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Are Optimal CO_2 Emissions Really Optimal?

Four Critical Issues for Economists in the Greenhouse

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Abstract. Although the greenhouse effect is by many considered as one of the most serious environmental problems, several economic studies of the greenhouse effect, most notably Nordhaus's DICE model, suggest that it is optimal to allow the emissions of greenhouse gases (GHG) to increase by a factor of three over the next century. Other studies have found that substantial reductions can be justified on economic grounds. This paper explores into the reasons for these differences and identifies four (partly overlapping) crucial issues that have to be dealt with when analysing the economics of the greenhouse effect: *low-probability but catastrophic events*; *cost evaluation methods*; *the choice of discount rate*; *the choice of decision criterion*. The paper shows that (i) these aspects are crucial for the policy conclusions drawn from models of the economics of climate change, and that (ii) ethical choices have to be made for each of these issues. This fact needs wider recognition since economics is very often perceived as a value neutral tool that can be used to provide policy makers with "optimal" policies.

Key words: climate change, cost-benefit analysis, decision criterion, discount rate, weight factors

JEL classification: D61, D62, D63

1. Introduction

Layard and Walters (1978) open their textbook Microeconomic Theory by stating that "economics is making the best of things." But – the authors continue – already Hume pointed out two centuries ago that one cannot deduce an "ought" from an "is." Any "ought" is intrinsically linked to value judgements in one way or another. Thus, there is a strong normative component in (welfare) economics.

In order to evaluate whether a project should be carried out, a number of assumptions have to be made, and some of these might be controversial from an ethical point of view. This is especially true in the context of long-term environmental problems. This is important to recognise, since our results are often perceived as if they were free of value judgements. Further, our economic vocabulary, e.g., the concept of optimality, conveys a Plato-inspired world view in which there *exists* – in an ontological sense – a best choice to be made, and more research will reveal what that choice is. This tends to enhance the perception about value neutrality. Consider, for instance, the economic literature on the question of how we should respond to climatic change.

There is much concern that emissions of greenhouse gases will cause severe climatic changes and subsequent threats to environmental and social sustainability. Yet, several economic studies, most notably Nordhaus's pioneering DICE model (Nordhaus 1994), have concluded that stringent measures to control emissions of CO_2 would be very costly even if the benefits of reducing the emissions (i.e., the avoided climatic changes) would be taken into account. Nordhaus, for instance, finds it optimal to allow the emission rates to increase threefold over the next century. Several other studies find similar results, e.g., Manne et al. (1995) and Peck and Teisberg (1993).

However, these results have been challenged by a growing number of studies, e.g., Cline (1992), Azar and Sterner (1996), Roughgarden and Schneider (1998), Schultz and Kastings (1997) and Hasselman et al. (1997). For instance, Cline finds that a stabilisation of global emissions at 4 Gton C/yr (30% below the present rate of fossil carbon emissions) is "justified on economic grounds alone." This rate of emissions would be sufficient to keep atmospheric concentrations close to the present level during the next century.

Thus, there are strong reasons to try and better understand the underlying reasons for these diverging results. Clearly, the divergence can partly be attributed to choices for parameter values that can be improved with more research (both within economics, ecology and climate research). However, such improvements will not suffice to bridge the different results. Rather, they stem – ultimately – from disagreements on certain key parameters and modelling choices that are value laden.

Grubb (1993) writes that "it should be recognized that global impact costing studies inherently involve contentious value judgements, concerning which differing assumptions may completely reverse the conclusions." Schneider (1997) stresses the importance of highlighting these value-laden assumptions in order to ensure that integrated assessment models of climate change (as well as other environmental problems) "enlighten more than they conceal."

In this paper, four crucial issues for cost-benefit analyses of climate change are identified: the treatment of low-probability but catastrophic impacts, valuation of non-market goods, the discount rate and the choice of decision criterion. They are discussed in Sections 2 through 5. It is shown that

- ethically controversial assumptions have to be made for each of these aspects,
- the policy conclusions obtained from optimisation models are very sensitive to these choices, and, finally,
- studies that find that minimal reductions are warranted have made choices that tend to reduce the importance of the most common arguments in favour of emission reductions.

Section 6 contains some concluding remarks.

2. Low Probability but Catastrophic Events

Although some features of climate change are virtually certain,[1] e.g., that the natural greenhouse effect will be enhanced with rising CO_2 concentrations, impacts are still very uncertain, in particular at the regional level. In cost-benefit analysis one may treat this problem in an expected utility framework. This approach requires knowledge about the probability of different outcomes. But such probabilities are not known, and one is forced to rely on subjective probability assessments.

2.1. SENSITIVITY

Several cost-damage studies have dealt with the uncertainties surrounding climate change (see e.g., Parry (1993), Peck and Teisberg (1993), Nordhaus (1994), Fankhauser (1995), Tol (1995), Azar and Johansson (1996), Manne (1996), Gjerde et al. (1997) and Roughgarden and Schneider (1998)).[2] These studies find that there are costs associated with uncertainty, but disagreement exists to what extent this extra cost is important for the overall policy conclusions. Several studies have concluded that uncertainty plays a minor role for the overall analysis, but this largely hinges upon the fact that they have focused on probability distributions in a fairly small interval around the expected damage. One study which has looked at low-probability catastrophic events is Manne (1996), who has compiled work done for the Energy Modelling Forum (EMF). Manne concludes that not much near-term abatement is needed to hedge against the risk of low-probability catastrophes.[3] Other authors, e.g., Tol (1995), Azar and Johansson (1996), Gjerde et al. (1997) and Roughgarden and Schneider (1998), find that catastrophic surprises may be very important and substantially alter the policy conclusions obtained (even if the probability for the surprise is small).

The results of studies that take into account catastrophic surprises are sensitively dependent upon the assumptions made for the probabilities and the associated damages, as well as assumptions about the inertia of the energy system, i.e., how rapidly we could restructure our energy system if climatic change turns out to be more severe than most policy makers initially expected.

2.2. VALUE JUDGEMENTS

The studies referred to above are all based on some expected cost approach. But this approach suffers from two difficult problems: How do we treat problems where the probability distribution is unknown? And, how do we calculate the costs of global catastrophic impacts and what is the maximum cost that could hit the global economy? This indeterminacy problem reduces the usefulness of cost-benefit analysis in the context of global warming (see e.g., Broome 1992; Read 1994). Since there are no reliable estimates of the probability for catastrophic surprises, the expected cost approach depends largely on the analyst's chosen probability distribution and almost any emission reduction can be defended.

The severity of risks we should expose our planet to is ultimately an ethical question that cannot be settled by expected cost approaches or other related economic methods that were developed to deal with uncertainties at a completely different scale. An alternative to cost-benefit analysis is the "maximin" strategy, namely to focus on the worst possible outcome and then maximise the welfare of that outcome. Applied to the greenhouse effect, the strategy implies strong reductions of greenhouse gas emissions in order to reduce the probability that catastrophic impacts will occur (see e.g., Krause et al. 1992). But this conclusion too, as well as any other, would largely depend on the analysts' subjective perception of what is "the worst outcome."

2.3. CONCLUSIONS

The risk of global environmental catastrophic surprises is a common argument in favour of emission reductions, but quantifying the probability for such events is impossible. Equally difficult would it be to quantify the costs associated with such surprises. Therefore such impacts are often omitted from CO_2 optimisation models. Unfortunately, this tends to be forgotten when the results from these models are presented, and particular emission scenarios are presented as optimal even if one argument favouring emissions reductions never entered the analysis.

3. Methods for Evaluating Costs

Several authors, e.g., Ayres and Walter (1991), Nordhaus (1991, 1994), Cline (1992), Titus (1992), Fankhauser (1995), Tol (1995) and Mendelsohn and Neumann (1998) have published comprehensive estimates of the economic costs of climatic changes. A review of this literature, can be found in IPCC (Pearce et al. 1996). Although progress has been made over the last couple of years, Nordhaus's (1994) conclusion that existing costing studies are "extremely tentative" and "in their infancy" still holds true. First, all studies (except Mendelsohn) have focused on the costs related to a CO_2-equivalent doubling. Damage for other levels are included in the analyses using some (arbitrarily) chosen non-linear function in temperature change. Second, all studies, except those of Tol (1995, 1996), assume damage functions that are independent of the rate of climatic changes, although this aspect is expected to be as important as the level of temperature change. Third, estimates for developing countries are even more uncertain than developing country studies. For instance, Nordhaus and Cline obtain global costs by extrapolating US damage estimates.

In general, market impacts are rather straightforeward to estimate. For non-market impacts, alternative techniques have to be applied,[4] and these are controversial. This is important since much concern in the climate change debate is related to non-market impacts (in several cost-assessments, such impacts actually dominate the analysis, see Pearce et al. 1996). For instance, these methods fail to recognise, or do not accept, the rights of other species than humans (in that they are only concerned with the value given by humans to these species). The sufferings of an animal exposed to poisonous chemicals are not taken into account unless a human is willing to pay for it to end. Further, Jacobs (1991) argues that these methods also fail to capture the value humans give to such sufferings (and environmental impacts in general) since they fail to "allow people to judge value collectively, as citizens, rather than simply individually, as consumers." Another interesting aspect of the cost problem that needs further attention is how assumptions about altruism may change the interpretation of CVM studies (see Johansson 1998).

In this short essay, I focus on just one cost issue: valuation of damages in developing countries. Only a few authors, e.g., Ayres and Walter (1991), Fankhauser (1995), Tol (1995), have attempted to explicitly value such costs (including both market and non-market impacts). Fankhauser and Tol based their calculations on willingness-to-pay estimates of various impacts, for instance, increased mortality risks. Since developing countries are poorer, the willingness-to-pay for increased safety is lower in a poor country than in a rich one. Thus, the value of a statistical life, assigned to a death in a rich country was (assumed to be) approximately 15 times higher than for a death in a poor country in the study by Fankhauser (with similar values reported by Tol). These estimates caused much debate and controversy world-wide, in particular when it became clear that they would form the basis for the cost-damage chapter in IPCC's Second Assessment Report (Pearce et al. 1996).

The critique stemmed from an unease with the use of lower value of a life in developing countries (as such) and/or from the fact that this way of valuing costs does not take into account that the utility of a dollar in a poor country is higher than in a rich. The latter issue can be used as a basis for the introduction of weight factors for costs that affect the poor countries (which in some cases would "recover" equal valuation across countries (Azar 1998).

3.1. SENSITIVITY

The introduction of weight factors may substantially affect the cost-estimate. The study by Ayres and Walter (1991), e.g., which is a critical assessment of an early draft of Nordhaus's cost-estimates, takes the higher marginal utility of income in developing countries into account when estimating the global costs related to sea-level rise. They estimate global costs for sea level rise to lie in the range 2.1–2.4% of world GDP, a cost which is nine times higher than the costs quantified by Nordhaus (1991). (Nordhaus's quantified cost-estimate 0.25% of GDP is raised to 1.3% to take into account unquantified items.) Similarly, Azar and Sterner (1996) estimate global marginal costs of CO_2 emissions, under the assumption that costs in poor countries should be weighted so as to reflect the welfare losses actually felt in developing countries. Taking this aspect into account raises costs by a factor of three (for a logarithmic utility function and a utilitarian welfare function). For higher degrees of inequality aversion, even higher costs estimates would be obtained.

It may also be noted that the introduction of weight factors implies that the required reduction level in developing countries is lowered. Further, although weight factors may substantially alter the required global emission reductions at present, the use of weight factors will play a minor role for the "optimised" emissions once developing countries grow richer in income and emissions (Azar 1998).

3.2. VALUE JUDGEMENTS

The introduction of weight factors may critically affect the cost estimates and thus the "optimal" response to climatic change. However, the choice of weight factors ultimately requires a social welfare function which is, of course, a highly value laden choice. But, that does not mean that the use of weight factors is more value laden than leaving them out, since that would also be an ethical choice.

3.3. CONCLUSIONS

The facts that poor people in poor countries are expected to suffer the most severe consequences from climate change and that they emit nine times less fossil CO_2 than industrialised countries on a per capita basis, are often invoked as arguments for reducing the emissions in the rich world. But in most economic analyses, the very fact that people are poor becomes – by the logic of the willingness-to-pay approach – the reason for giving their expected sufferings lower weight in the cost analyses.

4. The Choice of Discount Rate

In all investment analysis, the discount rate plays an important role for the profitability assessment. In particular, there has been much controversy over the choice of discount rate in public projects, e.g., in the construction of hydropower dams in the US in the sixties. Research into the appropriate choice of discount rate, when considering tax wedges and risk, has thus become almost a discipline itself (see e.g., Lind 1982).

4.1. SENSITIVITY

The cost of reducing CO_2 emissions are immediate, whereas the expected benefits of these reductions will accrue decades and/or even centuries ahead. Because of this time asymmetry and the long time scales involved, the choice of discount rate is probably the single most important parameter in cost-benefit analysis of climate change. Largely, this parameter explains why authors such as Nordhaus (1994) and Manne et al. (1995) refer to emission increases by a factor of three or so over the next century as optimal whereas Cline (1992), Azar and Sterner (1996), Hasselman et al. (1997) and Schultz and Kastings (1997) find that substantial reductions can be justified.

4.2. VALUE JUDGEMENTS

So, what value should be assumed for the discount rate? There are essentially two different roads that can be taken (Arrow et al. 1996):

- The first is generally referred to as *descriptive*. It focuses on the observed market interest rate in order to ensure that investments are made in the most profitable projects.
- The second is often referred to as *prescriptive*. It emphasises that normative questions are involved when making trade-offs between consumption today and in the future. Proponents of this method often base the discount rate on the social rate of time preference (SRTP). The SRTP is equal to $\gamma g + \rho$ (the Ramsey formula) where γ is the negative of the elasticity of marginal utility, g is the relative per capita growth rate and ρ is the utility discount rate (the pure rate of time preference).

Also the descriptive approach could employ the Ramsey formula (as, e.g., Nordhaus does) but in that case the utility discount rate, ρ, is chosen so as to equalise SRTP with the observed market interest rate. Proponents of the prescriptive approach often make the case that ρ should be very low or even zero, for intergenerational equity reasons (see e.g., Sidgwick 1907; Ramsey 1928; Harrod 1948; Rawls 1972; Spash and d'Arge 1989; Broome 1992; Cline 1992; Solow 1992; Price 1993; Eriksson 1994; Khanna and Chapman 1996; Azar and Sterner 1996; Rabl 1996; Schultz and Kastings 1997). It is hard to justify, from an ethical point of view, that the present generation should give lower value to impacts that affect future generations just because they live in the future. (Note that positive discount rates may still be justified, if income is assumed to grow over time.)

Both approaches encounter problems. Starting with the descriptive approach, which purports to pick the discount rate so that it coincides with the intertemporal trade-offs people actually make, it must be recognised that this is not as easy as it may first appear. Lind (1995) has pointed out that "we observe some people borrowing on credit cards at 15–25% and simultaneously investing at after tax rates of return in the range 1–3%. Which, if either, of these rates reflects these individual's rates of time preference?"

Secondly, it may be noted that even a constant discount rate as low as 1%/yr would not be "compatible" with the concern people express for radioactive waste. At this rate, even a radioactive leakage that would permanently destroy human civilisation (as an extreme example) would only have a present value of $7 \cdot 10^{-26}$ USD (sic!) if it were to happen 10,000 years into the future.[5] Thus, one may conclude that the descriptive approach fails to reflect the concern that many people express about long-term impacts.

A third difficulty in estimating the discount rate from observable market variables stems from the existence of externalities, such as environmental problems. If they are large, the social rate of return on capital is distorted but not reflected in market based interest rates.

A fourth difficulty is that the term "descriptive" largely loses its meaning for time horizons longer than a couple of decades. Descriptive of what, one may ask? For longer time horizons, the discount rate set by the descriptive approach becomes guesswork at best.

This latter difficulty may actually save the descriptive approach from some of the difficulties mentioned above. The descriptive approach could imply that the discount rate is set equal to 5% today but falling over time so that it slowly approaches zero. If so, the far future would still be valued at non-negligible levels. Studies with falling discount rates include Sterner (1994), Ayres and Axtell (1996) and Azar and Sterner (1996). Also Nordhaus (1994) assumes the growth rate, and consequently the discount rate, to decline over time, but since the utility discount rate is set constant at 3%/year, the value of the future still declines exponentially in his model.

One may also keep in mind that the descriptive approach only guarantees *potential* intertemporal efficiency. Assume, for instance, that the discount rate is 10%/yr. Then, it would not be intertemporally efficient to reduce an emission that would save us from a damage of 1050 USD the next year if the abatement cost is 1000 USD. The reason, of course, is that another investment could yield 1100 USD. However, intertemporal efficiency is only potential in that there are no guarantees that the alternative investment will actually be made. For climate change and other intergenerational environmental problems, we need to make sure that the initial investment is reinvested with compound interest for several decades and even centuries. One may doubt that this is likely to happen. Thus, the main argument in favour of the descriptive approach becomes weaker if very long time horizons are involved.

But, lowering the discount rate for long-term environmental problems may also be criticised. First, given a fixed budget for investments, the descriptive approach is a way of adjudicating between different projects and picking the most profitable ones. Wallace (1993) writes that "... an especially low discount rate would actually reduce the wealth passed on to future generations by financing projects whose rates of returns are lower than those for other available investments". Second, Nordhaus (1994) and Manne (1995) have pointed out that a lowered discount rate implies (in optimal growth models) a jump in the savings ratio that is not consistent with actual savings patterns. Note, however, that these two critiques cannot hold at the same time. The second objection, for instance, implies that the investment budget is not fixed, and therefore all investments with higher rates of return (than the environmental project) will also be carried out.

In my view, the discount rate should roughly be given by the descriptive approach when analysing *intra*generational trade-offs, whereas the discount rate should be set equal to the SRTP with a zero utility discount rate, when analysing intergenerational projects. In reality, intra- and intergenerational issues are not easily separated, and this points to an area of possible important research. This could be done within the framework of overlapping generation models (Howarth 1997; Manne 1997).

However, although more research is needed to resolve some of these problems, the fundamental observation that the choice of discount rate is ultimately a value judgement will not change. Thus, there is no such a thing as an "objectively correct discount rate." This is important since the choice of discount rate largely determines the "optimal" emission path.

4.3. CONCLUSIONS

Intergenerational concern is one key argument used in favour of emission reductions in the policy debate on greenhouse gas emissions. However, when using the descriptive approach, as has been most common in the economic literature, this concern for future generations is not reflected in the analysis.

5. The Choice of Decision Criterion

Cost-benefit analysis is based on the so-called Kaldor criterion, i.e., if total benefits exceed total costs, then the project should be carried out. In the preceding sections, I have argued that the concept of costs (and benefits) are not as well-defined as one is sometimes inclined to think. However, even if we disregard those objections, the Kaldor criterion is still controversial.

The Kaldor criterion is a necessary, but not sufficient, criterion for a Pareto improvement. If a project passes the Kaldor criterion, it offers a *potential* Pareto improvement, i.e., it is possible that at least one individual can be made better off without making any other individual worse off. But compensation cannot be guaranteed. And if losers are not compensated, then the ethical basis for using the Kaldor criterion is questionable. For instance, a Kaldor improvement may lead to a reduction in social welfare if the "improvement" also involves sufficiently large wealth transfers from the poor to the rich.

5.1. SENSITIVITY

One way of dealing with this would be to introduce weight factors (as discussed in Section 3). But a more appropriate valuation of the costs of climate change will not resolve the ethical dilemmas involved in the policy debate. The reason why climate change is considered by many as one of the most serious environmental problems is probably *not* that we expect our grandchildren to lose a couple of percent of their income (which anyhow may be expected to be several times higher than ours). Instead, there are certain features of global climate change that cause concern – for example the risk of increased frequency of droughts in some poor regions of the world, sea level rises inundating small islands, spread of tropical diseases and specific environmental impacts such as loss of biodiversity. Some people would consider these consequences as unacceptable. The risk of global catastrophic surprises just adds to this concern. Lind (1995) states that "the typical way in which the cost-benefit problem is posed obscures the basic choices we should be evaluating."

Global warming may be a problem where the use of constraints in the analysis is justified, i.e., where optimisation of costs and benefits may take place, but only subject to certain constraints on the absolute level and the rate of temperature change. Work along these lines include Rijsberman and Swart (1990), Azar and Rodhe (1997) and others. This way of reasoning also underlies the UN Framework Convention on Climate Change, which calls for a stabilisation of greenhouse gases at a concentration that would prevent dangerous anthropogenic interference with the climate system. If a low atmospheric stabilisation target is suggested, then the optimal emission level would be completely different from the results obtained by some (but not all) cost-benefit analyses. In this sense the "optimal" emission level is very sensitive to the choice of decision criterion.

5.2. VALUE JUDGEMENTS

In the context of environmental problems, the use of sustainability constraints has been suggested by e.g., Markandya and Pearce (1989) and Jacobs (1991). Jacobs writes that "the interests of future generations are safeguarded directly, by defining them in environmental terms and making their protection the first stage of the decision-making procedure."

The call for constraints not set on strictly economic grounds may be considered controversial. But it should be remembered that in many other cases, the usefulness of economic theory is admittedly limited (see Spash 1994; Bingham et al. 1995). Bingham et al. (1995), for instance, argue that there are many cases where "collective choices must be made before valuation can be made. For example, determining the efficient use of child labor in the United States was made moot by the collective decision that child labor – irrespective of potential economic benefits – is morally unacceptable."

Still, the use of such constraints is rare in most economic analyses. Sen (1987) explains: "Under the utilitarian tradition, which dominates neoclassical economic thinking, no intrinsic importance is attached to the fulfilment or existence of rights." A common line of argument is that constraints should not be used in economic analyses since they ultimately depend upon value judgements. The position is correct in the sense that the imposition of constraints must be based on value judgements, yet the conclusion is wrong since the exclusion of constraints does not make the analysis more value neutral. Excluding constraints is in itself a value choice!

5.3. CONCLUSIONS

Concern for human health and environmental impacts forms the basis for most people's concern about climatic change. In cost-benefit analysis, these costs are traded with, for instance, the extra costs car drivers would confront, if large carbon reductions were to take place. But should we really trade basic human needs with more luxury consumption? Cost-benefit analysis answers yes to this question, but this is a strong assumption. Thus, by a value-laden assumption, and not by inevitable economic logic, a central argument for reducing the emissions of greenhouse gases is erased. Spash (1994) concludes that "if rights that protect individuals from the results of our greenhouse gas emissions are accepted to exist, the scope for trade-offs usually assumed in economics is drastically reduced."

6. Some Concluding Remarks

This paper has reviewed four (partly overlapping) critical issues that one is confronted with when analysing the economics of the greenhouse effect. The way these four issues, the risk of global environmental catastrophes, cost-evaluation methods, the discount rate and the decision criterion, are dealt with largely determines the results obtained from various cost-benefit analyses of global warming. Further, it is shown that value judgements have to be made when dealing with each of these four aspects. This deserves more wide-spread recognition since economics is often perceived as a tool that can be used to provide policy makers with value-neutral advice. It also needs attention since several standard economic assumptions, that are fairly reasonable under normal circumstances, tend to discriminate against the most common argument in favour of emission reduction.

But this does not mean that cost-benefit optimisation models cannot and should not play any role in climate change policies. The problem only arises if we use optimisation models as "truth machines" (Schneider 1997). Rather, these models should be used to explore the implications of various choices for highly value-laden parameters.

In conclusion, it should be possible to reach agreement on the following two basic propositions:

- Cost-benefit analysis is *not* a value-free tool that provide policy makers with value neutral proposals on different policy alternatives.
- This, in turn, means that we have to be explicit on the value judgements involved in the assumptions that we make, and analyse the consequences of different assumptions. Value judgements must be highlighted and not obscured in seemingly value neutral mathematical and economic language.

Finally, these conclusions carry important implications for future research on the economics of climate change. Rather than trying to find the "optimal level of climate change", we should try to improve our understanding of a number of issues related to the realisation of the UNFCCC's main objective. For instance, we need to know more about the response of our societies and economies to carbon abatement policies, technological change and how it may be geared towards more energy efficient technologies and the improvement and development of renewables, the inertia of the energy system and the associated infrastructure, the degree of "no-regrets" options and the policies that are needed to tap them, and the incentives that can get developing countries on board, etc. An interesting discussion about the research needs for some of these issues is provided by Toman (1998) in this volume.

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Notes

1. This is important to keep in mind, since those who support a wait-and-see stance sometimes stress the uncertainties about climate change so much that they (deliberately?) create the impression that the greenhouse effect itself is in question. The interested reader is referred to Mahlman (1997) for a concise overview and classification of virtually certain "facts", virtually certain projections, probable projections as well as incorrect projections in the context of the climate change.
2. Uncertainty also plays important roles in other parts of the economics of climate change. For instance, in the debate about cost-efficient emission reductions towards atmospheric CO_2 stabilisation, Wigley et al. (1996) have argued that very little near-term abatement is justified. But this conclusions has been challenged by Ha-Duong et al. (1997) largely based on the assumption that there is a certain probability that a low stabilisation target (400 ppm) also needs to be considered.
3. The study assumes that uncertainty is resolved by the year 2020. If the low-probability catastrophe turns out to be real, then substantial reductions are justified beyond 2020.
4. These techniques can either be based on revealed preferences (e.g., hedonic pricing methods or the travel cost method) or hypothetical markets (e.g., the contingent valuation method).
5. Here I have assumed that global GDP is 1000 times (to generously allow for economic growth) its present level and that the human civilisation is valued at that level indefinitely.

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