OXFORD REVIEW OF ECONOMIC POLICY, VOL. 19, NO. 3

THE SOCIAL COST OF CARBON AND ITS POLICY IMPLICATIONS

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The shadow price, or 'social cost', of carbon is an important indicator of the global incremental damage done by emitting greenhouse gases today. Cost–benefit analysis would set the optimal amount of greenhouse-gas-emission reduction at the point where this social cost just equals the incremental cost of controlling emissions. The higher the value for the social cost of carbon, the more control is warranted. This comparison assumes that cost–benefit analysis is the correct way of determining climate-change policy, and many believe this is not the case because of the very long-term, irreversible, and potentially catastrophic nature of global warming. But, in the short run at least, a comparison of cost and benefits is required, and, in any event, all decisions imply costs and benefits. But what is the 'right' figure for the social cost of carbon? This paper reviews the UK government's assessment of the cost and concludes that it has been set far too high because of a misreading of the integrated assessment models used to balance costs and benefits. Moreover, adoption of the UK government's shadow price would have formidable implications for energy policy in the UK, and for policies on afforestation.

I. INTRODUCTION

The 1997 Kyoto Protocol to the 1992 Framework Convention on Climate Change sets targets for the industrialized countries to reduce their emissions of greenhouse gases by the period 2008–12. Analysis of the Protocol, the refusal of the USA to sign it, and the subsequent revisions to the Protocol in later Conferences of Parties, suggest strongly that the Protocol will secure little or no change in rates of global warming (see Böhringer, this issue). Accordingly, if global warming is to be tackled, 'Kyoto 2, 3' etc. need to be developed very soon. Debate surrounds the reasons for the highly probable failure of Kyoto to be environmentally effective (for an excellent discussion see Barrett, 2003), but the low participation rate in the agreement can in part be explained by individual countries' assessments of the costs and benefit to them of compliance with the targets. Certainly, the USA's stance can be ex-

[1] I am indebted to Richard Tol of the University of Hamburg and Rob Mendelsohn of Yale University for comments on an earlier draft. Any remaining errors are entirely my responsibility, as are the views expressed here.

plained by (*a*) a perception that the domestic costs of compliance are high, (*b*) recent work suggesting that the benefits of control are very low for the USA, and (*c*) the realization that future agreements will require significant side payments to developing countries to bring them 'on board' with the Protocols. Country-focused cost–benefit analysis is sufficient to explain the contrast between Kyoto and the Montreal Protocol on ozone-depleting substances. In the latter case, benefits are huge, and domestic costs and side payments very low (Barrett, 2003). Central to cost–benefit analysis are estimates of the total and marginal damage to the world as a whole, and to major players, from greenhouse-gas emissions. The benefits of control are approximated by the fraction of damage that can be avoided by taking preventive measures, although benefits may exceed the amount of avoided damage because of ancillary benefits. Ancillary benefits include any reductions in non-greenhouse emissions, e.g. jointly produced particulates, acidic pollutants, etc. This paper surveys what is known about the damage from greenhouse gases, focusing on carbon dioxide (CO_2) as the main gas. The purpose of the paper is to highlight legitimate differences of view about carbon damage, and to show that, while a monetized damage figure cannot, and should not, be avoided, analysis of the consequences of choosing a specific figure is of the utmost policy importance. Once selected, a value for the marginal damage of carbon must be applied consistently across all policy areas. The problems of this consequentialist approach are discussed in the context of the UK government's decision to opt for a 'high' shadow price of carbon, at £70 per tonne of carbon (henceforth, tC). It is important to recognize that, while the discussion is framed within the context of UK climate-change policy, there are more general lessons to be learned about (*a*) the interpretation of warming damage estimates in integrated assessment models, and (*b*) the need to assess the implications of selecting one shadow price (for any environmental impact) rather than another.

II. MONETIZING THE DAMAGE FROM GREENHOUSE GASES

The social cost of carbon refers to the estimate of the monetary value of world-wide damage done by anthropogenic CO_2 emissions. More precisely, the 'social cost of carbon' is defined as the monetary value of the damage done by emitting one more tonne of carbon at some point of time. The usual time reference is the current period, but the resulting 'marginal damage cost' can be expected to rise for future emissions owing to the fact that greenhouse gases cumulate in the atmosphere. Damage is a function of the cumulated stock, so one extra tonne in the future will have a higher associated damage than an extra tonne released now. Additionally, as incomes grow, so the monetary value of damage is likely to grow, owing to an associated higher willingness to pay to avoid warming damage. For ease of exposition we focus on the marginal damage done by emitting 1 tC (or carbon equivalent) now, leaving aside the fact that future marginal damages will rise.

As is well known, CO_2 is the oxidized form of carbon, and is the major greenhouse gas implicated in projections of global warming. The social cost is the damage done by CO_2 emissions compared to a baseline context in which those emissions do not increase. But it does not follow from this that the correct or socially desirable level of emissions is such that this social cost is zero. There are two reasons for this. First, greenhouse gases have long residence times in the atmosphere, so that climate damage today and in the near future is the result mainly of past, irreversible emissions. Since nothing can be done about those emissions, the relevant 'policy window' relates to the difference between projected levels of warming from 'doing nothing' and the level of warming that will occur anyway, owing to time lags in the climate system. Second, the socially optimal level of any pollutant or hazard is rarely zero. This is because reducing pollution is not costless. It makes sense to reduce pollution so long as the benefit of doing so exceeds the costs. But as soon as a further incremental ('marginal') reduction in pollution incurs greater costs than benefits, that is the time to declare the policy measures optimal and not go any further. As we shall see, while simple to state, this cost–benefit rule is immensely complicated to formulate in practice in the global-warming context.

It is not necessary for this estimate of social cost to be precise. Few magnitudes in economics or in policy analysis are precise. Acting on reasonable estimates is better than acting on no estimate, because the latter course of action necessarily implies a social cost. If there is uncertainty about a social-cost estimate, that uncertainty does not magically disappear by not adopting the social cost estimate. Indeed, as Thomas (1963) pointed out 40 years ago, it is not logically possible to avoid monetary valuation in the all-pervading contexts where policies cost money. If a policy costs $*X* then adopting the policy implies benefits must be at least $*X* and not adopting it implies that benefits are less than $*X*. Despite the cost–benefit logic, a substantial part of the policy-oriented literature on warming control either ignores, or explicitly rejects the commensurability of costs and benefits.

For a cost–benefit approach it is, of course, also necessary to have some idea of the costs of control, e.g. through energy conservation, slowing deforestation, switching to low- and non-carbon energy technologies, and so on. Curiously, looking at what it costs an economy to adopt warming-control policies tends to be widely accepted in the policy-oriented literature. What many people want is to avoid monetizing *benefits*. They prefer to set a target based on some principle or other, and then minimize the costs of achieving the target. This is cost-effectiveness, not cost–benefit analysis. But cost-effectiveness cannot answer the question: *how much* should we abate? It can only answer the question: which of several competing policies should be chosen, *given* that we must choose one or other of those policies? The focus therefore shifts to the criteria for setting the target.

Opponents of monetization argue that the way economists measure cost and benefit produces an inequity. A cost is any loss of well-being and a benefit is any gain in well-being. Those losses and gains are measured through the notion of willingness to pay (WTP) to avoid a loss or WTP to secure a gain. They might equally well be measured by willingness to accept compensation (WTA) to tolerate the loss or forgo the benefit. WTP and, less so, WTA are self-evidently influenced by wealth and income. Other things being equal, WTP will vary directly with income. Hence richer people get a bigger 'vote' than poor people. The 'unequal votes' argument appears especially powerful in the context of global warming, since, as climate-damage models show (e.g. Tol, 2002*a*,*b*), those who stand to lose most relative to their income levels are the poorest in the world. Markets work by allocating resources according to WTP, so opposition to the standard economic approach tends to be associated with a wider opposition to markets generally as a means of allocating resources in society. Not all of these critics make this connection. If they did, they might, however, argue that global warming is 'something special', i.e. it is all right to have market-determination of resource allocation for most things, but not for global warming control. This is an argument for 'ring fencing' global warming from other policy areas, and we return to it later. The essential point is that how 'equity' is treated affects the size of the social-cost estimate, as we shall see.

While the argument for rejecting market allocation of resources is based on equity concerns, it actually produces its own problem of equity. Unless global warming itself lowers future average incomes in poor countries—a prospect that some genuinely believe will be the case—action taken now will be for the benefit of communities who will be richer than the poorest people today. No global-warming model projects future incomes to be less than incomes today. Since action has an opportunity cost, it follows that the sacrifice of resources today could be at the expense of transfers of income to poor people today. If so, the poor today may bear sacrifices in terms of forgone benefits in order to benefit their richer descendants. As Schelling (1992, 1998) has argued, one reason for the higher economic sensitivity to damage in poor countries is that poor countries are more dependent on climate-sensitive economic activity than are rich countries. It may pay, therefore, to divert funds allocated to preventing climate change to improving economic development in poor countries so as to reduce their vulnerability to climate stress. This would have the added benefit of improving the well-being of the poor now. The relevant comparison is that of costs to poor people now from forgone development with benefits to their descendants in the future. While the Kyoto Protocol makes some provision for funding adaptation to climate change, the dominant theme of the Protocol is prevention through emission reduction.

Second, monetization as a measure of human preferences implies that those whose preferences should count are those who are living and present. Those yet to come—the future generations—cannot vote and, hence, appear to have no say. Yet it is they who will suffer the effects of warming, and at least some responsibility for that warming rests with the current generation. By definition, then, counting only current preferences disenfranchises future generations and must surely understate the 'true' social cost of carbon. Once again, these are telling points, but they are not as obviously destructive of the cost–benefit approach as they first appear. There is nothing in economics that says that any individual today is motivated solely by self-interest and that they are indifferent to other humans now or in the future, or even that they are indifferent to non-human well-being. If self-interest alone motivates choices, it would be hard to explain savings behaviour and charitable donations, for example. Future generations are not *necessarily* disenfranchised by the cost–benefit approach. It depends on what motivates preferences now. None the less, it is true that individuals will not feel the same way for persons to come in 10,000 years' time as for persons to come in 100 years' time. There will be 'time discounting', an issue to which we return. But even if future generations are no richer than we are, and even without discounting, it is unclear that reducing savings today to combat global warming is a better option than keeping savings high so as to leave a larger capital stock to future generations. This is Schelling's cost–benefit point again.

Ekins (2000) criticizes Schelling for 'missing the point' because the 'arguments for development aid are quite different from those relating to whether rich country lifestyles should cost poor country lives'. But they are not at all different. Aid is a transfer from rich to poor. Spending money on warming control does not benefit the poor now, and, by virtue of opportunity cost, is equivalent to not giving aid now. If the distinction is meant to be a moral one, not giving aid costs poor country lives now. Global warming costs poor people lives in the future, but those poor people are probably better off than poor people today. The idea that a deliberate commission of harm is morally different to the equally deliberate failure to do good when the agent knows that doing good is feasible, cannot be sustained.

A more philosophical critique is that of Spash (1994) who argues that (*a*) future generations have 'rights' to a stable global environment and (*b*) the harm from warming cannot be 'undone' by doing good through leaving them higher capital stocks. The non-compensability of harm is usually illustrated by saying that one cannot offset a murder by then doing good. But, it is hard to imagine any policy that would pass a test of 'do no harm' to unrepresented individuals. The brute fact of human existence necessarily implies imposing costs on future individuals, including costs of forgone lives. Moreover, much of the justice system, domestic and international, is based on the idea that harm can indeed be offset by good deeds. The 'do no harm' principle therefore tends to imply an illusory world in which there are no trade-offs. Further, it is philosophically unclear that non-existent future generations have 'rights' to anything, since the possession of rights is predicated on the existence of the individuals in question (Pasek and Beckerman, 2001).

The third objection to monetization is that it implies inappropriate fine-tuning in a context where damages are likely to be catastrophic, akin to past massive extinction periods. If the scenario is for the end of the world (as we know it) in the near future, it would obviously make little sense to talk about costs and benefits. The costs of damage would be extremely high at the margin. Indeed, cost–benefit analysis requires that the variance of the net benefits from climate-change control are finite (Tol, 2002*d*). If total catastrophe is feasible, then the variance would be infinite. The only rational action would appear to be to stop global warming immediately. But this is an empirical question, not a certainty by any means. No one appears to argue that catastrophe consists of the destruction of the entire human race. Rather, the kinds of events that are discussed are the melting of the West Antarctic ice sheet or reversal of the gulf stream. Thus it seems more correct to refer to extremely high marginal damages occurring with some unknown probability, rather than marginal damages being infinite. Even if catastrophe were a certainty, *when* it happens matters. If it happens in 10,000 years that is quite different to it happening in 100 years unless we believe that all lives are 'equal' regardless of when they occur (which is, however, what some people believe; see, for example, Broome, 1992).

So, there is uncertainty about the scale of damage and uncertainty about when that damage will occur. The appropriate action to avoid catastrophe still has to be informed by some notion of what it costs to avoid it, what the likelihood is of it occurring, when it occurs, and the degree of risk aversion. Deciding how averse we are to these risks in turn implies some assessment of the damages from catastrophes, and this is, in fact, a feature of more recent attempts to measure the social cost of carbon—see, for example, Downing *et al*. (1996), Gjerde *et al*. (1998), and Nordhaus and Boyer (2000). Costs and benefits still need to be compared.

The final objection to monetization is that it is not necessary in a context where the goal is one of *sustainable development*. Two competing interpretations of the meaning of sustainable development largely explain the differences in approach. An economic definition of sustainable development is framed in terms of rising per-capita levels of well-being through time. This definition says nothing about the time-horizon, but that might be inferred from analysis of preferences such that the 'end of time' is the future time where current concern for the future declines to zero. This reflects the point made earlier, namely that most people would not express a concern for humans 10,000 years from now, but might for humans 100 years from now. Clearly, this view is inconsistent with the notion that future generations have 'rights' to a stable or at least less warm environment than would otherwise be the case. An alternative interpretation is that sustainable development is about ensuring humans are present on Earth indefinitely. For example, Ekins (2000) says that 'The basic meaning of sustainability is the capacity for continuance [*sic*] more or less indefinitely into the future.' Just as the economic definition is hazy on the range of time over which per-capita well-being should rise, so this non-economic definition says nothing about per-capita well-being. It seems better to brand this notion of sustainability 'survivability'. The maximand becomes the survival time of humans on Earth. One obvious difficulty is that this maximand is consistent with each generation going to subsistence level in order to insure against threats to the existence of later generations. The result is akin to that arising from assuming that one should not discount the future, i.e. that the discount rate is zero (Olson and Bailey, 1981). The notion that one should not discount the future is a further example of the confusion embodied in non-economic approaches. Not discounting is formally equivalent to discounting at 0 per cent. Ekins (2000) criticizes economists for not knowing what 'the' discount rate is, but appears not to appreciate that discounting cannot be rejected. In any event, zero discounting produces the 'immiseration' result noted by Olson and Bailey (1981). In this sense, Ekins is consistent—setting survivability as a goal produces $N - 1$ generations with subsistence well-being, where N is the number of generations to come.

The conclusion of this discussion must be that costs and benefits always have to be compared, and this should be done explicitly rather than rejecting the approach and then adopting it under another guise.

III. MODELLING THE SOCIAL COST OF CARBON

The available quantitative estimates of the social cost of carbon emissions adopt models of varying degrees of sophistication. The essential linkages in all models are from emissions to atmospheric concentration, from concentrations to temperature change, and from temperature change to damage. The last link also involves an intermediate stage going from temperature change to sea-level rise. Highly simplified, the underlying form of the models is as follows. We work in discrete time for simplicity. This exposition relies on Nordhaus (1994) with some of the notation changed.

First, total damage done, V, from the emission of 1 tonne of greenhouse gas (say, carbon) will be equal to the present value of all future incremental damages, $\partial D/\partial E$, since the carbon resides in the atmosphere for a long period. Hence, with t denoting time, we have:

$$V = \sum_{0}^{T} \frac{\partial D_t}{\partial E_t} \cdot (1+s)^{-t}. \qquad (1)$$

In equation (1), s is the social discount rate. It is important to understand that equation (1) is an expression of the marginal damage cost of carbon. This records the change in the present value of all future damages from releasing one extra tonne of carbon in the present period. As noted earlier, since greenhouse gases are cumulative, the marginal damage figure will tend to increase with time. Population and income growth, as shown in equation (6), will also cause marginal damage cost to rise.

Second, atmospheric concentrations (C) of carbon are linked to emissions (E) via:

$$C_t = (1-\frac{1}{L}) \cdot C_{t-1} + \beta \cdot E_t \qquad (2)$$

where L is the residence time of carbon in the atmosphere and β is a factor that convert emissions (tonnes) into concentrations (parts per million). The first expression on the right-hand side captures the decay process, i.e. the rate at which carbon is removed from the atmosphere, e.g. by oceans.

Third, the link between temperature change and changes in carbon concentrations in the atmosphere constitutes the climate-change section of the model. Climate-change models are complex, but the essence is captured in two equations:

$$T_t^U = T_{t-1}^U + \frac{1}{R^U}\left[F_t - \lambda T_{t-1}^U - \frac{R^L}{\theta}(T_{t-1}^U - T_{t-1}^L)\right] \qquad (3)$$

$$T_t^L = T_{t-1}^L + \frac{1}{R^L}\left[\frac{R^L}{\theta}(T_{t-1}^U - T_{t-1}^L)\right]. \qquad (4)$$

T is temperature, U refers to the upper ocean layer and L to the lower ocean layer, R refers to the thermal capacity of the ocean layers, F is radiative forcing, θ is the transfer rate between upper and lower ocean layers, and λ is a parameter showing how much temperature changes for a given increase in radiative forcing. Equation (4) tries to capture the process whereby radiative forcing heats up the atmosphere, which then heats up the upper ocean, which then heats up the lower ocean.

Following Fankhauser (1995), the final basic equation links annual damage, D, to temperature, T:

$$D_t = k_t\left(\frac{T_t^U}{\Lambda}\right)^{\gamma} \cdot (1+\phi)^{t^*-t^\wedge}. \qquad (5)$$

The parameter Λ is the amount of warming (in °C) associated with a doubling of carbon-dioxide (CO_2) concentrations (by convention, doubling is always relative to pre-industrial levels); t^* is the year in which that doubling is expected to occur, usually taken to be 2050. If temperature rises by 1 per cent, damage, D, rises by γ per cent, i.e. γ links temperature and damage; ϕ is a parameter that makes impacts greater if they occur before t^* and lower if they occur after t^*—an attempt to account for damage being related to speed of change. If the temperature rise associated with $2\times CO_2$ is 2.5°C, then $\Lambda = 2.5$. If the temperature rise that actually occurs is 2.5°C, and if $t^* = t^\wedge$, then $D_t = k_t$ where k_t is the estimated damage done by $2\times CO_2$. This figure is estimated from 'bottom up' approaches whereby sectoral damage is estimated region by region (or, in the early studies, for the USA alone). Damage will rise with time owing to population growth and income expansion according to:

$$\frac{k_t}{k_{t-1}} = (1+\omega \cdot y_t + p_t) \qquad (6)$$

where y is the rate of growth of income per capita, p is the rate of growth of population, and ω is the income elasticity of willingness to pay to avoid damage. It is readily seen that the values of these three parameters can substantially influence estimates of future damage. For example, Fankhauser (1995) adopts a value of $\omega = 1.0$, whereas subsequent literature (Pearce, 2003) suggests that it is more likely to be 0.3–0.4. For a rate of income growth of, say, 2 per cent, $\omega \cdot y$ will be 2 per cent if $\omega = 1$, but only 0.6 per cent if $\omega = 0.3$.

Even with such a comparatively simple model, it is easy to see that differing estimates of the social cost of carbon are likely to emerge. The example of the assumed value of ω shows this. But there is also considerable debate about the choice of discount rate, and even the parameters in the climate section of the model. It should occasion no surprise that social-cost estimates will vary. The key parameters in such models are usually treated as being random, so that the actual figures reported by the models tend to be ranges.

To see how the model works, we borrow the numbers in Fankhauser (1995): $\Lambda = 2.5°$, $t^* = 2050$, γ= range 1–3, with best guess 1.3, ϕ is random with best guess of 0.006, k_t is the damage done by $2\times CO_2$ warming, assumed to occur in 2050, and is \$270 billion. This is estimated from a 'bottom up' procedure of aggregating individual damages. Ignoring income and population growth, in any period t, annual damage is given by

$$D_t = \$270 \cdot 10^9 \cdot (T_t/2.5)^{1.3}(1.006)^{t^*-t}.$$

For the $2\times CO_2$ year, for example, T_t=2.5 and t^*=t, so the last expression is equal to 1, as is the second expression. D_t is thus \$270 billion. Suppose

Table 1
Aggregate Social Cost of Global Warming (% of world GNP)

Benchmark temperature increase for $2\times CO_2$ (Λ)	Pearce *et al.* (1996)	Mendelsohn *et al.* (1996)		Nordhaus and Boyer (2000)	Tol (2002*a*)
	2.5°C	1.5°C	2.5°C	2.5°C	1.0°C
Developed countries	n.a	+0.12	+0.03	–0.5 to +0.4	
Less-developed countries	n.a	+0.05	–0.17	–0.2 to –4.9	
World	–1.5 to –2.0	+0.10		–1.5	+2.3

Notes: + indicates a benefit, – a cost (damage).
Sources: Cited studies and Tol *et al.* (2000).

temperature is predicted to rise by 0.1°C per decade, then

$$D_{+10} = \$270\cdot10^9\cdot(2.6/2.5)^{1.3}\cdot(1.006)^{10} = \$301.3 \text{ billion.}$$

And so on.

IV. ESTIMATES OF $2\times CO_2$ DAMAGE (k_t)

While the policy focus of the social cost of carbon is on the estimates of marginal damage cost, it is useful to look at the various measures of aggregate world social cost. In integrated assessment (mixed climate and economic models) this aggregate is benchmarked on a scenario in which pre-industrial CO_2 concentrations are doubled. Table 1 assembles the available estimates. The studies shown are recent and are compared to the 'first generation' of models which were surveyed in the Intergovernmental Panel on Climate Change (IPCC) Second Assessment (Pearce *et al.*, 1996). The important feature of the post-1996 studies is that some of them make allowance for adaptation to climate change, and some include catastrophes. The role of adaptation can be illustrated by the 'dumb farmer syndrome'. Damage occurs to, say, crops and in the no-adaptation case the farmer simply suffers a loss of output and profits. In the adaptation case, efforts are undertaken to switch into climate-resistant crops. Climate change with adaptation is self-evidently far more realistic, but the scope for adaptation is also likely to be less in the developing world than the developed world. Hence, even under adaptation models, the poor are likely to lose more than the rich. This is borne out by the models (details are not shown here—see, for example, Nordhaus and Boyer, 2000). The main model involving adaptation is that of Mendelsohn *et al*. (1996) (see also Mendelsohn and Neumann, 1999). It can be seen on this model that, on balance, the world actually *gains* from CO_2 doubling.

The main model accounting for catastrophes is that of Nordhaus and Boyer (2000). The importance of catastrophes in their work is that they account for two-thirds of the world damages (1.5 per cent GNP loss with catastrophescompared to 0.5°C without catastrophes). Tol's recent work suggests the world might *gain* significantly at around 2 per cent of GNP. Overall, then, the recent work suggests a range of damages, the lower bound of which is consistent with the first-generation models surveyed by Pearce *et al*. (1996) and the upper bound of which is a significant gain in world GNP. These aggregate figures mask the differential impacts on developed and developing countries, so that an equity problem remains even if there are net gains overall.

V. ESTIMATES OF THE MARGINAL SOCIAL COST OF CARBON

Not all studies reporting warming damage costs, report marginal social costs. Table 2 brings together the various estimates. The basis of the table is the set of estimates gathered in Clarkson and Deyes (2002), but other studies have been added. Most studies calculate the present value of future losses at 1990 prices and using 1990 as the base year. Clarkson and Deyes correct the estimates for 2000 prices with 2000 as the base year. The effect of both adjustments is to make the estimates higher than they appear in the literature. The studies not in the Clarkson–Deyes document are marked with asterisks. Comparison is difficult because of (*a*) the differing methodologies in the studies and (*b*) variations in the underlying assumptions about climate sensitivity and economic parameters. All estimates are especially sensitive to the discount rate. In Table 2, variations in the discount rate are given for the 'pure time preference rate' (the rate at which well-being is discounted), ρ, and the overall social time preference rate, s. The relationship between the two is given by $s = \rho + \mu \cdot g$, where μ is the elasticity of the marginal utility of income function, and g is the expected growth rate in per-capita consumption. Methodologies differ according to whether they are (*a*) based on a cost–benefit analysis (CBA) model, in which case the marginal social cost of carbon is the marginal damage done at the optimal level of abatement, or (*b*) based on a 'marginal cost' (MC) approach, in which case incremental damage is measured relative to a small increase in emissions now. As Clarkson and Deyes (2002) note, the MC approach should yield higher estimates than the CBA approach. One other methodology is shown here. Schauer's study (Schauer, 1995) uses 'expert' valuations based on either getting experts to say what they think the most likely parameter values are, or getting them to estimate directly the marginal social cost. The usefulness of expert valuations is open to some question if those consulted have little or no experience in thinking about monetized damage.

What can be gleaned from Table 2? One problem in comparing studies concerns the discount rate. Values are reported for the pure time preference rate in some studies and for the overall discount rate in others. Assuming income growth of 2 per cent p.a and an elasticity of marginal utility of income of –1, a pure time preference rate of 1 per cent would correspond to a social discount rate of 3 per cent, and so on. On this assumption, the recent estimates clearly fall into two categories. The Nordhaus and Boyer (2000), Tol (1999), Roughgarden and Schneider (1999), and Tol and Downing (2000) studies all produce near-term estimates in the bracket \$4–9 tC for a discount rate of 3 per cent , and –\$7 to +\$15 for a discount rate of 5 per cent. Tol and Downing's estimate for a 2 per cent discount rate is \$20 tC. To some extent there is overlap: the Roughgarden and Schneider study uses Tol's estimates as an input. But Tol and Downing use a quite different model to Tol (1999). The second category is the Eyre *et al.* (1997) study, which produces around \$40–50 tC for $s = 3$ and \$20–37 tC for $s = 5$. The basic difference between the Eyre *et al.* study and the Tol–Downing study is that the latter incorporates adaptive behaviour. As noted above, it is a serious weakness of an integrated model if it lacks adaptation—see also Mendelsohn (1999). Plambeck–Hope (1996) is one of the few earlier studies to consider adaptation and non-adaptation within a single model. Without adaptation, marginal social costs are \$32 tC, with adaptation they are \$21 tC. The Eyre *et al.* study uses as one of its models 'FUND 1.6' which was developed by Tol. The Tol and Downing study, however, uses an update (FUND 2.0) which reflects the more recent literature on adaptation. Accordingly, the Tol–Downing figures are likely to be more reliable. The other major study, and one which has the virtue of also including catastrophes, is Nordhaus–Boyer. Since Nordhaus–Boyer is a CBA study and the Tol–Downing work is based on MC, we would expect the Tol–Downing estimates to lie above those of Nordhaus–Boyer on this criterion, but perhaps below it because of the greater sensitivity to catastrophe in the Nordhaus–Boyer model. In fact, the Tol–Downing range encompasses the entire range in Nordhaus–Boyer. The upper bound of Tol–Downing reflects a pure time preference of 0 per cent, and this is inconsistent with the Olson–Bailey (1981) argument that time preference must be positive. However, it is consistent with positive discounting for income growth. Note that the lower bound of Tol–Downing is negative, i.e. there are net global benefits. The value of \$3.5 tC for $\rho = 1$ can be compared to the Nordhaus–Boyer estimate for $s = 3$ of \$9.1. Since $s = 3$ is a reasonable representation of a social discount rate, the probable range of marginal (unweighted) damages is in the region of \$4–9 tC.

VI. THE UK GOVERNMENT AND THE SOCIAL COST OF CARBON

The UK government, via DEFRA, the Department for Environment, Food and Rural Affairs, released a document early in 2002 on the social cost of carbon (Clarkson and Deyes, 2002). This is a workmanlike

Table 2
Estimates of the Marginal Social Cost of Carbon $tC (no equity weights)

Study	Estimate $tC—base year prices: 2000			
	1991–2000	2001–10	2011–20	2021–30
Nordhaus (1991)				
MC, ρ = 1	9.9			
MC, ρ = (0,4)	3.0–194.9			
Nordhaus (1994)				
CBA, ρ =3, best guess	7.2	9.2	11.6	12.8
CBA, ρ =3, expected value	16.2	24.3	24.3	—
Nordhaus and Boyer (2000)*				
CBA, optimal carbon tax, s=3	6.4	9.1	11.9	15.0
Fankhauser (1995)				
MC, ρ =(0,0.5,3)	27.4	30.8	34.2	37.5
MC, ρ =0	65.6	—	—	84.5
MC, ρ =3	7.3	—	—	11.1
Cline (1993)				
CBA, s = 0–10	7.8–167.5	10.3–208.0	13.2–251.2	15.9–298.5
Peck and Teisberg (1993)*				
CBA, ρ =3	13.5–16.2	16.2–18.9	18.9–24.3	24.3–29.7
Maddison (1994)				
MC, ρ = 5	8.0	10.9	15.0	19.9
CBA, ρ =5	8.2	11.3	15.5	20.5
Tol (1999) (FUND 1.6)				
MC, s = 5	14.9	17.5	20.2	24.3
Roughgarden and Schneider (1999)*				
DICE model: lower bound = *k* value in Nordhaus, upper bound = *k* value in Tol	6.7–14.9	8.1–17.5	10.8–21.6	13.5–28.4
Schauer (1995)*				
Expert, parameters	11.20			
Expert, direct	144.0			
Tol and Downing (2000)				
MC, ρ = 0		19.7		
MC, ρ = 1		3.5		
MC, ρ = 3		–6.8		
Plambeck and Hope (1996)* PAGE model				
ρ = 2	58.9			
ρ = 3	26.9			
Eyre *et al*. (1997)[a]		1995–2004	2005–14	
MC, s = 1		109–110	119–120	
MC, s = 3		42–53	49–63	
MC, s = 5		20–37	25–47	

Notes: [a] The range of values in the Eyre *et al*. study derives from two different models, FUND 1.6 and OF (Open Framework). See the text for a discussion of these figures. The values in Tol and Downing are the *unweighted* estimates for FUND 2.0, whereas Clarkson and Deyes (see below) report only the weighted results.
Sources: Clarkson and Deyes (2002) and own estimates based on the cited literature.

Table 3
Comparison of Eyre *et al.* and Clarkson–Deyes Revisions (FUND 1.6 model only) (unweighted, 2000 prices)

	s = 1%	*s* = 3%	*s* = 5%
Emission date 1995–2004			
Original Eyre *et al.* figure \$tC: assumed to be discounted to 1990	73	23	9
Clarkson–Deyes figure \$tC: assumed emission date 2000	109	42	20
Emission date 2005–14			
Original Eyre *et al.* figure \$tC	72	20	7
Clarkson–Deyes figure \$tC: assumed emission date 2010	119	49	25

Sources: Eyre *et al.* (1997) and Clarkson and Deyes (2002).

and well-researched document. Interestingly it was not released as a DEFRA publication but as a Government Economic Service Working Paper. It does not, therefore, appear with any of the other publications on climate-change policy, but in a format likely to be accessed only by diligent researchers. It carries a disclaimer to the effect that the views in the document are those of the authors and not necessarily those of DEFRA. However, a later document from DEFRA gives official guidance for 'Whitehall' on the use of the £70 tC figure that emerges from the Clarkson–Deyes paper—see DEFRA (2002). At the time of writing, the figure of £70 tC is under review.

While the literature surveyed in Clarkson–Deyes is generally well documented (the main exception is the Nordhaus–Boyer work which is significant and is not mentioned), the conclusion is starkly at odds with that reached here at the end of the last section. Our conclusion was that an unweighted 'price' of \$4–9 tC, or, roughly, £3–6 tC is probably about right. The conclusion in Clarkson–Deyes is that the right price is £70 tC, 4–23 times as high.

There are two basic explanations for the difference in these estimates. First, Clarkson–Deyes opt for the Eyre *et al.* study as being 'more sophisticated'. Second, they then double the figures for equity weighting.

Clarkson–Deyes opt for the figures in the Eyre *et al.* (1997) study, which they revise as follows. Two adjustments are made to the original figures: (*a*) an adjustment for inflation to convert 1990 prices into 2000 prices. This is implicitly put at 28 per cent in the early text but cited as 35 per cent in Table 1 of Clarkson–Deyes and elsewhere in the text; and (*b*) an adjustment for the base year of emissions. Table 3 shows the original Eyre *et al.* figures (both *without* equity weighting) and the Clarkson–Deyes figures. Clarkson and Deyes appear to have been slightly influenced by the fact that Eyre *et al.* is based on FUND 1.6 and is considered as peer-reviewed, but FUND 2.0, underlying the Tol–Downing paper has not been peer-reviewed. Events have overtaken this remark, however, as FUND 2.0 has been peer-reviewed and the results are published (see Tol, 2002*a*,*b*). The Eyre *et al.* study has not in fact been published other than as a working paper for the 'ExternE' programme, an EU programme that monetizes pollution impacts from energy and transport. But models based on FUND 1.6 have been published by Tol. Tol has since produced yet another update: FUND 2.4—Tol (2002*c*).

Assuming the inflation adjustment is 35 per cent for converting 1990 prices to 2000 prices, then all the original figures in the Eyre *et al.* study need to be multiplied by 1.35. The remaining element is then the adjustment for changing the baseline period for emissions. Whereas the other studies use 1991–2000 as the base year for emissions, the Eyre *et al.* study uses 1995–2004, an apparent difference of 4 years. One would therefore expect the upwards adjustment to be $(1+s)^4$ for the base year and $(1+s)^{14}$ for the next period. In fact, the Eyre *et al.* study uses 1990 as the base year (Tol, personal communication) and *not* the reported period of emissions. If so, an adjustment of 10 years is required, i.e. $(1+s)^{10}$. This is consistent with the Clarkson–Deyes estimates.

The choice of the Eyre *et al.* study is more problematic, for the reasons outlined earlier. Including adaptation in the models is important, even on the basis of common sense. But FUND 1.6, the model underlying the Eyre *et al.* figures, excludes adaptation and FUND 2.0, which underlies the Tol–Downing figures, includes it. Clarkson and Deyes cite Tol *et al.* (2000) as suggesting that FUND 2.0 may be 'optimistic, perhaps too optimistic'. However, Tol and Downing (2000) also remark that 'FUND 1.6 . . . may be too pessimistic'.

VII. EQUITY WEIGHTING

The second major adjustment in the Clarkson–Deyes study is for equity weighting. It was noted earlier that, expressed as a proportion of per-capita incomes, damage from global warming is higher in the developing world than in the developed world. An obvious issue of equity arises since $1 of damage to a poor person should attract a higher weight than $1 of damage to a rich person. In the original survey of damage estimates for the IPCC, Pearce *et al.* (1996) noted that damage estimates were based on willingness to pay, and they showed how equity weights could be introduced. Subsequent and somewhat manipulated criticism of the absence of *actual* equity-weighted estimates in the IPCC report produced a sequence of revised estimates using various forms of equity weighting (Tol *et al.*, 1996, 1999; Fankhauser *et al.*, 1997*a*,*b*). One obvious problem with equity weighting is that any number of social-welfare functions (SWFs) can be postulated, each producing different weightings and hence different overall climate-damage figures and different marginal social-cost estimates. However, just like 'not discounting', 'not equity weighting' implies a value of an equity weight equal to unity, i.e. $1 of damage to a poor person is treated as if it is the same as $1 of loss to a rich person. Hence, there is no procedure that avoids explicit or implicit equity weighting and it seems better to consider 'reasonable' SWFs and see what they imply for climate damage.

Two broad classes of SWF are (*a*) the utilitarian SWF and (*b*) the 'Rawlsian' SWF. (For more discussion of other SWFs and the choice of weighting factors, see Tol , 2001; Azar, 1999; Azar and Sterner, 1996). Applied to global warming damage, these are given by

$$D_{WORLD} = \sum_i^n D_i \cdot \left[\frac{\bar{Y}}{Y_i}\right]^{\varepsilon} \tag{7}$$

and

$$D_{WORLD} = D_P \cdot \left[\frac{\bar{Y}}{Y_P}\right]^{\varepsilon}. \tag{8}$$

In equations (7) and (8), Y is income, $\bar{Y}$ is average world per-capita income, Y_i is income of the *i*th person, P refers to poor people, D is damage, and ε is the elasticity of the marginal utility of income schedule, a measure of 'inequality aversion'. In (7), damage to all individuals counts, but anyone below the average world per-capita income secures a weight greater than unity, and anyone above secures a weight below unity, the size of the weight varying with the degree of inequality aversion. In (8), only damage to poor people counts; all other damage is given a weight of zero. One paradox in using a Rawls-type welfare function is that global damages are less than if no weights are used at all, implying a lower marginal social cost of carbon and less global action. See Fankhauser *et al.* (1997*a*,*b*) and Tol *et al.* (2003) for a discussion.

Generally, SWFs of the form shown in (7) have been those used in illustrating the effects of equity weighting on global warming damage. It can be seen that what matters is then the distribution of the initial level of damage between rich and poor regions, the income disparity between rich and poor, and the value of ε. Since, by and large, there is little dispute about real income data, variations in the estimates of global damage will therefore derive from the values chosen for D_R/D_P and ε.

To illustrate how the SWF is estimated, we rewrite it as:

$$D_{WORLD} = D_R \cdot \left[\frac{\bar{Y}}{Y_R}\right]^{\varepsilon} + D_P \cdot \left[\frac{\bar{Y}}{Y_P}\right]^{\varepsilon} \tag{9}$$

where R = rich and P = poor. Crude estimates of the relevant magnitudes are then D_R = $216 billion and D_P = $106 billion, for $2 \times CO_2$ (Fankhauser, 1995); Y_R = $10,000, and Y_P = $1,110; and $\bar{Y}$ =

\$3,333. Substituting in (9) produces estimates of world damage of

unweighted	\$322 billion
weighted, $\varepsilon = 0.5$	\$307 billion
weighted, $\varepsilon = 0.8$	\$343 billion
weighted, $\varepsilon = 1$	\$390 billion
weighted, $\varepsilon = 1.5$	\$600 billion.

Despite the rough and ready nature of the exercise, these numbers are consistent with those produced in Fankhauser *et al*. (1997*a*). In that paper, $\varepsilon = 0.5$ makes hardly any difference to the unweighted damage estimate, and $\varepsilon = 1$ produces a 25 per cent increase on the unweighted damages. Only if $\varepsilon > 1$ do the aggregate damages increase markedly. In contrast, Tol's (1995) estimates of total damage increase by nearly 70 per cent on the unweighted damages for $\varepsilon = 1$. The reason for this is that Tol has a larger share of world damages accruing to the developing world. The value of ε obviously matters. The value of ε in Eyre *et al*. is unity, and Clarkson and Deyes also opt for a value of unity, based on a survey of some of the literature.

Two issues now arise. First, is $\varepsilon = 1$ the correct estimate of ε? Second, even if $\varepsilon = 1$, what does it imply for a multiplication factor for the marginal social cost of carbon? As noted above, the answer to the second question depends on how estimates of aggregate damage are distributed between rich and poor countries.

VIII. THE VALUE OF ε

Clarkson and Deyes (2002) opt for a value of $\varepsilon = 1$. In their review of the previous literature, Pearce and Ulph (1999) observe that the apparent consensus in the literature on the value of ε such that $0.5 < \varepsilon < 1.5$ is based on a faulty reading of the literature. Details are not provided here, and the reader is referred to Pearce and Ulph (1999). However, one of the mistaken pieces of literature is that of Kula (1987) to which Clarkson and Deyes refer in support of their view that $\varepsilon = 1$. Clarkson and Deyes' second source of values for ε is an excellent survey paper by Cowell and Gardiner (1999). This survey suggests that work on savings behaviour implies a value of ε 'just below or just above one' (p. 31); that work on implied values of ε taken from UK tax schedules implies a range of 1.2–1.4; and that experimental work produces values of around 4. Cowell and Gardiner conclude that 'a reasonable range seems to be from 0.5 . . . to 4' (p. 33). The selected value in Pearce and Ulph (1999), based on the same savings models as are surveyed in Cowell and Gardiner (1999), is 0.8. Values below unity should therefore be entertained seriously. Values such as 4, however, imply a quite dramatic degree of inequality aversion and it is difficult to take such estimates seriously for policy purposes. To see this, consider two nations, rich and poor, with utility functions of the form:

$$U_i = \frac{Y_i^{1-\varepsilon}}{1-\varepsilon} \qquad i = R, P. \tag{10}$$

The ratio of the two *marginal* utilities is given by:

$$\left[\frac{Y_P}{Y_R}\right]^{\varepsilon}. \tag{11}$$

Suppose $Y_R = 10Y_P$ as is the case for international real-income comparisons between OECD countries and others. The range of social values is shown below, corresponding to various values of ε.

What this tells us is that at $\varepsilon = 4$, the social value of extra income to R is zero. At $\varepsilon = 1$, a marginal unit of income to the poor is valued ten times the marginal gain to the rich. At $\varepsilon = 2$, the relative valuation is 100 times. On this 'thought experiment' basis, then, values even of $\varepsilon = 2$ do not seem reasonable. A value of $\varepsilon = 1$ does seem feasible. Overall, looking at the implied values of ε in savings behaviour and at the thought-experiment above, values of ε in the range 0.5–1.2 seem reasonable.

IX. FROM UNWEIGHTED SOCIAL COST ESTIMATES TO WEIGHTED COST ESTIMATES

Clarkson and Deyes (2002) suggest that equity weighting with $\varepsilon = 1$ roughly doubles the unweighted estimates. As noted earlier, however, this depends on the distribution of absolute damages between rich and poor. Hence, the difference made by equity weighting to unweighted estimates of marginal social cost is model-dependent. Moreover, the multiplication factor varies with the discount rate, as one would expect. Table 5 reports the results for FUND 1.6, FUND 2.0, and OF ('Open Framework') which

Table 4
Effects of Inequality Aversion

ε =	0.5	0.8	1.0	1.2	1.5	2.0	4.0
Loss to *R* as a fraction of gain to *P*	0.31	0.16	0.10	0.06	0.03	0.01	~0

is also used in both Eyre *et al*. (1997) and Tol and Downing (2000). Results are shown only for near-term emissions.

The estimates of damage vary according to the discount rate and according to the methodology used for valuing statistical lives lost. The 'VSL' approach values a statistical life at the WTP for risk reduction divided by the size of the risk. This produces VSL estimates of several millions of dollars. The VLY (value of life year) approach seeks to avoid one of the problems with the VSL approach, namely that WTP appears to be very high for relatively small savings in life years. Hence, WTP for a saved life year appears more appropriate. However, the VLY approach adopted in Tol and Downing (2000) is that of the ExternE programme and it has been noted elsewhere that there is no economic rationale for this procedure (Pearce, 1998). None the less, we report the estimates here.

Table 5 suggests that the 'equity multiplier' varies with the model, the discount rate, and with the use of VSL or VLY. But all multipliers are contained within the bracket 0.9–3.6, embracing Clarkson–Deyes's 'rule of thumb' of doubling the estimates. This range also applies if FUND 2.0 is the preferred model.

X. DISCOUNTING

The sensitivity of social-cost estimates to the discount rate is well established. However, there is a further issue concerning the discount rate which is not addressed in any of the integrated assessment models, nor in the Clarkson–Deyes paper. They all assume a constant rate of discount, i.e. one that does not vary with time. Recent work is firmly suggesting, however, that discount rates for long-term issues such as global warming *decline* with time (Weitzman, 1998, 1999; Newell and Pizer, 2000, 2001; Gollier, 2002, forthcoming). The essence of these approaches is that either or both future discount rates and economic growth rates are uncertain. Uncertainty about the discount rate drives the results obtained in Weitzman (1998) and Newell and Pizer (2000, 2001), and uncertainty about future economic growth drives the results obtained in Gollier (2002). The argument can be illustrated by looking at uncertainty about the discount rate. What is uncertain is the *discount factor* (i.e. $1/(1+r)^t$), since this is the temporal weight attached to future periods in terms of today's preferences. Suppose the discount rate, and hence the discount factor, is not known with certainty and is a random variable. Suppose it takes the values 1 . . . 6 per cent, each with a probability of 0.167. Table 6 shows the relevant values.

While the weighted average (expected value) of the discount rate stays the same in all periods (3.5 per cent), the discount factor obviously varies with time. The value of the implicit discount rate, s^*, is given by the equation:

$$\frac{1}{(1+s^*)^t} = \frac{\sum DF_{t,i}}{n} \text{........} i = n \qquad (12)$$

where n is the number of possible discount rates, DF is the discount factor, and t is time. Table 6 shows that the 'certainty equivalent' discount rate goes down over time, even though the average discount rate stays the same for each period.

Uncertainty about the future value of the discount factor is thus sufficient to generate a time-varying discount rate. Just what the time-path of this rate is varies according to the model chosen for simulating the effects of the uncertainty. Newell and Pizer (2001) work with the Nordhaus–Boyer 'DICE' model of climate change and show that the marginal social cost of carbon in the model needs to be multiplied further by the following factors:

s = 2%: 1.07 to 1.56
s = 4%: 1.14 to 1.82
s = 7%: 1.21 to 1.95

Table 5
The Effects of Equity Weighting on the Marginal Social Cost of Carbon

	$s = 2$	$s = 3$	$s = 5$
FUND 1.6			
VSL unweighted	38.9	26.1	12.3
VSL weighted	109.5	73.8	37.0
Equity multiplier	2.8	2.8	3.0
FUND 2.0			
VSL unweighted	19.7	3.5	–6.8
VSL weighted	27.5	12.5	1.3
Equity multiplier	1.4	3.6	n.a.
VLY unweighted	6.1	5.1	4.1
VLY weighted	15.1	8.9	3.8
Equity multiplier	2.5	1.7	0.9
Open Framework			
Unweighted	74.5	45.8	16.3
Weighted	104.0	64.0	22.8
Equity multiplier	1.4	1.4	1.4

Source: Adapted from Tol and Downing (2000).

Table 6
Values of the Discount Factor and the Certainty Equivalent Discount Rate

s	DF_{10}	DF_{50}	DF_{100}	DF_{200}
1	0.9053	0.6080	0.3697	0.1376
2	0.8203	0.3715	0.1380	0.0191
3	0.7441	0.2281	0.0520	0.0027
4	0.6756	0.1407	0.0198	0.0004
5	0.6139	0.0872	0.0076	0.0000
6	0.5584	0.0543	0.0029	0.0000
Sum	4.1376	1.4898	0.5900	0.1589
Sum/6	0.7196	0.2483	0.0983	0.0265
s^*	3.34%	2.82%	2.34%	1.83%

Notes: DF_{10} = discount factor for year 10, etc. s^* is the value of s that solves the equation shown in the text.

where the ranges reflect two different approaches to simulating future uncertainty based on long-run historic interest rates in the USA. While Newell and Pizer do not consider equity weighting, the multiplication procedure is just as applicable to equity-weighted damages as it is to unweighted damages. This suggests that there are two potentially major adjustments to unweighted social-cost estimates, one for equity across current generations and one for time-varying discount rates.

XI. CONCLUSIONS ON THE MARGINAL SOCIAL COST OF CARBON

We conclude that the 'base case' estimate of the marginal social cost of carbon is \$4–9 tC without equity weighting and using a constant discount rate. This may *understate* damage due to the omission of very major catastrophes and due to the omission of 'socially contingent' damages, e.g. the costs of any induced mass human migration. However, the range may *overstate* damage because the integrated assessment models generally exclude any amenity benefits from global warming. That the amenity benefits may be significant is evidenced by the contributions in Maddison (2001*a*). For example, Mendelsohn (2001) finds that warming generates potential benefits to the US economy of some 0.5 per cent of its GNP. Frijters and van Praag (2001) find some benefits to Russian households, Maddison (2001*b*) finds beneficial amenity effects in the UK, while Maddison (2001*c*) finds evidence of a small net cost in India. While Clarkson and Deyes (2002) stress the likelihood of understatement of costs, they make no mention of potential amenity benefits.

Assuming $\varepsilon = 1$, and applying the lowest equity weight to the highest discount rate, and the highest weights to the lowest discount rate, equity weighting changes the marginal social-cost estimate from \$4–9 tC to \$3.6–22.5 tC. In UK sterling this is around £2.4–15 tC, compared to the Clarkson–Deyes estimate of £70. Thus the choice of model matters enormously. Choosing a model with high baseline unweighted marginal social cost automatically produces a very high equity-weighted estimate. Moreover, this range makes no allowance for values of ε less than and greater than unity. So, it would be easy to expand the range in terms of both the lower and upper bounds.

The effect of allowing for time-varying discount rates is to raise both sets of estimates by perhaps 80 per cent again, taking the upper bound of the Newell–Pizer estimates (which they prefer). This would make the Clarkson–Deyes estimates around £126 tC, and the estimates suggested here about £4.3–27 tC.

XII. SOME POLICY IMPLICATIONS OF THE SOCIAL COST OF CARBON ESTIMATES

The previous sections discuss the £70 tC figure in the context of the models from which the estimate was derived. Clearly, there is always room for debate over the choice of models, but the suggestion here is that the £70 tC figure is too high. There is, however, a second way of analysing the correctness or otherwise of the £70 tC estimate. The DEFRA (2002) guidance on the £70 tC figure very correctly points out that, whatever the figure is, it should be used consistently across government departments. Hence, a second approach to analysing the correctness of the estimate is to see what it would imply in some selected policy areas. If those implications are, in some sense, unacceptable, then the figure should be treated with caution. However, before looking at some of the policy implications, arguments for 'ring fencing' the £70 tC figure need some discussion. The argument here is that £70 tC is the 'right' figure to use in the context of global warming, but that this has no implications for any other policy. As noted above, the DEFRA (2002) guidance acknowledges the generality of the shadow price, i.e. it should be used in all relevant policy applications. But the Clarkson–Deyes paper takes a different view, arguing that equity weighting is central to the £70 tC figure, but that equity weighting need not apply outside the global warming context.

Equity weighting has a firm rationale in what might be termed unreconstructed utilitarianism. On this approach, what matters are 'utils' rather than magnitudes reflecting willingness to pay. Hence, some form of equity weighting is justified on moral utilitarian grounds. Other moral judgements will produce different sets of weights. Economics has nothing to say about which welfare function should be chosen. Indeed, it is not easy to think of a meta-ethical principle that would justify one function rather than another. None the less, those functions illustrated earlier tend to be the ones that have influenced the climate-change literature.

But once equity weighting is adopted, it has to be adopted consistently. One virtue of policy appraisal procedures is that they provide a framework for at least guiding policy measures so that they allocate resources *across* government expenditures in a consistent manner. On this basis it is not logical to argue that equity weighting applies to global-warming control but not to any other form of government policy. Clarkson–Deyes come too close to arguing that global-warming control is generically different to other policies:

> The fact that the developed world is responsible for the majority of the damage inflicted makes this issue different to foreign aid and other similar policies. Equity weighting goes some way to incorporating the full impact of our

emissions on others into our policy making, which is in line with the polluter pays principle. (p 52)

But, as noted earlier, trying morally to ring-fence global warming control from all other policies is indefensible. *Not* giving foreign aid imposes a potentially substantial cost on the developing world and that is an act of deliberate policy. Using resources to combat global warming is at the potential expense of foreign aid and other transfers. The World Bank estimates that OECD country policies of industrial and agricultural protection cost the developing world over $100 billion per annum *now*, twice the annual flow of official aid (World Bank, 2002). It is hard to see any empirical or moral distinction between action that damages the immediate well-being of the poor, and which does so quite consciously, and warming damage from rich-country emissions that will affect mainly future generations. Equity weighting in which the weights are not unity is not, therefore, an option for one area of policy and not for others. Yet, once that is accepted, the implications for appraisal procedures are substantial. Interestingly, and for the first time, UK Treasury appraisal guidance quite explicitly recommends equity weighting (HM Treasury, 2003, ch. 4 and Annex 6). However, it is unclear from the text if the full implications have been recognized. First, one of the criteria for deciding whether to use equity weighting is 'whether there is an explicit distributional rationale to the proposal under consideration' (p. 49). This would obviously fit foreign-aid decisions, but it is not clear that the Treasury Guidance is meant to extend to this budget-level decision. It ought clearly to affect any decision about state aid to agriculture and industry, both of which have formidable implications for the well-being of poor nations. Second, the Treasury text reads as if the decisions to be appraised with equity weights are those that are confined to UK geographical boundaries, i.e. the relevant weights are to be applied to the social distribution of income within the UK.

(i) Does UK Climate Policy Pass a Cost–Benefit Test?

The UK is a member of the European Union and the European Union has ratified the Kyoto Protocol. This process of ratification makes the targets legally binding within the Union, regardless of what else happens to the Protocol. The burden-sharing agreement within the EU (revised at the subsequent Conferences of Parties) gives the UK a legally binding target of 88.8 per cent of 1990 emissions for all greenhouse gases. Hence, it could be argued that the relevant cost figure is not the marginal social cost of damage, but the marginal abatement cost at this level of emission reduction. The targets have been agreed and hence the *implied* total social cost of carbon must be above whatever the total abatement cost is, and the marginal social cost must be above the marginal abatement cost.

There are several powerful reasons for not adopting this argument. First, it comes close to falling into the trap noted at the beginning, namely that whatever governments agree to do is in some sense the 'right' thing. The purpose of appraisal procedures, such as cost–benefit analysis, is to cast light on those decisions and to check whether they meet reasonable criteria for justifying policy. Otherwise there would be no point in policy analysis: simply saying that the political process produces the 'right' answer is Panglossian—whatever happens happens for the best. Second, the UK government espouses cost–benefit analysis. Indeed, HM Treasury issues guidance on policy appraisal that makes it quite clear that cost–benefit analysis *should* be used to guide policy, while accepting that net benefit gains are not the only criterion for good policy (HM Treasury, 2003). Third, the Kyoto Protocol has to be the first in a sequence of Protocols or amendments—as noted, the Protocol itself does little or nothing to reduce rates of warming. While it might be expedient to allow ratification of one agreement that fails a cost–benefit test, it would seem distinctly unwise to allow ratification of future agreements if they systematically fail a cost–benefit test. As Clarkson and Deyes (2002) note, abatement costs are likely to rise through time, so that the cost burden on UK citizens will rise.

Does the UK's commitment to the Kyoto Protocol pass a cost–benefit test? Table 7 brings together the estimates and assumes that ancillary benefits from control are some £35 tC. Table 7 suggests that the UK has signed up to a treaty that passes a cost–benefit test, but only if ancillary benefits are significant. Some studies find these ancillary benefits to be negligible. On the basis of avoided damage alone, the cost–benefit test is met if and only if the 'official' figure of £70 tC marginal damage is accepted.

Table 7
The Kyoto Protocol and UK Costs and Benefits

	Marginal control cost	Marginal avoided damage	Marginal ancillary benefit	Marginal total benefit	Cost–benefit passed?
Kyoto	£ 45 tC	£70 tC	£35–50	£105–120	yes
		£16 tC	£35–50	£ 51–66	yes
CO_2 target	£100 tC	£70 tC	£35–50	£105–120	no
		£16 tC	£35–50	£ 51–66	yes

Time-varying discount rates obviously affect the outcome. As noted earlier, these would probably raise the marginal avoided damage figure (only) by around 80 per cent.

Similarly, the marginal cost of control, set here at £45 tC based on an estimate quoted by DEFRA, may be an overestimate. It is assumed to reflect abatement technologies within the UK, and excludes the potential for buying emission-reduction credits through the Kyoto 'flexibility mechanisms'. A notable possibility is the potential purchase of Russian 'hot air' which would very probably sell at far lower prices. ('Hot air' refers to the fact that Russia has emission targets above its likely actual emissions in 2010 and can hence sell the difference, even though this has no effect on emission reductions.) Equally, it is hard to envisage the United Kingdom purchasing hot air while maintaining a credible political image on environmental improvement. Even without hot-air trading, it is well known that trading *per se* lowers abatement costs, as does the use of policy measures such as taxes, the revenues from which are used to reduce other 'distortionary' taxes. For a review showing that estimates of marginal abatement costs vary enormously, see Hourcade and Shukla (2001).

Overall, UK climate policy may or may not pass a cost–benefit test, depending on the climate-damage model chosen, the role of ancillary benefits, the treatment of the discount rate, and the stance the UK takes with respect to emission trading. Public documents that produce social-cost estimates below estimated abatement costs have the potential for being politically embarrassing, but it is just as arguable that the emphasis that positive net benefit estimates give to emissions reduction may be at the cost of better directed policies, e.g. by investing in adaptation, especially in the developing world. The DEFRA guidance on the social cost of carbon (DEFRA, 2002) comes close to suggesting that the £70 tC figure is a convenient justification for the UK's climate-change policy to achieve its (modified) Kyoto target: 'In addition, the figure is likely to be at least roughly consistent with the level of effort that will be needed to meet our international commitments on climate change' (DEFRA, 2002, para.10).

(ii) Energy Policy: A Carbon Tax

Any carbon tax should, on cost–benefit grounds, be equal to the marginal damage from global warming at the point where marginal damage equals marginal control cost: the 'Pigovian' solution. Alternatively, if benefit estimation is not pursued, the tax should equal the marginal control cost at the target level of emission reduction. The UK does not have a pure carbon tax, but does have two taxes that are considered to be climate-related taxes. These are the climate change levy (CCL) and the fuel duty escalator (FDE).

The CCL is a tax on fossil fuels and electricity. While explicitly introduced as a climate-control tax, political considerations dictated that it would not vary directly with the carbon content of fuels. In other words, it is not, as it should be, a carbon tax. The 2000 Budget confirmed the following tax rates—there are several discounts and exemptions so that the effective tax rate is not easy to calculate. Here, we have taken the pre-allowance tax rates.

coal:	0.15 pence kWh
gas:	0.15 pence kWh
electricity:	0.43 pence kWh

These rates can be converted into carbon taxes as follows:

coal:	£16 per tonne C
gas:	£30 per tonne C
electricity:	£31 per tonne C

Clearly, if the CCL were a carbon tax, the tax rate per tonne of carbon would be the same. None the less, what we have is a range of £16–31 tC. This range can be compared to the £70 tC marginal damage figure. If marginal damages do not change with control effort—a reasonable first-cut assumption—then the correct 'Pigovian' tax rate is also £70 tC, two to four times the implicit carbon tax in the CCL. The £70 tC figure would, therefore, justify a substantial increase in the CCL, even allowing for the fact that the CCL is a long way from being a proper carbon tax.

The second form of carbon tax is the fuel duty escalator (FDE). The FDE was introduced in 1993 by the then Conservative government as a perpetual increase in the real price of petroleum fuels. It was also explicitly introduced as a climate-related tax, although in later years the message as to the purpose of the tax became very confused (Pearce, 2001). It was abandoned as an automatically rising tax in late 2000 after the 'fuel tax protests'. Taking the escalator between 1993 and 1999, the nominal increase in FDE amounted to some 21p/litre for gasoline and about 25p/litre for diesel (that is, the increase in fuel duty over and above 1993 levels; the 1993 levels were not environmentally motivated). In real terms—the relevant basis for the environmental component of the FDE—this was about 17p/litre and 21p/litre respectively. But a £70 tC marginal damage tax corresponds to a tax per litre of 4.4p for gasoline and about 5p for diesel (gasoline has 855 kgC per tonne, with 1,345 litres per tonne, i.e. 0.63 kgC per litre; for diesel the figures are 857 kgC per tonne, 1,190 litres per tonne, and hence 0.72 kgC per litre).

If the FDE was intended to be solely a carbon tax, then the tax rate went well beyond what would be justified by the £70 tC damage figure, by a factor of five, and even further beyond what would be justified by the lower marginal-damage figures suggested here. However, as noted above, the precise purpose of the tax became blurred over the years. Tax rates beyond 4–5p/litre could be justified by including other pollutants—as was implied in some public pronouncements.

(iii) Energy Policy: Choice of Fuel

It should also be obvious that the number chosen for the marginal social cost of carbon affects the design of energy policy. Consider the issue of the future of nuclear power in the UK. British Energy has not found it possible to compete in the electricity market in the wake of falling electricity prices. This is because nuclear electricity *private* costs are greater than, say, gas-fired electricity. But nuclear power could have a *social* cost less than its competitors once due allowance is made for the value of carbon. Nuclear power emits substantially less CO_2 over its life cycle than do fossil-fuel energy sources. Table 7 shows emission factors for different fuel cycles. The implication is that, at the £70 tC social-cost figure, nuclear power carries with it a 'carbon credit' of around 0.8 pence per kilowatt-hour (p/kWh) relative to natural gas, and over 1.5p/kWh relative to other fossil fuels. While these differentials are unlikely to make nuclear power competitive in social-cost terms compared to gas, they are very likely to tip the balance relative to other fossil fuels. If we adopt the maximum lower figure for the social cost of carbon suggested here, £15 tC, then the nuclear carbon credit is only 0.2p/kWh relative to gas, and 0.3–0.4p/kWh relative to other fossil fuels. These differentials are unlikely to tip the balance between nuclear power and its competitors. But enough has been said to show that the value of the marginal social cost of carbon matters significantly for the debate about the future of nuclear power in the UK. The 'official' value for carbon implies that that future is far more assured than if the lower values suggested here are used. A full analysis would also account for other greenhouse gases, such as methane, and also for conventional pollutants, such as particulate matter and nitrogen oxides. Time-varying discount rates would also affect the social cost of nuclear power (OXERA, 2002).

(iv) Energy Policy: Renewables

Policy on the introduction of renewable energy in the UK is driven by the 'Renewables Obligation', a requirement that electricity generators supply 10 per cent of their electricity from certified renewable sources by 2010. Proof of supply is via a Renewables Obligation Certificate (ROC). Failure to meet the target involves generators buying ROCs from those

Table 8
Carbon Emission Factors for Competing Fuel Cycles in the UK

Fuel cycle	Grams CO_2/kWh	Grams C/kWh	Carbon damage p/kWh at £15 tC	Carbon damage p/kWh at £70 tC
Coal	955–987	260–269	0.39–0.40	1.82–1.87
Oil	818	223	0.33	1.54
Orimulsion	905	247	0.37	1.73
Natural gas	446	122	0.18	0.84
Nuclear	4	1	0.00	0.00

Source: Emissions only from Bates (1995).

who have over-complied, or paying a 'buy-out' fee of 3p/kWh. Since renewables have private costs greater than current fuels, the Renewables Obligation comes at a resource cost, while the benefit is primarily (but not exclusively) in terms of the avoided carbon emissions. Accordingly, the Renewables Obligation has an implicit price. This has been put at £310 tC (*Utilities Journal*, 2001). Clearly, if the marginal damage from carbon is £70 tC, renewables policy fails a cost–benefit test, since it is costing £310 tC to secure a benefit of £70 tC. The difference, some £240 tC, is unlikely to be made up by other avoided pollutants.

(v) Forestry Policy

Growing trees sequester CO_2. Afforestation in the UK is widely regarded as being unprofitable in terms of commercial timber, but social arguments have been widely used to justify some forest expansion. The main non-timber benefits considered are recreational use and carbon sequestration. Brainard *et al*. (2003) estimate that the value of carbon sequestered in English woodland is some £770m p.a., using a social discount rate of 3.5 per cent. However, the Brainard *et al*. estimate is based on a shadow price of carbon of £6.7 tC (with 1 per cent p.a. increases). If £70 tC is the right shadow price of carbon, this annual value needs to be multiplied by a factor of ten, making annual sequestration worth some £7.7 billion. CJC Consulting *et al*. (2003) estimate the average English per-hectare value of sequestration at the £6.7 tC figure as £1,380. The £70 tC figure would raise this to £15,200 for broadleaves and £13,450 for conifers. As CJC Consulting *et al*. note: 'Here, the gains from planting are so large that rapid afforestation is called for' (p. 64). In short, the £70 tC figure would totally transform the economics of forestry in the UK.

(vi) Green Accounting and the Social Cost of Carbon

The value chosen for the social cost of carbon also affects any attempt to modify the national economic accounts for environmental damage. Conventional accounting measures gross and net national product (GNP, NNP) but fails to deduct from these measures any environmental damage. There is now a substantial literature that makes these adjustments—see, for example, Atkinson *et al*. (1997). The essential result is given by the identity:

$$gNNP = GNP - d_M - d_E$$

where gNNP denotes 'green' net national product, d_M is depreciation on conventional 'man-made' capital assets, and d_E is depreciation on environmental capital; d_E would then be measured by the value of the economic rents from depleted natural resources and the value of pollution damage. Focusing *solely* on carbon emissions and using the £70 tC figure for marginal social cost of carbon produces the following results for the UK:

GNP in 2000 at 2000 prices = £890 billion
CO_2 emissions in 2000 = 145m tC = £10.15 billion.

The £70 tC figure amounts to total damage equal to 1.1 per cent of GNP, compared to just 0.2 per cent if the lower value for carbon is used. Green accounting need not be confined to nations. Damage estimates can also be used to adjust corporate accounts. Note that the correct adjustment involves damage estimates, not control-cost estimates as is commonly and erroneously done in some 'corporate sustainability' accounts. Atkinson (2000) reports adjusted accounts for UK electricity generator, Powergen. These suggest that, once pollution damage is subtracted from operating profits, the resulting measure of 'genuine savings' shows net losses from 1992 to 1995, but a modest net gain in 1996. Effectively, Powergen was not 'sustainable' in social terms. Atkinson's value of carbon is £12 tC, so if this is raised to £70 tC, Powergen would be even less sustainable in the first few years and almost certainly for 1996 as well (Atkinson does not report emission figures). Once again, adopting a specific damage estimate requires that the implications be scrutinized. The £70 tC figure could have formidable implications for corporate accounting.

XIII. CONCLUSIONS

The central conclusions from this discussion are as follows.

(*a*) While the figures are necessarily uncertain, it is possible to estimate the aggregate and marginal social costs of greenhouse-gas emissions.

(*b*) The marginal social-cost estimates have a role to play in appraising climate-change policy, and especially in determining whether 'too much' or 'too little' abatement is being considered.

(*c*) Marginal social-cost estimates are model dependent. Recent models suggest quite wide ranges of estimates.

(*d*) Few early models incorporate adaptive behaviour, most being based on the 'dumb farmer syndrome'. Yet adaptation is clearly going to be an integral part of dealing with climate change.

(*e*) Those generally more recent models that have adaptive behaviour show marked reductions in social-cost estimates relative to those without such behaviour. While adaptive models may be 'too optimistic', it is equally likely that non-adaptive models have been 'too pessimistic'.

(*f*) Recent models suggest a range for the marginal social cost of carbon, without equity weighting, of £3–6 tC. Equity weighting, using a marginal utility of income elasticity of unity, raises this range to £3–15 tC.

(*g*) There is increasing evidence that the correct approach to discounting in the global-warming context is to use a time-varying discount rate. Borrowing estimates from recent US work, the £3–15 tC range should be multiplied by around 1.8 to give a range of £4–27 tC.

(*h*) A UK government document opts for a central estimate of the marginal social cost of carbon of £70 tC. The difference reveals the sensitivity of the estimates to the model chosen. The chosen model in this case largely excludes adaptation.

(*i*) At the lower set of estimates, UK policy in joining the EU in ratifying the Kyoto Protocol may not pass a cost–benefit test, and future Protocols or Amendments would be even less likely to pass a cost–benefit test. On the 'unofficial' UK government estimate of social cost, however, Kyoto would pass a cost–benefit test, but the domestic 'target' of 20 per cent reduction in CO_2 would not. Thus even this figure raises serious doubts about whether a second and third Protocol would meet the cost–benefit criterion. However, if time-varying discount rates are adopted, UK policy would pass a cost–benefit test both in terms of Kyoto and the 20 per cent carbon reduction target. Much also depends on whether control costs are being accurately portrayed here.

(*j*) The negative results for climate policy do not imply 'doing nothing', but rather point the way for a reappraisal of the balance between investing in emissions reduction and investing in adaptation, especially in developing countries.

(*k*) Equity weighting has a strong utilitarian rationale to it, but the choice of the utility of income elasticity is more open than UK government documents suggest. More importantly, once equity weighting is accepted, as it appears to have been in new UK Treasury appraisal guidance, it has to be applied consistently across all policies with distributive impacts within the UK *and* beyond. It is not defensible to argue that global warming is 'special' because the damage is the responsibility of the rich countries. Responsibility arguments are just as valid in other contexts, such as aid and trade protection. Efforts to ring fence global warming as if it is wholly separate from other policy concerns, and hence deserving of special treatment, are illicit.

(*l*) A second approach to assessing the 'reasonableness' of a social-cost figure is to investigate the policy implications. If energy policy was rationally decided on the basis of overall private plus external costs, the £70 tC figure would have major implications for nuclear power relative to fossil fuels, and there would be a sizeable but probably undecisive credit compared to natural gas. Prevailing 'carbon taxes' would need either to be increased (the Climate Change Levy) or acknowledged as too high (the Fuel Duty Escalator). Renewables policy in the UK fails a cost–benefit test even at the 'high' estimate of £70 tC, but such a figure would give the green light to extensive afforestation, a complete reversal of forestry policy in the UK. As far as green accounting is concerned, the £70 tC figure also produces a fairly dramatic adjustment to GNP of over 1 per cent, ignoring all other pollutants. The £70 tC figure is also like to have potentially dramatic effects on the 'sustainability' of some corporations.

What does seem to be clear is that the choice of shadow price for carbon, whatever it is, brings to light the serious inconsistencies in government policy on energy, climate control, and forestry. Getting the number right matters.

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