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The Aggregation of Climate Change Damages: A Welfare Theoretic Approach

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Abstract. The economic value of environmental goods is commonly determined using the concepts of willingness to pay (WTP) or willingness to accept (WTA). However, the WTP/WTA observed in different countries (or between individuals) will differ according to socio-economic characteristics, in particular income. This notion of differentiated values for otherwise identical goods (say, a given reduction in mortality risk) has been criticized as unethical, most recently in the context of the 'social cost' chapter of the IPCC Second Assessment Report. These critics argue that, being a function of income, WTP/WTA estimates reflect the unfairness in the current income distribution, and for equity reasons uniform per-unit values should therefore be applied across individuals and countries. This paper analyses the role of equity in the aggregation of climate change damage estimates, using basic tools of welfare economics. It shows one way of how WTP/WTA estimates can be corrected in aggregation if the underlying income distribution is considered unfair. It proposes that in the aggregation process individual estimates be weighted with an equity factor derived from the social welfare and utility functions. Equity weighting can significantly increase aggregate (global) damage figures, although some specifications of weighting functions also imply reduced estimates. The paper also shows that while the postulate of uniform per-unit values is compatible with a wide range of 'reasonable' utility and welfare specifications, there are also cases where the common-value notion is not compatible with defensible welfare concepts.

Key words: climate change impacts, valuation, welfare economics, aggregation, benefit-cost analysis

1. Introduction

The principles of willingness to pay (WTP) and willingness to accept compensation (WTA) that form the basis of economic valuation have a feature that some, particularly non-economists, often find irritating and even morally offensive: values depend on income. If the marginal rate of substitution between income and environmental services is decreasing with increasing income, as will normally be the case, rich people require a higher compensation, or are willing to pay more for a given change in environmental quality. One implication is that, in absolute terms, environmental damage imposed on a poor person is less important than the same damage imposed on a rich person. This is often considered unjust. Most recently, the issue has been raised in the context of climate change impacts, in particular the valuation of climate change-induced mortality risks (e.g., Ekins 1995; Meyer and Cooper 1995).

The basic concern is that, if it is to be contained, climate change involves significant policy measures to abate the emission of greenhouse gases. Deciding *how much* control to exercise is problematic. A benefit-cost test appears to fall foul of the inequity of economic valuation: many who will suffer the adverse consequences of climate change will be in the developing countries. If those adverse consequences receive low weights due to low (because income-dependent) WTP or WTA, then the benefit-cost comparison may result in limited action on global warming control. In particular, if human life is at risk, as it is with climate change, then the benefit-cost test may produce the result that less should be spent to 'save a life' in developing countries than in developed countries. 'Lives', it seems, are valued unequally, and it is this apparent implication that offends the critics.

Some authors have suggested to use uniform WTP/WTA values for all countries instead, either for all or a selection of damages. Usually they utilise values at WTP/WTA at OECD level (e.g. Ekins 1995; Hohmeyer and Gärtner 1992; Meyer and Cooper 1995). The approach is not without problems either, as values in developing countries now depend on the source of the risk. 'Lives' at risk through climate change are valued higher than domestic mortality risk, and hence it pays off to concentrate on saving those (implying that health care and development aid budgets should be cut in favour of greenhouse gas reduction expenditures).

Much of the controversy seems to have arisen from the fusion of the two separate issues: the valuation of environmental damages at an individual level, which is a matter of empirical analysis, and the comparison and aggregation of these effects, which is a political process involving ethical judgements on, among other things, the socially desirable distribution of income.[1]

There is nothing unfair *per se* in differentiated WTP/WTA values. Consider a situation where income is distributed fairly, i.e., in accordance with the prevailing notion of equity. This ideal distribution may or may not involve a uniform allocation of income across individuals. Under some welfare concepts it is acceptable to allocate higher incomes to certain people (for example, because they are gifted viola players, or have other useful talents), under others it is not. If income disparities are possible, differences in WTP/WTA will occur as a consequence of the privileged status society has granted to some individuals. In addition, people's WTP/WTA may differ because they have different preferences for environmental goods. In both cases, disparities provide important signals for decision makers which should not be ignored.

The situation changes if the income distribution is unfair. In this case, differences in WTP/WTA still manifest the privileged position of some (in addition to differences in taste), but this time there is no ethical justification for the higher status of these people. When comparing individual estimates or aggregating them, it now becomes necessary to adjust estimates according to the desired income distribution and the currently observed distortions.

The issue is not new. In the early debates on benefit-cost analysis a number of suggestions were made for integrating an equity judgement into the efficiency outcomes that benefit-cost dictates. An early discussion can be found in Pearce (1971). One such rule is to adjust WTP measures by the ratio of individual income, Y_i, to average income, $\overline{Y}$. That is, WTP_i^* is the equity weighted WTP_i such that

$$WTP_I^* = WTP_i \cdot \left(\frac{\overline{Y}}{Y_i}\right) \tag{1}$$

In this formulation, as long as $WTP_i/Y_i = WTP_j/Y_j$, i.e., if *WTP*s as proportions of income are the same across individuals, then the equity adjusted *WTP*s are the same.

More generally, social weights reflecting some judgement of the 'right' distribution of income can be integrated into benefit-cost analysis, indeed explaining why benefit-cost was prefaced with the term 'social' in the 1970s. The early manuals of benefit-cost analysis addressed this issue extensively – see for example Marglin et al. (1972) and Squire and van der Tak (1975).

None of the damage estimates surveyed in IPCC (1996a) have been corrected in this way. Three reasons (none of which is fully convincing) may be given to justify this omission. First, it could be assumed that the current income distribution is just, or that distributional issues do not matter. Such an assertion would clearly be hard to defend. Second, the combination of identical and linear utility functions with a symmetric, linear welfare function also leads to a situation where no equity weighting is necessary. There is only limited empirical support for this case. Although a linear welfare function is for example compatible with utilitarianism, the assumption of linear utility would be unusual. Third, it could be argued that distributional issues should not be mixed with global warming abatement. They should be dealt with separately. This third point is in keeping with perhaps the main criticisms that can be raised against equity weights. Equity weighting can be opposed on the grounds that investment projects are not an appropriate means of altering the distribution of income. In this line of argument, changing the income distribution is better reserved for wider macroeconomic and fiscal policy, as well as for specifically oriented projects targeted at the needs of the poor. Not least for this reason, equity weighting has fallen out of general use in applied benefit-cost appraisal. The argument has been refuted by Dreze and Stern (1987), however, who point out that as long as redistribution incurs costs, the impact of projects on the need for redistribution cannot be ignored. In the case of global warming, it can further be argued that objections raised in the narrow context of project appraisal should not apply to such a far reaching and globally pervasive issue as climate change.

Generalizing equation (1) above, this paper takes the uncorrected damage estimates of IPCC (1996a) and shows how estimates could be corrected in different ways, depending on the type of welfare function adopted. The difficulties and scope of including equity considerations into economic valuation have also been discussed on a more theoretical level by e.g. Burtraw and Kopp (1994), and in the context of mortality risk valuation, by Jones-Lee and Loomes (1995). Other issues that were raised in the discussion on the IPCC social cost chapter are dealt with in Fankhauser and Tol (1995, on purchasing power parity correction), and Fankhauser et al. (1996, on issues relating to valuation, including the choice between WTP and WTA).

The paper is structured as follows. Section 2 reviews the theory of aggregation and shows how equity weights are calculated. Section 3 summarizes the climate change damage estimates of IPCC (1996a). Section 4 shows how these figures change when equity weights are applied. The section works with different types of welfare functions, including utilitarian, Bernoulli-Nash, and maximin. Section 5 reverses the argument and asks what choice of welfare function and parameter values would imply uniform WTP/WTA values between regions, the suggestion put forward by authors such as Hohmeyer and Gärtner (1992). Section 6 concludes.

2. Aggregation Theory

2.1. Valuation of Individual Damages

Global warming damage estimates measure the change in individual utility that results from a change in climate, and express it in monetary terms. Formally, utility for individual *i* can be described as a function of income *Y* and a vector of non-market services, *Z* (such as good health and an agreeable climate)

$$u^i = u^i(Y^i, Z) \tag{2}$$

Climate change is likely to cause market as well as non-market damages (IPCC, 1996a; see Section 3). That is, it affects people's income – e.g. through changes in productivity – as well as the vector of non-market services. Say income and non-market services decrease from levels Y_0 and Z_0 to Y_1 and Z_1, respectively. Monetary damage estimates, *D*, measure people's willingness to pay to avoid this deterioration as follows

$$u^i(Y_0^i - D^i, Z_0) = u^i(Y_1^i, Z_1) \tag{3}$$

That is, D^i is chosen such that an individual is indifferent between sacrificing income D^i and facing the impacts of climate change on Y^i and *Z*.[2]

2.2. Aggregation

To obtain global estimates, the individual WTP estimates D^i have to be aggregated. To this end, a social welfare function, *W*, is defined. *W* combines the utility levels of individuals to create a ranking of different states of the world from the point of view of society. Formally,

$$W = W[u^1, \ldots, u^n] \tag{4}$$

The welfare function is of the Bergson-Samuelson form, and it is assumed that society's view on equity and fairness can be reflected in W through an appropriate choice of functional form. Making these assumptions involves strong value judgements with which not everybody may agree. On the other hand, it is well known that unless policy makers are willing to make certain judgements about the form of the welfare function, very little can be said and obtaining an acceptable welfare ordering may not be possible (see Arrow 1951; a good discussion of the issue is found in Boadway and Bruce 1984).[3] Once an appropriate welfare function is defined, the change in social welfare due to climate change can be expressed as

$$\Delta W = -(W_1 \cdot u_Y^1 \cdot D^1 + \ldots + W_n \cdot u_Y^n \cdot D^n) \tag{5}$$

where W_i denotes the first order derivative of social welfare with respect to u^i, and u_Y^i the marginal utility of income of person i. Note that initial income and non-market services are measured at pre-climate change level (Y_0 and Z_0, respectively). Instead of a complex pattern of market and non-market impacts, social welfare is affected by the equivalent change in income $\Delta Y^i = D^i$ (see equation (3)).[4]

Equation (5) denotes the social welfare change ΔW associated with climate change. Note that the total welfare effect is a *weighted* sum of individual WTP estimates D^i. However, it is easily shown that, as long as the observed income distribution is just (i.e., satisfies the equity concerns of society), distributional weights will actually be *identical*. To see this, recall that all equity concerns are embedded in the social welfare function. The most desirable income distribution from an equity point of view is therefore the one that maximizes social welfare. Optimality in turn will assure equal marginal contributions to social welfare across individuals, and hence identical equity weights.

To illustrate this point, consider the problem of the optimal distribution of a given amount of income M. The most desirable distribution is obtained by maximizing equation (4) with respect to all Y^is, subject to the constraint $\Sigma Y^i = M$. This yields the first order condition

$$W_1 u_Y^1 = \ldots = W_n u_Y^n \tag{6}$$

Equation (6) assures that the equity concerns reflected in the welfare function are observed in the best way possible.[5] At the same time, equation (6) also implies that the weights of equation (5) are identical. That is, as long as equity concerns are taken care of (i.e., the generally accepted social welfare function (4) is optimized), all damages can be treated equally. Different weights only occur, and are only needed, if the observed income distribution is not just.

It is also worth to reemphasize that an optimal income distribution does not necessarily imply equality of WTP/WTA. As noted above, and made clear in equation (3), WTP/WTA estimates depend on preferences, income and other socio-economic characteristics. That is, only if income is distributed equally, if this distribution is considered fair, and if tastes are identical across individuals will WTP/WTA estimates be the same for everybody.

2.3. MONETISATION

Equation (5) measures the welfare effect of climate change in utility units, or 'utils'. To obtain a *global monetary damage estimate*, equation (5) has to be converted. This is done by dividing ΔW by the marginal welfare gain from income, $W_M = \partial W / \partial M$.

A common way of defining W_M is to interpret it as the welfare increase that is obtained by marginally slackening the income constraint, evaluated at the optimal point.[6] It is equal to the Langrangean multiplier of the maximization problem that yielded equation (6)

$$W_M = W_i \cdot u_Y^i|_{(Y^i = Y^{i*})} \tag{7}$$

where Y^{i*} denotes the optimal amount of income allocated to i according to equation (6). Note that since W_M is evaluated at the optimal point, equation (6) holds, and $W_i u_Y^i$ will be identical for all i.

Combining equations (5) and (7), total, worldwide damage can now be expressed as

$$D^{\text{world}} = \left(\frac{W_1 \cdot u_Y^1}{W_M}\right) D^1 + \ldots + \left(\frac{W_n \cdot u_Y^n}{W_M}\right) D^n \tag{8}$$

where the terms in brackets denote the equity weights. It is easily seen that if the income distribution is just (i.e., if equation (6) holds), weights will be equal to unity. That is, given a just income distribution, individual damage estimates can simply be added up. The same will be the case for a symmetric, linear welfare function and identical, linear utility functions, that is, if $W_i u_Y^i$ is constant and identical for all individuals and income levels.

Section 4 provides estimates of equation (8) for the case of climate change impacts. Before we do this, the next section reviews available estimates of individual damages D^i (disaggregated to regional level).

3. Climate Change Damage Costs

Working Group II of the Intergovernmental Panel on Climate Change (IPCC) has extensively reviewed the physical impacts of climate change on human society and natural ecosystems (IPCC 1996b). Chapter 6 of IPCC Working Group III has assessed the available monetary damage assessments (IPCC 1996a; see also Fankhauser 1994, 1995; Fankhauser and Tol 1995; and Tol 1995).

Information on the impacts of global warming is available for several regions and countries. The best studied regions are developed countries, in particular the United States, where climate change impacts have been analyzed in a series of studies. Far less information is available on impacts in developing countries, although the number of studies is increasing.

Studies usually deal with only a subset of damages, and are often restricted to a description of impacts in physical terms. Estimates generally combine the costs of adaptation (such as sea level rise protection) and the costs of residual damages (such as the inundation of unprotected areas). By far the best studied impact categories are agricultural impacts and the costs of sea level rise (see IPCC 1996a). Several types of impacts have largely been ignored so far, because they could not be sufficiently quantified. Other damages were estimated on the back of an envelope. Attempts at a comprehensive monetary quantification of all impacts are relatively rare, and usually restricted to the United States (Cline 1992; Titus 1992; Nordhaus 1991). Fankhauser (1995) and Tol (1995) have provided preliminary monetary damages for different world regions. Valuation is based on a mix of WTP, occasionally WTA, and various approximations, including benefit transfers.

Available estimates on the costs of climate change are therefore neither accurate nor complete. There is a considerable range of error. Figures on developing countries in particular are usually based on approximation and extrapolation, and are clearly less reliable than those for developed regions. Nevertheless, the available estimates can serve as an indication of the relative vulnerability of different regions.

The scientific research on global warming impacts has focused predominantly on the (arbitrarily chosen) $2 \times CO_2$ scenario – the impacts of an atmospheric CO_2 concentration of twice the preindustrial level. The figures reported here reflect the impact of a $2 \times CO_2$ climate on the current society. Table I shows the aggregate damages, based on the assessment of Fankhauser and Tol (1995). Compared to IPCC (1996a), the Fankhauser and Tol (1995) figures are additionally corrected for differences in purchasing power parity. Figures vary between 0 and 7 percent of real (purchasing power parity corrected) GDP, with relative damages in developing countries typically higher than those in OECD countries.

The figures in Table I are *best guess* estimates – they do not reflect the uncertainties. The estimates neglect the possibility of impact surprises (such as social and political unrest), and of low probability/high impact events (such as a shut down of the ocean conveyor belt).

Table I highlights the substantial differences between regions. For the former Soviet Union, for example, damage could be as low as 0.4 percent of rGDP, or even negative (climate change is potentially beneficial). Asia and Africa, on the other hand, could face extremely high damages, mainly due to the severe life/morbidity impacts. Developing countries generally tend to be more vulnerable (in relative terms) to climate change than developed countries, because of the greater importance of agriculture, lower health standards and the stricter financial, institutional, and knowledge constraints on adaptation.

4. Results for Different Specifications of Utility and Welfare

In this section the theoretical aggregation concept of section 2 is applied to the IPCC damage estimates introduced in the previous section. To do this specific

Table I. Monetary $2\times CO_2$ damage in different world regions.

	Fankhauser (1995)		Tol (1995)	
	bn$	%rGDP[a]	bn$	%rGDP[a]
European Union	63.6	1.4		
United States	61.0	1.3		
Other OECD	55.9	1.2		
OECD America			74.5	1.5
OECD Europe			57.4	1.6
OECD Pacific			60.7	3.8
Total OECD	*180.5*	*1.3*	*192.7*	*1.9*
E. Europe/Former USSR	29.8[b]	0.4[b]	−14.8	−0.4
Centrally Planned Asia	50.7[c]	2.9[c]	−4.0	−0.1
South and South East Asia			92.2	5.3
Africa			46.4	6.9
Latin America			40.3	3.1
Middle East			11.5	5.5
Total Non-OECD	*141.6*	*0.9*	*171.7*	*1.7*
World	*322.0*	*1.1*	*364.4*	*1.8*

[a] Real (or purchasing power parity corrected) GDP; note that the GDP base may differ between the studies. Tol's initial estimate for the Middle East was corrected for a typographical error.
[b] Former Soviet Union only.
[c] China only.

Source: Fankhauser and Tol (1995). The figures in this table differ from the sources and those reported in IPCC (1996a); they are fully corrected for purchasing power parity.

functional forms need to be defined for the general functions used in section 2. To underline the sensitivity of results to different ethical paradigms, we work with three different welfare functions: Utilitarian, Bernoulli-Nash (Cobb-Douglas), and maximin. They are among the most popular and often used welfare concepts.

The specification of the utility function should in principle include two variables, income *Y* and non-market goods *Z*. However, because climate change impacts are assumed to be already reflected in the WTP estimate *D* (see equation (3)), non-market services remain constant and variable *Z* can be ignored. We therefore use a conventional iso-elastic utility function that depends solely on income (superscripts are suppressed for simplicity)

$$u = \frac{a}{1-e} \cdot Y^{(1-e)} \tag{9}$$

Non-market services can be thought of either as an additive argument to the function, or as being included in factor *a* (i.e., *a*(*Z*)). For example, if climate change affects mortality, factor *a* would denote the probability of being alive to enjoy utility (Freeman 1993). Different values for parameter *e* (the income elasticity of marginal utility) will be used below. Values between 1 and 1.5 are commonly used in the literature (see e.g. the discussion in Cline 1992), although Pearce and Ulph (1994) note that household behaviour models also support lower values of about 0.8.[7]

A useful specification for the welfare function that encompasses a number of concepts is (see Boadway and Bruce 1984)[8]

$$W = \frac{\sum_{i=1}^{n} u^i(\cdot)^{(1-\gamma)}}{1-\gamma} \tag{10}$$

where γ is a parameter of inequality aversion. The larger is γ, the larger is the concern about equality. For $\gamma = 0$, equation (10) reduces to a utilitarian welfare function. Letting γ approach 1 gives a Bernoulli-Nash function, while $\gamma \to \infty$ represents the maximin case.

4.1. Utilitarian Welfare Function

The utilitarian welfare function takes the form

$$W = \sum_{i=1}^{n} u^i(\cdot) \tag{11}$$

that is, the utility of each person is given equal weight, and utilities are simply added up.

To express equation (8) using the specific functional forms (9) and (11), we first calculate the value of income W_M. Recall that W_M denotes the welfare gain obtained from an increase in income, evaluated at the point of optimal income distribution. Since the welfare function (11) is symmetric, the fairest distribution of income (the one which maximizes equation (11), given *M*) is to allocate to each party an equal share of income. The value of income (equation (7)) thus is

$$W_M = u_Y\left(\frac{M}{n}\right) = u_Y(\overline{Y}) \tag{12}$$

where $Y = M/n$ is the identical, average income granted to each individual. That is, the marginal welfare gain from an increase in income is equal to the marginal utility of income evaluated at average income.

Using this result and equation (9), total damage (equation (8)) is then easily derived as which is a general form of the simple rule given in equation (1) (where $e = 1$).

$$D^{\text{world}} = \sum_{i=1}^{n} \left(\frac{\overline{Y}}{Y^i}\right)^e \cdot D^i \tag{13}$$

Table II. Global 2×CO_2 damages, corrected for inequality (annual damages, bn$).

	Fankhauser (1995)	Tol (1995)
Uncorrected damages	322.0	364.4
Utilitarian welfare function		
e = 0.5	315.6	411.4
e = 1.0	405.2	614.3
e = 1.5	621.9	1057.6
Bernoulli-Nash welfare function[a]	405.2	614.3
Maximin welfare function		
e = 0.5	95.8	89.4
e = 1.0	181.0	172.2
e = 1.5	342.7	331.8

[a] Bernoulli-Nash weights are independent of e, and correspond to the case e = 1 of the utilitarian welfare function.

Source: own calculations based on Fankhauser and Tol (1995).

In the case of a utilitarian welfare function, welfare weights are inversely related to the per capita income of a person, raised to the power e. People with a below average per capita income are given a weight greater than one, people with an above average income are assigned weights less than one. Table II illustrates how the application of these welfare weights affects the damage calculations of Fankhauser (1995) and Tol (1995). The calculations are based on 1988 income data, corrected for differences in purchasing power parity (see Fankhauser and Tol 1995).[9]

Tol's equity weighted global damage is considerably higher than non-equity weighted damage, and increases with inequality aversion e. Fankhauser's equity weighted damage is lower than non-weighted damage for e = 0.5, but increases rapidly for higher values of the inequality aversion parameter. The explanation is that, in general, Fankhauser estimates the poorer regions to be slightly less vulnerable than the richer regions (hence an initial drop in damage). At the same time the weight assigned to China, which is highly vulnerable, increases rapidly with e. For both sets of estimates, damages would increase rapidly for $e > 1.5$.

4.2. Bernoulli-Nash (Cobb-Douglas) Welfare Function

In the symmetric form of the Bernoulli-Nash welfare function, social welfare is the product of individual utilities,

$$W = \Pi_{i=1}^{n} u^i(\cdot) \tag{14}$$

Taking the logarithm of equation (14) (a monotonic transformation) yields a function where social welfare is the sum of the logarithms of individual utility. This is the specification we use.[10]

Symmetry again implies that the most desirable income distribution would be to allocate equal shares to all individuals. The value of income W_M (equation (7)) is therefore again evaluated at average income, as in the utilitarian case. Global damages are then calculated as

$$D^{\text{world}} = \sum_{i=1}^{n} \left(\frac{\overline{Y}}{Y^i} \right) \cdot D^i \tag{15}$$

Equity weights in the case of a Bernoulli-Nash-type welfare function are inversely related to the per-capita income of an individual. Interestingly, damages do not depend on the income elasticity of marginal utility (parameter *e*). Equation (15) coincides with equation (13) for $e = 1$. The corresponding aggregated damage figures are given in Table II.

4.3. Maximin welfare function

In the case of a maximin welfare function,

$$W = \min[\mathrm{u}^{\mathrm{i}}(\cdot)] \tag{16}$$

only the welfare of the poorest individual (or group of individuals) matters. That is, $W_p = 1$ for the poorest individual(s) *p*, and $W_i = 0$ for all other individuals $i \neq p$. The maximin concept has a rough similarity with the welfare theory of Rawls, and is therefore sometimes associated with his name. However, as has been argued by Elster (1992), such a label would be misleading, since Rawls' theory of justice is essentially non-welfarist.

Maximin again implies a uniform income distribution at the optimum, and the value of income is again evaluated at average income. Total damage is therefore

$$D^{\text{world}} = \left(\frac{\overline{Y}}{Y^p} \right)^e \cdot D^p \tag{17}$$

Total damages are much lower than in the other two cases, since the only impacts that matter are those that occur in the poorest region of the world.[11] Impacts in all other regions are given a weight of zero.

Table II provides the figures. Fankhauser's equity weighted figures equal the damage in China, Fankhauser's region with the lowest per capita income. Damages are much lower than the simple aggregate for low values of *e*, but exceed the non-equity weighted aggregate for higher values. Tol's figures equal African damage, Tol's poorest region. Damages are slightly lower than Fankhauser's.

5. The Implicit Assumption Behind Uniform Values

Some papers on climate change damage estimation have advocated the use of uniform per-unit values for damages (e.g. Ayres and Walter 1991; Hohmeyer and

Gärtner 1992; Ekins 1995; Meyer and Cooper 1995).[12] The case in favour of equal per-unit values in all these papers is made entirely on the basis of *ad hoc* judgements with an undeveloped ethical justification, not on the basis of welfare theoretic reasoning. This section analyses these value judgements in the framework of the model of section 2, and calculates the type of welfare function implicitly prescribed when using uniform per-unit damage values. Jones-Lee and Loomes (1995) have used a similar approach to analyze the question of mortality risk valuation, using a more general set of welfare functions.

For simplicity, we assume that there are only two types of individuals, inhabitants of OECD countries (denoted by superscript *r*) on the one hand, and inhabitants of non-OECD countries on the other (denoted by superscript *p*). We are interested in the difference in per-unit damage values (for example the relative WTP/WTA per acre of wetlands lost) between these groups. Suppose the ratio actually observed, based on the current income distribution, is V^r/V^p. The aim then is to choose the parameters of the utility and welfare functions such that the ratio of *equity weighted* per-unit values is unity. Using equation (8) this requirement can be written as

$$\left(\frac{W_r \cdot u_Y^r}{W_p \cdot u_Y^p}\right) \cdot \frac{V^r}{V^p} = 1 \tag{18}$$

Using equation (10) for welfare and equation (9) to specify utility, equation (18) becomes, after some manipulation

$$e \cdot \gamma - \gamma - e = \Omega \tag{19}$$

with $\Omega = [\ln(V^p) - \ln(V^r)]/[\ln(Y^r) - \ln(Y^p)]$. Recall that γ is the parameter for inequality aversion in the welfare function, and *e* the income elasticity of the marginal utility. That is, for any given value for Ω and *e* (which are both determined empirically in the ideal case), the presumption that climate change impacts are to be valued equally implies a certain value for γ, and thus a certain degree of inequality aversion.

Table III presents γ as a function of *e* and V^r/V^p. As before, we assume values for *e* between 0.5 and 1.5, the most likely specification according to empirical evidence (see Cline 1992; Pearce and Ulph 1994).

The ratio V^r/V^p is more difficult to determine, as empirical evidence is scarce. An often used starting point is to assume an income elasticity of WTP of one (Pearce 1980). In this case WTPs as proportions of income are identical across individuals. That is, $V^r/Y^r = V^p/Y^p$, which in turn implies $V^r/V^p = Y^r/Y^p$, or a per-unit value ratio of about four (recall that *Y* is purchasing-power corrected per capita income and that the poor group includes middle income as well as low income countries). The estimates quoted in IPCC (1996a) took the same starting point, but rounding and extrapolation inaccuracies, as well as deviations from this rule for some damage categories, mean that the average income elasticity of WTP

Table III. Implied inequality aversion (γ) as a function of the income elasticity of marginal utility (e) and empirical value ratio (V^r/V^p)

V^r/V^p	1.36	2	4[a]	8	10
Elast. of WTP	0.35	0.66	1.00	1.16	1.20
γ, for					
e = 0.5	−0.56	−0.01	1.00	1.98	2.31
e = 1.0	$\pm\infty$[b]	$\pm\infty$[b]	1.00	$\pm\infty$[c]	$\pm\infty$[c]
e = 1.5	2.56	2.01	1.00	0.02	−0.31

[a] corresponds to the case $V^r/V^p = Y^r/Y^p$.
[b] $\gamma \uparrow \infty$ for $e \downarrow 1$, and $\gamma \downarrow -\infty$ for $e \uparrow 1$.
[c] $\gamma \downarrow -\infty$ for $e \uparrow 1$, and $\gamma \uparrow \infty$ for $e \downarrow 1$.

Source: own calculations, using the Fankhauser (1995) GDP data.

is slightly higher than one, in the order of 1.15–1.20. This implies a V^r/V^p ratio of about 8 to 10.[13] Flores and Carson (1995) and Kriström and Riera (1996) on the other hand argue that elasticities generally tend to be less than one, and Krupnick et al. (1995), for example, have assumed a value of 0.35 to 1 for statistical life estimates in Eastern Europe. This second set of studies would imply a much lower V^r/V^p ratio in the order of perhaps 1.3 to 4.0. Table III presents estimates of γ for both sets of assumptions.

As Table III shows, the postulate of uniform per-unit values is compatible with many sets of 'reasonable' parameter assumptions, but by no means with all of them. For several parameter specifications common values imply degrees of inequality aversion in the utilitarian ($\gamma = 0$) or Bernoulli-Nash range ($\gamma = 1$).[14] In the case of a unitary income elasticity of WTP, for example, uniform per-unit values imply a Bernoulli-Nash welfare function. Other parameter sets imply higher degrees of inequality aversion, and in the case of a logarithmic utility function ($e = 1$) common values are in the limit only compatible with a maximin welfare function ($\gamma = \infty$).

There are also cases where the notion of common per-unit values would seem untenable. As Table III shows, there are parameter combinations for which common per-unit values would imply negative values for γ, that is, 'inequality attraction', which could in the limit go to a maximax welfare concept ($\gamma = -\infty$). With certain parameter combinations, it can happen that weighed per-unit damages estimates for the poor region are higher than those for the rich region. The restriction of equal values then favours the rich. Clearly, this would be an indefensible welfare concept, and it would therefore be hard to make a case for common per-unit values should these particular parameter values prevail. As noted, the question of the appropriate utility and WTP parameters is an empirical one, about which little is known to date.

Finally, it should be noted that the analysis in this section was only concerned with the equality of per-unit values. It has not prescribed equal values at a particular level. Most proponents of uniform per-unit values, in contrast, have also specified the level of per-unit values that should be used. Usually, damages are to be uniformly valued at OECD level (Ekins 1995; Meyer and Cooper 1995). The uniform use of OECD values would require the following extra restriction, in addition to equation (19)

$$W_r \cdot u_Y^r = 1 \tag{20}$$

With the current choice of welfare function, which only has one policy parameter, it would evidently not be possible to satisfy both equations (19) and (20), except by coincidence.

6. Conclusions

Climate change may involve potentially large and pervasive impacts on the well-being of both rich and poor communities in the world. After the exploitation of any ‘no regret’ or ‘win-win’ measures to reduce greenhouse gas emissions, costs of control will be incurred. One approach to determining the optimal degree of control is based on benefit-cost comparisons involving monetized impacts and costs. But such comparisons throw up concerns that link equity considerations with the degree of control: the use of income-constrained WTP (or WTA) measures will produce results that will differ from those that would ensue if developing countries’ WTP to avoid life risks and other damages was weighted by some distributional coefficient reflecting a judgement about equity. The suspicion then is that ‘orthodox’ benefit-cost analysis will result in less global warming control than an equity weighted approach.

Leaving aside the issue of whether, in practice, policy makers will pay much heed to benefit-cost comparisons of climate control, however they are performed, this paper has noted that the equity weighting issue is at least 25 years old in the history of benefit-cost analysis. Although equity weighting atrophied in the practice of benefit-cost analysis, it is arguable that climate change is such a large and pervasive issue that it is right for equity judgements to be integrated into any benefit-cost comparison.

Equity weighting can lead to significantly higher global damage figures than those reported in IPCC (1996a), although some specifications also imply reduced estimates. We re-estimated existing measures of climate change damage using equity weights derived from a utilitarian, a Bernoulli-Nash and a maximin welfare function. In the utilitarian case, the estimates based on Tol (1995) increase systematically with the value of e (the income elasticity of marginal utility), while those of Fankhauser (1995) show an increase only for values of $e > 0.5$. In the maximin case, Tol’s damage figures stay below the unweighed estimates for all likely values of e, while Fankhauser’s damage figures stay below unweighed estimates for $e <$ 1.5. In the case of a Bernoulli-Nash welfare function, equity weights are independent of the shape of the utility function; global damages are about 25%–75% higher than those reported by IPCC. Like the figures in the underlying IPCC report, these estimates are uncertain and not more than rough indications of the likely order of magnitude.

The choice of welfare function is essentially a political question that cannot be addressed here. However, by allowing for several welfare notions, results should have a broader appeal than the initial estimates. Even so, they are not free from value judgements. Equity weighting necessarily requires the existence of a social welfare function and the need to measure welfare on an absolute scale. The axioms and assumptions needed for these conditions to hold may not appeal to everybody. Nor may the notion of ‘welfarism’ that is underlying the concept, and the particular functional forms we have chosen. One may also ask whether decision makers will indeed be able to agree on a unique social welfare function (Brekke et al. 1994). Nevertheless, compared to the *ad hoc* procedures used in some parts of the literature (e.g. Meyer and Cooper 1995), the method proposed in this paper has the advantage of being firmly based on the principles of welfare economics. The main strengths of welfare economics are its consistency and rigour.

Finally, we address the issue of ‘common values’. In the debate on the IPCC damage cost chapter common per-unit values were mainly discussed in the context of life risk, since unequal valuations of statistical lives appeared to present an ethical challenge. In order to explore this issue in the context of a benefit-cost model we ask what degree of inequality aversion is required before unit damage values would be the same in rich and poor countries. Although we show that the postulate of common per-unit values is compatible with a wide range of ‘reasonable’ utility and welfare parameters, there remain doubts about the notion. For one, there are several cases where the notion is incongruous with defensible welfare concepts. More importantly, uniform values ignore differences in tastes and socio-economic structures that are likely to prevail even in an equitable world.

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Notes

1. We abstract from the complication that equity considerations influence valuation. Although conceivable in theory, no empirical evidence to this extent has been put forward in the context of climate change.
2. For simplicity the exposition is restricted to WTP. The equivalent formulation in the case of WTA would be

$$u^i(Y_1^i + d^i, Z_1) = u^i(Y_o^i, Z_0) \qquad (2')$$

that is, an income increase of d^i is necessary for people to accept the impact of climate change on income and non-market goods. (Note that d^i is not necessarily equal to $-D^i$.) For a discussion of the two concepts in the case of climate change, see Fankhauser et al. (1996).

3. For alternative ways to provide information to decision makers, see Brekke et al. (1994).
4. To allow for the non-marginal change in income the intermediate-value theorem is assumed to hold (see Johansson, 1993).
5. For example, suppose that the two individuals *k* and *l* are of equal importance to society, i.e., $W_k = W_l$. Further assume that *k* initially has a higher income than *l* so that $u_Y^k < u_Y^l$; *k*'s marginal contribution to social welfare is then lower than *l*'s. Total welfare can be increased by shifting income from *k* to *l* until the two marginal contributions are equalized. At this point, $u_Y^k = u_Y^l$ and $Y^k = Y^l$, which satisfies the premise of equality between *k* and *l* set out in the welfare function.
6. Alternatively, W_M could be defined on the basis of the current income distribution, for example as the maximum welfare increase than can be obtained with an additional unit of income, or the increase obtained by spreading additional income equally across individuals.
7. As equation (3) makes clear, different assumptions about parameter *e*, i.e. the shape of the utility function, would in principle also affect WTP/WTA estimates. We abstract from this difficulty here.
8. A generalized version of this welfare function would allow for different weights for individual utilities. We will use symmetric welfare functions throughout, a property sometimes called 'anonymity' (see Boadway and Bruce 1984): Welfare is determined in ignorance of which household will get which utility level. We use total and not average utility; the difference is irrelevant as population is assumed fixed (see Blackorby et al. 1995).
9. The calculations are based on the data used in the original sources. Income data may therefore differ in the two sets of calculations.
10. Since we assume absolute measurability of welfare, this transformation will change absolute welfare. As is easily checked, the monotonic transformation suggested here increases aggregate damages by a factor W_{max}/W, where W denotes current welfare, and W_{max} the level that could be achieved if the income distribution were just.
11. We abstract from the complication that climate change may change the poverty ranking of countries (e.g., as a consequence of climate change, relatively well off, but heavily affected nations such as small island states may become poorer than less well off, but not so heavily affected states). Note that a maximin welfare function raises serious concerns regarding the choice of scales, and regarding its applicability to a problem with high regional uncertainty.
12. Note the difference between a global assessment without regional distinction and a global assessment with regional distinction. In the former case, the common way to proceed would be to value everything at a global average, just like Fankhauser and Tol valued at regional averages. It is the latter case we are interested in, where regions are distinguished, and damage is regionally assessed and subsequently compared and aggregated.
13. The figure is an average value between middle income and low income country ratios, which are all subsumed in the 'poor' group. The middle income country ratio assumed by Fankhauser (1995) is about 4:1, while the low income country ratio is in the order of 10:1 to 15:1.
14. Although γ only approaches unity for $e \uparrow \infty$ and $e \downarrow \infty$.

References

Arrow, K. (1951), *Social Choice and Individual Values.* New Haven, CT: Yale University Press.

Ayres, R. and J. Walter (1991), 'The Greenhouse Effect: Damages, Costs and Abatement', *Environmental and Resource Economics* **1**, 237–270.

Blackorby, C., W. Bossert, and D. Donaldson (1995), 'Intertemporal Population Ethics: Critical-Level Utilitarian Principles', *Econometrica* **63**(6), 1303–1320.

Boadway, R. and N. Bruce (1984), *Welfare Economics*. Cambridge, MA: Basil Blackwell.

Brekke, K. A., H. Luras, and K. Nyborg (1994), *Sufficient Welfare Indicators. Allowing for Disagreement in Evaluations of Social Welfare*, Discussion Paper No. 119. Oslo: Statistic Norway.

Burtraw, D. and R. J. Kopp (1994), *Cost Benefit Analysis and International Environmental Policy Decision Making: Problems of Income Disparity*, Discussion Paper 94-15. Washington, DC: Resources for the Future.

Cline, W. R. (1992), *The Economics of Global Warming*. Washingon, DC: Institute for International Economics.

Dreze, J. and N. Stern (1987), 'The Theory of Cost-Benefit Analysis', in A. J. Auerbach and M. Feldstein, eds., *Handbook of Public Economics, Volume II*. Amsterdam: North-Holland.

Ekins, P. (1995), 'Rethinking the Costs Related to Global Warming. A Survey of the Issues', *Environmental and Resource Economics* **5**, 1–47.

Elster, J. (1992), *Local and Global Justice*. New York: Russell Sage Foundation.

Fankhauser, S. (1994), 'The Economic Costs of Global Warming Damage: A Survey', *Global Environmental Change* **4**(4), 301–309.

Fankhauser, S. (1995), *Valuing Climate Change. The Economics of the Greenhouse*. London: Earthscan.

Fankhauser, S., R. S. J. Tol and D.W. Pearce (1996), *Extensions and Alternatives to Climate Change Damage Valuation. On the Critique of IPCC Working Group III*, draft, Centre for Social and Economic Research on the Global Environment (CSERGE), University College London, and Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

Fankhauser, S. and R. S. J. Tol (1995), *The Social Costs of Climate Change: The IPCC Second Assessment Report and Beyond*, Working Paper W-95/34, Institute for Environmental Studies, Vrije Universiteit, Amsterdam.

Flores, N. E. and R. T. Carson (1995), *The Relationship between the Income Elasticities of Demand and Willingness to Pay*. San Diego: Mimeo, Department of Economics, University of California.

Freeman, A. M. III (1993), *The Measurement of Environmental and Resource Values. Theory and Methods*. Washington, DC: Resources for the Future.

Hohmeyer, O. and M. Gärtner (1992), *The Costs of Climate Change*. Report to the Commission of the European Communities, Fraunhofer Institut für Systemtechnik und Innovationsforschung, Karlsruhe (Germany).

IPCC (1996a), *Climate Change 1995 – Economic and Social Dimensions. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

IPCC (1996b), *Climate Change 1995 – Impact, Adaptation and Mitigation of Climate Change – Scientific-Technic Analysis. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Johansson, P. O. (1993), *Cost-Benefit Analysis of Environmental Change*. Cambridge: Cambridge University Press.

Jones-Lee, M. W. and G. Loomes (1995), *Valuing International Safety Externalities: Does the 'Golden Rule' Apply?* Mimeo, University of Newcastle upon Tyne.

Kriström, B. and P. Riera (1996), 'Is the Income Elasticity of Environmental Improvements Less Than One?', *Environmental and Resource Economics* **7**, 45–55.

Krupnick, A., K. Harrison, E. Nickell, and M. Toman (1995), *The Value of Health Benefits from Ambient Air Quality Improvements in Central and Eastern Europe: An Exercise in Benefit Transfer*, Discussion Paper ENR 93-19-REV. Washington DC: Resources for the Future (revised version, May).

Marglin, S., A. K. Sen, and P. Dasgupta (1972), *Guidelines for Project Evaluation*. Vienna: United Nations Industrial Development Organisation.

Meyer, A. and T. Cooper (1995), 'A Recalculation of the Social Costs of Climate Change', Working Paper, *The Ecologist*.

Nordhaus, W. D. (1991), 'To Slow or Not to Slow: The Economics of the Greenhouse Effect', *Economic Journal* **101**(407), 920–937.

Pearce, D. W. (1971), *Cost Benefit Analysis*. Basingstoke: Macmillan (2nd edition 1986).

Pearce, D. W. (1980), 'The Social Incidence of Environmental Costs and Benefits', in T. O'Riordan and R. K. Turner, eds., *Progress in Resource Management and Environmental Planning*, Vol. 2. Chichester: Wiley.

Pearce, D. W. and D. Ulph (1994), *Discounting and the Early Deep Disposal of Radioactive Waste*. A Report to United Kingdom NIREX Ltd, Centre for Social and Economic Research on the Global Environment, University College London and University of East Anglia, Norwich.

Squire, L. and H. van der Tak (1975), *Economic Analysis of Projects*. Baltimore: Johns Hopkins University Press.

Titus, J. G. (1992), 'The Cost of Climate Change to the United States', in S. K. Majumdar, L. S. Kalkstein, B. Yarnal, E. W. Miller, and L. M. Rosenfeld, eds., *Global Climate Change: Implications Challenges and Mitigation Measures*. Pennsylvania: Pennsylvania Academy of Science.

Tol, R. S. J. (1995), 'The Damage Costs of Climate Change – Toward More Comprehensive Calculations', *Environmental and Resource Economics* **5**, 353–374.