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6 Calculating the costs and benefits of GHG control

Impact assessment by the IPCC has been described by the heads of the WMO (Obasi) and UNEP (Dowdeswell) as establishing a common base of knowledge about 'potential costs and benefits of climate change including the evaluation of uncertainties, to help Conference of the Parties (COP) determine what adaptation and mitigation measures might be justified' (Watson *et al*., 1997: v). As discussed in the last two chapters, the scientific community has been concerned to evaluate the weak uncertainty associated with potential consequences from the enhanced Greenhouse Effect. The economic approach encapsulated within cost–benefit analysis attempts to formalise assessment of potential pros and cons of a policy or environmental change using monetary valuation.

Economics has been regarded as making a contribution to the understanding of environmental problems in two ways. First through analysis of those human welfare impacts which are signalled through markets and the price mechanism. These are recognised as changes in the level and distribution of costs and benefits. Second, as a method of producing institutions for the control of pollution which minimise control costs while achieving given environmental standards (e.g. taxes, subsidies, tradable permits). While the two areas are usually assumed separable they are connected because any pollution control policy requires a set of institutional mechanisms which have their own associated implications for human welfare. In both cases monetary valuation of change is used as the key signal of success or failure, i.e. benefits should exceed costs and policy instruments should be efficient or at least cost-effective.

As noted in the last chapter, how an environmental problem is characterised varies with belief and perception of the degree to which society is committed to a given path. Faced with the threat of global climate change, society has normally been regarded as having three options:

- do nothing and conduct 'business as usual'
- prepare to adapt as sea level and temperature rise, or
- reduce emissions of GHGs.

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The first implies the enhanced Greenhouse Effect is either unimportant or beneficial. The second and third options take the problem seriously enough to warrant action, and can be carried out simultaneously. Note, the international discourse has moved from discussing prevention to mitigation, and thus implicitly accepts an unspecified amount of human-induced climate change.

Adaptation would include measures such as strengthening sea defences, changing cropping patterns, population migration, increasing irrigation and altering land use patterns. A policy solely relying on adaptation implies that all future consequences will remain within the boundaries of human adaptability and physical impacts can be offset by *expost* reaction. Risk aversion under weak uncertainty, irreversible damages and preparing for 'surprise' events under partial ignorance all argue in favour of controlling GHGs. However, to the extent that global climate change is already irreversibly underway society has no choice but to adapt and this option has been slowly getting more attention (for examples see Rosenberg *et al*., 1989; Reilly, 1996; Peake, 1998; Tol, Fankhauser and Smith, 1998; Fankhauser, Smith and Tol, 1999).

The control option with reduction of GHG emissions at source remains the policy most commonly studied by economists and is the subject of this chapter. This approach may be recast as achieving stabilisation of a given level of atmospheric concentrations by cutting sources and increasing sinks rather than just cutting GHG emissions. As will be seen the benefits of control have proven most controversial and yet the methodological problems and ethical issues which arise are equally applicable to cost assessment. Similarly, the methodological issues and many of the problems in economic assessment, which will be discussed here, are also relevant to the evaluation of adaptation options.

In the next section some of the economic theory relating to pollution control is critically explained. The main part of the chapter then reviews various attempts at monetary valuation of the impacts of enhancing the Greenhouse Effect and controlling for GHG emissions. A short historical overview leads into the studies covering both costs and benefits. These studies include the work of Ayres and Walters, Cline, Fankhauser, Nordhaus and Tol. Some analysts prefer to work solely on the costs of pollution control, sometimes assuming a given standard will be politically set. Such cost-effectiveness studies are reviewed with reference to the work of Barker, Ekins, Manne and Richels, Nordhaus and others. The overall aim is to show how monetary assessment has been conducted and raise some of the areas of controversy which are pursued further in the next chapter.

The theory behind economic assessment

Climate forcing could be reduced by cutting CO_2, CH_4, CFCs, N_2O or other trace gas emissions, and/or increasing the sinks for these GHGs (e.g. increasing CO_2 absorption by reforestation). A stream of consequences are associated with adopting such actions and these can be classified as costs and benefits. Optimal levels of GHG

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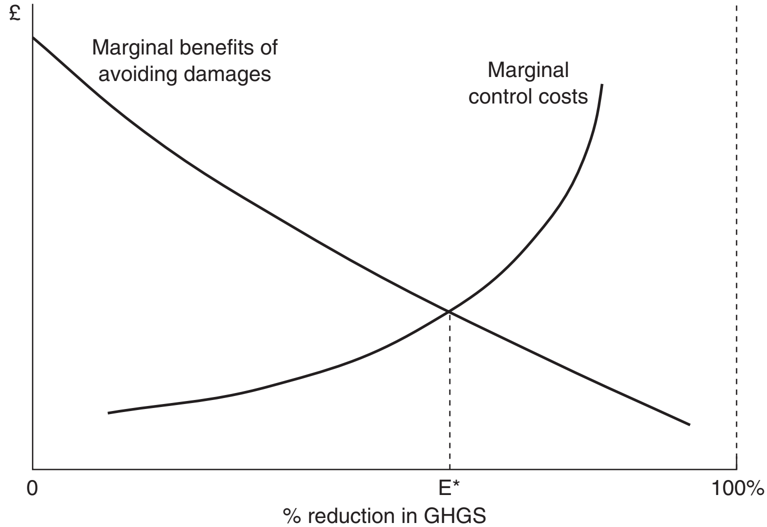

Figure 6.1 Marginal costs and benefits of reducing greenhouse gas emissions

reductions are meant to be deduced from an examination of how pollution-control costs and the benefits of avoiding damages vary with the level of reduction. However, as explained in the last chapter, such a model in fact describes the outcome which is consistent with the assumptions and constraints of the model, rather than a 'best' outcome.

Control costs are normally assumed to rise with the reduction in emissions, and be higher the quicker a given reduction is attempted. Conversely, the marginal benefits of reducing GHGs are assumed to fall with the level of control because fewer damages are avoided per unit of GHG reduced. The 'optimal' level of control is defined as occurring when the marginal benefits of GHG reductions, in present value terms, are just equal to marginal control costs.[1]

Figure 6.1 gives a standard graphical representation of this static equilibrium model. Marginal pollution control costs are shown as rising with the level of emission reduction while marginal benefits fall. 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 per cent. This is because the output associated with GHG production is valued more highly the scarcer it becomes. That is, the products from the petro-chemical industry, energy use in buildings, agro-chemical energy intensive farming and the fossil fuel intensive transportation system are all regarded as creating welfare for humans which is valued and would in part need to be sacrificed under a strict reduction of GHGs. Thus, pollution control costs can include impacts from lost production, and this will be particularly relevant where input substitution is limited, e.g. where there is no alternative to the use of fossil fuels in the production of a good or service. Emissions

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are usually partially separable from production so that they can be controlled without cutting output but instead raise production costs, e.g. placing scrubber units on power plants or catalytic converters on cars. This theoretical model has proven attractive as an explanation of why positive levels of pollution are necessary evils. However, the discussion of GHG emission reduction immediately exposes some weaknesses of the approach in terms of the characterisation of the cost and benefit functions and their relationship to human well-being.

Control costs with respect to GHG control have been classified by Boero, Clarke and Winters (1991), cited by Perman (1994), as comprising the following three categories:

- negative costs due to correcting market failures, i.e. gains in gross domestic product (GDP)[2]
- ongoing costs relating to diverting resources from other uses, e.g. curtailed energy use or forgone output
- short-term transitional costs such as scrapping capital prematurely or creating unemployment because of structural changes in the labour market.

As Perman (1994) notes, most studies concentrate upon the second cost category, ignoring the third, while the first remains controversial, i.e. appearing in some studies and being ignored by others.

The first cost category above has been termed ‘secondary benefits’ or more popularly ‘no regrets’ strategies. These are basically actions that society should be undertaking now in any case but which also reduce GHG emissions. That is, there can be ‘secondary benefits’ to the control of GHG emissions and these must be included as a reduction of the net costs of pollution control. For example, curtailing the use of fossil fuels would reduce other air pollution problems and their associated damages. Improving energy efficiency is another common example, discussed further below. The result of these gains would be to reduce pollution control costs, e.g. the cost function would shift or rotate downwards. However, the question remains as to why no action has been taken to obtain these gains before. The implication is that production and consumption processes are far less efficient than commonly assumed and institutional barriers may prevent efficiency gains. This in turn questions the applicability of the simple model which ignores institutional structures.

The benefits function is based upon microeconomic demand theory and welfare measures (see Hanley and Spash, 1993: chapter 2). These measures are constructed assuming smooth continuous functions, and that price (or quantity) changes represent a small fraction of an individual’s income. If there are catastrophic or irreversible events then the functions will no longer be smooth or continuous. If climate change is characterised by major impacts rather than marginal changes then the assumptions underlying welfare measures will break down and money values will no longer relate uniquely to welfare (e.g. Willig conditions[3] fail, marginal utility of money changes).

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In particular, Pareto and Kaldor-Hicks tests of welfare economics are designed to judge the relative positions of individuals after a marginal change and rely upon the fact that other relevant things have remained the same, i.e. the assumption of *ceteris paribus*. The range and scale of impacts under the enhanced Greenhouse Effect clearly violate this condition (Brown, 1988), and more generally this brings into question the relevance of partial equilibrium analysis.

Most discussions of monetary value forget (or dismiss) the fact that cost–benefit analysis (CBA) techniques were developed for small-scale projects and that their theoretical basis (as measures of human welfare) lies in demand for consumer goods. The *ceteris paribus* assumption might make sense for adding or removing a unit of a product from the bundle of goods a consumer purchases, but the extensions beyond this theoretically sound region of analysis soon violates required conditions. In the case of large-scale, long-term changes the assumptions simply fail to hold. A serious GHG reduction programme would alter the technological base of the economy, e.g. developing alternative energy sources, new transportation systems and lifestyles. The basis for comparison of winners and losers is then no longer identifiable. This affects both benefit estimation and cost analysis.

Baseline scenarios in cost studies provide the basis of comparison for calculating costs, but are dependent upon an artificial distinction between 'business as usual' and policy intervention. As Hourcade *et al*. (1996: 281–2) note, multiple baseline scenarios make cost assessments non-comparable. The multiple feedback mechanisms between development patterns (population growth, energy use, transport systems, consumption patterns) and economic variables mean assumptions about one determines the treatment of the other. For example, costs vary with assumptions about energy production, such as the role of nuclear power or biomass, and this impacts the level of baseline GHG emissions, as well as other factors. The assumptions about different GHG emissions affect damages while those about energy production affect control costs. In addition, programmes undertaken for one reason may be justified under another if there is some advantage, e.g. expansion of nuclear power may be sold (quite literally) as removing GHG emissions while this expansion would have occurred with or without the threat of climate change. This latter problem is particularly relevant as carbon trading from baseline scenarios moves on to the political agenda. Thus, for example, a forest which would be planted or exist without GHG control is not an additional cost of that control.

Besides these concerns, E^* in figure 6.1 is an impractical policy goal because no authority can accurately estimate marginal benefit or control cost functions. This is often taken to mean that monetary calculations to obtain CBAs of controlling GHGs could, at the very best, and in the absence of other problems, only be one input to a larger process of information gathering. This then raises questions as to the exact nature of the decision-making process into which this information is to be fed and how the information is used relative to other information. One concern here is the ability for institutional capture of information (see Hanley and Spash,

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1993: 160–3). The institutes producing CBA studies must be questioned for their own impartiality and the extent to which vested interests can determine outcomes. For example, nobody would really expect a study funded by an electricity generating industry with heavy investments in coal-fired power stations to argue in favour of large carbon taxes. CBA has also been a popular tool for use within government bureaucracies because of the power wielded by the Treasury. Thus, financial information flows can become dominant without regard to the assumptions upon which that information is based or the partial ignorance within which it is constructed, e.g. economics addresses resource efficiency and positively excludes a range of other policy goals such as equity, fairness, justice and moral rights. Yet these other considerations are impossible to exclude from the analysis and, as will be shown below, dominate a debate which is being presented as objective, free of value judgements, and solely concerned with efficient resource allocation.

An overview of monetary valuation of GHG control

The earliest example of a CBA of climate change is d'Arge (1975). This study, initiated in 1973, brought together 40 economists from across the US to evaluate the impacts on climate of emissions into the upper atmosphere due to jet aircraft. The economic assessment was the final stage which built upon five scientific research reports (the natural stratosphere of 1974, propulsion effluents in the stratosphere, the stratosphere perturbed by propulsion effluents, the natural and radiatively perturbed troposphere, and the impacts of climatic change on the biosphere). The primary concern was for the threat posed by proposed new fleets of supersonic jets, such as Concorde, on the chemistry of the stratosphere, although subsonic jets on long-haul flights were also implicated. Thus, the research was commissioned by the US Department of Transport. At this time climatic change was acknowledged to be capable of either heating or cooling the troposphere, and both scenarios were analysed. In most other respects little has changed concerning the approach to valuation and in some areas the report surpasses more recent work. Decision analysis was put forward as a useful but imperfect tool along with CBA. A range of sectors were addressed including world agriculture (corn, cotton, wheat and rice), US forestry, US water resources, world marine resources, world health, and US urban impacts (wages, housing, household expenditure, fossil fuel demand, public expenditures). In addition, specific sections of the report addressed, without valuation, possible social (family and community) and political impacts. This report certainly appears far more coherent than that on economics under the second assessment of the IPCC (Bruce, Hoesung and Haites, 1996).

Economic research on climate change largely disappeared until the late 1980s and then the major expansion of interest in the area was during the early 1990s. At the First World Climate Conference in 1979 the only presentation addressing economic impacts was by d'Arge (1979). An edited volume relating to climate change issues was produced by Resources for the Future (Cumberland, Hibbs and Hoch,

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1982), and a section of the American Economic Association meetings discussed the subject with papers being duly published (d'Arge, Schulze and Brookshire, 1982; Lave, 1982; Nordhaus, 1982). In general, environmental economics and policy analysis were minority pursuits at this time, and interest in the enhanced Greenhouse Effect was dominated by scientific research.

Key aspects of the economic debate were, however, developing. The work by d'Arge followed a traditional CBA approach but also emphasised the intergenerational problems raised by such analysis, including the asymmetry of costs and benefits and the ethics of discounting. In contrast Nordhaus applied optimisation theory without questioning the applicability of standard assumptions, and so disregarded equity and ethics. Indeed the gap between these models and the reality they are addressing is a major methodological problem (Lawson, 1997). This division of economists, between those with deep faith in the models and those questioning theoretical constructs, continues to be apparent and relevant to the policy advice being offered.

Pachauri and Damodaran (1992) have described economists as following one of two distinct theories as to the correct behaviour for dealing with climate change. One is a strategy of 'acting then learning' to allow experimentation, foresight, cost-effective prevention and the adjustment of investment decisions. This position favours actions which, even without the enhanced Greenhouse Effect, offer major benefits. The alternative is 'learning then acting', requiring all uncertainties be resolved before any action is taken and favouring research and new technologies. This is characterised as the 'wait and see' school and Nordhaus (1991c), Manne and Richels (1990), and Peck and Teisburg (1993) are all described as being biased towards this approach in their work (Pachauri and Damodaran, 1992: 251).

In the early 1990s numerous studies appeared relating to the enhanced Greenhouse Effect and the literature on this subject continues to grow. In 1991 both the *Economic Journal* and *American Economic Review* published commissioned papers on climate change issues. There was, however, little or no follow-up to these articles in mainstream journals and no replies were printed. Yet the arrival of climate change on the political stage firmly placed it on the economic research agenda. Economic approaches to climate change have clearly been driven by the international political process. The initial phase was one of deciding on whether action was necessary and once this was largely accepted the debate moved to how soon action and what type of action was required. Thus, CBA studies have given way to papers on the costs of action and flexible economic instruments as promoted under the Kyoto Protocol, e.g. tradable permit schemes.

A variety of economic approaches have been applied to the economic impacts from climate change. These range from country-specific studies (Ingham and Ulph, 1991) to world models (Manne and Richels, 1990; Nordhaus, 1998), and analyses include partial equilibrium (International Energy Agency, 1989), general equilibrium (Bergman, 1991; Cameron, 1993) and input–output (Symons, Proops and Gay, 1994). Thus, the analysts can choose their approach. However, the modelling

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community is fairly small and interconnected, so that models and model attributes tend to be shared. This means apparently independent studies by different authors may indeed be fundamentally related. For example, work by Nordhaus (1991b; 1991c) has been used as the basis for the CETA (carbon emissions trajectory assessment) model of Peck and Teisberg (1992; 1993). Both Peck and Richels are affiliated with the US Electric Power Research Institute and the control cost model of the former is based upon that of the latter. Similarly, Demeritt and Rothman (1999) show how all the benefit assessments up to 1996 derived some of their key damage estimates from one study, i.e. Smith and Tirpak (1989). These links are important because of the way in which scientific replication of results lends validity and results from different studies are reported as converging on a specific policy conclusion as if this were confirmation of an underlying truth rather than an artefact of the model and its assumptions.

The main focus has been the control cost of CO_2 reductions (see surveys in Ayres and Walters, 1991; Hoeller, Dean and Nicolaisen, 1991; Nordhaus, 1991a; Hourcade *et al.*, 1996). In comparison, there have been relatively few studies attempting to account for the benefits of control and these have often proven most controversial (e.g. Ayres and Walters, 1991; Nordhaus, 1991b; Cline, 1992a; Nordhaus, 1994; Fankhauser, 1995; Tol, 1995). Controversy also surrounded the IPCC Second Assessment Report on economics and specifically the chapter on the benefits of preventing global climate change (Pearce *et al.*, 1996). This created considerable debate over the basis for the monetary valuation of human life. The authors of this chapter rejected the critical policymakers summary of their work and sought to formally distance themselves from that summary (Grubb, Vrolijk and Brack, 1999: 304). This has undoubtedly contributed to the focus upon cost-effectiveness of policy instruments to achieve predetermined standards. The Third Assessment of the IPCC appear to have tried ignoring the issues raised by the debate over the benefits of control on the basis of meeting given political emissions reductions, although the same problems can arise under cost estimation. Some limited initial attempts at obtaining new benefit estimates have been reported (e.g. sea level rise in the US; Yohe, Neumann and Ameden, 1995), but there appears to be no comprehensive research agenda.

In the following sections a selection of CBA and cost-effectiveness studies are reviewed in order to illustrate some of the key issues and controversies. This is followed by a closer look at how value judgements are implicit in economic assessment. As will be shown, the impossibility of reducing value conflicts to objective facts raises questions both for economics and science as to how complex environmental problems should be analysed and discussed in the public arena.

Studies using cost–benefit analysis

At the start of the 1990s the work of Nordhaus was almost alone in trying to formally model the costs and benefits of climate change on the economy. The particular

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estimates of Nordhaus are important because of their implication in supporting the US negotiating stance at the international level. *The Economist* (27 October 1990) ran a leader referring to the work of Nordhaus as 'the best (though magnificently simplified) cost–benefit analysis' on the issue and regarded the estimates as 'hard-nosed calculations'. Rowlands (1995: 138) notes that the lack of systematic studies of the benefits of GHG control has resulted in the verdict of Nordhaus against co-operative action commanding 'significant respect and currency in the US debate'. Controversy over the calculations occurred very quickly with both critiques and re-estimations. Most notable amongst the latter were the article by Ayres and Walters (1991) and the study by Cline (1992a; 1992b).

The initial work by Nordhaus (1991b; 1991c; 1992) divided the US into three sectors by susceptibility to climate change:

- very susceptible, such as agriculture
- medium susceptibility, such as construction
- unsusceptible, such as finance.

In 1981 these sectors were attributed by Nordhaus with 3 per cent, 10 per cent and 87 per cent of US gross national product (GNP) respectively.[4] The economic benefits of emissions reductions in the high and medium sensitivity sectors is small at only 0.25 per cent of GNP, or $6.23 thousand million for double CO_2 equivalent, because they account for a low proportion of total GNP. The work assumed that impacts would occur in 2050 and that the composition of world GNP at that date would be the same as that of US GNP in 1981. The marginal benefits from emissions reduction, given under three scenarios, using a discount rate 1 per cent above growth and 1989 dollars, are shown in table 6.1 (Nordhaus, 1991c: 927).

Nordhaus excludes undesirable effects of global warming on non-marketed resources such as biodiversity and species loss, human health, non-commercial recreation, and ecosystem damages. These are impacts he views as too difficult to value. Instead he relies upon his 'judgement' (Nordhaus, 1991b: 148), that this is no more than seven times the estimated value of 0.25 per cent of GNP. He states, '… my hunch is that the overall impact upon human activity is unlikely to be bigger than 2 per cent of total world output' (Nordhaus, 1991c: 933). In effect the overall

Table 6.1 Double CO_2 equivalent GHG damages in Nordhaus 1991

Damage scenario	*$/ton*	*GNP (%)*
Low estimate	1.83	0.25
Medium guess	7.33	1.00
High guess	14.64	2.00

Source: Nordhaus (1991c).

Note: 1989 US dollars, discount rate 1 per cent above growth rate.

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loss for a doubling of CO_2 equivalent is a guess on the basis of 'an adjustment' which is 'purely *ad hoc*'.

An impact of 0.25 per cent loss of GNP resulting from a 3°C temperature rise associated with a doubling of CO_2 equivalent is argued to require 'very little CO_2 abatement' (Nordhaus, 1991b: 149). That is, his preferred estimate of benefits is outweighed by the estimated control costs. In calculating costs of emissions reductions the lowest cost methods are assumed to be employed. Nordhaus argues that these costs will depend upon the speed required, and that marginal control costs increase steeply beyond a 10 per cent emissions reduction. Reforestation is excluded because of the assumed high marginal cost of $100/ton of CO_2 removed. The medium control option (assuming a discount rate 1 per cent above the growth rate) is described as an 11 per cent reduction in GHGs split between CFCs at 9 per cent, and CO_2 at 2 per cent (Nordhaus, 1991c: 935).

Such minimalist recommendations and the approach by which they are derived have been criticised as misleading and biased by various authors (Ayres and Walters, 1991; Daily *et al*., 1991; FitzRoy, 1992; Pachauri and Damodaran, 1992; Funtowicz and Ravetz, 1994; Price, 1994). Criticisms of this work note problems in both cost and benefit estimation. On the cost side, energy conservation is argued to achieve GHG reductions at no cost or even producing a gain, while other secondary benefits which have been excluded might prove substantial. On the benefit side, the estimates are regarded as too low, inaccurate and unrepresentative. On the methodological front, the approach is regarded as questionable because of the way it purports awareness of uncertainty but then actually neglects its importance. Several of these issues are dealt with in turn here and in some detail because most remain relevant to work since, and monetary valuation currently ongoing.

The costs of reducing GHGs are argued to be negative over some range, because society is better off with fewer of the substances generating GHGs regardless of climate change. There are two reasons for this conclusion. First, market distortions (e.g. oligopoly, government subsidies) are argued to result in excessive and inefficient use of energy. This is part of the first category of costs noted earlier in this chapter, i.e. negative costs (gains in GDP) due to correcting market failures. Second, profitable opportunities for energy conservation exist but are currently ignored, e.g. due to myopia on the part of individuals and institutions, and lack of information. Ayres and Walter (1991: 255) note that the economic expectation that all efficiencies will be exploited fails because, internally, large firms are bureaucratic, hierarchical, rule driven central planners rather than competitive, profit maximising and price driven.

Cutting energy demand and increasing energy conservation would reduce the largest source of GHGs. Ayres and Walter (1991) provide case-study evidence for Italy and the US to support these general arguments. If some GHG emissions can be cut at no net cost to society, then, *ceteris paribus*, a higher optimal level of emission reduction is required. According to the IPCC many studies show that energy efficiency gains of 10–30 per cent are feasible within two to three decades at little or no cost,

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via technical conservation measures and improved management practices (Watson, Zinyowera and Moss, 1996: 41). In addition, efficiency gains of 50–60 per cent are also cited as being technically possible for many countries within the same time frame. Cline (1992a: 63–5) estimates 20–25 per cent of carbon emissions could be cut back at zero cost via improved energy efficiency.

Net costs are also reduced if cutting GHG emissions has environmentally beneficial side effects. For example, a carbon tax would mean coal facing 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 acidic deposition. Similarly, CFC reductions would help reduce stratospheric ozone depletion. Ayres and Walters (1991) claim that the indirect benefits of reduced air pollution for industrialised countries is between $20 and $60 per ton of CO_2. Secondary benefits would also accrue if the strategy to reduce GHG concentrations involved afforestation. This could generate a stream of non-market amenity benefits, depending on the type of forest planted. In fact, a decade ago the UK Forestry Commission started to include carbon absorption benefits in its investment appraisals of new tree planting (Whiteman, 1991). As with some other aspects, Nordhaus (1992: 64) was apparently aware of the potential for environmental gains reducing costs and some market imperfections in the energy market maintaining excessive consumption, but these considerations were excluded from the calculations.

The estimates of the benefits of cutting GHGs in the work of Nordhaus also appear excessively conservative. The susceptibility attributed to different sectors is highly questionable. The financial and service sectors seem to be excluded on the basis that they will avoid direct physical damages. However, there are many repercussions from human-induced climate change. For example, an economy may be affected by the size and balance of foreign investment. Thus, capital flight might be expected from countries under threat of or suffering damages. Alternatively, a country may lose substantial GNP due to foreign investment losses while the domestic economy (GDP) remains unaffected, at least initially. This would feed back into financial institutions which find their overseas capital under water, their foreign crops failing on an unprecedented scale or a foreign economy in crisis due to climate change impacts. There is already some concern in the insurance industry about the increasing frequency of extreme weather events (Pearce, 1995). Financial institutions are in fact susceptible to a range of damages due to the enhanced Greenhouse Effect, e.g. the insurance industry, property investment, long-term capital investment (see Dlugolecki, 1996).

The estimates for the US economy were extended by Nordhaus to the world level without structural adjustment, i.e. implicitly assuming all countries have the same economic structure as the US. Nordhaus (1992: 44) claims 'on average high income countries have less than 5 per cent of their GDP originating in agriculture'. However, for example, in Western Europe those countries with more than 5 per cent in agriculture include Finland, Greece, Iceland, Ireland, Portugal and Spain.

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Direct agricultural production ignores the importance of the food sector which includes restaurants, fast-food outlets, cafés, hotels, the wine and drinks industry, supermarkets and so on. Such broad generalisation also ignores the fact that the countries expected to suffer most are those with a low income and high dependency on climate-sensitive food production, e.g. the 20 African countries with 30–60 per cent of GDP in agriculture (see GDP figures in Cantor and Yohe, 1998: 22–9).

Of course, GDP in such countries may be relatively small so that the global loss in GDP is also relatively small. Yet this is more a reflection of the failure to account for distributional inequity and the inadequacy of the measure than the irrelevance of the problem. In this latter regard note should be taken that GDP is a widely criticised measure of economic well-being because it ignores non-monetary welfare (e.g. ecosystems functions, biodiversity, aesthetics) and informal economic activity (e.g. housework, or the 'black' economy), is boosted by disasters (e.g. clean-up of oil spills), and is generally concerned with material throughput rather than quality of life. If concern were really being expressed for human well-being a multiple index with independent categories would seem more appropriate rather than conversion of all values into income and expenditure flows.

Excessive aggregation (as under the GDP studies) means losing sight of who suffers and who gains. Treatment of the regional impacts of global climate change is a major concern both within and between nation states, as explained in chapter 3. Developing industrial economies are more susceptible to global warming with a large dependence upon climate sensitive production, a limited ability to adapt, and a sizeable population of subsistence farmers (d'Arge and Spash, 1991). Population growth rates seem set to exacerbate damages. FitzRoy (1992) has argued that the benefits of reducing global warming are underestimated by Nordhaus because 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 water levels in major world aquifers would also aggravate this situation. Nordhaus (1992: 46) relies entirely upon the CO_2 fertilisation effect to argue that net benefits will be produced in the agricultural sector. Even if this were true, a presentation in terms of net GNP gains neglects the uneven distribution of gains and losses.

In presenting their critique Ayres and Walters concentrate on sea level rise. Their revised calculation includes: increasing the area of land loss by a factor of 10, a higher value for that land in less industrially developed economies (e.g. Egypt and Bangladesh), and the cost of resettling refugees forced to move as a result of sea level rise. Even without attempting to include other market or non-market effects, these revisions in damages from global warming are stated to be 10 times greater than the comparable damage scenario estimates given by Nordhaus. This can be seen by roughly calculating the total damages in the two papers. The estimated total sea level rise impact over 50 years (excluding migration) are just over $264 thousand million in Nordhaus (1991c: 932) compared with $1,750 to $2,000 thousand million in Ayres

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and Walters (1991). The major difference here is in terms of the value of land lost which was estimated at just over $77 thousand million in the former and $1,500 thousand million in the latter.

In recalculating the benefits of preventing just sea level rise, Ayres and Walters (1991: 245) raised the annual damages giving the range as 2.1–2.4 per cent of gross world income. The lower limit of quantifiable damages is then given as $30–$35 per ton of CO_2 equivalent excluding secondary benefits, non-market impacts and improved energy efficiency. If we include the 'ad hoc' adjustment for non-market impacts used by Nordhaus the loss of world income would be 3.85–4.15 per cent.

Further criticisms of the calculations relate to the construction of the model by Nordhaus. This assumed a resource-steady state and a linear relationship between greenhouse damages and emissions. The former implies a constant level of CO_2 emissions over time, which is clearly unrealistic (see chapter 2). The latter results in assuming that damages remain constant regardless of the concentration of CO_2. Damages in fact rely upon the increasing atmospheric concentration of GHGs and the resulting radiative forcing. As Fankhauser (1995: 60) notes, a ton of CO_2 added to a small atmospheric stock is expected to add less damage than a ton added to a large stock (i.e. high concentration). The atmospheric lifetime of a GHG may also increase with concentration as available sinks are removed. Thus, non-linear relationships would then be appropriate when considering GHG damage functions and the benefits of GHG control. However, the situation is further complicated by rapid changes in climate, causing sharp discontinuities, threshold effects and irreversibilities.

Cline (1992a; 1992b) offers a far more comprehensive estimation of impacts increasing the number of detailed categories from just three (agriculture, sea level, energy) to fourteen. The more extensive range of categories and emphasis on long-term damages is probably due to a better understanding of the science than many economists (see Cline, 1991). Whereas Nordhaus attributed over 70 per cent of damages to sea level rise and only 6 per cent to agricultural losses, Cline's figures gave 11 and 28 per cent respectively. He also introduced significant levels of damages in water supply and human mortality and morbidity contributing around 10 per cent each to total damages, and forest damage and species loss at around 5 per cent each. A very different conclusion from that of Nordhaus is also found on the basis of extending the damage estimates and time horizon. Rather than claiming only modest action is required he suggests 'an aggressive program of international abatement' (Cline, 1992a: 1–2). The damages are again built upon the US economy and the numbers are highly speculative in the same vein as the work of others. His best-guess estimate for a double CO_2 equivalent warming of 2.5°C is a loss of $60 billion or 1 per cent of US GDP in 1990 dollars, which is estimated at seven times that of Nordhaus (Cline, 1992b: 61). The main contributions are clarifying the need for much higher damage estimates, refining the different impact categories and, perhaps most importantly, extending the time frame from 50 to 300 years.

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There is clearly no reason to restrict attention to an arbitrary point such as a doubling of CO_2 and Cline therefore gives long-term estimates as well. His baseline projections give a CO_2 concentration eight times the pre-industrial level by 2275 (Cline, 1992a: 23). The damage function is non-linear. The central estimate is that damages reach 6 per cent of GDP with a 10°C warming and under the pessimistic scenario losses rise to 20 per cent of GDP. In the first 30 years (of which 10 have now gone) forestry is the main means of reducing concentrations. By 2100 carbon reductions of 80 per cent are required with taxes of $100 to $250 per ton. Even an 'aggressive' emissions reduction programme would be unable to avoid 2.5°C of warming because stabilisation of radiative forcing would only be achieved by 2100. This also means that for each decade in which policymakers delay action, an additional 0.25°C in long-term warming is added (Cline, 1992a: 27).

Discounting is crucial to the outcome of long-term impacts, but far from the only issue creating a divergence in study results (contrary to some commentaries). Even with a 5 per cent rate, incorporating only a small probability of catastrophe is required to justify 'aggressive' action (Cline, 1992a: 6). The study showed the estimates of Nordhaus to be on the conservative bottom end of the scale in terms of possible damages. However, despite Cline's work the debate has remained largely based in that conservative zone and concentrates upon the double CO_2 scenario with 2.5°C equilibrium warming and a 50 cm sea level rise.

Fankhauser (1995) also presents a more comprehensive assessment than Nordhaus, and borrows largely from Cline in terms of designating his 10 main damage categories. Probability distributions are applied to model damage estimates in an attempt to formalise the treatment of uncertainty. The characteristic of the probability density function then becomes important and this is argued to be skewed to the right, even without catastrophic events, i.e. a severe damages outcome is more likely than a moderate one. This work has added significance as it formed a large part of the controversial chapter 6 of the IPCC's Second Assessment addressing monetary valuation of damages (Pearce *et al*., 1996).

Compared to Cline the estimates in Fankhauser downplay the relative roles of impacts on agriculture, energy consumption and leisure while raising the importance of species and ecosystem loss, and sea level rise. In terms of GNP the impact on the world is 1.4 per cent which is stated to be confirmation of the findings in other studies. However, comparison of such findings is far from straightforward, for example, the date for the 2.5°C rise is 2100 while in Nordhaus 3°C was reached by 2050. Fankhauser supplies a breakdown of per centage impacts on GNP for five regions as follows: European Union 1.4, US 1.3, former Soviet Union 0.7, China 4.7 and OECD 1.4. This implies worse impacts for China due to the losses in the agricultural sector which account for 47 per cent of Fankhauser's estimate (although see discussion of Tol's work below). Greater regional refinement aims to explore the inequity of impact distribution but in this case the calculations seem too aggregate and their basis extremely abstract. There are also questions over the meaning of the

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same losses in different regions, their comparability, and measurability. Besides lack of data, this is perhaps why analysts generally prefer to discuss only highly aggregated categories and GDP percentages.

At the same time as this work was being conducted, Nordhaus moved on to combine a traditional optimal growth model with climate and an enhanced Greenhouse Effect damage component, called the Dynamic Integrated Climate Economy or DICE model (Nordhaus, 1994). According to Fankhauser (1995: 61) this model recognised and corrected earlier shortcomings, although he states the damage estimates remained 'in the same order as Nordhaus' previous results', i.e. the new best-guess estimate of $10.03 per ton by 2025 compares to $7.33 per ton in the earlier work (see Nordhaus, 1994: table 5.7). In fact, Nordhaus (1994: 131) states the new estimates use a 6 per cent discount rate declining to 3 per cent, as growth slows, whereas the old figure, with which Fankhauser is encouraging us to compare, used a rate of 1 per cent above the growth rate. A similarly misleading comparison of several studies is made in chapter 6, table 6.11 of the IPCC SAR (Pearce *et al*., 1996). Variations in baseline case, scenarios and assumptions across studies make any direct comparisons difficult. Attempts at standardising the results of different studies show the extent to which variations exist (e.g. Smith, 1996). Perhaps the closest estimate in Nordhaus' earlier work is for a 4 per cent discount rate which gave an estimate of $0.31 per ton (this is without ad hoc adjustment which is apparently absent from DICE). Loss of GNP under the DICE base run is 1.3 per cent compared to the previous 0.25 per cent from doubling of CO_2 equivalent. Thus, Nordhaus appears to have dramatically increased his estimate of damages. This also seems apparent from the DICE sensitivity analysis where a base run with a 3 per cent pure time preference results in a 12.5 per cent reduction in GHGs and a carbon tax of $13.68 per ton by 2045, while a 1 per cent rate requires a 25.2 per cent reduction and $52.58 per ton tax (Nordhaus, 1994: 109).

Interestingly, despite an apparently more rigorous model, both the earlier work and DICE produce a recommendation of an 11 per cent control of GHGs in the first half of the twenty-first century. Indeed in several respects the DICE model fails to adequately address earlier critiques and maintains restrictive constraints. The upper boundary for losses by a country with 'a great deal of coastal activity and a large part of the economy in agriculture' is 4 per cent of GNP (Nordhaus, 1994: 53). In fact the model continues to extrapolate from the US economy using the same coefficients as in the 1991 studies, although adding some weightings for global estimates, and, as Nordhaus (1994: 55) notes, his results are heavily dependent on these choices. On using the DICE model himself Cline concluded that parameter choice was a cause of underestimating damages. Cline shows estimates of damages from DICE could range between $11.80 to $221.00 per ton of carbon by 2025 (cited by Fankhauser, 1995: 61), which compares with the optimal $10.03 of Nordhaus (1994: 94). The results vary in particular due to the choice of discount rate and size of damages allowed in the model. The range of damage categories also

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remains limited with the previous three types being supplemented by the addition of a fourth major category of 'other' impacts accounting for over 50 per cent of the total (this appears to have replaced the ad hoc adjustment).

In addition, there are a range of issues which bring into question the construction of the model (Spash, 1996). These, as discussed in chapter 4, relate both to the simplification and representation of both scientific understanding and the economy, as well as the reduction of strong uncertainty to weak uncertainty. Choices affecting the base case are crucial in such modelling and there is a lack of clear reasoning as to the treatment of various GHG emissions scenarios in this regard (e.g. several gases are treated as exogenously determined rather than by economic activity). The treatment of the sinks for CO_2 (e.g. ignoring the 'missing sink', unrealistic assumptions about ocean uptake) also mean the benefits of control are underestimated at low discount rates by a factor of four (see Price, 1994). The DICE model is particularly unrepresentative of any real economy, with its perfectly competitive markets and production assumptions which would in fact result in no world trade. The continued use of GNP figures bounded by historical estimates ignores the impact of climate change on relative prices, i.e. the impact of agricultural losses and flooding will be felt through land and commodity price changes. Past sector importance is a poor guide to the future under the type of changes being forecast.

As in Fankhauser, the treatment of uncertainty is brought to the fore, but again this is in order to reduce surprise and partial ignorance to probabilistic known outcomes. Nordhaus makes use of a survey of an unknown number, group and class of US 'experts' to bound the range of uncertainty on climate impacts and provide support for his own work. On this basis catastrophic impacts are characterised and this work has been used to inform further models (Nordhaus, 1998). The deviation of mean and median in these results shows clear divergence of opinion. Overmuch has been made of this survey work – it appears as substantive data in the IPCC report on damages which also notes the sample size as 19 (Pearce *et al*., 1996: 205, 208–9). Regardless of the validity of this particular study the approach itself is highly questionable as a way to address strong uncertainty. Similarly, Nordhaus uses a survey of resource and environmental economists (with very few details supplied) to support his choices on discounting (Nordhaus, 1994:155) as if this could bound the uncertainty relating to the choice. The thrust of the survey approach to uncertainty is to obtain subjective probabilities so standard economic models can avoid having to address partial ignorance and indeterminacy. Similarly, Tol (1995: 360) is correct to point out that uncertainty is no reason for neglecting information, but then argues that '… a more rational option is to assess carefully what is known, translating uncertainties into probabilities, and to evaluate the value of the consequences of the enhanced greenhouse effect'. However, he has then to admit that in trying to apply this approach: 'most of the analysis is based on educated guesswork and heroic *ad hoc* assumptions'.

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Tol (1995) has also conducted benefit estimates for a 2.5°C warming and 50 cm sea level rise. As in the case of Fankhauser, the research of Tol informed chapter 6 of the IPCC SAR. The work of Tol offers greater regional representation than other calculations of damages, including nine regions.[5] He includes seven main categories of impact as compared to the five in Fankhauser. As with Cline and Fankhauser sea level rise is broken down into three additional sub-categories.

The overall estimates are argued to be in line with other studies for the US while those for world damages are regarded as 'considerably higher' based upon new literature. In fact the estimate of a net 1.9 per cent loss of GDP is within 0.5 per cent of Fankhauser and 0.6 per cent of Nordhaus, while his US estimates are within 0.3 per cent and 0.5 per cent of the same respectively. One substantive difference is in terms of showing large regional disparities in net benefits. Thus, while the US loses 1.5 per cent of GDP, in the African case the loss is 8.7 per cent of GDP and for the former Soviet Union and Eastern Europe there is a net gain of 0.3 per cent.

The case of China is an example worth considering further as this was also analysed by Fankhauser (1995) and appears in Nordhaus (1998). As shown in table 6.2, Tol and Fankhauser's overall net figures for GDP loss are relatively close – within 0.5 of each other – and Nordhaus is the outlier. There is a bias convergence in Fankhauser and Tol (and other studies) due to use of the same base sources and extrapolation from the US to other countries and the world. Yet agreement within the regional rankings of the two studies was taken as significant by the IPCC SAR (Pearce *et al*., 1996: 205):

> The similarity of estimates should therefore not be interpreted as evidence of their robustness. A substantial degree of uncertainty remains. Nevertheless, the relative ranking of regions appears reasonably robust, with the most severe impacts to be expected in Asia and Africa, and northern and developed regions suffering less.

The point that is being missed here concerns the relative importance attributed to different impacts within such studies. Chinese agriculture is a major loser according to Fankhauser and a major winner according to Nordhaus. Human health and loss of life are the overwhelming impact for Tol. In Nordhaus the willingness to pay for avoiding the risk of an unspecific major GDP loss is the largest category which, due to being an ad hoc and vague calculation, seems best classified as under miscellaneous (as in table 6.2). Clearly there is a large divergence in opinion as to the nature of impacts and their relative sizes, and much detail and information is lost by aggregation and the presentation of net GDP figures (as favoured by the aforementioned IPCC report).

In this latter regard the regional analysis presented by Nordhaus (1998) in his RICE model, a development from the DICE model, is also of particular concern.

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Table 6.2 Benefits of GHG control for China as weighted by CBA studies

	Fankhauser 1995 China (%)	*Tol 1995 Centrally Planned Asia (%)*	*Nordhaus 1998 China (%)*
Losses avoided			
Agriculture	47	0	0
Forest	0	0	0
Species/ecosystem	13	5	0
Sea level rise	4	5	8
Energy consumption	4	0	0
Human morbidity/mortality	17	73	10
Migration	4	12	0
Hurricanes	1	0	0
Leisure	0	5	0
Water supply	10	0	0
Urban infrastructure	0	0	6
Tropospheric ozone	1	0	0
Miscellaneous	0	0	76
Total[a]	100	100	100
Gains missed (as % of losses avoided)			
Agriculture	0	–14	–43
Energy consumption	0	0	0
Outdoor recreation	0	0	–30
Temperature °C	2.5	2.5	2.5
Measurement basis	\$1000 m	\$1000 m	GDP
Net GDP loss %	4.70	5.20	0.22
Base year	1988	1988	1995

Data source: Fankhauser (1995) table 3.15; Tol (1995) table A1; Nordhaus (1998) table 10.

Note: a May not add to 100 due to rounding errors.

This follows the trend for including regional breakdowns by estimating impacts on eight regions and five regional income groups. The 2.5°C by 2100 seems to be the consensus scenario amongst this group of studies. What is different here is the inclusion of major gains from global warming. Those from agriculture have already been extensively discussed and their uncertainty was emphasised in earlier chapters. However, there is a large new category which substantially alters the net GDP figures.

The new group here is what Nordhaus calls 'non-market time use', but which in essence consists of recreational and sport activities specified as camping, golfing, walking and hiking. How value is meant to be added by future climatic changes is unclear, but presumably the characterisation of climate change is of a world much as today but a bit warmer with fewer rainy days. If so, the scientific scenarios have been

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totally neglected. In addition, the main constraint on such recreation would seem to be time and thus the need to work, and for most the world's population to survive, rather than a lack of sunny days. This characterisation of gains from a changing climatic regime seems rather parochial. The concept is doubtful for the US, but stretches credulity for most of the world. However, as in his earlier studies, the characterisation of the US is used as representative of the entire world to produce net GDP figures. The new recreational gains then play a major role. Hence the losses to agriculture in Europe are almost matched by recreational gains and in China are three times the size of mortality and morbidity. In other words even with three times the amount of morbidity and mortality the recreational and sports gains would compensate for the loss. The result for the US is that Nordhaus reduces damages by 38 per cent due to recreational gains and has returned his net GDP figure to 0.45 per cent. Nordhaus believes the enhanced Greenhouse Effect is only a real problem for the likes of India and Africa whose recreational opportunities are expected to worsen.

This picture seems to fit closely with the US political stance on emissions control, and who should pay. The message is that other countries, besides the US, especially the industrially developing countries, had better get involved because the main polluter has little incentive to act. Unfortunately, this neglects the rising damages and distributional consequences faced within the US. The 'wait and see' approach then means that awaiting exceedance of these estimates would mean irreversible commitment to further damages, which become greater the longer the delay. Any extra recreational opportunities seem likely to prove inadequate and ethically questionable compensation for loss of life, flooding, ecosystems damage and crop failure.

Overall, the CBA studies of the enhanced Greenhouse Effect show no consistency in their development of damage estimates over time, as evidenced by including or dropping categories without reason. Thus, the idea that a process of development of economic assessment is moving towards some consensus is clearly false. Attempts to standardise the various studies by correcting the variation in scenarios show the wide variation in assumptions. Initially standardising estimates to a 2.5°C increase and 50 cm sea level rise seems to show convergence (Smith, 1996). However, this requires accepting studies at face value, and ignoring the wide variation in the weighting of categories. Even after standardising the estimates, wide variation is clear if the worst case is calculated on the basis of the highest damages across categories and the best case the lowest figures. The results of doing so for five US case studies shows damages ranging from 0.35 per cent of GDP to 2.16 per cent or $17.6 to $108.4 thousand million in 1990 dollars (Demeritt and Rothman, 1998). Standardisation of available studies seems to reduce the aggregate values but does little to address the range of variation due to author choice of variables and their relative importance (Smith, 1996). In addition, there is variance of estimates across

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the work of the same authors so that the specific version of their work being used will affect such calculations.

Cost-effectiveness studies

The major advantage of cost-effectiveness is regarded to be the avoidance of debated ethical and political issues surrounding the setting and acceptance of a target for emissions reduction. Most economic studies of the enhanced Greenhouse Effect have centred around the cost efficiency of achieving a given reduction in CO_2 emissions, thus avoiding benefit estimation altogether. For example, a common initial target used in studies was the Toronto agreement's 20 per cent cut in CO_2 emissions by 2005. Cost-effectiveness analysis has been generally regarded as more robust and less susceptible to criticism despite many of the points already made concerning the conduct, methodology and validity of benefit estimation being equally applicable.

A cost is a monetary value placed upon objects in the same way as a benefit. The main difference is one of defining a status quo position from which to discuss a specific policy. Thus, for example, planting a forest creates benefits in terms of reducing CO_2 concentrations, creating recreational opportunities and wildlife habitat. Logging a forest creates costs in terms of releasing carbon emissions and loss of habitat. The control of GHGs regards planting forests as a cost of CO_2 control which has negative costs (secondary benefits) in terms of recreation and wildlife. Thus, categories of costs and benefits are defined by the policy position, i.e. what the action is under consideration. In the market place one person's cost is another person's benefit; you pay for a product and the supplier accepts your payment as fair exchange. The basic rule is to choose the status quo, or in the market the property rights, and define costs and benefits accordingly.

The current literature on the enhanced Greenhouse Effect tends to confuse status quo positions. Some studies merely suffer from inaccurate and sloppy use of terminology, but others make an implicit statement about who should pay for emissions control. Thus, the use of the term 'damage costs' rather than 'benefits' from emissions control can be symptomatic of a fundamental difference and more than a matter of semantics. Those who phrase the question as one of 'gaining the benefits from global warming' and warn against overemphasising 'the costs from damages' are in fact assuming a specific position with regards to what is 'normal'. The policy action required is deliberate climatic warming which costs a certain amount in terms of, say, African droughts and allows the benefits of, for example, reduced winter heating bills in the Northern Hemisphere and cheaper energy (i.e. avoiding emissions control). Despite the unknowable consequences, such authors may discuss climatic 'engineering', such as shooting particles into space or seeding the oceans with trace iron, as a cost-effective strategy to reduce damage, because their presumption is against emissions control. The concept of cost is then being used for that category of outcomes which would be described as benefits under an emissions

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control strategy, that is damages avoided under emission control are the benefits of that control but when taking deliberate emissions as the status quo these same damages are regarded as the costs of failing to continue to emit. Whether harm created is a cost or benefit is dependent upon choice of status quo position and the analysts perspective. In addition, there is clearly a moral context to the idea of regarding environmental damages as either costs or benefits, which is a point to be discussed further in the next chapter. More generally, an emphasis on the costs associated with any action is far from neutral and will convey specific moral and social connotations under different circumstances.[6]

The setting of parameters in all cost-effectiveness studies is crucial to the outcome. This includes making assumptions about underlying economic growth rates, and the method by which emissions reductions or concentration stabilisation are to be achieved. A base-case 'policy off' scenario is required for comparison with the 'policy on' scenario. For example, a no-intervention growth rate of GDP might be compared with the growth rate under a 20 per cent CO_2 reduction by a specific date. An obvious concern, expressed by those countries trying to achieve or maintain fast rates of material growth, is that GHG control may limit GDP growth. Modelling cost-effectiveness also requires background assumptions concerning energy supply and demand, expectations from research and development, and the 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 market mechanisms (e.g. tax or tradable permits) will be the lowest cost options. As Ekins (1995: 290) points out, an increase in the price of energy on the basis of carbon content would have a variety of effects: reducing demand for carbon-based fuels; improving fuel efficiency; encouraging development of less carbon-intensive technologies, products and processes; generating energy saving via improved efficiency of buildings and transport systems. There would also be several substitution effects: a reduction of carbon-insensitive fuels and the introduction of non-carbon fuels; switching between other factors of production and energy; a decline in the carbon intensity of products and processes. How the possibilities for substitution, efficiency improvements and technological change are modelled will determine whether energy price rises are predicted to reduce or increase GDP.

Manne and Richels (1991) used a dynamic optimisation model (Global 2100), which divided the world into five regions with nine energy sectors. This model predicted CO_2 emissions from fossil fuel sources through to the year 2100, and has been used to examine the cost of various policy options. A 20 per cent reduction of CO_2 emissions by 2020, with that level maintained until 2100, was compared to a 'do nothing' scenario where GDP grew at around 2 per cent a year, while energy efficiency grew at between 0.5 to 2.0 per cent depending on the region (making total energy demand per unit of GDP fall). The model had CO_2 emissions in the absence of action rising at 0.7 to 2.1 per cent per year. The principle policy simulation was of a tax levied on the carbon content of fuels. In the model this hit a peak of

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$400 per ton carbon, then fell to $250 per ton by 2100. The costs in terms of reduced GDP per annum peaked at approximately 3 per cent for the US by 2030, 1–2 per cent for other OECD countries by 2010, 4 per cent for the former Soviet Union and Eastern Europe by 2030, and 10 per cent for China by 2100.

Just as benefit studies by Nordhaus were influential in the US debate so were the control cost estimates of Manne and Richels (1990). They argued that a 20 per cent CO_2 reduction by 2020 would cost the US economy between $800 thousand million and $3,600 thousand million. These costs were cited by the 1990 *Economic Report of the President* (Paterson, 1996: 81). The upper scenario calculates the present value of costs from 1990 to 2100 discounted at 5 per cent and means 5 per cent of annual GDP would be committed to emissions control by 2030.[7] These figures have aided the US perception that even small reductions could be very costly. This is despite the fact that Manne and Richels (1990: 70) themselves state:

> Experience has shown that energy forecasting, even over decades, is a highly inexact art. At best, one can ask a series of 'what if questions' in the hope of gaining some insights into the relative attractiveness of various means of reducing CO_2 emissions.

As with the benefit estimates, guessing the future is a crucial part of the game.

Whalley and Wigle (1991) considered a wide range of possible taxes, all aimed at a 50 per cent reduction in global CO_2 emissions. A production tax high enough to hit this target produces much larger losses in developing countries than in Europe or North America. The loss of GDP in present value terms over the period 1990–2030 was estimated at 7.1 per cent for industrially developing countries, 4 per cent in Europe and 4.3 per cent in North America. The cost of CO_2 reduction in this model has been criticised as resulting from low supply elasticities for energy (Nordhaus, 1991a: 45). Bergman (1991) used a computable general equilibrium model to calculate the costs of reducing CO_2 emissions in Sweden using a carbon tax. For a reduction in annual emissions from 88 million tons to 63 million tons (28.4 per cent) by the year 2000, the costs are given as 4.5 per cent of GDP. Bergman also found that tax rates needed to rise with the level of cuts in CO_2 because the marginal control cost schedule is rising.

Conrad and Schroder (1991) have argued that the cost, in terms of loss of GDP, depends upon the structure of any tax. They used a general equilibrium approach to estimate costs of hitting the Toronto target for Germany, which – to have met the target by 2005 – would then have required an annual reduction of 1.17 per cent in CO_2 emissions. If only the 'energy intensive industries' were taxed (such as iron and steel, and refining) the cost increased compared to taxing all sectors, because restricting the tax base reduces the possibility for substitution across energy uses. Ingham and Ulph (1991) have raised the issue of how industry responds to carbon taxes, in terms of deciding whether to scrap plant that becomes inefficient to operate

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under a carbon tax. The need to phase out technologies as new capital investments are required has been seen as a key to keeping costs low, although this locks in a delay between the implementation of a carbon reduction policy and emissions reduction while the capital stock turns over.

Many modelling exercises, such a those mentioned, predict that tax rates will need to increase with the level of emissions reduction, and that even quite small reductions in CO_2 emissions could require large rises in fossil fuel prices. In the case of the UK, for example, Ingham and Ulph (1991) have predicted oil prices would need to rise by 57–128 per cent in real terms, depending on underlying assumptions, for a 20 per cent reduction in CO_2. The proposed carbon tax in Manne and Richels (1990) is $250 per ton carbon which was estimated to increase coal prices by a factor of five. However, both the implicit and explicit assumptions about energy elasticities in such models have been criticised (see Barker, Ekins and Johnstone, 1995).

Contrary to the thrust of the above work, Ekins (1995) has questioned the assumptions being made and concluded that even substantial reductions in fossil fuel use could be achieved without a net cost even if there are only moderate benefits from preventing global warming. He argues that the assumptions and techniques used predetermine the outcome and in particular that the following factors should be scrutinised: the treatment of unemployed resources, revenue recycling, distortions in the economy due to the tax system and dynamic effects of a carbon tax. Some of the points made by Ekins (1995) are worth considering in more detail.

Although perhaps obvious, the way in which the revenues from a carbon tax are used has a major influence on estimated impact on GDP. Saving tax revenues results in contraction of the economy and reductions in GDP, while reducing other taxes could increase GDP. Modelling a carbon tax as a cause of contractionary pressure led the US Congressional Budget Office to claim that a 2 per cent loss of GDP would be the result. Thus, a revenue-neutral modelling approach is called for, although many models have failed to do so. Reducing payroll taxes can reduce unemployment, and positive employment effects will also occur due to the lower relative price of labour and the relative labour intensity of non-carbon sectors. In a study by Barker and Lewney (cited by Ekins) the reduction of value added tax (VAT) in the UK by revenues from a carbon tax to achieve 20 per cent CO_2 reductions meant GDP effects were so small the authors state they should be ignored. Other studies show that such revenue recycling leads to GDP gains as distortionary taxes are removed.

This raises another problem with the conduct of economic modelling. General equilibrium models assume that deviations from the base run are distortions. Thus, introducing a carbon tax appears as a distortion, reducing efficiency. This is despite the fact that the tax is reducing an economic distortion, i.e. correcting the failure to price a production input at its social cost. The approach can be worse still if models allow for revenue recycling but do so by removing non-distortionary taxes. This means such models are biased by assuming that:

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- the economy is in equilibrium with all resources fully employed
- the carbon tax introduces a distortion while raising revenue
- revenue is recycled by replacing non-distortionary rather than distortionary taxes.

Taxes can cause welfare losses (deadweight loss) and their size can determine the impact of revenue recycling. For example, using the DICE model, Nordhaus (1994: 120–1) found annual GDP gains of $137 thousand million (1989 dollars) when taking this into account, and that the optimal emissions reduction rose from 8.8 to 32.0 per cent, which was associated with tax moving from $5.24 to $59.00 per ton of CO_2 equivalent. These results were for a deadweight loss of $0.3 per dollar of revenue, although Nordhaus notes estimates for the US are $0.5 to $1.0. Hence the entire outcome of the model is reversed from GDP losses to GDP gains. For some reason these results failed to get any emphasis.

The above discussion on policy has been in terms of a tax on CO_2 generation. Tradable permits for CO_2 emissions have received less attention but are increasingly on the agenda since the Kyoto Protocol. However, there are many questions over their equity and practicality. Schelling (1992) even casts doubts over whether trades would actually occur.

Some other commonly cited alternatives are reforestation, preventing deforestation and cutting CFCs. Tropical forests are estimated to store about 60 per cent of total carbon held by forests. Deforestation, particularly in the Amazon, is a major source of CO_2 emissions, at around 3 billion tons a year. This occurs due to the burning of felled timber releasing CO_2, the oxidation of carbon in soil and a reduction in carbon absorption in following years.

Reddy and Price (1999) note that mitigation policies involving forestry fall into four categories: increasing the inventory of standing forest to sequester carbon, increasing storage in long-lived wood products, replacing non-wood products with long-lived wood products, and utilising biomass energy crops for fuel. The concentration has been on the first option. In this regard they find good reasons for supporting carbon sinks in tropical plantation forestry, which include rapid growth, availability of waste and fallow lands, low establishment costs and relatively low opportunity costs of land (subject to the impacts of population growth). However, forestry can be negative in several respects and to produce social benefits requires appropriate management. For example, plantations in the UK have been criticised for reducing biodiversity compared with traditional forests. As Brown and Adger (1994: 218) explain, over the past 50 years, UK afforestation has caused a net emission of carbon because of the replacement of old growth forests and use of drained peatland.

Thus, reforestation is offered as a method of sequestering CO_2 from industrial sources which, under appropriate management, can deliver multiple benefits. However, there appears to be wide disagreement over the costs of reducing CO_2

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emissions by increasing tree cover. Nordhaus (1991a) estimates the cost of preventing further deforestation as much lower than costs of reforestation, although his cost figures are very partial and exclude secondary benefits. For reforestation, Nordhaus (1991a: 59) estimates the cost at $40 per ton of carbon in tropical areas and $115 in marginal areas of the US. This contrasts with Bloc, Hendriks and Turkenberg (1989) at $0.7 per ton of carbon. A more detailed analysis is offered by Dixon *et al*. (1993) for a large number of countries, and shows a range of dollars per ton of carbon sequestered from $0.5 in Nepal to $77.9 in Egypt with most countries nearer the bottom end of the range, e.g. the US at $5.5, the former Soviet Union $4.6, Australia $5.9, China $5.2, Thailand $1.7. Brown and Adger (1994) cite several actual projects financed to achieve international carbon offsets and report the following costs per ton in various countries: $5.6 Ecuador, $1.0–2.0 Russia, less than $1.5 Paraguay, $1.16 Guatemala.

Finally, cutting CFC emissions is the most cost-effective way of achieving reduction in GHG emissions because the marginal control costs appear low and banning CFCs is essential to preventing further depletion 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 per cent reduction in CFC use. Note, 1 ton of carbon equals 3.67 tons of CO_2 (Brown and Adger, 1994: 217), so this estimate is equivalent to $1.4 per ton of carbon. Thereafter, marginal control costs rise steeply. However, the UNEP (1991) reported that CFCs could be completely phased out, along with other halocarbons, by 1997, at little or no cost.

Conclusions

There have been claims of consensus over assessment results each time a new study produces a figure within the 1 to 2 per cent net GDP loss range despite the wide variation in assumptions across studies which makes any comparability at best difficult. Information on different assumptions is often absent from studies, e.g. the assumed date of a temperature change and the related date at which impacts will be felt (the two are distinct and expected to be delayed by decades). As Tol (1995: 354) notes, the estimates throughout the 1990s have been ‘at a highly aggregated level, based on the literature on case studies, and educated guesswork and extrapolation’. There was some movement toward increasing the number of damage categories. Cline offered fourteen but others have persisted with only four and employing ‘catch all’ groupings such as ‘other’. Regional analysis has been slow to arrive and crudely performed while distributional analysis has been lost in excessive aggregation.

The estimates of emissions reductions would be greater if distributional weights were included in benefit calculations in order to reflect damage suffered by low GHG emitters, and Ekins (1995: 300) has argued in favour of such weightings. He notes that because high GHG emitters are also likely to be richer they will have a higher willingness to pay and so the damages they suffer actually gain greater weight

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in a CBA calculus. The poor low GHG emitters should be weighted more highly and he believes this would also help correct an unfair intergenerational distribution due to suffering damages without having been responsible for their cause.

Cost-effectivness requires macroeconomic modelling to understand the impacts of changes in the fiscal system. Revenues raised from a carbon tax could be used to reduce distortions in the tax system at net GDP gains. Such revenues might also be used to remove imperfections in the transport and energy sectors. Changes in capital stock will be important but are beyond the control of consumers, e.g. vehicle purchase versus road construction. Government policy can easily affect substitution possibilities, although models based upon market responses find this difficult to take into account, e.g. the impact of policy on elasticities of demand for fuels. Yet this may be very significant for an aggressive abatement strategy (Barker, Ekins and Johnstone, 1995: 312). Thus, GHG reduction will operate on energy markets through behavioural factors on the demand side, and institutional, structural and technological factors on the supply side. However, Barker, Ekins and Johnstone (1995: 311–12) emphasise that macroeconomic and general equilibrium models operate through monetary values and are not designed for analysis of such fundamental changes as implied by a carbon tax. They state that 'the basic assumption of most models is that the future is nothing more than a continuation of the past'.

The critiques and scepticism concerning benefit estimation are generally absent from cost-effectiveness analysis but without good cause, and even the meaning given to control 'costs' can prove fallible. The fact that a 'cost' seems to convey greater credibility and appear as a factual statement has affected the use of terminology, where 'damage costs' is preferred to 'benefit' estimation. There is also a moral perspective here because avoiding damages as a benefit of control is fundamentally different from incurring a 'damage cost' in order to benefit from greater material throughput. The latter phrasing is used to pass the moral burden on to future generations (and other countries) who are assumed to benefit from GDP growth and must accept damages as another production cost.

The problems outlined here show how economic assessment fails to provide an answer as to what should be done. The costs of reducing CO_2 emissions may be quite high or there may be net gains depending upon the options chosen by the analyst. The benefits of reducing emissions are beyond economists' ability to estimate so the extent to which control options should be adopted, on efficiency grounds alone, is unknown. That political debate is unavoidable, disputes over values normal and ethics inseparable from economic analysis is explained further in the next chapter.

Notes

1 As Ingham and Ulph (1991) note, the optimality condition requires that, in each time period, the present value of marginal control costs and benefits should be equal; present value is calculated using the social rate of discount plus the natural rate of pollutant decay.

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2 Also sometimes called national income. GDP is, in theory, a measure of the total flow of goods and services produced by the economy over a year. The value of goods and services is aggregated at market prices. The term 'gross' means no deduction has been made for capital depreciation. Income from foreign investment is excluded, but if added the measure becomes gross national product (GNP).

3 Willig described the conditions under which a consumer's surplus could be used to approximate a change in their underlying utility. See Willig (1976).

4 Gross national product is gross domestic product (see endnote 2) plus the income accruing to domestic residents arising from investment abroad less income earned in the domestic market accruing to those residents in foreign countries. Although different measures, the two terms are often used loosely and interchangeably as a reference to a country's output. This seems to be the case in several of the works reported in this chapter. The distribution of regional differences could be important and create a divergence. Of course at the global level there is no difference, and indeed the idea of foreign investment becomes meaningless, hence some authors use the term world income. In this chapter, where referring to the work of others, usage in the original source is followed.

5 Note that table A1 in this reference which presents the damage estimates has several errors in the summation columns. The most significant is the absence of $100 thousand million, which is 30 per cent of the total net loss for the world, from the life/morbidity category.

6 Some examples may help here. When giving gifts, the social practice is to remove the price label rather than emphasise to the recipient how much the item cost. When seeing a person drowning, the expected action of a potential rescuer in a nearby boat is to spontaneously go to their aid rather than sit down to consider the costs in terms of, say, the petrol used, their time and the inconvenience.

7 In the comment following this article Hogan notes that the 1987 US military expenditure was $282 thousand million or 6.2 per cent of GNP as cited by the *Economic Report of the President* for 1989.

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