied to utility across countries with huge differences in consumption and over 100 years or more into the future, when consumption can rise perhaps 20 or 30 times over. The formal approach to the problem has been cost-benefit analysis beginning in the 1990s (e.g. Cline, 1991, 1992; Nordhaus, 1991a and b, 1994 and 2007b; Nordhaus and Boyer, 2000). In simplified terms, the costs of climate change are set against the benefits of taking action in a way that allows comparison with other potential uses of public revenues. The price of carbon (the CBA literature is focused on the specific "social cost of carbon") is calculated in a supply-demand framework, such that the costs of climate change arising from the marginal addition of CO_2 into the atmosphere are matched in equilibrium with the benefits of not making the addition, i.e. the mitigation or marginal abatement, giving the "maximum benefit" for humanity, discounted over all future generations. The treatment of uncertainty and risk has been to ignore deep uncertainty and convert the asymmetric risks of long-term irreversible damages into certainty-equivalent damages, which are then discounted when compared to short-term costs of mitigation. The outcome is an "optimal" price of carbon, an indefinite "optimal" rise in global temperatures, and very modest prescriptions for action.

This method rests on the idea that individual preferences are fixed and utilities can be aggregated and converted into well-behaved mathematical equations in a "social welfare function", and differentiated to give stable marginal properties, as the basis for climate policy. It also crucially assumes that all natural services can be converted to money and back again at any time, i.e. that there are no irreversible effects of climate change. These and other assumptions render CBA inadequate and misleading for climate policy analysis (Azar and Lindgren, 2003; van den Bergh, 2004; Ackerman and Heinzerling, 2004). In summary, CBA "does not yield transparent or objective evaluations of benefits; rather, it renders the discussion of benefits obscurely technical, excluding all but specialists from participation. At the same time, political debate continues behind the veil of technicalities, as rival experts battle over esoteric valuation problems." (Ackerman, 2004). The approach (Arrow *et al*., 1996; Pearce *et al*., 1996) became highly controversial in the IPCC Second Assessment Report, when the governments rejected an assumption used in the analysis that the costs of human life should be different for different countries, depending on their income levels. Since the CBA literature is voluminous, it is covered in subsequent IPCC reports, but any implications for policy are heavily qualified and extensive lists are given of damages that are not or cannot be monetised (IPCC 2007, Table SPM3)

However CBA continues to be the theoretical basis for those advocating the traditional climate policies. A leading example of the post-Stern CBA approach to the climate problem is Nordhaus (2007b), who concludes that "the Gore and Stern proposals … are more costly than [doing] nothing."(p. 177) A peer-reviewed survey of the costs of "doing nothing" in the CBA is to be found in (Tol, 2005), which covers 80 peer-reviewed estimates, i.e. fulfilling Beinhocker's definition of traditional economics. Tol concludes "One can therefore safely say that, for all practical purposes, climate change impacts may be very uncertain but [it] is unlikely that the marginal damage costs of carbon dioxide emissions *exceed* [\$14/tCO_2][9] and [they] are likely to

[9] To avoid confusion and conform to IPCC AR4 WG3 usage, all estimates have been converted to \$/tCO_2 in this editorial. The price base is given where known. Despite their apparent precision, Tol's estimates cover different base years and price bases, because he does not appear to have converted the estimates to a consistent basis. They are all in real terms in his original sources, but typically adopt different base years for the discounting and prices. This lack of comparability in the underlying data renders his averages undetermined, a problem not mentioned by Tol.

be substantially smaller than that." (p. 2073, italics added). An update (Tol, 2007) covering 125 such studies confirms the median estimate of $4/t$CO_2$. For comparison, a carbon tax of $5/t$CO_2$ in 2005 dollars (arguably close to the starting rates of the "optimal" tax from this mainly 1990s literature before any extra allowance for risks of dangerous climate change was introduced in response to the issues raised by the Stern Review) converts to an increase of $2.5/bbl in US crude oil prices in 2005, or about 2% in US gasoline prices. Such numbers from this established body of literature appear unbelievably small if they are taken to be, as intended over the last 16 years, the estimated "optimal" costs of risking climate catastrophe[10].

In summary, the key policy messages, extremely stylized[11], from traditional economics have been: (1) introduce a small carbon tax, rising indefinitely in real terms and, if technological change is considered, (2) wait rather than act now because the costs of mitigation will fall as a result of technological change. These policy prescriptions have come from an approach relying on deterministic cost-benefit analysis and high discount rates, assuming that technological change is exogenous to the economic system or not affected by the carbon price, and ignoring deep uncertainty.

Contrast the tone and implications of these statements with Stern's conclusions: "the benefits of strong early action far outweigh the economic costs of not acting" and "even at moderate levels of warming, all the evidence … shows that climate change will have serious impacts on world output, on human life and on the environment." (pp. xv and xv1). Stern acknowledges that technological change is partly driven by economic factors, such as the price of carbon, implying that the benefits from waiting are replaced by benefits from acting so as to induce the change and reduce the future costs (Köhler *et al*, 2006). Stern commissioned an application of the PAGE model (Hope, 2003), which computes a probabilistic risk-based CBA, and considered the CBA approach as one of three lines of evidence from the literature[12]. Stern asserts that the economics of climate change are now more appropriately concerned with risk rather than return, and with the development of technologies for mitigation, both features of the problem that has been evident from the early 1990s, when the scientific assessments began in earnest. This in turn implies that the economic problem is one of achieving political targets and lowest costs compatible with equity and effectiveness, rather than with the political and scientific problem of choosing the targets themselves.

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[10] They are also 5 times smaller that the carbon prices revealed by the market. Phase 2 of the EU emission trading scheme has a carbon price over $20/t$CO_2$ (March 2008), arguably to achieve a much weaker internal EU target than that implied as optimal by the CBA literature.

[11] Dasgupta (2007, p. 5) summarises the traditional view (incorrectly but reflecting academic and political perceptions) as: "Nordhaus … has been studying the economics of climate change for over three decades. The most remarkable conclusion of his studies - conducted on his Dynamic Integrated Model of Climate and the Economy (DICE) - has been that, despite the serious threats to the global economy posed by climate change, little should be done to reduce carbon emissions in the near future; that controls on carbon should be put into effect in an increasing, but gradual manner, starting several decades from now. This conclusion has withstood the many modifications Nordhaus and others have made to the climate science embodied in DICE. Their idea is not that climate change should not be taken seriously, but that it would be more equitable (and efficient) to invest in physical and human capital now, so as to build up the productive base of economies (including, especially, poor countries), and divert funds to meet the problems of climate change at a later date." Nordhaus (2007b, p. 237) in fact has carbon taxes starting in 2005. Others using DICE (see note 13), but altering the assumptions, come up with Stern-like conclusions.

[12] It is significant that his critics have mainly criticized technical assumptions about discounting in a CBA and have asserted that he has based his conclusions on this CBA. In fact the results of the CBA are to be viewed as "indicative only" and to be "interpreted with great caution" (p. 174) and their discussion takes up only 16 out of nearly 700 pages of the Review.

Contrast also the pre-Stern traditional conclusion that "optimal" temperatures should rise indefinitely (Nordhaus, 1994, p. 89; 1997, p. 324)[13] with the potential impacts of such warming from the IPCC: "Partial loss of ice sheets on polar land could imply metres of sea level rise … projected to occur over millennial time scales, but more rapid sea level rise on century time scales cannot be excluded." (IPCC, 2007, p. 13). Baer and Mastrandrea (2006) present a risk analysis of such dangers: "a precautionary approach requires near immediate efforts to 'bend the curve' of global emissions, and much steeper reductions [80% by 2050] than are currently contemplated" (p. 8). The traditional approach is unsuitable mainly because it simplifies or just ignores such deep uncertainties of long-term climate projections. It requires knowledge about the far distant future under climate conditions radically different from those of today (van den Bergh, 2004), as well as many other assumptions about human welfare and behaviour needed to make the mathematics tractable (Nelson, 2006, p. 93).

However, the literature coming to the conclusions from traditional economists does not exist in isolation from that of other disciplines addressing the same problem. Climate scientists address the likelihood and risks of extreme events, and draw conclusions about what "one can safely say, for all practical purposes". Ethics considers issues of intergenerational equity, when climate damages are uncertain and far in the future. Engineering and architecture give insights into how the capital stock can be designed to reduce greenhouse gas emissions. Economic geography and history provides understanding as to how economies grow and how technologies diffuse and evolve. Political science considers how societies make decisions regarding public policy. Furthermore, economics is not confined to the study of equilibrium in various guises, assuming groups of identical representative agents, with entirely self-interested consumers and known, quantifiable social welfare functions. All these economic assumptions and more are standard in the traditional cost-benefit analysis that lies behind the conclusions of Nordhaus and Tol[14] (DeCanio, 2003). The weakening of the neoclassical analysis of climate change has been accompanied by a more general undermining of the ideology and prescriptions of traditional economics by deconstruction of the origins of the theory in physics and cybernetics (Mirowski, 1989, 2002). Behavioural economics going back to (Kahneman and Tversky, 1989) has revealed key relevant empirical findings for risk aversion and utility maximisation that are inconsistent with traditional treatments. Complexity theory and agent-based modelling has developed a theory of economic evolution (Arthur, 1994; Beinhocker, 2006).

Traditional economics has developed an approach to climate change, which has persistently ignored the conclusions and insights of other disciplines. The new economics, as it has developed in the literature covered by Stern, is more pluralistic and respectful of other disciplines. The CBA approach is formally replaced by a Multi-Criteria Analysis (MCA) developed in management science and applied to sustainable development (Munda, 2005) in which socio-economic, ecological, and ethical perspectives are taken into account. Most of the insights and techniques of CBA can be incorporated into the market (monetised) criterion in MCA, but as in the Stern Review and IPCC Reports, intrinsic values (non-monetised) of human

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[13] ".. the optimal climate change policy reduces long-run global warming from 6.6˚C to 6.2˚C." (Nordhaus, 1997, p. 324). His current "optimal" rate is closer to 3˚C, see below.

[14] The literature covered by Tol requires the monetization of the costs of climate change and almost without exception adopts the standard assumptions. Alternatives approaches are provided by Barker, 1996b; Barker et al., 2006; Ackerman and Heinzerling, 2004; Padilla, 2004; Maréchal, 2007.

suffering, damages to nature, and risks and uncertainties are also taken into account as criteria for social choice.

3 Uncertainty in economic systems: equilibrium versus complexity

A critical issue in the understanding of climate change and its mitigation is the treatment of uncertainty. The use of the word "dangerous" in the UNFCCC objective[15] is interpreted by the IPCC (IPCC, 2007, p.19) in terms of risks of climate change being balanced against the risks of threatening economic sustainability by the response measures. The problem is clearly one entailing unknown risks (uncertainties) of the climate system responding to the anthropogenic pulse of additional greenhouse gas, primarily CO_2, into the atmosphere being compared to the largely known risks associated with mitigation policies and the even lower risks of the co-benefits of mitigation, such as improved air quality. The treatment of these risks and uncertainties distinguishes the traditional and the new economic analysis.

The classic text (Knight, 1921) defines risk as the property of outcomes with quantifiable probabilities and uncertainty as that with unknown probabilities. Keynes made a similar distinction: 'By uncertain knowledge I do not mean merely to distinguish what is known for certain from what is only probable. About these matters there is no scientific basis to form any calculable probability whatever. We simply do not know.' (1973 pp. 113-14 quoted by Holt (2007)). In the traditional CBA, the form of the probability density function is simply assumed, deep uncertainties are set aside despite the complexity of the scientific understanding, the risks are assumed to be symmetric despite the key feature of disproportionately higher risks from higher temperatures, and average discount rates are used for both costs and benefits, despite the differences in risks (Frederick *et al*., 2002). Many CBAs are simply deterministic, neither converting uncertainty into "certainty equivalence" nor subjecting the final model to a sensitivity analysis[16]. However, the shape of the damage function is uncertain and that the climate science suggests a significant (i.e. more than 1%) chance of catastrophe, defined by Weitzman (2007) as average global temperatures rising by more that 5˚C above pre-industrial. Weitzman has extended the traditional CBA analysis to convert the uncertainty into a second-order risk and his interpretation of the results is to question the validity of CBA: "Perhaps in the end the climate-change economist can help most by *not* presenting a cost-benefit estimate for what is inherently a fat-tailed situation with potentially unlimited downside exposure as if it is accurate and objective." Instead, he argues, economists should be "explaining better to policy makers that the artificial crispness conveyed by conventional IAM-based CBAs is *especially and unusually* misleading". And that "in rare situations like climate change ... we may be deluding ourselves and others with misplaced concreteness if we think that we are able to deliver anything much more precise than this with even the biggest and most-detailed climate-change IAMs as currently constructed and deployed." (p.42)

The CBA estimates prevalent in the literature on the economics of climate change are highly misleading because the studies set aside or ignore deep uncertainty in costs and benefits. A critical example is that the global long-run growth rates are almost entirely exogenous in the models (coming from labour supply and technology), so that the uncertainties of the effects of climate change on labour and technologies and then on growth are ignored. The estimated costs

[15] UNFCCC, 1992, states as its objective: "to achieve stabilization of greenhouse gas concentrations in the atmosphere at a low enough level to prevent dangerous anthropogenic interference with the climate system."

[16] Dietz, et al. (2007) show how risk analysis can change the conclusions of the CBA.

of climate change and the optimal carbon tax rates from the CBAs are essentially the subjective views of Nordhaus, Tol[17] and others presented as scientifically precise results. Tol in 2005 presented quantified ranges although he repeatedly acknowledges the uncertainty of the results; in contrast in 2007, responding to Weitzman's analysis, he acknowledges that the upper bounds to the costs may be unquantifiable.[18] Another example is the conclusion from Nordhaus' DICE study (July 2007) that "The total discounted economic damages with no abatement are in the order of $23 trillion" (p. 181). Such an estimate is much too precise because the uncertainties in the projections include possible worlds with temperatures >5˚C above pre-industrial averages. This matters because the economists who have made the calculations have developed a "scientific" consensus in defending the approach. They have argued that the "social cost of carbon" can be precisely estimated and ranges given with sufficient precision to form climate policy. Wietzman's point is that the upper boundaries in such ranges e.g. a top 95 percentile of about $100/t$CO_2$ in Tol's 2005 study, are subjective and misleading. With notable exceptions[19] the literature on the social cost of carbon, by ignoring some uncertain damages, truncating probabilities and discounting risky outcomes, has been promoting an over-optimistic picture of the uncertainties of climate damage for the last 16 years.

There are also uncertainties associated with the costs of mitigation. In traditional economics, the *Marginal Abatement Cost (*MAC) is the cost of abating the marginal emission of GHGs and the *Marginal Abatement Benefit* (MAB) is the benefit, in terms of the reduction in the damages caused by the emissions and converted into money. By assumption, as the level of abatement rises, costs go down and benefits go up, so that there is an equilibrium solution for this level in which the marginal cost equals the marginal benefit, utility is maximized and the optimal carbon tax rate can be calculated. When used correctly, *marginal* means 'vanishingly small' since it is calculated by differentiating cost curves that are required by the theory to be continuous, but in equilibrium models of climate change 'marginal' is used, loosely, to refer to discrete, system-wide changes, e.g. a shift from fossil fuel to hydrogen in transportation. The *benefits* in the MAB are the avoided costs of "doing nothing" as discussed above, including the monetary estimates of avoiding long-term catastrophe. The *costs* in MACs can be a large range of disparate, but largely shorter-term, costs both private and public (or social) with and without market-based valuations, but all associated with the abatement. It is clear that these costs do not normally include any political costs of introducing abatement policies and measures. These economic costs may be offset by ancillary environmental benefits or improvements in efficiency from the use of tax revenues, but the CBA literature often either ignores these associated benefits or sets them aside as being too uncertain or assumed to be managed by non-climate policies.

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[17] Tol ignores the value judgments underlying all cost-benefit analysis, namely that the equilibrium outcome of rational self interest is in some sense optimal for society. He presents his survey of a set of essentially subjective estimates, often done by the same clique of authors, as observations of probability density functions, when they are basically undetermined (see note above), not properly sampled, or even independent.

[18] "... the uncertainty is so large that a considerable risk premium is warranted. … More importantly, there is a 1% probability that the social cost of carbon is greater than $78/tC. This number rapidly increases if we use a lower discount rate – as may well be appropriate for a problem with such a long time horizon – and if we allow for the possibility that there is some truth in the scare-mongering of the gray literature." Tol, 2007 (conclusion). Tol (2005) does not mention a risk premium or that the damages may be unbounded, although the fat tail of damages is emphasised as a feature of the analysis.

[19] Examples, using Nordhaus' DICE model are the studies by Mastrandrea and Schneider (2001, 2004), Azar and Lindgren (2003) and Ackerman and Findlayson (2007).

There are serious problems with the MAC concept and the total costs derived from the models that use it[20]. The first problem lies in the treatment of uncertainty and technology. The reasoning assumes that the future schedules of costs are known in advance and independent of policy. In fact they are uncertain and evidence shows that they are likely to respond to policy: low-carbon technologies can be expected to develop in response to higher real prices of carbon, just as energy-saving technologies have responded to energy prices (Popp, 2002). If so, the MAC schedule is not independent of the cost of carbon, so the schedule is both uncertain and unstable. As noted above, in general the risks and uncertainties of abatement are much less than those of the damages. If decision-makers are risk averse, or wish to follow the Precautionary Principle, the fact that abatement costs are less uncertain is likely to justify action involving higher costs than what otherwise would be the case. Additionally mitigation reduces the risks of the damages *and* of future adaptation, i.e. it reduces the cascade of risks from the emissions. A deterministic equalisation of estimates of costs and benefits without taking into account these uncertainties ignores fundamental differences between them.

A second problem is the one Stern identifies as the non-marginal nature of the economics. As a result of discontinuities and path dependence in the economic system, the placing of system changes within the apparatus of continuous cost schedules is misleading because different mixes of old and new technological systems (e.g. a mix of oil-based and hydrogen-based systems) appear to be highly unlikely because of economies of scale and specialization and lock-in effects. The complex system effects may be large enough to achieve significant reductions in costs under new technologies. If there are indivisibilities, e.g. a global electricity grid for low-cost renewable generation, there is no longer a unique solution for the equilibrium carbon tax. There is evidence for such system properties from the investigation of future costs of energy systems undertaken by researchers at IIASA (Gritsevskyi and Nakicenovic, 2000). It is also obvious at the micro scale that the technologies and costs of mitigation are not continuous. This appears to be the case at the macro scale because of network economies and technological lock-in. Not only are there significant discontinuities in the abatement cost schedule, the costs are likely to go up or down for different levels of abatement depending on the technological system under study.

The Stern Review's assessment (p. 338) of escalating macroeconomic costs of mitigation as targets become more stringent (450ppm CO_2-eq and below) is also open to question, since the underlying literature largely assumes continuity and exogenous technological progress. Macroeconomic costs may not escalate when policies lead to decarbonisation, although carbon prices, energy investments and the policy "effort" are all likely to rise, perhaps disproportionately and the macroeconomic costs do become more uncertain at higher carbon prices[21]. One of the key findings of the AR4 is that the literature on stringent mitigations is insufficient to draw reliable conclusions (WG3, SPM, p. 16). All the available mitigation options have not been investigated and included in the models in terms of the speed at which they need to be implemented or their eventual scale. Extrapolation of the costs in the literature (Barker and

[20] This is not to undermine the usefulness of the static incremental abatement schedule, showing abatement options as a set of non-linear steps rising as the carbon price rises, and usually referred to as the MAC.

[21] Tol (2007) asserts that high carbon taxes would bankrupt some countries. He seems to be confusing tax revenues with tax payments. The tax revenues accrue to governments and benefit their finances; they benefit the population if used wisely. One such use is to ensure that all home owners adopt low-GHG technologies. The tax payments may not be a problem if safeguards to protect vulnerable social groups predate or accompany the introduction of a carbon tax.

Jenkins, 2007) suggests that, depending on policies, macroeconomic costs for more stringent mitigation will remain negligible, but risks of policy mistakes increase.

The modelling of economic risks in the context of climate change has been taken forward with the post-Stern work of Dietz *et al*. (2007), in which the effects of adding risk to the CBA are shown to increase the costs of climate change significantly. The key features of a risk analysis of the problem are that the risks and uncertainties associated with the climate damages are much greater, because of systemic irreversibilities and non-linearities, compare to those of mitigation, which are largely known from past experience, and that the air quality benefits of mitigation are even less risky, more immediate, and well-documented (Barker *et al*., 2007). A more flexible "new economics" alternative modelling approach to CBA (Barker *et al*., 2006) is based on the economic history of institutional structures. It emphasizes the importance of accounting and economies of specialization and allows for increasing returns to scale in the factor demand equations. In critical sectors, technology is modelled to allow for reductions in unit costs as the scale of production increases and the markets develop. Scenarios incorporating system-wide changes in technology, e.g. those involving the hydrogen economy, can be developed consistently. This approach does not impose costs of mitigation by assumption, unlike general equilibrium, so that an alternative low-carbon world economy may be less costly than business as usual, depending on the reductions in costs that emerge when new technologies come into widespread use.

4 Economic ethics, intergenerational equity and the discount rate

Neoclassical economists claim that their work is value-free (Robbins, 1932), scientific (Nordhaus, 2007b) or purely descriptive (Pearce et al, 1995; Nordhaus, 2007b). In doing so, it has been plausibly argued that they are drawing on 19th Century science to promote a secular, rationalist religion (Nelson, 2001, p. 133). Their faith is in the path-independence of consumer preferences and producer technologies, a faith shown to be empirically false in psychology, physics and history. Their thinking, apparently logical, is based on the fallacy that "the pursuit of self interest is guided by objective laws to a socially beneficent outcome" when instead this pursuit involves moral choices, at both personal and social levels (Foley, p. xiii).

Nordhaus (2007b, p. 140-1) characterises economics as scientific in being peer-reviewed and reproducible; he derives the discount rate from a pure description of the market rather than from a consideration of ethics and moral philosophy. He contrasts his approach with that of the Stern Review, which he finds unscientific[22]. The many critiques of the Stern

[22] There is a literature devoted to the issue of whether economics is a science or not. See (Mirowski 1989, 2002; Weintraub, 2002; Katzner, 2003). It is a science in that theory and observation are considered together when and where possible or in that mathematics is a science (Samuelson's position). However, neoclassical path-independent economics as a mathematical science is strictly a branch of mathematics rather than economics, since it violates a basic law of physics, the Second Law of Thermodynamics. Nordhaus (2007b) himself is ambiguous about whether economics is a science or not, since he repeatedly distinguishes economics from science.

Review have been dominated by the discussion of the discount rate[23] (e.g. Nordhaus, 2007a; Dasgupta, 2007a, 2007b; Tol and Yohe, 2007). The "pure rate of time preference" is one component of the discount rate used in calculating the costs of doing nothing in relation to climate change (see Quiggin below for an explanation). Stern adopts a pure rate of time preference of near zero, drawing on moral arguments, compared with the rate adopted by the traditional literature, e.g. 1.5%pa in (Nordhaus, 2007b) down from 3%pa in earlier applications of his DICE model. The difference in discount rates between Stern and the traditional literature is one of the reasons (cited by several of the critics as the main reason) for the much higher costs of 5 to 20% of global GDP "now and forever" estimated by Stern (p. 15)[24] for business-as-usual of 2 to 5˚C warming or more, compared with the cost of 6% of GDP for a 10˚C warming from Cline (1992), who also used a near-zero discount rate as quoted in the IPCC Second Assessment Report (Pearce *et al*, 1995, p. 208), but had a different approach to risk, yielding lower costs.

The detailed deconstruction of this difference in the "costs of doing nothing" is covered by the paper in this issue by Quiggin, so the discussion here can be brief. The first point is that moral philosophers have long debated the relative weighting to be given in utility theory between social groups living at different times. The Stern Review commissioned a review of the ethics of climate change from Broome (2006), who had written earlier on the issue (1992). He makes uncomfortable reading for traditional economists, partly because he insists, rightly, that economics is not ethics-free, that basing economics on the ethics of individuals assumed to be entirely self interested can go badly wrong, and that "willingness to pay" is invalid as a means of valuation (Broome, forthcoming). This is in direct contradiction to the analysis of Pearce *et al.* (1995, p. 196-7) and Nordhaus[25], when they contrast prescriptive with descriptive valuations of human life. In considering the ethics of climate change, Broome positions *justice* centre stage, arguing that those who cause climate change should cease to do so because it is unjust, and if they cannot cease, then they should compensate those who suffer.

Justice as a theory of ethics (Rawls, 1971) deserves serious attention as an alternative to utilitarianism in climate-change analysis. Consider two population groups: a well-off urban majority, burning fossil fuels, and a subsistence rural minority, dependent on the weather for food and water. Assume that the costs of mitigation are negligible as the literature suggests. Assume also that the rural minority do not share in average global growth; they can be said, in Rawls' words, to be the 'least advantaged group'. In his theory, the standard of living of the

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[23] The use of a zero discount rate specifically for climate damages in a cost-benefit analysis of climate change (Hasselmann et al, 1997) anticipated in some respects Stern's use of low discount rates and also set off a fierce debate with those supporting an aggregate discount rate for all types of damage (including loss of human life) or sectors, which they justified by the traditional neoclassical treatment (Heal, 1997; Nordhaus 1997) relying on the assumption of social groups being identical representative agents having full information and foresight. This traditional approach also denies any significance to the empirical finding of differences between sectors in the discount rates actually used (e.g. private rates being several times public discount rates). Hasselmann's reply (1999) also anticipates the emerging resolution of the post-Stern debate discussed here, specifically the conclusions in (Hoel and Sterner, 2007) from a two-sector model.

[24] It is not the only reason. Dietz *et al* (2007) provide four reasons for the higher costs in the Stern Report. Previous studies, with important exceptions, have "(i) … mostly omitted to adequately employ the probabilistic results of recent science; (ii) …tended to consider a narrow range of impacts, a product of focusing largely on 2°C–3°C warming, whereas we now know that there is a possibility of far higher temperatures; (iii) … not used the economics of risk to the extent appropriate; (iv) … not paid adequate attention to the underlying ethics." The overall effect has been to give "on average, strong downward bias on damage estimates in the previous literature". (pp. 156-157)

[25] Nordhaus (2007b) claims that his 1.5%pa pure rate of time preference is "designed to provide the most accurate projections rather than to be normative in nature." (p. 40).

most advantaged would be justified only if their privileges maximised the welfare of the least advantaged group, for example through the general effect of incentives on the economy. Let us assume there is no such Rawlsian theory of justice in place. If policy were to be formulated according to the traditional assumptions with the results described above, the outcome would be a triple injustice:

1) The rural minority have not been responsible for today's GHG concentrations causing climate change, and have not benefited from the comfort and power given by the fossil energy services, yet being dependent on the weather suffer most of the consequences.
2) The minority will suffer much more from future climate change because droughts and floods threaten their subsistence income, and they cannot buy their way out of the problems.
3) The minority's future income is discounted by an average dominated by the well-off majority's income growth, so their future utility counts for much less in the CBA of global climate-change policy. This outcome is a direct consequence of the discounting of average consumption net of climate damages (including mortality) by Nordhaus and others, supported by Dasgupta (2007a)[26].

Since global inequalities over the last century have been increasing (Maddison, 2001) and a subsistence minority of countries (and social groups within countries) may continue into the far future, the assumptions may well be more realistic than those of the traditional model. Rawlsian ethics would focus social policy on preventing the climate change and caring for the subsistence minority. Instead, traditional models have been used to justify weak policies and inaction.

Broome (2006) also considers expected-utility theory alongside justice as a guide to social policy. Importantly he distinguishes "value" from "utility" and allows for intrinsic value in human life and nature. He considers the utilitarian view of climate change, arguing that (1) lives should not be valued by the method of willingness-to-pay, which makes the value of people's lives depend on how much they can afford to spend on prolonging them and (2) future lives should not be discounted in value relative to present lives of similar quality[27]. The argument that because people in the future are expected to be better off in real money terms, so that we can then discount a monetary value of their lives (or their health) runs into serious logical and moral problems, which are not solved by recourse to the term "statistical lives". Nordhaus (2007b, p. 47) is discounting the quantity and quality of human life when he includes valuations of mortality and morbidity in the damages from catastrophe (which are stated to include health damages)[28]. Implicitly, those who discount such damages at 1.5%pa and higher are valuing the next generation's lives and health at a fraction of their own. An equal valuation would transform the policy prescriptions towards urgent action and high carbon tax rates.

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[26] Like Broome, Dasgupta is an authority on economics and ethics, but he argues that traditional economics has solved the ethical problems (2005). However, Dasgupta does not mention the ethical problems involved with the averaging done in CBA, when the assumed monetary estimates of health and lives are discounted.

[27] Broome's view on discounting is supported by the utilitarian philosopher R M Hare, who likewise argued that a discount rate above zero cannot be justified ethically (Hare, 1981, p.100-101)

[28] Dasgupta (2007a) supported Nordhaus's approach, but not his adopted pure rate of time preference. In contrast, Stern argues that human lives and environmental quality should be treated separately (p. 165), although the PAGE model (used to calculate the 5-20% range on costs) appears to include valuations of human life and health implicitly in its damage functions. Dasgupta (2007b) no longer supports Nordhaus, and concludes that "an optimum policy may not exist", and (implicitly) that CBA is "an overly formal analysis" leading to "misplaced concreteness" in its conclusions (since 1991) on climate change.

Nordhaus and others rely on the market to provide an estimate of the social discount rate. The preferences underlying the rate are assumed to be fixed and to take into account far-future climate damages. Such assumptions are not empirically valid and the procedure short-circuits the political process, in which for example democratically elected politicians aim to lead and change preferences (see below). The preferences are also assumed to take a particular form, in which no *ethical* preferences are allowed, although in fact people might prefer that natural resources be preserved as a matter of principle, even though they have no utility for them. Finally these authors are assuming fungibility of natural and man-made assets, i.e. that they all have monetary values and can be exchanged. Irreversible changes, e.g. warming of the oceans leading to loss of coral reefs for the indefinite future, means that such exchange is impossible. Hoel and Sterner (2007) have explored an extension to the traditional model allowing for human and natural services and the likelihood that as the natural services become scarcer, their prices will rise. They conclude that under reasonable assumptions the discount rate could become negative.

It is the implicit assumption on the part of traditional economists of a 'moral' superiority of the market that is at the heart of this debate. Utilitarian philosophers will have none of it. Traditional economists evade this implication of their analysis, claiming that they are being descriptive rather than prescriptive, but their logic does not stand up to scrutiny[29]. This is economics as a religion (Nelson, 2001), in which society is composed of self-interested individuals, whose behaviour is to be assumed rational, then to be interpreted and described by economics as a mathematical science, e.g. in finding and using the pure rate of time preference, or the value of human life. The underlying fallacy is that market forces lead by themselves to intrinsically good outcomes (Foley, 2006), a fallacy explored in more detail by Jaeger *et al* below. A "new economics" approach is to acknowledge that there are ethical, aesthetic and other values, and that all life should not be converted into money, with the exchangeability that money permits (Ackerman and Heinzerling, 2004; Gowdy, 2005). The use of the discount rate to account for time preference and risk should be re-thought to allow for subjective time preference and a risk analysis independent of the return (Price, 2005). Climate change economics should learn from organizational sciences applied to management of high-risk activities (Nelson, 2008). The distribution of rights consistent with sustainable development should be considered (Padilla, 2004). The anti-utilitarian moral philosopher Bernard Williams has criticised the reductionism of "utilitarian thought" and "the device of regarding all interests, ideas, aspirations and desires as on the same level, and all representable as preferences of different degrees of intensity, perhaps, but otherwise to be treated alike… The assimilation does not give our convictions enough weight in our own calculations. At the same time, it can give other people's convictions too much weight" (Williams, 1985, p86). The utilitarian approach has much to offer, but its claims should be qualified and limited by considerations other than that of utility, such as those of justice, well-being of future lives, and benevolence.

5 Engineering and history: induced technological change and the costs of GHG mitigation

The costs of GHG mitigation in traditional economics are derived from the production function, a concept basic to the determination of the allocation and growth of economic output,

[29] See Broome (forthcoming). Nelson (2008) reveals other hidden value judgments that may underlie the traditional neoclassical approach to climate change, leading to the tendency to rigidity and blindness to errors evident in the critical responses to the Stern Review.

conventionally measured as marketed output, i.e. GDP in national accounts. In the models this function takes special forms, typically Cobb-Douglas or Constant Elasticity of Substitution (CES) with tractable properties: they are continuous, typically with constant returns to scale, and reversible in that outputs can be expressed in terms of their inputs of labour, capital, materials, and vice versa, a feature that contradicts path dependence, i.e. the second law of thermodynamics[30]. This economics has been derived by analogy with physical process of the first law of thermodynamics by Walras drawing on 19thC textbooks of physics (Mirowski, 1989; Beinhocker, 2006) without an adequate treatment of time or the later second law with the underlying physical requirement that all processes involve increasing entropy. In the case of the burning of fossil fuels, this means the return into the atmosphere of the original CO_2 captured by plants and fossilised over millions of years as fuels.

More striking still, technological change has been assumed in the traditional muti-industry treatment to be independent of production change, implying no learning by doing or by researching (Barker *et al.*, 2007, 11.5). If the general equilibrium models are to include such endogenous technological change it is usually grafted on to the neoclassical production function by linking it with an engineering model, typically for the energy supply and demand sectors. The outcome is inconsistent in that endogenous technological change is allowed for energy output but not other sectors (as well as carbon prices, many other relative prices will change as an effect of climate policies) nor for other economic variables, such as exports, employment or even consumption. It is also incomplete, in that it ignores the potential interaction between the information economy, energy and new low-GHG technologies, which accelerates their adoption and diffusion throughout the world economy.

The aggregate production functions, used in the equilibrium economic models, have been subject to detailed and severe criticism over many years, both of the underlying theory (Mirowski, 1989; Felipe and Fisher, 2003; DeCanio, 2003) and of the validity of the empirical estimates (Felipe and McCombie, 2005). Theoretically, the use of an aggregate production function requires two (heroic) assumptions: 1) that it is a meaningful exercise to combine the processes of e.g. furniture-making, oil-refining, and food-retailing, and 2) that ALL markets are perfectly competitive. Empirically, the use of National Accounts data on flows in current prices to estimate production functions is usually flawed, because the dataset imposes an accounting identity on the monetary value of production and the combined values of the inputs to production (namely materials, labour and capital), when capital services are measured as residual profits. The estimates in the literature are often based on accounting identities, not causal relationships, and hence the very good fits obtained are entirely artefacts of the data[31].

The implication of the production function in the traditional models, both the one-sector models of Nordhaus and others and the multi-industry general-equilibrium models, is that because the functional form assumes that the economy is at full employment and maximal efficiency, *any* climate policy leads to costs in the form of loss of potential output. It is this feature that leads to the contrast between the energy-engineering, bottom-up models, providing

[30] The second law of thermodynamics is an expression of the universal law of increasing entropy, stating that the entropy of an isolated system which is not in equilibrium will tend to increase over time, approaching a maximum value at equilibrium. (Wikipedia, 15.01.08)

[31] See (Felipe and McCombie, 2005). The empirical basis of the functions actually included in the climate-policy models is even more compromised, being no more than a collection of guess-estimates from an inconsistent literature (DeCanio, 2003).

estimates of some 6 $GtCO_2$-eq mitigation potential by 2030 at net negative costs, i.e. “no regret options”, compared with no such unrealized potential estimated by the top-down equilibrium models (IPCC, 2007, p. 14-16). The potential for energy saving assessed by countless engineering studies is simply ignored in the equilibrium models by assuming full information, maximum efficiency and full employment, now and forever, in violation of the facts. New evolutionary economics can provide insights into the non-economic barriers to energy efficiency and how they may be overcome (Maréchal, 2007, p.5183-5184).

The traditional treatment of production also normally rules out of court any modelling outcome that increases the growth rate of the economy as an outcome of climate policy. There are many conditions under which GDP may increase, e.g. use of carbon tax revenues to reduce distortionary taxes, the effect of policy in reducing the widespread under-employment in developing countries, and the possibilities of more productive technological pathways. Although documented in the theoretical and empirical literature (Barker *et al.*, 2007, 11.4 and 11.5), these conditions are routinely and implicitly set aside by assumption in the traditional treatment.

However, complexity economists (Arthur, 1994) strongly argue for path dependency and increasing returns and economic historians have long argued that technological change and economic growth are intimately related (Maddison, 2001) and path dependent (David, 2000). The scientific requirement to decarbonise the global energy system is in effect suggesting the need for another technological revolution, implying major structural shifts in the energy industries and requiring the diffusion of low-carbon technologies, particularly across the developing world, which holds the greatest potential for adoption, radical changes and impacts. In contrast to the 18th and 19thC changes, the context is now one of the global spread of almost free information, instantaneously. The potential for global, induced technological change to reduce costs and even increase GDP is recognised in the Stern Review and AR4, as is the modelling that relaxes the assumption of constant returns to scale. In contrast to the equilibrium approach, such modelling has the great advantage that it aims to explore technological and institutional options that give rise to opportunities rather than costs, making the problem for international negotiations much more tractable (sharing out the benefits of a technological revolution, to put it crudely, but a revolution that will only happen if countries co-operate). At the same time it should be recognized that badly designed policies and regulatory frameworks, as in banking, could lead to potential inflation or financial collapse of investments and programmes.

6 Social choice

The switch in policy required to address the climate change problem is an issue of social choice. Traditional economics approaches this problem by the use of the social welfare function, which is a mathematical equation, or a set of equations, in an economic model, intended to represent the social good. However, the concept is fundamentally flawed. When national governments act, it is much more likely to be ‘in the national interest’ than in any formal manner capable of being represented as a ‘criterion function’, an ‘objective function’ or a ‘social welfare function’ as some key concepts are known in equilibrium modelling of the economy and the environment. As Arrow (1967, p. 736) remarks about Samuelson’s neoclassical treatment, ‘Whose behaviour or whose judgement is referred to in the social welfare function is never clarified.’

In theory, the concept depends on the validity of adding up the welfare of households or people such that the aggregate social welfare function is stable and predictable over time. Arrow (1950) showed that for a set of reasonable assumptions (inter alia: a heterogeneous population, universality, "independence of irrelevant alternatives") such aggregation is impossible except under extremely restrictive conditions. Traditional economics has resorted to assuming that members of the population, or social groups such as households or firms, are in fact identical "representative agents", whose welfare and behaviour can be aggregated. This assumption, required for the macroeconomic equilibrium models to be theoretically valid in relation to microeconomic behaviour, is 'both unjustified, and leads to conclusions that are usually misleading and often wrong.' (Kirman, 1992, p.117). The aggregate approach also often ignores specific issues of equity and the distribution of wealth, which are especially important for climate change economics because the costs tend to be met disproportionately by those who cannot afford insurance, re-location or adaptation investments.

In addition, the social welfare function is not politically viable. The idea that there is a stable relationship between different policy objectives such as reduction of greenhouse gases, economic development, growth in consumption, reduction in unemployment or in the rate of inflation, does not make sense when the actual political process of policy formation is considered, whatever the political complexion of the government or the prevailing consensus about sound policy promoted by international organizations such as the OECD, the IMF or the World Bank. Institutional decision-making (e.g. that by national governments) is normally characterised by the achievement of consensus between people and groups with potential conflicts of interest. If this is so, it is quite easy to envisage the simultaneous pursuit of conflicting goals, and the sudden alteration of policies as different interest groups gain precedence. There is no escaping the fact that the goals of national, economic and social policy are different for different interest groups, and that the national interest cannot be restricted to a fixed formula. In the face of these difficulties, traditional economists have resorted to another counter-factual assumption (usually implicit, but required for an optimal solution), that of a global planner, i.e. a policy dictatorship for good or bad[32].

Social choice regarding the climate policy involves social groups, "stakeholders", such as government, industry, NGOs, and political parties, in a process of consensus (Ostrom 1990). But it also involves information and the law (Heinzerling and Ackerman, 2007). A real choice requires the equal and simultaneous presentation of feasible alternatives. When a policy is the subject of political debate and possible implementation by government, policy advisors consider the benefit that such implementation would produce in each of various mutually exclusive 'states of nature' that might follow it, the good being considered for each group affected over space and time.

The actual process of developing such information for the global community has been chaotic. Different governments have produced their own analysis, sometimes as in the case of the US Administration in 2001, selectively choosing scenario results to meet obvious political

[32] The traditional cost-benefit analysis has been taken up by Lomborg in the "Copenhagen consensus" to promote the idea that global problems other than climate change (e.g. HIV) are more worthy of funding. It is inherently unlikely that the national interest can be identified with the functions for aggregate utility in the equilibrium models and then solved to obtain 'optimal' set of policies. If an attempt were made to elicit the function by asking a series of hypothetical questions of governments, rather than Lomborg's selection of economists, it would fail because the answers would most likely be inconsistent in terms of the equation. In any case, politicians would refuse to commit themselves on hypothetical questions.

requirements. The paper by Hasselmann and Barker below discusses a way forward to improve the information basis in developing international climate policy under the UNFCCC and the IPCC. These bodies have arisen out of the international political process and are in keeping with decentralised and varied political structures. This process has brought questions of equity to the fore as witnessed by the crisis in the IPCC's adoption of the Second Assessment Report in 1995, with the neoclassical economists' insistence on valuing human life on an insurance basis. The use of values of "statistical lives" came into conflict with a perception that human life at present and in the future should be valued equally irrespective of income or circumstance, for the purpose of agreeing international policy. The governments of the developing countries arguing their case for equality prevailed over the expert IPCC economists advising them. However, it is perfectly feasible that a consensus approach in international negotiation can help to establish policies and social values in difficult and controversial areas, such as abatement of climate change, where the interests of different countries and future generations are to be taken into account. For example, the IPCC's Summaries for Policy Makers are agreed by all governments explicitly at international meetings.

7 Towards a new economics of climate change

The IPCC's sceptical approach to the use of cost-benefit analysis (CBA) as the sole basis for the economics of climate change has been supported by Stern. The CBA of climate change after Stern has been developed by Weitzman (2007) to the point of destruction. Just as a central bank, faced with the risk of the collapse of the banking system, will act on perceived risks rather than a monetary CBA, so governments have eschewed CBAs in which the "optimal" solution involves risks of dangerous climate change. The intemperate and rushed reaction by a clique of neoclassical economists criticizing the economics of the Stern Review illustrates the sensitivity to the implied criticism of their conclusions.

The subsequent development of the literature in supporting Stern's conclusions illustrates how radical the shift in mainstream economic thinking has been. It is now acknowledged that the economics of climate change is now more appropriately concerned with uncertainty rather than return, a feature of the problem that has been evident from the early 1990s, when the scientific assessments began in earnest. It can also reasonably be argued that CBA is useless for the climate problem because of the uncertainty and risks of catastrophe. The discounting of costs and benefits in which risks are converted into certainty equivalents and discounted at market rates has been shown to be misleading and biased. This in turn implies that the economic problem is one of achieving political targets, based on scientific evidence, at lowest costs compatible with equity and effectiveness, rather than with the economics of choosing the targets themselves.

The new information and evidence on the increasing risks of climate change has reinforced earlier perceptions about the dangers, and raised scientific and political alarm, but the general message has been to strengthen the evidence, and bring it home to the public through debate on weather-related catastrophes. In summary, the problem is clear and the solution appears to be almost costless in macroeconomic terms, but requires the long-term transformation of the global energy system. Decarbonisation of the global energy system by 2050 seems to be feasible at reasonable carbon prices (at least 100$/t$CO_2$ by 2020 in year 2000 prices and continuing to rise thereafter), with benefits to health and negligible effects on economic growth, but it will require unprecedented global co-ordinated action.

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