Economic Estimates Of Climate Change Impacts

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1. Introduction

While many unknowns remain, a better picture is gradually starting to emerge about the impacts of climate change. There is wide agreement now that the impacts will be diverse, with winners as well as losers. Some effects may be positive, others may at least be easy to adapt to. For the majority of people, however, the consequences of climate change will probably be negative. For some regions, they could be disastrous.

Working Group II of the Intergovernmental Panel on Climate Change has extensively reviewed the potential impacts of climate change (IPCC, 1990b, 1996a). The best studied regions remain the developed countries, in particular the United States. Studies usually deal with only a subset of damages, and are often restricted to a description of impacts in physical terms. By far the best studied areas are agricultural impacts (e.g. Reilly et al, 1994; Rosenzweig and Parry, 1994; Adams et al, 1995) and the costs of sea level rise (e.g. Yohe et al, 1996; Fankhauser, 1995b). Attempts at a comprehensive monetary quantification of all impacts are relatively rare, and usually restricted to the United States (Nordhaus, 1991; Cline, 1992a; Titus, 1992). Among the most comprehensive studies with respect to regional coverage and the number of included impacts are Fankhauser (1995a) and Tol (1995).

This paper reviews the available economic assessments of climate change impacts drawing on the work of IPCC Working Group III (see IPCC, 1996b). It is structured as follows. Section 2 starts with a brief summary of expected impacts in qualitative terms. The next two sections then summarize the main quantitative findings of IPCC Working Group III. Section 3 is concerned with the results of equilibrium analysis, while Section 4 deals with dynamic aspects. Section 5 discusses the main shortcomings of the current models and analyses how economic assessments might change in the light of recent findings. Section 6 concludes with an outline of how climate change may affect the prospect for sustainable development.

2. Climate Change Impacts

Global warming will have a variety of effects on both human and natural systems. IPCC (1996a) foresees a shift in the current agricultural production pattern away from current production areas to more northern latitudes. Together with changes in soil water availability, the increased occurrence of climatic extremes and crop diseases this may lead to an overall reduction in agricultural yields, and could result in serious regional or year-to-year food shortages. The forestry sector may have to adjust to altered growing conditions and a change of species mix. Fisheries will face a similar challenge. The IPCC also predicts that the increased stress on unmanaged ecosystems may lead to the extinction of species unable or too slow to adapt.

The rise in sea levels connected with a warmer climate will threaten low lying coastal areas. Sea level rise will particularly affect densely populated coastlines and small island states. Health experts expect a rise in climate related diseases such as heat strokes and an increased incidence of vector borne diseases like malaria. Adverse effects like these may trigger a stream of climate refugees away from the worst affected regions and coasts.

Others have warned about the consequences of increased water shortages. Climate dependent economic activities like construction, transport and tourism will be affected, with improved conditions for some activities, and deterioration for others. The need to adapt could affect energy consumption, with higher demand for air cooling in summer, and lower heating needs in winter.

A large unknown is the effect of climate change on extreme weather events such as droughts, floods and storms. Many experts predict an increased incidence of such events, that would entail greater vulnerability for areas such as coastal zones. An increase in extreme events would also have repercussions on the insurance industry.

The following sections assess the impact of these changes on human welfare in quantitative terms.

3. Damage Assessment I: Equilibrium Analysis

The scientific research on global warming impacts has focused predominantly on an (arbitrarily chosen) scenario called $2xCO_2$-the impacts of an atmospheric CO_2 concentration of twice the preindustrial level. Most of the figures reported below are based on the $2xCO_2$ scenario.

Climate change impacts can be classified as either market related (effects which will be reflected in the national accounts) or non-market related (impacts affecting "intangibles" such as ecosystems or human amenity). Table 1 categorizes the expected impacts from global warming. It also assesses how carefully they have been estimated in the literature so far.

Climate change impacts can be expressed either quantitatively, or in a common unit of measurement such as money. Monetary estimates of both market and non-market damages are ideally expressed in the form of willingness to pay (WTP), or willingness to accept compensation (WTA), as described in Box 1. Unfortunately, WTP/WTA estimates are not always available for the assessment of global warming impacts, and approximations were often used. In addition, several damages that could not so far be estimated have been ignored altogether in the aggregated damage estimates (IPCC, 1996b).

Available estimates on the costs of climate change are therefore neither accurate nor complete, and a considerable range of error can be expected. Figures on developing countries in particular are clearly less reliable than those for developed regions.

Based on an extensive survey of the literature, IPCC Working Group III expects the following aggregate damages for $2xCO_2$:

World impact:	1.5 percent to 2.0 percent of world GNP
Developed country impact:	1 percent to 1.5 percent of national GNP
Developing country impact:	2 percent to 9 percent of national GNP

A wide range of sectoral and ecosystem impacts contribute to these total damages. Table 2 shows the relative importance of different damage categories, using figures for the United States. Impacts on coastal zones, human health, water supply and agricultural production are likely to be among the most serious effects. Note that estimates include both adaptation costs and residual damages. Examples of the former include the costs of coastal protection, the costs of migration, and the change in energy demand due to alterations in space heating and cooling requirements. Examples of residual damages include agricultural impacts, and the loss of dry - and wetlands. The underlying adaptation assumptions, however, are not explicitly stated for most impact categories.

A caveat is necessary. The above figures are best guess estimates they do not reflect the uncertainties they neglect the possibility of impact surprises, and of low probability/high impact events (see Section 5). To avoid long- term predictions, figures have been derived by imposing $2xCO_2$ onto a society with today's structure.

Considerable regional differences are likely, with potentially higher impacts for some countries such as small island states. Table 3 shows some of the estimates underlying the above conclusions in more detail highlighting the substantial differences between regions. The Table shows that some developing countries could face extremely high damages. Although the South will face less warming than northern latitudes developing countries tend to be more vulnerable to climate change, Their economies are more dependent on climate-sensitive sectors, in particular agriculture. They have less technical, institutional and financial capacity for adapting to changing conditions. In addition, they tend to be more exposed to extreme whether events such as tropical cyclones. The combination of these effects could result in particularly severe damages.

4. Damage Assessment II: Dynamic Analysis

The analysis so far was confined to comparative statics. All figures in Tables 2 and 3 are estimates of the impact of one specific change of the climate ($2xCO_2$) on the current economy. This is clearly insufficient. Not only will we, for the larger part of the future, be confronted with climate change substantially different from $2xCO_2$, but socio-economic vulnerability to climate change will also shift as a consequence of economic development.

What would be relevant to know from a policy point of view are marginal figures, ie, estimates of the extra damage done by one extra tonne of carbon emitted. Unfortunately, the requirements for marginal damage calculations go far beyond the information available from 2xCO_2 studies. Greenhouse gases are stock pollutants. That is, a tonne of gas emitted will affect climate over several decades, as fractions of the gas remain long in the atmosphere. Calculating marginal costs therefore requires the comparison of two present value terms: The discounted sum of future damages associated with a certain emission scenario is compared to the sum of damages in an alternative scenario with marginally different emissions in the base period. (In estimates based on optimal control models the marginal costs are calculated as the shadow price of carbon, ie, the carbon tax necessary to keep emissions on the socially optimal trajectory, see, e.g. Nordhaus, 1994; and Peck and Teisberg, 1993.)

The current generation of models deals with this challenge in a rather ad hoc manner, using very simplistic representations of the complex dynamic processes involved. In older studies damage costs were typically specified as a polynomial (usually linear to cubic) function of global mean temperature, calibrated around the 2xCO_2 estimates. Damage is usually fully reversible and assumed to grow with GNP. Only recently, studies have started to emerge which explicitly incorporate regionally diversified temperatures and sea levels, model individual damage categories (e.g. agriculture) separately, or at least distinguish between damages related to absolute temperature level and those related to the rate of change (e.g. Hope et al, 1993; Dowlatabadi and Granger, 1993; Tol, 1996). Table 4 provides estimates of marginal damages obtained from polynomial damage models. Figures range from about \$5 to \$125 per tonne of carbon, with most estimates at the lower end of this range. The wide range reflects variations in model assumptions, as well as the high sensitivity of figures to the choice of the discount rate.

The pioneering paper on the social costs of CO_2 emissions is Nordhaus (1991). Using a simplified version of a dynamic optimization model, he calculates social costs of 7.3 \$/tC. The model had a number of shortcomings, however, in particular the assumption of a resource steady state and of a linear damage function (see Cline, 1992a). These objections are also relevant to the study by Ayres and Walter (1991), whose calculations are based on the Nordhaus model. The paper has additional shortcomings. Particularly questionable is the use of uniform commodity values, e.g. for land, in all world regions.

The shortcomings of the earlier model were recognized and corrected in Nordhaus' subsequent approach, the DICE (Dynamic Integrated Climate Economy) model (Nordhaus, 1994). The shadow values of carbon derived from DICE are in the same order as the previous results, starting at 5.3 \$/tC in 1995 and gradually rising to about 10 \$/tC in 2025. Note that figures for future periods are current value estimates, i.e. they denote the social costs valued at the time of emission. Values of a similar order of magnitude were found by Peck and Teisberg (1993), using a similar model. Tol's (1994) alternative specification of DICE yields shadow prices of \$13 for 1995, rising to \$89 for 2095. These model runs all assume that parameter values are known with certainty. In the case of DICE, shadow prices more than double, once uncertainty is added to the model. All three authors assume a pure rate of time preference (or utility discount rate) of 3%. (For discussions on discounting see IPCC, 1996b; and Nordhaus, 1994.) In contrast, Cline (1992b) finds significantly higher shadow prices by using a zero utility discount rate. His reproduction of the DICE model generates a path of shadow prices beginning at about $45 per ton, reaching $243 by 2100. Other parameter specifications provide even higher values.

Fankhauser (1994) identifies a lower and flatter trajectory for the shadow price of carbon, rising from $20 per tonne by 1991-2000 to $28 per tonne by 2021-2030. He uses a probabilistic approach to the range of discount rates, in which low and high discount rates are given different weights. His sensitivity analysis with the discount rate suggest that moving from high (3%) to low (O%) discounting could increase marginal costs by about a factor 9, from $5.5 to $49 per tonne of carbon emitted now.

5. Shortcomings And Extensions

Comprehensive damage assessments have been fiercely criticized by many authors (e.g. Grubb, 1993; Ekins, 1994). While not all criticism is based on sound analysis, the damage estimates of Tables 2 to 4 do have a number of shortcomings. The most important points of contention are as follows.

Valuation

Probably the main objection concerns valuation, in particular the validity of economic valuation techniques, and their applicability to such damage aspects as increased mortality. Grubb (1993) for example criticized 2xCO_2 damage estimates as being based on a "largely subjective valuation of non-market impacts" (p.153). However, while many of the existing figures are indeed based on approximations (see Table 1), it would be wrong to take this as an indication of the ineptitude of economic valuation techniques in general.

Economic valuation of non-market goods is controversial (see Box 1). Nevertheless, the problem of greenhouse damage estimates is currently perhaps not so much the accuracy of valuation methods as such, but the fact that they have not yet been applied to the problem to a sufficient degree. This is not to say that a full and complete valuation of all greenhouse impacts will ever be possible. Given the size of the problem and the uncertainties involved, it will probably not be, at least not within reasonable time. However, existing estimates are clearly far from perfect and the policy debate would gain from their improvement. Further, and more detailed valuation studies are thus warranted. What is particularly needed is a broadening of the scope from the emphasis on agriculture and sea level rise to the inclusion of other damage aspects such as ecosystems loss, climate amenity, health and morbidity. Better estimates are also needed with respect to the damage costs to developing countries, where only little is known e.g. about the willingness to pay for non-market goods like wetlands, or the value of a lower mortality risk.

Aggregation

The calculation of global estimates such as those in Table 3 requires the aggregation of regional figures. Usually, regional estimates are simply added up. This process has sometimes been criticized for not giving enough prominence to damages in developing countries. It is one of the consequences of the WTP/WTA approach that regionally diversified unit values are used to assess impacts in different regions. People's willingness to pay is a function of their income, among other factors. The value of an acre of wetland, for instance, or of a lower mortality risk therefore varies between regions that have different income levels.

As a consequence, impacts in regions with low incomes may not be given enough importance, especially if the observed income distribution is not just (as is currently the case). Damage aggregates that simply sum up regional impacts reflect this unfair distribution. One may therefore prefer an aggregation procedure which corrects for equity considerations.

An alternative that has sometimes been suggested is to use uniform, usually average, unit values across countries. This would also assure that impacts in different regions are given equal weight. While the use of global averages would not be problematic for the calculation of global damages, it would not significantly change the global damage assessment. Damage calculations were made in such a way that using average values would produce aggregate estimates that are very similar to those reported in Table 3. Using global averages to assess damages in only one region, on the other hand, could cause significant problems and may lead to logical inconsistencies. The value of a coastal wetland, for example, would differ depending on whether it is threatened by local development or by sea level rise. A regional value would be applicable in the first case, while the global average value would be used in the second. Although providing exactly the same service in both cases, the asset would have two completely different values. To avoid such inconsistencies, the assessment of regional damages needs to be based on regional averages.

Catastrophic Events

The estimates of Tables 2 to 3 concentrate on the most probable damage scenario, i.e. they merely provide a best guess assessment of what damages are most likely to be. Given the complexity of the climatic system and the unprecedented stress imposed on it, this focus maybe too narrow, though. Other, more disastrous scenarios cannot be excluded with certainty. Rather than with only one point, we are confronted with an entire damage probability distribution. Unfortunately, only little is known about the shape of this distribution, and in particular about the probability of an extremely adverse outcome. Several catastrophe scenarios have been portrayed in the literature so far (IPCC, 1996b):

- The melting of the polar ice caps. A possible disintegration of the west- antarctic ice sheet would rise sea levels by up to 6 meters. This process is however slow and would take place over a time span of 300-500 years.
- A shut-down of the ocean conveyer belt may lead to changes in ocean circulation patterns. A redirection of the gulf stream would somewhat ironically cause significant cooling in Western Europe, with temperatures comparable to those currently observed in Canada (abstracting from the amount of warming which will already have occurred at that date).
- The runaway greenhouse effect: Initial warming levels may be amplified through massive feedback effects, e.g. through the liberation of methane from previously frozen sediments into the atmosphere.

- Abrupt, non-linear changes in climate patterns. There is paleo-climatic evidence from ice-cores pointing at the prospect of a highly unstable climate with temperature changes of several degrees Celsius within only a few years.

  In addition to such worst case impacts, there may also be surprises, events which are impossible to predict before hand and for which no probability of occurrence therefore exists.

Evidently, by their very nature nothing can be said about the direction or magnitude of such events. However, in neither considering the entire damage distribution, nor the possibility of surprises, existing estimates are clearly incomplete. This has to be remembered in the decision about the optimal greenhouse policy response.

New Findings

The scientific understanding of climate change and climate change impacts is increasing rapidly. Socio-economic analysis, which uses these scientific findings as input, will inevitably lag behind. Most of the studies surveyed in the previous Section work with the climate and impact scenarios of the 1990 and 1992 IPCC reports (IPCC, 1990a, b; 1992). New findings and methodological advancements that have taken place since then only now start to trickle down into socio-economic analysis. Important recent developments include an increased emphasis on adaptation to climate change and on climate variability and extreme events. The importance of non-climate change related stress factors and of integrated climate change assessment is also increasingly stressed (see Fankhauser and Tol, 1996). As a consequence of these and other scientific developments, Fankhauser and Tol (1996) identify three broad tendencies in damage assessment:

1. Increasing Regional and Sectoral Differences: Recent findings stress the regional diversity of impacts. The notion that a warmer world will know winners as well as losers now features far more prominently than in the first generation of assessments. Agricultural studies like Rosenzweig and Parry (1994) or Reilly et al (1994), for example, identify many developed and other northern latitude countries as possible winners, provided farmers take adequate adaptation measures. Food insecurity in the South, on the other hand, is likely to further aggravate. Differences are also increasingly emphasized between different regions within a country, and between different agents, sectors and commodities.
2. Lower Market Impacts in DeveLoped Countries: Re-assessments of market-related impacts in developed countries have in many cases lead to a reduction in expected impacts compared to earlier estimates. Yohe et al (1996), for example, observe a continuous decrease in estimated damage costs from sea level rise. Calculations for the US by Rosenthal et al (1994) suggest that earlier estimates of energy sector costs may have been too high, and that climate change may in fact be beneficial for many US regions. More recent agricultural estimates also tend to be lower than earlier assessments (eg, Adams et al, 1995). Adjustments in estimates have occurred for a variety of reasons. One of the most important factors is the better incorporation of adaptation into impact models. Whether this trend to decreasing market impacts can be extended from industrialized countries to other regions is therefore not clear. As

mentioned above, developing countries often lack the financial, institutional and technical capacity to efficiently adapt to a warmer world in the same way as industrialized countries will.

3. Increasing Importance of Non-Market Impacts: While estimates of market impacts are often corrected downwards, new results on non-market impacts suggest that these effects may initially have been underestimated. Improvements in this area have not so much occurred with respect to the accuracy of figures it remains low than with respect to their comprehensiveness. Some non-market impacts that were neglected in earlier analysis for lack of data can now be quantified. This is most notably the case for health impacts, where numerical estimates are now available for the expected spread of malaria in a warmer world (see Matsuoka et al, 1994; Martens et al 1994). Recent work about a link between climate change and the spread of diseases such as cholera and dengue fever also suggests that the health impacts of climate change may have been underestimated so far (see e.g. Stone, 1995).

6. Policy Implications And Conclusions

Frameworks for Decision Making

What are the policy implications of the above global warming damage results? There is hardly an aspect of greenhouse economics which is more fiercely disputed than the question of the optimal policy response. Several approaches to the problem can be distinguished on a methodological level, and not all of them require a knowledge of greenhouse impacts in monetary terms.

The most prominent approach, at least among economists, is probably the cost-benefit approach. In the cost-benefit approach the optimal policy is determined through a trade off between the costs of policy action and the benefits from greenhouse damage avoided. This need not necessarily imply a strict cost-benefit analysis in the traditional sense, with costs and benefits expressed in monetary units, though. The cost-benefit philosophy is more broadly centered around the general notion of weighing up "goods" against "bads".

Alternatively emission targets could emerge from ethical, political or precautionary considerations, more or less independently of the resulting costs and benefits. This is for example the stance taken by Howarth and Monahan (1992), who propose a rule for greenhouse action based on the sustainability principle. Today's generation has a moral obligation to defend the safety and well being of future generations, "if doing so would not noticeably diminish ...[today's] quality of life" (p. 6-85). Even if climate impacts were not catastrophic overall, obligations could still occur towards a minority of severely affected people, e.g. the inhabitants of small island states. Carbon targets based on the precautionary principLe have for example been proposed by Krause et al (1989) and Swart and Vellinga (1994).

It is not the purpose of this paper to decide on the respective merits of each of these approaches. Our interest rests with the economic assessment of greenhouse impacts, and consistent with this scope, the following analysis will concentrate on those approaches which require some knowledge about the economic costs of global warming.

Cost-Benefit Results

The first application of the cost-benefit method to global warming is the influential paper by Nordhaus (1991). On the basis of a marginal CO_2 damage of 7.3 $/tC in the best guess case (see Table 4), the paper concludes that only a limited amount of greenhouse abatement would be warranted. An alternative to the controversial Nordhaus model has been provided by Cline (1992a). Owing to the inclusion of features like no regrets options and risk aversion, and by using a different discount rate Cline found favorable benefit-cost ratios for an aggressive abatement plan of freezing CO_2 emissions at 4 GtC per annum, about two thirds of their 1990 level.

More sophisticated optimal control models that were developed since provide a similarly differentiated picture, see for example the results from the models MERGE (e.g. Manne and Richels 1995) CETA (Peck and Teisberg, 1992, 1993) and DICE (Nordhaus, 1994). While most models tend to be similar to Nordhaus' earlier results - DICE for example calculates an optimal CO_2 reduction of only about 15% off baseline projections by 2100 - the results are extremely sensitive to the underlying assumptions.

This has been noted by Cline (1992b) who replicated the DICE model and observed that the Nordhaus result of only modest abatement "does not stem inherently from the optimization model and approach used, but hinges on the particular assumptions applied" (p.31), the most important one being the choice of the discount rate. In some of Cline's alternative calculations CO_2 emissions are virtually phased out by the end of the 21st century. Other critical features include the availability of a carbon free backstop technology and the treatment of non-market damages. By interpreting non-market damages as a direct element in the utility function, rather than a production cost, Tol (1994b) found significantly higher abatement levels than Nordhaus.

A similar, although less extreme picture also arises from the sensitivity analyses done by Peck and Teisberg (1992, 1993). Over the first forty or fifty years the various optimal emission trajectories calculated in the model barely differ from each other and all closely follow the baseline. The subsequent trajectory, however, strongly depends on the chosen damage parameters, particularly on the slope of the damage function. Significant emission reductions only occur for a steep damage- temperature relationship (Peck and Teisberg, 1993).

Hedging Against Catastrophes

It is one of the main weaknesses of many greenhouse cost- benefit models that they tackle the problem as if all parameters were known with certainty. Clearly, this is not the case, and an optimal greenhouse policy has to take uncertainty into account. Many advocates of immediate action interpret greenhouse gas abatement as an insurance, and argue that for the same reasons as individuals are willing to secure themselves against hazards of all sorts, society should be willing to spend some money to protect itself against adverse climatic effects, particularly since these may be irreversible and potentially disastrous. This view is implicit in much of the literature on the precautionary principle. An explicit analysis of the insurance argument is Manne and Richels (1992, 1995).

Much of the persuasiveness of the insurance argument hinges on the fear of a possible climate catastrophe. The question of how to handle such high impact/low probability events is however far from settled. Two archetypal methods of decision theory have been applied so far. The first is the expected utility approach, as used by e.g. Peck and Teisberg (1994). The second is a maximin approach, as proposed by e.g. Krause et al (1989). To minimize the risk of a climate catastrophe the approach requires that an emission target be set at the maximum level of emissions under which a climate catastrophe can reasonably be excluded.

In the Peck and Teisberg (1994) model the atmosphere is interpreted as an exhaustible resource of unknown stock. Exhausting the resource (passing a climate threshold) would trigger a climate catastrophe. People take precautions against this event by reducing emissions, and the optimal rate of emissions is determined in a trade off between abatement costs and the risk of catastrophe. The amount of abatement undertaken crucially depends on the degree of people's risk aversion, as well as on their perception of the likelihood of a catastrophe. Surprisingly, the Peck and Teisberg results hardly differ from those achieved with a conventional damage function (e.g. Peck and Teisberg, 1992). In the main scenario CO_2 emissions continue to rise throughout the next century and reach almost 40 GtC/year by the Year 2100, about six times 1990 levels. In a more pessimistic scenario emissions still rise to about 20 GtC/year in 2100, and are only gradually reduced below 1990 levels thereafter.

With a maximin approach the picture is completely different. Under a maximin strategy society is only concerned with the worst possible outcome (i.e. an early catastrophe) and implements the policy which would maximize the payoff under this scenario. As a consequence the resulting abatement targets are rather high. In the analysis of Krause et al. (1989) it leads to the imposition of a maximum warming target of 0.1 øC/decade, and 1.5 C in total. Working backwards they found that this would translate into a reduction in emissions of 20% below 1985 levels by 2015 and 75% by 2050.

Policy Implications

The variability of methodologies and the high sensitivity of results makes it difficult to derive policy conclusions. Existing optimal control models on the one hand have a tendency to favor relatively moderate abatement levels. A risk minimization strategy on the other hand would require significant emission cuts within the next two decades or so. Outside the cost-benefit paradigm a case for more stringent abatement could also be made for reasons of intergenerational equity, or on the grounds that the fate of the worst affected nations, e.g. small island states, should merit particular attention.

Fortunately, the problem is less severe once it is recognized that decisions can be taken sequentially (Manne and Richels, 1991). While model predictions heavily differ over the medium and long term, there is far less divergence with respect to the immediate future the time period with which current abatement decisions are concerned. Cline (1993, p.18) even observes "a surprising convergence of the various analyses" for the first decade, with a 10-15% emission cut emerging as a possible consensus policy for the next ten years or so.

For subsequent periods, there are signs that the inclusion of secondary environmental and economic benefits (e.g. lower air pollution damage because of carbon abatement, see IPCC, 1995b) into cost-benefit analyses could tilt the balance in favor of a more stringent abatement policy in the medium run. This would be consistent with the precautionary and equity views held by many authors, and would hopefully leave enough time to learn more about the emission policy required in the long term. Insuring the world against global warming may not be too expensive, after all.

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