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March 1994

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MPRA Paper No. 38666, posted 08 May 2012 12:45 UTC

Discussion Paper in Ecological Economics

94/6

Series Editor Dr. Clive L. Spash

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MARCH 1994

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COST-BENEFIT ANALYSIS

AND

THE GREENHOUSE EFFECT

by

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INTRODUCTION

The threat of global climatic change due to human related emissions of greenhouse gases raises difficult policy questions for governments around the world. One approach to deciding how serious the problem is and what action to take envolves weighing-up the costs of control against the benefits of preventing damages. In this paper we explore the issues which confront the application of cost-benefit analysis to such a complex global issue. We start by outlining the scientific understanding of the main greenhouse gases. Next we discuss the impacts expected from increases concentrations of those gases in the atmosphere; emphasising the asymmetry of damages over time. Having established this background we introduce the cost-benefit approach to global climate change and analse some of the work which has recently been published in this area. One aspect of this work which has been neglected is the implications for future generations and this is given grater attention in the following section. Finally we draw our conclusions concerning the potential for employing the cost-benefit approach.

SCIENTIFIC BACKGROUND

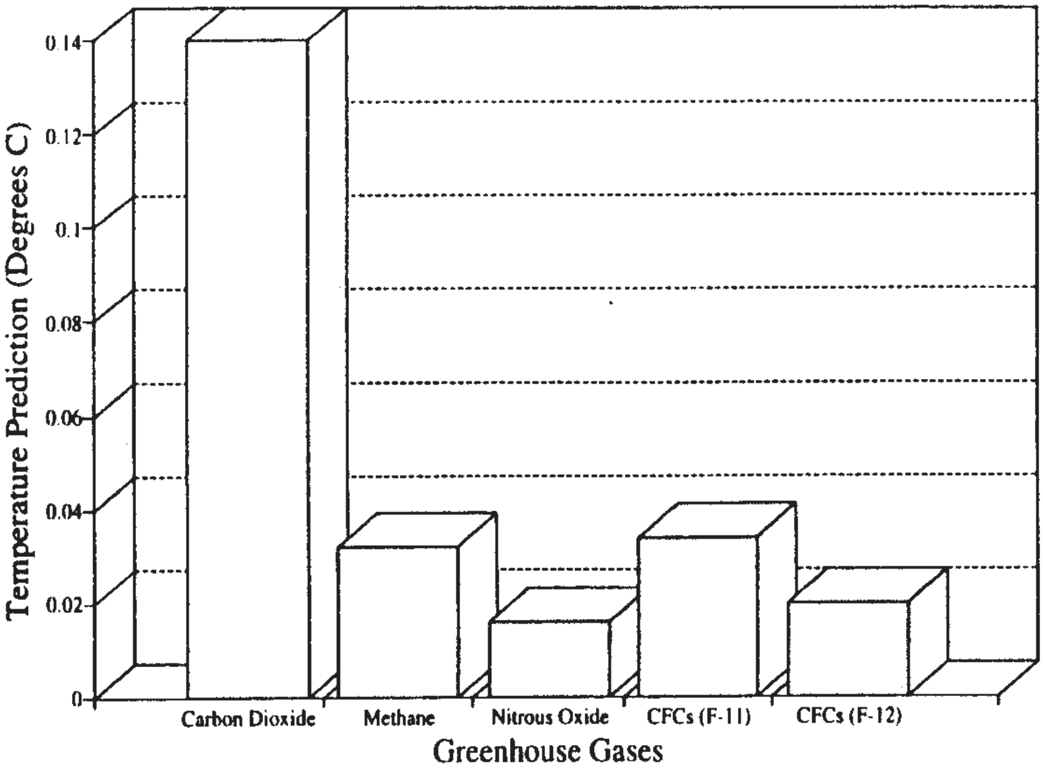
The greenhouse effect refers to the phenomenon whereby carbon dioxide and other gases trap long-wave infra-red radiation (heat) in the atmosphere, thereby warming the earth. The infra-red radiation emitted by the earth can be trapped by atmospheric carbon dioxide (CO_2), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), methane (CH_4), ozone (O_3), and other gases. The concentration of these greenhouse gases (GHGs) in the atmosphere reduces the re-radiation of heat into space. The operation of this natural, radiative balance mechanism has become a problem because of the rate at which anthropogenic emissions of infra-red trapping gases have increased, creating a stock in the atmosphere.

The greenhouse effect is one of the better understood features of the atmosphere. Since the work of John Tyndall, circa 1861, water vapour and carbon dioxide have been recognized as radiative absorbers affecting climate (Idso, 1982). Anthropogenic emissions of CO_2 from fossil fuel combustion were hypothesized as climate altering in 1896 (Jamieson, 1988). At that time a doubling of CO_2 was expected to cause a 4°C to 6°C increase in temperature (remarkably close to current predictions, see below). Surface warming due to the GHGs does maintain a livable climate; their entire removal from the atmosphere (if possible) would reduce the earth's surface temperature by 33°C (Frior, 1989).

Carbon dioxide has formed the central concern in the discussion of atmospheric pollution and climatic change since at least 1957 (Revelle and Suess, 1957). While CO_2 remains the most important single gas expected to cause increases in global temperature, more recently several other gases have been recognized as substantial sources of climate forcing (Marland and Rotty, 1985). Cumulative climatic effects of other GHGs are likely to be of comparable magnitude to that of CO_2 (Dowd, 1985). Figure 1 shows how, during the 1970s, CFCs,

Figure 13.1

Global Warming for GHGs Added in 1970s



Source: after Marland and Rotty (1986) Figure 3.

CH_4 and N_2O had a warming effect that wasequivalent to 70% of that of CO_2 alone. Thus, in order to understand the potential for anthropogenic impacts on global climate, background information is required on a host of gas species.

Carbon Dioxide

CO_2 is a product of complete combustion which industry regards as "good" in comparison to toxic carbon monoxide from incomplete combustion (Henderson-Sellers, 1984). Fossil fuel sources of CO_2 in order of importance are coal, oil and natural gas. Natural sources are vegetative decay and atmospheric oxidation of methane; natural sinks are biomass via photosynthesis and solution in water bodies (e.g., the oceans). Atmospheric CO_2 has increased steadily with industrialization from 280-300 parts per million (ppm) by circa 1880 to current levels of 355ppm (IPCC, 1992). The principal cause of the increase in atmospheric CO_2 in recent years has been the combustion of fossil fuels (Detwiler and Hall, 1988). Atmospheric residence time is in the order of 500 years (Wuebbles and Edmonds, 1988, p.9).

A large amount of CO_2 emissions are unaccounted for by atmospheric concentrations, implying another major sink (Rotty and Reister, 1986). Theories that the "missing" CO_2 is absorbed by biota have been largely discounted. Biota are in fact a net source, due to deforestation and the burning of fuel-wood, a major energy source in less developed countries (Adams et al., 1977). The oceans are too small a sink for the required amounts of CO_2 (Kerr, 1977). Thus, the global CO_2 budget remains unbalanced (IPCC, 1992).

At current growth rates CO_2 concentrations by the year 2000 will be 373 ppm and the accompanying surface temperature will rise between 0.5°C and 0.8°C, depending on ocean heat capacity (Hansen et al., 1986). Rapid expansion of the world economy could triple or quadruple CO_2 concentrations by the end of the next century. To keep future emissions low enough to avoid large atmospheric CO_2 concentrations may also require reductions in the growth rates of population, production of goods, and per capita income (Rotty and Reister, 1986).

Nitrous Oxide

Anthropogenic production of N_2O occurs primarily in the combustion of fossil fuels, especially coal, and in the use of nitrogen fertilizers. Between 1950 and 1980, global annual production of nitrogen in fertilizer increased by seventeen times, and is implicated in the 0.2-0.4%/year increases of N_2O in the atmosphere (Marland and Rotty, 1985). Anthropogenic emissions are estimated to be approaching 50% of natural releases. Natural sources include soils, oceans, estuaries and lakes, burning of vegetation, lightning and volcanoes. The main sink for N_2O is photodissociation in the stratosphere by oxygen giving nitrogen oxide and nitrogen dioxide. The atmospheric life-time of N_2O is estimated at about 150 years.

Chlorofluorocarbons (CFCs)

CFCs are used as aerosol propellants, refrigerants, solvents, foam-blowing agents, plastics and resins. Important sinks are the oceans, desert sands and chemical scavenging in the stratosphere. The lifetimes of Group I CFCs, F-11 and F-12, in the atmosphere are 75 years and 110 years respectively (Wuebbles and Edmonds, 1988; National Research Council, 1984). On a molecular basis, CFCs are about 100,000 times more effective than CO_2 as contributors to the greenhouse effect, and may be equally important as a cause of climate forcing by the year 2000 (Cumberland, 1982). If the rates of increase were 10%/year, i.e., pre-1973 growth rates (twice current Group I growth rates), the temperature increase attributed to CFCs would be 0.3°C for 1990, and 0.7°C by 2000 (Forziati, 1982).

Under the Montreal Protocol (signed 1987, effective 1989, London amendment 1990, Copenhagen amendment 1992), certain signatories undertook to reduce emissions of CFCs, but the agreement is complex and allows developing countries and the former Soviet Union to increase emissions. Without the Protocol, Group I CFCs would have doubled over their 1986 levels by 2009; given adherence to the original Protocol (that is, a 50% reduction in CFCs in developed countries) and no increase in developing countries' exports of CFC-related products, emissions could range from a 20% increase to a 45% decrease from 1986 levels (Office of Technology Assessment, 1989). The inadequacies of the original agreement were recognized at the London conference in July 1990 where a complete phase-out by the end of this century of CFCs and halons was agreed. This agreement also established a fund to aid developing countries in reaching the targets set. At Copenhagen the phaseout of CFCs was advanced to January 1996 and halon phaseout to January 1994 and carbon tetrachloride to January 1996 (DOE, 1992).

Methane

The atmospheric concentration of CH_4 has doubled over the last century. The lifetime of atmospheric methane has been increasing (due to the depletion of OH radicals that remove CH_4 from the atmosphere) and is currently estimated at 9-13 years (IPCC, 1992). Anthropogenic sources include production and transportation of coal, oil and gas, enteric fermentation, rice paddy fields, biomass burning, landfills and sewage treatment. Concentrations of CH_4 started increasing rapidly 100 to 200 years ago after being constant for perhaps 20,000 years or more. The trend in CH_4 appears to coincide with the changing trends of population and may be caused largely by industrial and agricultural activities associated with the production of food and energy. The growth of atmospheric CH_4 is estimated at 1.0-1.9%/year (Khalil and Rasmussen, 1987).

Table 1 summarizes the preceding discussion. Ozone is excluded as currently its greenhouse role is relatively small, but its importance in atmospheric chemistry and as a potential source of future warming should be remembered. The relative sizes of sources and sinks, trace gas abundance in the atmosphere and emission trends are all changing over time, as is the mixture of gases contributing to climate forcing. Additional uncertainty surrounds the role of sources and sinks. For example, while forests are referred to as a sink for CO_2, deforestation throughout the globe currently makes forests a net source of CO_2.

Table 1 Summary of the Principal Greenhouse Gases

	Principal Greenhouse Gases			
	CO_2	CH_4	CFCs (F11 & F12)	N_2O
Main Anthropogenic Sources	Fossil fuel	Rice paddies, cattle, fossil fuel	Propellants, foams, fridges	Fossil fuel, fertilizer
Main Sinks	Oceans and Forest	Chemical scavenging	Stratospheric photodissociation	
Atmospheric Lifetimes (years)	500	9 to 13	75 and 110	150
Climate Forcing (% of total change in temperature)	50	11	19	6
Atmospheric Increase (% per year)	0.4	1.0-1.9	4.0	0.3

Source: adapted from Spash (1990), Table 2.5.

PHYSICAL IMPACTS

Mean global temperature has in the past been much warmer than at present: 1°C during the Holocene climatic optimum (5000 to 6000 years ago), 2°C higher during the last interglacial warming (125,000 years ago), and 3°C to 4°C higher during the Pliocene (3 to 4 million years ago) (MacDonald, 1988). However, over the last 10,000 years, from the Holocene to the Little Ice Age, the mean temperature of the northern hemisphere has varied by no more than about 2°C (Gates, 1983). The earth's mean surface temperature has increased between 0.5°C and 0.7°C since 1860 (Abrahamson, 1989, p.10), coinciding with the increased combustion of fossil fuels due to industrialization. Hansen et al. (1986) predict the warming of most mid-latitude northern hemisphere land areas at between 0.5°C to 1.0°C by 1990-2000, and 1°C to 2°C by 2010-2020. The evidence from more than 100 independent studies gives estimates of average global warming within the 1.5°C to 4.5°C range for a double CO_2-equivalent scenario (Jamieson, 1988).[1] Such a doubling is expected sometime in the next century. Thus, global warming due to the release of GHGs represents a potentially drastic temperature increase over a relatively short period of time.

Yet, there appears to be a period during which aggregate benefits from greenhouse gas emissions dominate costs. Most obviously, society benefits from the relatively cheap use of fossil fuels, but there are other benefits as well. An average global warming of 0.5°C is expected to produce net benefits in terms of heating, agriculture and water use (d'Arge, 1975). Research suggests that Great Lakes fish may benefit, with Walleye yields in Lake Michigan increasing 29-33%, although trout may simultaneously decrease by 2-6% (Mlot, 1989). Idso (1983) maintains that increased levels of atmospheric CO_2 will increase future well-being via crop fertilization. This is achieved if escalated CO_2 concentrations enhance crop productivity (by increasing rates of photosynthesis), and reduce water use (by decreasing rates of transpiration). The projected yield increases range from 16% for corn to 60% for cotton under a CO_2 doubling (Seneft, 1990). In the past an argument has been put forward in favour of deliberately increasing mean global temperature to reap the benefits of delayed glaciation and increased agricultural range (Calendar, 1938, p.236). More recently, a similar line of reasoning can be found in Crosson (1989) where the costs of stopping warming are to be weighed against the potential loss from doing so too soon.

Such benefits are often ignored and would of themselves imply serious economic impacts, for example, on world trade. However, as temperature increases, benefits are likely to diminish. The positive CO_2-fertilization effect will only prove beneficial while CO_2 remains a dominant gas in climate forcing. As other gases become relatively more important, this benefit will diminish, at the same time as negative impacts of global warming on crop yields increase. Crop yields will also be affected by water shortages caused by global warming. Agriculture and, particularly, forestry will be more susceptible to serious decline if climate change occurs rapidly. For example, in North America each 1°C rise in temperature translates into a range shift of about 100 to 150 kilometres (Roberts, 1989). The rate of northward dispersal of trees due to historical warming (shown by fossil records) is 10 to 45 kilometres a century, with Spruce the fastest at 200 kilometres. Abrahamson (1989) estimates, given current gas emissions, that global warming is proceeding at between 0.15°C and 0.5°C per decade. Thus, almost all forest species in North America will expand into colder northern climates at slower rates than their current range becomes uninhabitable. A similar problem may exist for agriculture, but no thorough analysis of adaptive capacity has yet been conducted for the agricultural sector (Parry, 1990). Wildlife will also be forced to migrate as ecosystem characteristics change. Costs will also escalate as the ability to adapt is restricted by the absolute size and increasing *rate* of sea-level rise. Studies suggest the rate of change of sea level will be relatively small in the first quarter of the next century compared to the last quarter, a situation which is true for a variety of underlying emissions scenarios (Titus, 1989). The absolute rise is estimated at between two-thirds of a metre to over three and a half metres by 2100 (Thomas, 1986; Titus 1989). Cost estimates for protecting against a one meter rise include $4.4 billion for the Netherlands (Goemans, 1986), and up to $100 billion for the east coast of the United States (Jaeger, 1989). Broadus, (1986) provide an indication of the damages to unprotected nations from a one meter rise. These include the loss of around one-tenth of the land area in both Bangladesh and Egypt, resulting in the dislocation of over 16 million people. Meanwhile, other expectations are that low-lying islands, such as the Maldives, would disappear completely.

The intertemporal asymmetry of impacts is apparent as initial benefits to most regions, from slight global warming, turn into very large economic costs as warming continues. Population migration will undoubtedly occur as land is lost to rising seas and storm surges, and agricultural productivity is reduced in semi-arid regions. The more extreme and rapid the temperature increases, the greater are the costs and the fewer the benefits. Thus, not only will the damages of preceding generations' greenhouse gas releases be placed upon those in the distant future, but the cost of continuing to release those gases will escalate (d'Arge and Spash, 1991).

The majority of evidence concerning global warming limits itself to a double CO_2-equivalent scenario and ignores what happens beyond that point. There is, as Crosson (1989) has noted, no reason to believe that global warming will stop there. The lifetimes of key GHGs in the atmosphere run into centuries, as shown earlier. Emissions of GHGs prior to 1985 have already committed the earth to a warming of 0.9°C to 2.4°C, of which about 0.5°C has been experienced. The warming yet to be experienced is unrealized warming of 0.3°C to 1.9°C, and is unavoidable (Ciborowski, 1989). Emissions of the principal GHGs are increasing at rates between 0.3 and 5 % per year. Within 50 years we are likely to create an irreversible increase of 1.5°C to 5°C and, in the 40 years following that, a further 1.5°C to 5°C increase (Ciborowski, 1989). As Cline (1991) reports, a sixfold increase in CO_2 has been estimated by 2250 and an eightfold increase by 2275 associated with central estimates of 7.5°C and 10°C respectively. Beyond this point the role of ocean uptake is hoped to be our saviour, with CO_2 levelling out at 3.5 times pre-industrial levels in 750 years time (given that the system is not chaotic). The implication is of continually rising temperatures and associated damages for at least the next 250 years followed by 500 years of stabilization.

CBA OF GREENHOUSE GAS CONTROL[2]

Faced with the threat of global warming, society has three options: do nothing, prepare to adapt, or reduce emissions of GHGs. The first implies that the greenhouse effect is either unimportant or beneficial. The second and third options take the problem seriously enough to warrant action, and could be carried out simultaneously. Adaptation would include measures such as strengthening sea defences, changing cropping patterns, organizing population migration and increasing irrigation. A policy solely relying on adaptation implies that it will be within the bounds of human ability to adapt to all future consequences and to offset undesirable physical effects. Irreversible damages, uncertainty and ignorance of future consequences argue in favour of controlling GHGs. However, to the extent that global warming is already irreversibly underway, society has no choice but to adapt. The third option is the one most commonly studied by economists and is the subject of this section.

GHG emissions could be reduced by cutting CO_2, CH_4, CFC and N_2O emissions and/or by increasing sinks for GHGs (e.g., increasing CO_2 absorption by reforestation). A stream of costs and a stream of benefits are associated with such actions. Optimal levels of GHG reductions could, in principle, be deduced from an examination of how costs and benefits of control vary with the level of reduction. Control costs will be higher the greater are the reductions in emissions and the quicker a given reduction is attempted. The marginal benefits of reducing GHGs will fall with the level of control, since fewer damages are avoided per unit of GHG reduced. The optimal level of control will occur when the marginal benefits of GHG reductions, in present value terms, are just equal to marginal control costs.[3] This is shown in Figure 2, where marginal control costs are shown as rising with the level of emission reduction, and marginal benefits are shown as falling. The emission reduction E^*

is the optimal target. If the assumptions concerning control costs and benefits are correct, this analysis implies that the optimal reduction in GHGs will be less than 100%, since the output associated with GHG production is valued more highly the scarcer it becomes. However, E^* in Figure 2 is an impractical policy goal because no authority can accurately estimate marginal benefits or marginal costs. CBAs of controlling GHGs can therefore only be one input to indicate the degree of control required.

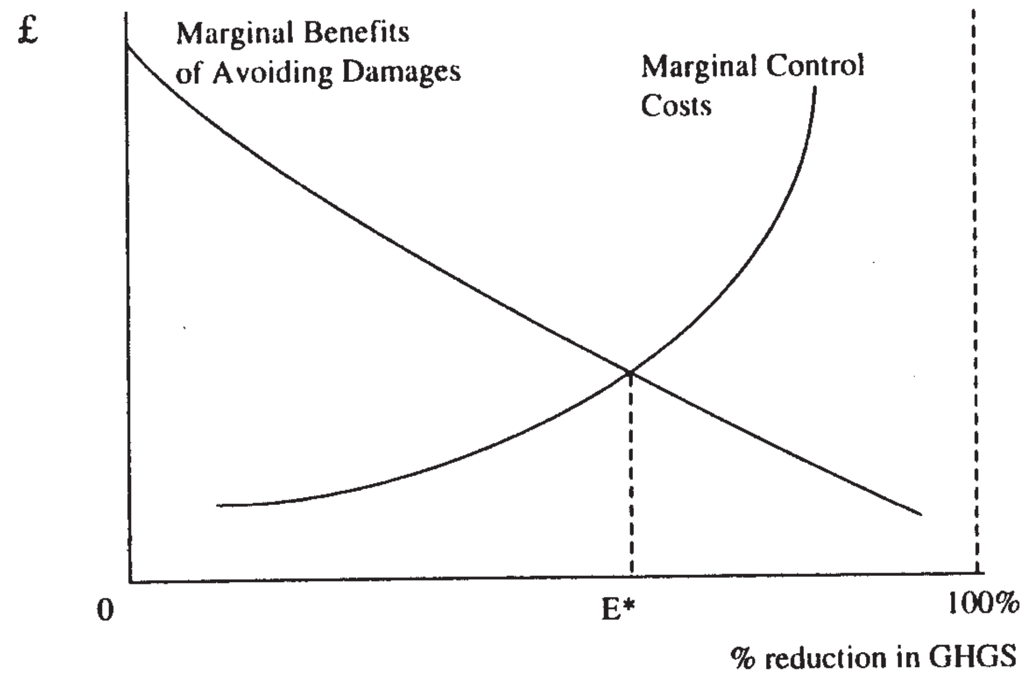


Figure 13.2: Costs and benefits of reducing GHG's

The earliest example of a CBA of GHG control is d'Arge (1975), but the area remained very quiet throughout the 1980s (a notable exception is Cumberland et al., 1982). Since the early 1990s numerous studies have appeared and the literature on this subject is growing rapidly. Approaches range from the country specific (Ingham and Ulph, 1991) to world models (Manne and Richels, 1991), and from partial equilibrium (IEA, 1989) to general equilibrium studies (Bergman, 1991). The almost exclusive focus of these studies is the control cost of CO_2 reductions. Surveys of this work may be found in Hoeller et al. (1991) and Ayres and Walter (1991). The studies chosen here serve to illustrate the issues which such work must address.

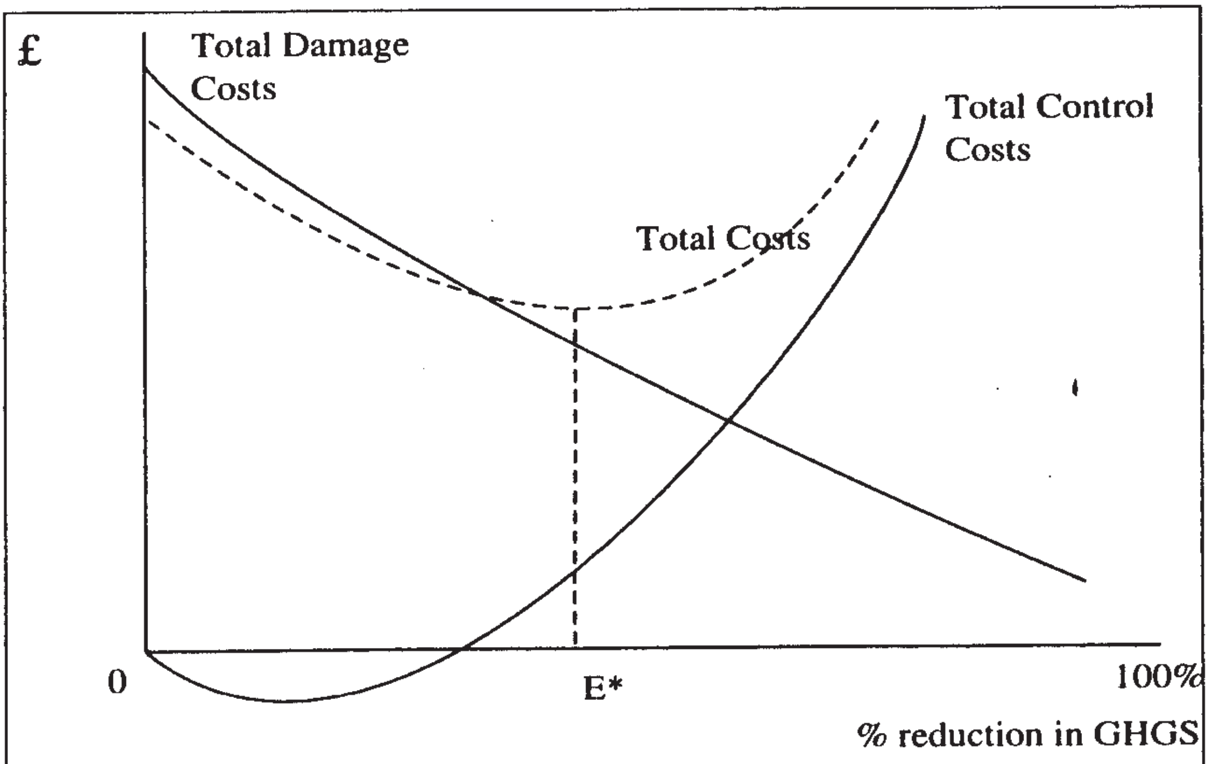
Studies by Nordhaus

Perhaps the best-known CBA work on reducing GHGs is that of Nordhaus (1982, 1991a, 1991b). In his most recent studies, Nordhaus divides the USA into three sectors by susceptibility to climate change: (i) very susceptible, such as agriculture; (ii) medium susceptibility, such as construction; and (iii) unsusceptible, such as finance. These sectors accounted for 3%, 10% and 87% respectively of US Gross National Income (GNI) in 1981. The economic benefits of emissions reductions in the high and medium sensitivity sectors is slight (only 0.25% of GNI, or $6.23 billion for double CO_2-equivalent) because these account for a low proportion of total GNI. Marginal damage costs under three scenarios are $1.83/ton CO_2 for low damages (i.e., 0.25% of GNI), $7.33/ton CO_2 for medium damages (i.e., 1% of GNI) and $66/ton CO_2 for high damages (i.e., 2% of GNI). Nordhaus excludes undesirable effects of global warming on non-marketed resources (such as wildlife), viewing such impacts as too difficult to value. However, he states, "my hunch is that the overall impact upon human activity is unlikely to be bigger than 2% of total world output" (Nordhaus 1991b, p.933). In calculating control costs, he assumes GHG reductions will be achieved by methods offering the lowest control cost. He argues that control costs will depend on how fast reductions in GHGs are required, and that marginal control costs will increase steeply beyond a 10% reduction. Thus, Nordhaus calculates the optimal control policy for the greenhouse effect as being to cut CFCs by 9% and CO_2 by 2% under the medium damages scenario (assuming a 1% discount rate).

Such minimalist recommendations have been criticized as misleading, for example, by Daily et al. (1991) and Ayres and Walter (1991). The latter make three main points. First, up to a certain point, the costs of reducing GHGs are negative. In other words, society would be better off reducing its use of substances generating GHGs. This principally means cutting energy demand, since energy production and consumption comprise the single largest source. There are two reasons for this conclusion: (i) due to market distortions energy is currently overused, and (ii) profitable opportunities for energy conservation exist but are currently ignored. Ayres and Walter provide case-study evidence for Italy and the US; whilst Fitzroy (1992) cites similar evidence produced by Flavin and Lenssen (1990). Thus, some GHG emissions can be cut at no net cost. As shown in Figure 3, this implies, ceteris paribus, a higher optimal level of emission reduction than the case where control costs are always positive.

The second criticism that Ayres and Walter make is that cutting GHG emissions has environmentally beneficial side-effects, which add to the benefits of cutting GHGs. If a carbon tax were imposed, European coal consumption would be cut, since coal would face a higher tax rate than either oil or natural gas due to its relatively high carbon content by weight. Reduced coal use would reduce SO_2 emissions and so mean lower acid deposition. If the strategy to reduce GHG concentrations involved afforestation, this would generate a stream of non-market amenity benefits, depending on the type of forestry planted. In fact, the UK Forestry Commission has started to include carbon absorption benefits in its investment appraisals of new tree planting (Whiteman, 1991). Similarly, CFC reductions will help reduce stratospheric ozone depletion.

Finally, Ayres and Walter criticize Nordhaus' estimates of the benefits of cutting GHGs as



Ayres and Walter 1991

Figure 13.3: Total costs and benefits of reducing GHG's : an alternative possibilty

excessively conservative. They revise his estimates of the area of land lost upwards by a factor of ten, and increase the value of land lost in LDCs, such as Bangladesh. They also add an amount to cover the cost of resettling refugees forced to move as a result of sea-level rise. Nordhaus extended his estimates for the US economy to the world level, and Ayres and Walter target their criticism at these world figures. As d'Arge and Spash (1991) have pointed out, developing countries are more susceptible to global warming with extensive dependence upon climate sensitive production, a limited ability to adapt, and a sizeable population of subsistence farmers. Fitzroy (1992) has also argued that the benefits of reducing global warming are underestimated in Nordhaus, since climate change combined with soil erosion in food-producing regions would reduce world food supplies at a time when the world population will have doubled. Declining levels in major world aquifers would aggravate this situation. Even without attempting to include non-market effects, the Ayres and Walter's revisions result in costs of global warming ten times greater than the medium damage scenario estimates given by Nordhaus (that is, 2.5% of gross world income).[4]

Carbon Tax Studies

Most studies of reducing global warming have centred around the cost efficiency of achieving a given reduction in CO_2 emissions, thus avoiding benefit estimation altogether. For example, a common target has been the Toronto agreement's level of a 20% cut in CO_2 emissions by 2005. Two key parameters in all such studies are (i) the assumptions about underlying economic growth rates, and (ii) the method by which emissions reductions are to be achieved. If controls act to reduce the growth of GDP, a base-case no-intervention growth rate is needed as a comparator. This indicates that countries with high growth rates (e.g., fast developing countries like Malaysia and China) may have the most to lose in terms of common measures of GDP. Background assumptions will be included concerning energy supply and demand, and the development and cost of low-carbon backstop technologies. The method for achieving the target is crucial to the cost, with the general expectation in the pollution control literature that a market mechanism (e.g., tax or tradeable permit) will be the lowest cost option.

One of the best known world studies is Manne and Richels' (1991) dynamic optimization model, which divides the world into five regions with nine energy sectors. This model, which predicts CO_2 emissions from fossil fuel sources through to the year 2100, has been used to examine the cost of various policy options. The target assumed is a 20% reduction of CO_2 emissions by 2020, with that level maintained until 2100. This is compared to a "do nothing" scenario where GDP grows at around 2% per annum (pa), and energy efficiency grows at between 0.5% and 2% pa depending on region (thus total energy demand per unit of GDP is falling). CO_2 emissions in the absence of action rise at 0.7-2.1% pa. The principal policy simulation is of a tax levied on the carbon (C) content of fuels. This hits a peak of $400/tonne C, then falls to $250/tonne by 2100. The cost in terms of reduced GDP is between 2% and 10.5% by region. Whalley and Wiggle (1991) consider a wide range of possible taxes, all aimed at a 50% reduction in global CO_2 emissions. A production tax high enough to hit this target produces much larger losses in developing countries than in the EC or North America: the loss in the present value of GDP over the period 1990-2030 is 7.1% in the LDCs, 4% in Europe and 4.3% in North America.

While many modelling exercises carried out so far show how increasing rates of tax are required for greater emissions reductions, even quite small reductions in CO_2 emissions imply large rises in fossil fuel prices. Manne and Richel's $250/tonne C tax would increase coal prices by a factor of five. In the case of the UK, Ingham and Ulph (1991) also find that high tax rates on the carbon content of fossil fuels are necessary for a 20% reduction in CO_2. For example, oil prices would need to rise by 57-128% in real terms, depending on underlying assumptions.[5] In Sweden, Bergman (1991) uses a computable general equilibrium model to calculate the costs of reducing CO_2 emissions by a carbon tax. For a reduction in annual emissions from 88 million tonnes to 63 million tonnes by the year 2000, the costs are about 4.5% of GDP. Bergman also finds that higher tax rates are necessary to cut CO_2 by increasing amounts, since the marginal control cost schedule is rising, as Figure 4 shows.

Conrad and Schroder (1991) use a general equilibrium approach to estimate the costs of hitting the Toronto target for Germany. This implies an annual reduction of 1.17% in CO_2 emissions if the target is to be met by 2005. Conrad and Schroder find that the cost, in terms of loss of GDP, depends on what sort of tax is used. If only the "energy intensive industries"

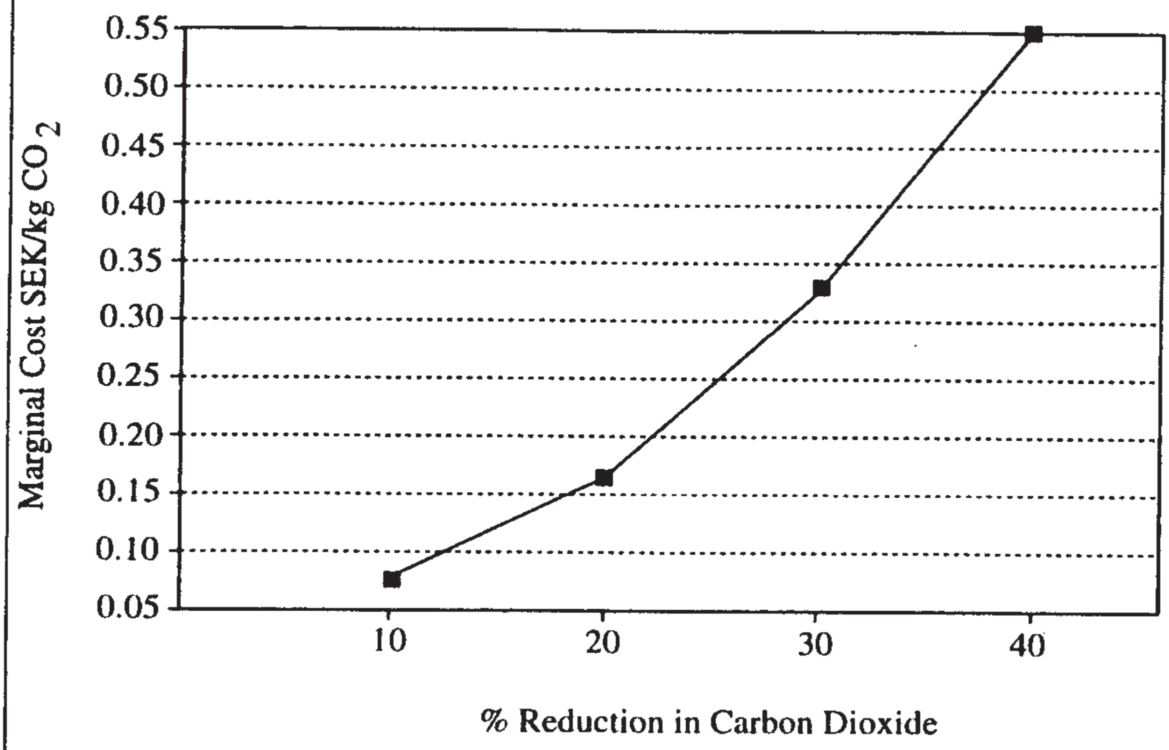


Figure 13.4: Marginal costs of reducing CO2 emmisions in Sweden

are taxed (such as iron and steel, and refining), then the cost is higher, at 32 billion DM by 1996, than if all sectors are taxed (which costs 22.8 billion). This is because restricting the tax base reduces substitutions in energy use relative to the "tax everyone" case. Tradeable permits for CO_2 emissions have received much less attention; Manne and Richels (1991) present some results for such a system, but Schelling (1992) casts doubts over whether trades would actually occur.

The above discussion on policy has been in terms of a tax on CO_2 generation.[6] Some commonly cited alternatives are reforestation, preventing deforestation and cutting CFCs. Deforestation, particularly in the Amazon, is a major source of CO_2 emissions, at around 3 billion tonnes a year. This occurs due to the burning of felled timber releasing CO_2, the oxidation of carbon in the soil and a reduction in carbon absorption in following years.

Reforestation would lock up CO_2 released from industrial sources. There appears to be wide disagreement over the costs of reducing CO_2 emissions by increasing tree cover. Nordhaus estimates the cost of preventing further deforestation as much lower than costs of reforestation (although his cost figures are very partial, excluding additional benefits and costs of deforestation/reforestation). For reforestation, Nordhaus' cost figures are $40 per tonne C in tropical areas and $115 in marginal areas of the US. Bloc et al. (1989) produce a much lower average figure of $0.7 per tonne C, whilst Dixon et al. (1989) give a figure of $4 to $8 per tonne C.

Finally, cutting CFC emissions is a most cost-effective way of achieving reductions in GHG emissions, in that (i) marginal control costs appear low and (ii) cutting CFCs is essential to prevent further depletions of the stratospheric ozone layer. Nordhaus finds that the marginal costs of cutting CO_2-equivalent emissions by reducing CFCs are about $5 per ton of CO_2 up to a 60% reduction in CFC use. Thereafter, marginal control costs rise steeply. However, UNEP (1991) reports that by 1997 CFCs could be completely phased out, along with other halocarbons, at little or no cost.

Economists have been able to produce estimates of the costs of reducing GHG emissions, but for the most part have avoided estimating the benefits of that control. Thus most work has been in terms of cost-effectiveness analysis, rather than cost-benefit analysis. This is because estimating the benefits of reducing GHGs is fraught with problems. There are many areas of uncertainty, for example, concerning regional impacts of climate change, how people and natural systems will adapt, and the nature of the world's economies in the distant future. There are also the standard problems of valuing non-market effects such as the displacement of wildlife and the human misery of environmental refugees. Another area which has received little attention is the treatment of long-term damages incurred by future generations.

RESPONSIBILITIES TO FUTURE GENERATIONS

Earlier in this paper we argued that the greenhouse effect could have serious impacts upon future generations while actually benefiting their predecessors. The standard application of cost-benefit analysis to the greenhouse effect, even if all costs and benefits could be calculated, would give the impression that the future is almost valueless. As Nordhaus (1991a, p.936) has stated,

> The efficient degree of control of GHGs would be essentially zero in the case of high costs, low damages, and high discounting; by contrast, in the case of no discounting and high damages, the efficient degree of control is close to one-third of GHG emissions.

The distribution of net costs in the future, and net benefits now, makes the emission of GHGs appear falsely attractive. Following Spash (1993), four reasons for giving less weight to the expected future damages of global warming, than if they were to occur now, can be advanced and criticized. These concern who constitutes the electorate, uncertainty over future preferences, the extinction of the human race, and uncertainty over future events.

First, taking into account the benefits to unborn generations of greenhouse gas abatement may be considered to widen the concept of democratic voting in an unacceptable way. Yet, if future voters are ignored, resources will be wasted because investments will be needed to reverse the effects of actions which shifted damages to the future. Unfortunately, once GHGs are emitted they are almost entirely beyond our control; that is, the action is irreversible (Spash and d'Arge, 1989).

Second, if the vote of future generations over greenhouse gas control is to be included in some manner, the argument has been put forward that this is impossible since future preferences are unknown. However, current individuals can recognize that certain actions will harm future persons despite indeterminacy concerning their identities and our ignorance of their special needs. For example, the destruction of the Maldavian's homeland and the dislocation of millions of people in Egypt and Bangladesh might qualify as such wrongs.

Third, the argument has been made that due to the inevitable extinction of the human race, the future must be regarded as less important; for example see Heal (1986). As the human race will no longer exist, the degradation due to global warming can therefore be dismissed or at least discounted. Resources used for greenhouse gas control are then better used for increased consumption for the immediate generation. This approach in the case of global warming is in line with a self-fulfilling expectation.

Fourth is the case where uncertainty over the impacts of global warming are such that there is a positive probability that no damage will occur, a probability which might be increasing over time. From an economic perspective, the suggestion has been made that when deciding to undertake an emissions abatement project, the future should be discounted at some positive rate to account for risk. However, except under special circumstances, there is no well-defined way to adjust the discount rate such that it will make the appropriate adjustment for risk in the present value of uncertain future benefits and costs in each period. On moral grounds, the fourth argument is equivalent to justifying actions which can harm others because there is a chance they will remain unharmed (Routley and Routley, 1980).

Cost-benefit analysis as commonly applied would use an arbitrary but positive social discount rate. Thus, implicitly, some concern for the future effects of global warming would be shown, but the extent of this concern would depend upon the discount rate chosen. The problem which faces economists, in falling back on the use of a positive rate, is that their policy conclusions still have serious long-term implications which raise the need for a moral justification for the procedure.

However, there is a persistent view that the current generation should be unconcerned over the loss or injury caused to future generations because they will benefit from advances in technology, investments in both man-made and natural capital, and direct bequests. Adams (1989, p.1274) has raised this exact issue in terms of alleviating our responsibilities for global warming. While fossil fuel combustion implies foregone opportunities for future generations, they "typically benefit (in the form of higher material standards of living) from current investments in technology, capital stocks, and other infrastructure". However, this line of reasoning confuses actions taken for two separate reasons. That future generations may be better-off has nothing to do with societies consciously deciding to compensate the future.

If society has in fact been undertaking investments with the express purpose of compensating future generations for global warming, the lack of publicity has been conspicuous. More importantly this would imply that the extent to which the future will be better off has in some sense been balanced against *all* the long-term environmental problems. That is, society cannot take global warming and see the future as better off, and then ignore global warming and take ozone depletion as compensated, and then ignore ozone and balance nuclear waste against supposed future well-being. Each case of long-term damage implies compensation which is distinct from catering for the general needs of future individuals.

This distinct nature of such compensatory transfers has been neglected (Spash, 1993). The greenhouse effect as characterized earlier creates an asymmetric distribution of losses and gains over time. Intergenerational compensation would counterbalance the negative outcomes of global warming by positive transfers, while not interfering with basic transfers. For example, assuming egalitarianism, the maintenance of the same welfare level fails to compensate for global warming. Yet the suggestion has been made that spreading the costs of global warming equitably across generations is an acceptable solution (Crosson, 1989).

Assume individuals of a nation are accepted to have a right to live in their own homeland. A sea-level rise due to global warming floods the Maldives and violates this right. Of course the Maldavians can be relocated and compensated, but this approach is unacceptable given the previously stated right. The objection free-market economists might raise to the imposition of such rights is that freely contracting parties are prevented from entering into agreements of their own free will. That is, the individual is his/her own best judge of welfare changes. If the Maldavians believe they are better off in their new homeland, then who is to deny the acceptability of this exchange. The difficulty in the intergenerational context is that the individuals who will be impacted are unavailable for comment. In order to protect these individuals from unjustified harm, rights could be used, so that what appeared to be a problem for the use of rights can be viewed as an argument in their favour.

The appeal to the "safe minimum standard" can be viewed as an example of constraining economic trade-offs by introducing rights. This standard advocates the protection of species, habitats and ecosystems unless the costs of doing so are "unacceptably large". In the case of global warming Batie and Shugart (1989) argue that the safe minimum standard would support emission reductions despite apparently high costs. However, the withdrawal of the right of, say, a species to exist at some cost implies a basis of the right within utilitarian morality. This view contrasts with rights in the context of a deontological philosophy.[7]

If rights which protect future individuals from the results of our greenhouse gas emissions are accepted to exist, the scope for trade-offs commonly assumed in economics will be drastically reduced. Compensation payments are no longer licences for society to pollute, provided the damages created are less than the amount of compensation. In which case compensation cannot be used to excuse the continuation of GHG emissions. Irreversible damages which will occur regardless of GHG emissions reductions would require compensation. In order to protect the future from potential infringements upon this right, actions with uncertain intertemporal consequences would have to be avoided, and environmentally benign production and consumption processes encouraged.

Stopping the build-up of GHG emissions in the stratosphere is complicated by the delay in transportation. That is, concentrations would continue to increase for over one hundred years. For example, in the case of chlorofluorocarbons, total emissions in the world would have to be reduced by approximately 85% immediately in order to stabilize the concentration of CFC-12 (Hoffman, 1986). Due to the cost of enforcing the rights of future generations to remain unharmed, the current generation has a vested interest in denying those rights. Continuing to emit GHGs at current rates denies the future the right to remain undamaged and asserts the dominance of the current generation. The current generation is in effect being asked to change the present rights structure, as found within society, in a manner detrimental to its own interest. The dictatorship of the current generation allows the imposition of damages regardless of the gain now and the extent of future damages. Yet, the abolition of slavery is an example of just such a change within society.

By appealing to CBA, economists are attempting to take losses and gains of controlling harmful activities directly into account. In doing so the rights of future generations are violated when the costs of controlling the greenhouse effect are deemed to exceed the benefits of that control. The use of cost-benefit analysis therefore denies the existence of inalienable rights. Reliance upon the potential compensation principle prevents actual compensation and allows the welfare of a subgroup of individuals to be reduced. Even the Pareto criterion allows harm to be inflicted, but at least this harm must then be compensated for by resource reallocation. That is, harm and good are seen as equivalent. However, harm is recognizably different from good and the deliberate infliction of harm is morally objectionable. If rights preventing harm to future individuals are accepted, actual compensation is required if these rights are violated. If at all possible, these rights should not be violated and people should be freed from actions which deliberately externalize the risk of damages by imposing it upon others. This can be viewed as a stricter definition of the Pareto criterion because it prevents harm, rather than allowing harm which is then actually compensated. These issues begin to reflect upon the role of CBA and some of the problems apparent with WTA measures where a structure of rights enforces a compensation principle.

CONCLUSIONS

Global warming is one of the most serious environmental threats humanity currently faces. CBA runs into problems due to uncertainty in the estimation of benefits, attitudes towards future generations and, more fundamentally, the very size of the problem (there is a point at which marginal welfare analysis loses its theoretical basis). These problems prevent a clear answer as to what should be done and economics cannot, of course, provide a complete answer. The costs of reducing CO_2 emissions may be quite high, but because the benefits of reducing emissions are beyond economists' ability to estimate, the extent to which control options should be adopted, on efficiency grounds alone, is unknown. Thus, a practical way forward is to adopt "no regret" or "double dividend" policies. These are actions which can be justified on their own account, but which also reduce global warming. Such policies include solving third world food insecurity, increasing energy efficiency, cutting CFC emissions, preventing deforestation, and encouraging reforestation. If planting a broadleaved forest on farmland in the English Midlands is justified on CBA grounds, regardless of its impact on global warming, then GHG reductions are an added bonus. Similarly, if it is known that energy prices are below their marginal social cost (excluding global warming impacts), then raising energy prices will make utilization more efficient and reduce GHG emissions.

In addition to no regret policies, reducing GHG emissions is desirable even if the costs of doing so are known to be large. This will be so if society is risk averse. The cost of reducing GHG emissions by 75% might be known to be $1 trillion. The costs of not reducing GHG emissions might range from $0.25 trillion to $10 trillion, with an expected value of $0.8 trillion. If society is risk averse, it will prefer to incur the certain loss of $1 trillion (the "certainty equivalent") to the expected loss of $0.8 trillion. In a fragmented world, risk aversion leads to risk externality; that is, the risk is placed upon "other" societies.

Externalizing the harm created by our actions can be viewed as having led us to the dramatic risks of damages faced by the world under global warming. Whether this issue materializes in the devastating form some predict or not, the moral implications go to the heart of modern industrial society. Economic analysts are in the uncomfortable position of justifying immoral actions if society or individuals can potentially (but not actually) transfer resources to those harmed. Unfortunately, current models tend to perpetuate the myth that the consequences of such actions will be felt by those on the other side of the world and living in the distant future so that even the potential need for such considerations can be discounted. The rising popularity of global warming as a matter for economists to consider will either force these matters into open debate or show how blinkered our minds can remain to the potential consequences of our actions.

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ENDNOTES

1. Double CO_2-equivalent is used to account for the atmospheric changes which are expected on reaching a global equilibrium of twice carbon dioxide, but which can be achieved by any mix of greenhouse gases.

2. Cline (1992) gives an up-to-date account of economic research into the greenhouse effect.

3. As Ingham and Ulph (1991) point out, the optimality condition is that in each time period, current value marginal control costs should be equal to the present value of marginal control benefits, where discounting takes place at the social rate of discount plus the rate at which the pollutant decays naturally.

4. Outside of the recalculation of the Nordhaus study, more general reasons exist for going beyond the suggested 10% emissions reduction. Since the world has never experienced such rapid changes in temperature as predicted (Schneider, 1989), the uncertainty over estimates of damage costs must include the possibility of sharp discontinuities; that is, threshold effects.

5. Ingham and Ulph's work details how industry would respond to carbon taxes, in terms of deciding whether prematurely to scrap plant which becomes inefficient to operate under a carbon tax.

6. There are many issues (such as international policy coordination) that we have not addressed; the reader is referred to Dornbusch and Poterba (1991) for a more complete picture of greenhouse economics.

7. A deontological philosophy sees certain features in a moral act as themselves having intrinsic value. This viewpoint contrasts with teleological systems which consider the ultimate criterion of morality in some non-moral value that results from actions. For example, lying is wrong regardless of the consequences; see Pojman (1989). Neo-classical economists operate with a teleological outlook but a considerable number of individuals may exist who hold to deontological philosophies. For example, the refusal to play and extreme bidding found in contingent valuation studies may be symptomatic of this.

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