ON INTERNATIONAL EQUITY WEIGHTS AND NATIONAL DECISION MAKING ON CLIMATE CHANGE

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Abstract

Estimates of the marginal damage costs of carbon dioxide emissions require the aggregation of monetised impacts of climate change over people with different incomes and in different jurisdictions. Implicitly or explicitly, such estimates assume a social welfare function and hence a particular attitude towards equity and justice. We show that previous approaches to equity weighing are inappropriate from a national decision maker’s point of view, because domestic impacts are not valued at domestic values. We propose four alternatives (sovereignty, altruism, good neighbour, and compensation) with different views on concern for and liability towards foreigners. The four alternatives imply radically estimates of the social cost of carbon and hence the optimal intensity of climate policy.

Key words

Domestic climate policy; social cost of carbon; equity weights

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1. Introduction

Equity weights, in one form or other, are now frequently used to aggregate the monetized impacts of climate change that would befall different countries (Azar, 1999; Azar and Sterner, 1996; Fankhauser *et al.*, 1997, 1998; Pearce, 2003; Tol, 1999). Equity weights reflect that a dollar to a poor person is not the same as a dollar to a rich person. That is, one cannot add up monetized welfare losses across disparate incomes. Instead, one should add up welfare losses and then monetize. Equity weighting does just that, albeit with a linear approximation.

The aggregation of welfare losses to different countries assumes a supranational perspective. Indeed, the formal derivation of equity weights presumes a global social planner. As an academic exercise, this is fine. However, equity-weighted worldwide marginal damage cost estimates for carbon dioxide are also used by the European Commission and the UK Government in their cost-benefit analysis of domestic policies (CEC, 2005; Clarkson and Deyes, 2002).

This is peculiar. Within countries, equity weights are shunned. Instead, the welfare loss of some average person is used.[1] This is because the democratic principle of "one person, one vote" sits awkwardly with the notion that some people are worthier than others. Between countries, matters are different, as the world is made up of sovereign nations.

One can, of course, argue that as a matter of principle one should act on the basis of how the world ought to be, not how the world is. If one then further believes that democracy is good, then one would probably argue for using the global average welfare loss to guide climate policy. Combined with the assumption that willingness to pay for climate change impacts varies linearly with per capita income, certain equity weights are indeed equivalent to global average values (see below). These are many ifs.

The UK Government and the European Commission, however, answer to the people of the UK and (ultimately) the EU, respectively, not to the people of the world. Using equity weights for impacts of climate change, impacts in Africa, say, are valued higher than the average African would; while impacts in Europe are valued lower than the average European would. At the same time, in Europe, health impacts, say, due to climate change are valued less than health impacts due to air pollution, say. This is most peculiar. Pretending to be the world government, the UK Government and the European Commission short-change the people they actually represent. And, the application of monetization and cost-benefit techniques introduces inconsistencies.

This of course is the consequence of using equity weights only for specific policy areas, i.e. climate change, which is wrong from a theoretical point of view. Equity weights are an all-or-nothing thing: Once a decision-maker opts to use equity weights, she has to use equity weights for all her decision-making procedures, otherwise inconsistencies between various policy arenas will arise. If the UK opted to use equity weights for all its cost-

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[1] Note that, although every citizen is in principle considered equally worthy regardless of their income, poorer areas are often dirtier (Brown, 1995).

benefit analysis, no such problems would arise. While in theory it is clear how equity weights should be used by a national decision maker without introducing inconsistencies in its decision making process, these guidelines are not followed in practise. Equity weights are used in the context of climate change by the UK government and the EU, but not for other policy areas. The resulting inconsistencies are grave and cannot be justified by any known theoretical argument.

Instead, in the absence of international cooperation, a national government committed to climate policy and cost-benefit analysis has five options. First, a country could ignore impacts outside its territory. Second, a country could care about foreign impacts to the extent that its citizens care about foreigners. These two options are numerically close; and they reflect tough *realpolitik*. Third, a country could argue that it has the duty to protect foreigners to the same extent as it does its own citizens. This is common practice for health and safety: Foreign visitors and resident enjoy the same level of protection as do citizens. Here, foreign impacts would be valued the same as domestic impacts. Fourth, a country could argue that it has the duty to be a good neighbour[2] and prevent damage to others and, failing that, feel guilty about the welfare loss it caused abroad. Fifth, a country could offer compensation for the damages it caused abroad, because it feels morally obliged to do so; or because it is told to by a court. Compensation presumably equals the damage done, and foreign impacts would be assessed with foreign values. We argue below that option 3 and 4 are identical under certain conditions. This paper therefore presents four alternative estimates of the marginal damage costs estimates for various world regions – and we compare these four alternatives to two estimates that are commonly used. We show that the different estimates differ not only in the values assigned to impacts abroad, but also in the discount rate used.

Section 2 formalizes the above discussion and reviews the relevant literature. Section 3 presents the numerical model used for estimating marginal damage costs. Section 4 shows the results. Section 5 discusses and concludes.

2. Equity weighting

2.1. Previous work

Fankhauser *et al.* (1997) defined equity-weighted impacts as

$$D_W = \sum_{i=1}^{N} \left(\frac{W_{U_i} U_{C_i}}{W_M} \right) D_i \tag{1}$$

where D_i is the damage in country i, i=1,2, …, N; U is the utility function of country i, and U_C is its first partial derivative to average per capita consumption C; W is the global welfare function, and W_U is its first partial derivative to utility; W_M is a normalization

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[2] Climate change is a global phenomenon, so all are neighbours.

constant to go back from welfare to money – W_M is the first partial derivative to average per capita consumption, evaluated at the optimal point; D_W is the global damage.

The normalization constant has an element of arbitrariness. In this case, the anchor point is a world that is fair (according to the welfare function), and the damage is spread in an equitable manner. If the anchor point were an unfair world because of reasons other than climate change, the valuation of climate change would reflect such inequities – and we may end up using greenhouse gas emission reduction to rectify other wrongs than climate change. In this sense, the chosen normalisation reflects first-best policy.

If we use a utilitarian global welfare function, and a CRRA (constant rate of risk aversion) utility function, equation (1) becomes

$$D_W = \sum_{i=1}^{N} \left(\frac{C_W}{C_i} \right)^{\varepsilon} D_i \tag{2}$$

where C_W is the world average per capita consumption, and ε is the elasticity of marginal utility with respect to income. Clearly, countries with an income above (below) the world average receive a low (high) weight, and this is more pronounced as the utility function is more curved. Indeed, with a linear utility function ($\varepsilon = 0$), equity weights would equal unity.[3]

We now reconstruct (1) and (2) for a national decision maker.

2.2 *Welfare functions*

Let's assume that an individual utility function is specified as:

$$u(C) = \frac{C^{1-\varepsilon}}{1-\varepsilon} \tag{3}$$

This is a conventional CRRA utility function.

We further assume that the national policy maker optimises a welfare function that is defined over the utility of individuals. In particular, we look at welfare functions that take the sum of individual utilities. This utilitarian assumption is disputable, but it is beyond

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[3] Climate change damages are typically approximated by the direct costs (that is price times quantity) with constant prices. If the "price", or rather unit value, is linear in per capita income (that is, the income elasticity of willingness to pay is one); and we further assume that $\varepsilon = 1$, then we have that

$$D_W = \sum_{c=1}^{C} \frac{Y_W}{Y_c} D_c = \sum_{c=1}^{C} \frac{Y_W}{Y_c} V_c I_c = \sum_{c=1}^{C} \frac{Y_W}{Y_c} V_0 \frac{Y_c}{Y_W} I_c = \sum_{c=1}^{C} V_0 I_c$$

where I_c is the impact in country c, V_c is its unit value, and V_W is the world average value. Under these assumptions, all impacts are effectively valued the same – and at the world average. Note that the crucial assumption is that the relative rate of risk aversion equals the income elasticity of willingness to pay, not that both are unity. Although these parameters are related, they are the same under exceptional circumstances only.

the scope of this paper. Instead, we focus on variations of utilitarian welfare and the consequences for the social cost of carbon. Each represents a specific policy position of a national decision maker.

2.2.1 Impacts abroad are ignored

If a national planner is indifferent to what happens abroad, the welfare function is

$$w^s\left(C_{t,i}\right)=\sum_{t=0}^{T}\sum_{i=1}^{N_t}u\left(C_{t,i}\right)(1+\rho)^{-t} \tag{4}$$

where $C_{t,i}$ is consumption of agent *i* at time *t*, *T* is the end of the time horizon the policy maker is taking into account, N_t is the population size at time *t* and *ρ* is the pure rate of time preference.

In practise, policy makers do not have data on an individual basis. We therefore use a welfare function based on average per capita consumption:

$$\overline{w}^s\left(\overline{C}_t\right)=\sum_{t=0}^{T}u\left(\overline{C}_t\right)P_t(1+\rho)^{-t} \tag{5}$$

where $\overline{C}_t$ is average per capita consumption at time *t* in the region of the policy maker and P_t is the population size of the region at time *t*. We omit the average bars from here on.

The social cost of carbon (SCC), or marginal damage cost of carbon dioxide emissions, is defined as the damage done by a small change in emissions *E* today (*t*=0). In utils, we take the utility effect of a marginal change in consumption caused by climate change, and add that up:

$$scc^s=\sum_{t=0}^{T}\frac{\partial u(C_t)}{\partial C_t}\frac{\partial C_t}{\partial E_0}P_t(1+\rho)^{-t} \tag{6}$$

In money, the corresponding SCC figure is

$$\begin{aligned}SCC^s&=\left(\frac{\partial u(C_0)}{\partial C_0}\right)^{-1}\sum_{t=0}^{T}\frac{\partial u(C_t)}{\partial C_t}\frac{\partial C_t}{\partial E_0}P_t(1+\rho)^{-t}=\sum_{t=0}^{T}\left(\frac{\partial u(C_0)}{\partial C_0}\right)^{-1}\frac{\partial u(C_t)}{\partial C_t}\frac{\partial C_t}{\partial E_0}P_t(1+\rho)^{-t}\approx\\&\approx\sum_{t=0}^{T}\left(\frac{\partial u\left(C_t\right)}{\partial C_t}\right)^{-1}(1+\varepsilon g_t)^{-t}\frac{\partial u\left(C_t\right)}{\partial C_t}\frac{\partial C_t}{\partial E_0}P_t(1+\rho)^{-t}\approx\sum_{t=0}^{T}\frac{\partial C_t}{\partial E_0}P_t(1+\rho+\varepsilon g_t)^{-t}\end{aligned} \tag{7}$$

where g_t is the average annual growth rate of per capita consumption between now and year *t*.

2.2.2 Impacts abroad reduce domestic welfare

If the social planner is altruistic towards people abroad, the welfare function is

$$w^a\left(C_t,C_{t,i}\right)=\left[\sum_{t=0}^{T}u\left(C_t\right)P_t(1+\rho)^{-1}\right]+\left[\sum_{t=0}^{T}\sum_{i=1}^{N}u^*\left(C_{t,i}\right)P_{t,i}(1+\rho)^{-1}\right] \tag{8}$$

Here $C_{t,i}$ is average per capita consumption in country i at time t; N is the number of countries; u^* specifies the foreign utility function of the domestic planner; it may be a scaled transformation of u, that is $u^*= \varphi u$ with $0<\varphi<1$.

The corresponding *scc* (in utils) follows as

$$scc^a=\left[\sum_{t=0}^{T}\frac{\partial u\left(C_t\right)}{\partial C_t}\frac{\partial C_t}{\partial E_0}P_t(1+\rho)^{-1}\right]+\left[\sum_{t=0}^{T}\sum_{i=1}^{N}\frac{\partial u^*\left(C_{t,i}\right)}{\partial C_{t,i}}\frac{\partial C_{t,i}}{\partial E_0}P_{t,i}(1+\rho)^{-1}\right] \tag{9}$$

If u^* is proportional to u, the corresponding regional SCC (in money) is

$$\begin{aligned}
SCC^a&=\left(\frac{\partial u(C_0)}{\partial C_0}\right)^{-1}\left[\sum_{t=0}^{T}\frac{\partial u(C_t)}{\partial C_t}\frac{\partial C_t}{\partial E_0}P_t(1+\rho)^{-t}+\varphi\sum_{t=0}^{T}\sum_{i=1}^{N}\frac{\partial u(C_{t,i})}{\partial C_{t,i}}\frac{\partial C_{t,i}}{\partial E_0}P_{t,i}(1+\rho)^{-t}\right]\\
&\approx\sum_{t=0}^{T}\frac{\partial C_t}{\partial E_0}P_t(1+\rho+\varepsilon g_t)^{-t}+\varphi\sum_{i=1}^{N}\left(\frac{\partial u\left(C_0\right)}{\partial C_0}\right)^{-1}\frac{\partial u\left(C_{i,0}\right)}{\partial C_{i,0}}\sum_{t=0}^{T}\frac{\partial C_{t,i}}{\partial E_0}P_{t,i}(1+\rho+\varepsilon g_{t,i})^{-t} \qquad (10)\\
&=\sum_{t=0}^{T}\frac{\partial C_t}{\partial E_0}P_t(1+\rho+\varepsilon g_t)^{-t}+\varphi\sum_{i=1}^{N}\left(\frac{C_0}{C_{0,i}}\right)^{\varepsilon}\sum_{t=0}^{T}\frac{\partial C_{t,i}}{\partial E_0}P_{t,i}(1+\rho+\varepsilon g_{t,i})^{-t}
\end{aligned}$$

where $g_{t,i}$ is the average annual growth rate of per capita consumption between now and year t in region i.

For $\varphi=0$, this reduces to (7).

2.2.3 Good neighbour

It is well established, both morally and legally, that one should not do damage to others, or compensate them if damage is done nonetheless. Here we assume that compensation is not possible. Compensation is dealt with below.

If the obligation not to do damage is interpreted as a hard constraint, the implications are simple: One should reduce greenhouse gas emissions to zero. Here we instead assume that the domestic policy maker takes welfare losses abroad caused by herself into account.

Note that this is not the same as altruism. An altruistic agent cares about other agents. A good neighbour only cares about her impact on other agents. Altruism may evolve if survival and procreation are enhanced by the well-being of others. These others are probably a small group of close relatives. Good neighbourliness may evolve if survival and procreation could be reduced by the wrath of others. We do not present an evolutionary game, however, but simply assume that good neighbourliness is in the welfare function.

This may be specified as

$$w^n = \sum_{t=0}^{T} u\left(C_t\right) P_t (1+\rho)^{-t} - \sum_{t=0}^{T}\sum_{i=1}^{N} \Delta u_{t,i} P_{t,i} (1+\rho)^{-t} \tag{11}$$

where Δu is the damage done abroad by domestic action, expressed as a reduction in welfare abroad.

The *scc* is then

$$scc^n = \sum_{t=0}^{T} \frac{\partial u\left(C_t\right)}{\partial C_t} \frac{\partial C_t}{\partial E_0} P_t (1+\rho)^{-1} + \sum_{t=0}^{T}\sum_{i=1}^{N} \frac{\partial u\left(C_{t,i}\right)}{\partial C_{t,i}} \frac{\partial C_{t,i}}{\partial E_0} P_{t,i} (1+\rho)^{-1} \tag{12}$$

In money, this becomes

$$\begin{aligned} SCC^n &= \left(\frac{\partial u\left(C_0\right)}{\partial C_0}\right)^{-1} scc^n \approx \\ &\sum_{t=0}^{T} \frac{\partial C_t}{\partial E_0} P_t (1+\rho+\varepsilon g_t)^{-t} + \left(\frac{\partial u\left(C_0\right)}{\partial C_0}\right)^{-1} \sum_{i=1}^{N} \frac{\partial u\left(C_{i,0}\right)}{\partial C_{i,0}} \sum_{t=0}^{T} \frac{\partial C_{t,i}}{\partial E_0} P_{t,i} (1+\rho+\varepsilon g_{t,i})^{-t} = \\ &\sum_{t=0}^{T} \frac{\partial C_t}{\partial E_0} P_t (1+\rho+\varepsilon g_t)^{-t} + \sum_{i=1}^{N} \left(\frac{C_0}{C_{i,0}}\right)^{\varepsilon} \sum_{t=0}^{T} \frac{\partial C_{t,i}}{\partial E_0} P_{t,i} (1+\rho+\varepsilon g_{t,i})^{-t} \end{aligned} \tag{13}$$

Note that (13) equals (10) for $\varphi=1$.

Note further that, if the income elasticity of the willingness to pay for climate change impacts equals the rate of risk aversion, then Equation (17) is equivalent to assuming that impacts abroad are valued at domestic prices (cf. footnote 3). This is an alternative interpretation of good neighbourliness.

2.2.4 Impacts abroad are compensated

One can imagine a situation in which climate change damages are fully internalized, i.e. the emitter of greenhouse gas emissions fully compensates those that suffer damages. In particular, one can imagine a set of international treaties which puts the obligation to pay compensation for damages caused to every nation. We are not particularly concerned in this paper how or whether such a situation could arise. We merely assume that there is some external forcing or reasoning due to which compensation is paid. This is not the same as good-neighbour-with-compensation, as that would have compensation as a decision variable.[4] The important point is that compensation payments are not happening because there is a desire to do so; rather there is an obligation.

In this case, the welfare function is

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[4] Note that the solution would lie somewhere in between the good-neighbour-without-compensation case derived above and the full-compensation case derived below.

$$w^c\left(C_t,L_t^*,L_{t,i}\right)=\sum_{t=0}^{T}u\left(C_t+\frac{L_t^*-\sum_{i=1}^{N}L_{t,i}}{P_t}\right)P_t(1+\rho)^{-t} \tag{14}$$

where L is the total compensation paid to country i and L^* is the compensation received. The *scc* follows as

$$scc^c=\sum_{t=0}^{T}\frac{\partial u}{\partial C_t}\left(\frac{\partial C_t}{\partial E_0}-\frac{1}{P_t}\sum_{i=1}^{N}\frac{\partial L_{t,i}}{\partial E_0}\right)P_t(1+\rho)^{-1} \tag{15}$$

as $\partial L^*/\partial E = 0$. The corresponding SCC follows as

$$SCC^c=\sum_{t=0}^{T}\left(\frac{\partial C_t}{\partial E_0}-\frac{1}{P_t}\sum_{i=1}^{N}\frac{\partial L_{t,i}}{\partial E_0}\right)P_t(1+\rho+\varepsilon g_t)^{-1} \tag{16}$$

Note that the compensation is discounted with the social discount rate based on the *domestic* growth rate. This follows because the welfare loss is a domestic loss through compensation. Intuitively, the damage abroad is paid for by the domestic consumers and should therefore be discounted using their discount rate.

If compensation is paid to exactly offset the damage done, (16) becomes

$$SCC^c=\sum_{t=0}^{T}\left[\frac{\partial C_t}{\partial E_0}+\frac{1}{P_t}\sum_{i=1}^{N}\frac{\partial C_{t,i}}{\partial E_0}P_{t,i}\right]P_t(1+\rho+\varepsilon g_t)^{-t} \tag{17}$$

There are two differences between (14) and (17). Firstly, damage abroad has an equity weight in (14) but not in (17). Secondly, damage abroad is discounted with the discount factor abroad in (14), but with the domestic discount rate in (17).

2.2.5. Overview

The social cost of carbon is given by

$$SCC=\sum_{t=0}^{T}\frac{\partial C_t}{\partial E_0}P_t(1+\rho+\varepsilon g_t)^{-t}+\varphi\sum_{i=1}^{N}\omega_i\sum_{t=0}^{T}\frac{\partial C_{t,i}}{\partial E_0}P_{t,i}DF_{t,i} \tag{18}$$

The alternative positions follow from the appropriate choices for φ, the equity weight ω, and the discount factor DF. See Table 1. For completeness, Table 1 also includes the cooperative solution – in which the regions jointly maximise the sum of the sovereign welfare as specified in Equation (4) – equity weights for the global decision maker (Equation 2), and a case inspired by symmetry, but for which we could not find an interpretation.

Note that in all cases domestic impacts are valued with domestic values.

3. The model

This paper uses version 2.9 of the *Climate Framework for Uncertainty, Negotiation and Distribution* (*FUND*). Version 2.9 of *FUND* corresponds to version 1.6, described and applied by Tol (1999, 2001, 2002a), except for the impact module, which is described by Tol (2002b,c) and updated by Link and Tol (2004). A further difference is that the current version of the model distinguishes 16 instead of 9 regions. The model considers emission reduction of methane and nitrous oxide as well as carbon dioxide, as described by Tol (2006a). Finally, the model now has sulphur hexafluoride (SF_6) and a newly calibrated radiative forcing code. A full list of papers, the source code and the technical documentation for the model can be found on line at http://ww.uni-hamburg.de/Wiss/FB/15/Sustainability/fund.html. Readers familiar with *FUND* can skip to Section 4 without loosing any continuity in our argument.

Essentially, *FUND* consists of a set of exogenous scenarios and endogenous perturbations. The model distinguishes 16 major regions of the world, viz. the United States of America, Canada, Western Europe, Japan and South Korea, Australia and New Zealand, Central and Eastern Europe, the former Soviet Union, the Middle East, Central America, South America, South Asia, Southeast Asia, China, North Africa, Sub-Saharan Africa, and Small Island States. The model runs from 1950 to 2300 in time steps of one year. The prime reason for starting in 1950 is to initialize the climate change impact module. In *FUND*, the impacts of climate change are assumed to depend on the impact of the previous year, this way reflecting the process of adjustment to climate change. Because the initial values to be used for the year 1950 cannot be approximated very well, both physical and monetized impacts of climate change tend to be misrepresented in the first few decades of the model runs. The 22nd and 23rd centuries are included to assess the long-term implications of climate change. Previous versions of the model stopped at 2200.

The period of 1950-2000 is used for the calibration of the model, which is based on the *IMAGE* 100-year database (Batjes & Goldewijk, 1994). The scenario for the period 2010-2100 is based on the EMF14 Standardized Scenario, which lies somewhere in between IS92a and IS92f (Leggett *et al.*, 1992). The 2000-2010 period is interpolated from the immediate past (http://earthtrends.wri.org), and the period 2100-2300 extrapolated.

The scenarios are defined by the rates of population growth, economic growth, autonomous energy efficiency improvements as well as the rate of decarbonization of the energy use (autonomous carbon efficiency improvements), and emissions of carbon dioxide from land use change, methane and nitrous oxide.

Welfare comparisons between regions figure prominently in some of the national social cost definitions of Section 2, in the form of ratios of per capita consumption. Therefore, we measure income in purchasing power parity exchange rates (PPP). This also affects the scenario. The original scenario is formulated in terms of market exchange rates (MER). It assumes a narrowing of the income gap between rich and poor. Following Tol (2006b), we assume an income elasticity of –0.28 for the PPP to MER ratio. That is, in the PPP scenario, poor regions are richer at the start, but grow more slowly. This also affects emissions. Following Tol (2006b), we also adjust the scenario for energy efficiency improvements, such that the drop in the growth rate of energy use is halfway between the drop in economic growth rate and zero. That is, emissions grow less fast in the PPP scenario, but faster than a naïve adjustment with the economic growth rate would suggest (cf. Castles and Henderson, 2003). At the same time, the adjusted scenario for energy efficiency does not fully offset the adjusted income scenario either (cf. Gruebler *et al.*, 2004).

The scenarios of economic and population growth are perturbed by the impact of climatic change. Population decreases with increasing climate change related deaths that result from changes in heat stress, cold stress, malaria, and tropical cyclones. Heat and cold stress are assumed to have an effect only on the elderly, non-reproductive population. In contrast, the other sources of mortality also affect the number of births. Heat stress only affects the urban population. The share of the urban population among the total population is based on the World Resources Databases (http://earthtrends.wri.org). It is extrapolated based on the statistical relationship between urbanization and per-capita income, which are estimated from a cross-section of countries in 1995. Climate-induced migration between the regions of the world also causes the population sizes to change. Immigrants are assumed to assimilate immediately and completely with the respective host population.

The tangible impacts are dead-weight losses to the economy (cf. Fankhauser and Tol, 2005). Consumption and investment are reduced without changing the savings rate. As a result, climate change reduces long-term economic growth, although consumption is particularly affected in the short-term. Economic growth is also reduced by carbon dioxide abatement measures. The energy intensity of the economy and the carbon intensity of the energy supply autonomously decrease over time. This process can be accelerated by abatement policies, an option not considered in this paper.

The endogenous parts of *FUND* consist of the atmospheric concentrations of carbon dioxide, methane, nitrous oxide and sulphur hexafluoride, the global mean temperature, the impact of carbon dioxide emission reductions on the economy and on emissions, and the impact of the damages to the economy and the population caused by climate change. Methane and nitrous oxide are taken up in the atmosphere, and then geometrically depleted. The atmospheric concentration of carbon dioxide, measured in parts per million by volume, is represented by the five-box model of Maier-Reimer and Hasselmann (1987). Its parameters are taken from Hammitt *et al*. (1992). The model also contains sulphur emissions (Tol, 2006a)

The radiative forcing of carbon dioxide, methane, nitrous oxide, sulphur hexafluoride and sulphur aerosols is determined based on Ramaswamy *et al*. (2001). The global mean temperature T is governed by a geometric build-up to its equilibrium (determined by the radiative forcing RF), with a half-life of 50 years. In the base case, the global mean temperature rises in equilibrium by 2.5°C for a doubling of carbon dioxide equivalents. Regional temperature follows from multiplying the global mean temperature by a fixed factor, which corresponds to the spatial climate change pattern averaged over 14 GCMs (Mendelsohn *et al*., 2000). The global mean sea level is also geometric, with its equilibrium level determined by the temperature and a half-life of 50 years. Both temperature and sea level are calibrated to correspond to the best guess temperature and sea level for the IS92a scenario of Kattenberg *et al.* (1996).

The climate impact module, based on Tol (2002b,c) includes the following categories: agriculture, forestry, sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, diarrhoea, energy consumption, water resources, and unmanaged ecosystems. Climate change related damages can be attributed to either the rate of change (benchmarked at 0.04°C/yr) or the level of change (benchmarked at 1.0°C). Damages from the rate of temperature change slowly fade, reflecting adaptation (cf. Tol, 2002c).

People can die prematurely due to temperature stress or vector-borne diseases, or they can migrate because of sea level rise. Like all impacts of climate change, these effects are monetized. The value of a statistical life is set to be 200 times the annual per capita income. The resulting value of a statistical life lies in the middle of the observed range of values in the literature (cf. Cline, 1992). The value of emigration is set to be 3 times the per capita income (Tol, 1995), the value of immigration is 40 per cent of the per capita income in the host region (Cline, 1992). Losses of dryland and wetlands due to sea level rise are modelled explicitly. The monetary value of a loss of one square kilometre of dryland was on average $4 million in OECD countries in 1990 (cf. Fankhauser, 1994). Dryland value is assumed to be proportional to GDP per square kilometre. Wetland losses are valued at $2 million per square kilometre on average in the OECD in 1990 (cf. Fankhauser, 1994). The wetland value is assumed to have logistic relation to per capita income. Coastal protection is based on cost-benefit analysis, including the value of additional wetland lost due to the construction of dikes and subsequent coastal squeeze.

Other impact categories, such as agriculture, forestry, energy, water, and ecosystems, are directly expressed in monetary values without an intermediate layer of impacts measured in their 'natural' units (cf. Tol, 2002b). Impacts of climate change on energy consumption, agriculture, and cardiovascular and respiratory diseases explicitly recognize that there is a climatic optimum, which is determined by a variety of factors, including plant physiology and the behaviour of farmers. Impacts are positive or negative depending on whether the actual climate conditions are moving closer to or away from that optimum climate. Impacts are larger if the initial climate conditions are further away from the optimum climate. The optimum climate is of importance with regard to the potential impacts. The actual impacts lag behind the potential impacts, depending on the speed of adaptation. The impacts of not being fully adapted to new climate conditions are always negative (cf. Tol, 2002c).

The impacts of climate change on coastal zones, forestry, unmanaged ecosystems, water resources, diarrhoea malaria, dengue fever, and schistosomiasis are modelled as simple power functions. Impacts are either negative or positive, and they do not change sign (cf. Tol, 2002c).

Vulnerability to climate change changes with population growth, economic growth, and technological progress. Some systems are expected to become more vulnerable, such as water resources (with population growth), heat-related disorders (with urbanization), and ecosystems and health (with higher per capita incomes). Other systems are projected to become less vulnerable, such as energy consumption (with technological progress), agriculture (with economic growth) and vector- and water-borne diseases (with improved health care) (cf. Tol, 2002c). The income elasticities in Tol (2002c) are estimated with cross-sections measured in MER incomes. Following Tol (2006b), they were adjusted for PPP.

4. Results

Table 3 shows the marginal damage cost of carbon dioxide for a pure rate of time preference of 1% per year and a constant rate of relative risk aversion of 1. The simple sum of the regional marginal damage costs is \$16/tC, well within the range of estimates in previous studies (Tol, 2005). Split over 16 regions, under sovereignty, the marginal damage costs per region are obviously much lower. China stands out as very vulnerable. This is due to a range of factors, including its large size, aging population, precarious water supply, and economic concentration in the coastal zone.

The equation for compensated marginal damage costs is similar to that in the cooperative case, but the discount rate is different. For regions with slow (fast) growth, the compensated marginal damage costs are higher (lower) than the cooperative costs. Cf. Table 2.

The equity-weighted marginal damage costs are \$28/tC, almost double the simple sum as more weight is placed on the higher impacts in the poorer regions. Good-neighbourliness is similar to equity-weighting, but the normalisation is done with the regional rather than the world average income. As a result, good-neighbour marginal damage costs are much higher than equity-weighted damages for rich regions, and lower for poor regions. Cf. Table 2.

The altruistic marginal damage costs are somewhere in between the sovereign costs and the good-neighbour costs. We here use φ=0.1.

The relative magnitudes of the marginal damage costs also give some insight into the preferences of regions. In every region, the sovereign damage costs are lowest. That is, free-riding pays. In the OECD, cooperation would lead to lower emission reduction than compensation and good neighbourliness.[5] In the poorest regions, being a good neighbour would imply the lowest emission reduction obligations (apart from sovereignty). In middle income countries, compensation would imply the minimum emission reduction. It is therefore unlikely that regions would be anonymous in agreeing what would be the “right” framework for setting marginal damage costs and hence marginal abatement costs.

Tables 4 and 5 show the same information, but for pure rates of time preference of 0% and 3%, respectively, in Table 3, the value is 1%. As one would expect, lower (higher) discount rates lead to higher (lower) marginal damage costs estimates. However, the relative positions of sovereign, cooperative, equity-weighted, altruistic, compensated, and good neighbour marginal damage costs is unchanged.

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[5] The equity-weighted marginal damage costs are also lower than the compensated and good neighbour ones for the OECD. However, equity-weighted marginal damage costs cannot be compared to unweighted regional marginal abatement costs.

Tables 6 and 8 repeat this information for constant rates of relative risk aversion of 0.5 and 1.5, respectively; in Table 3, the value is 1.0. Changing the CCRA has two effects: First, the equity weights change. Second, the discount rate changes. These two effects work in the opposite direction.

Equity weights are unity for sovereign, cooperative, and compensated marginal damage costs. A higher (lower) CRRA implies a higher (lower) discount rate and lower (higher) marginal damage costs.

For equity-weighted, altruistic, and good neighbour marginal damage costs, both effects are at play. In Tables 7 and 9, we keep the discount rate as in the base case. A higher (lower) CRRA implies higher (lower) equity-weights and higher (lower) marginal damage costs.

Returning to Tables 6 and 8, we see that the equity-weight effect tends to dominate the discount-rate effect, but there are exceptions, as for example good-neighbour marginal costs in Japan and South Korea.

5. Discussion and conclusion

Climate change is a global problem, but decisions are made by national decision makers. In previous papers, researchers have discussed the appropriate carbon tax for a global decision maker. Here, we discuss the appropriate carbon tax for a national decision maker. We distinguish four different cases. First, the national decision maker does not care about what happens abroad. Second, the national decision maker is altruistic towards foreigners. Third, the national decision maker compensates damages done abroad. Fourth, the national decision makers feels responsible for damages done abroad, but cannot compensate. Carbon taxes are lowest in the first case (sovereignty). They are highest in the fourth case (good neighbour) for the richest regions, and in the third case (compensation) for the poorest regions. Middle income regions may face the highest carbon taxes under international cooperation. This order is robust to the choice of the pure rate of time preference and the constant rate of relative risk aversion, but carbon taxes are higher if the pure rate of time preference is lower, and carbon taxes tend to be higher if the rate of risk aversion is higher.

Further research in this field would certainly be welcome. The analysis here should be reproduced with other integrated assessment models. A wider range of utility and welfare functions should be explored, and the link between the utility function and the willingness to pay for climate change impacts should be made. The interactions between risk and inequity aversion should be added. The resolution of the model should be refined, and further interactions between actors should be added. The analysis should be extended to a cost-benefit analysis.

The policy implications are twofold. On the one hand, a wide range of carbon taxes can be defended. The highest carbon tax differs from the lowest carbon tax by up to a factor 70 for a 1% pure rate of time preference, and up to a factor 470 for a 0% PRTP. On the other hand, this large difference is due to different ethical positions on the kind of responsibility one country should have towards other countries. Such positions can be debated, and although reasonable people will disagree, politicians should be able to resolve this. Indeed, some would argue that that is what politicians are for.

The results presented here show that, without cooperation, different regions should have different carbon taxes. This is not news. See Bradford (2005), Helm (2002), Rehdanz and Tol (2005), and Tol (2005) for ways to reconcile non-cooperative target-setting with international trade in emission permits. However, this paper also shows that a lack of international cooperation on target-setting does not necessarily lead to low carbon taxes. If countries agree to compensate one another for the damage they do to one another, carbon taxes would be substantial. One may argue that that obligation already exists in principle – it still has to be confirmed and put into practice for climate change, though.

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References

Azar, C. and T.Sterner (1996), 'Discounting and Distributional Considerations in the Context of Global Warming', *Ecological Economics*, **19**, 169-184.

Azar, C. (1999), 'Weight Factors in Cost-Benefit Analysis of Climate Change', *Environmental and Resource Economics*, **13**, 249-268.

Batjes, J.J. and C.G.M.Goldewijk (1994), *The IMAGE 2 Hundred Year (1890-1990) Database of the Global Environment (HYDE)*, RIVM, Bilthoven, **410100082**.

Bradford, D.F. (2005), *No Cap but Trade,* Mimeo*,* http://www.wws.princeton.edu/~bradford/globalpublicghgcontrol01.pdf

Brown, P. (1995), 'Race, Class, and Environmental Health: A Review and Systematization of the Literature', *Environmental Research*, **69**, 15-30.

Castles, I. and D.Henderson (2003), 'The IPCC Emission Scenarios: An Economic-Statistical Critique', *Energy & Environment*, **14**, (2-3), 159-185.

CEC (2005), *Winning the Battle Agains Global Climate Change -- Background Paper*, Commission of the European Communities, Brussels.

Clarkson, R. and K.Deyes (2002), *Estimating the Social Cost of Carbon Emissions*, The Public Enquiry Unit - HM Treasury, London, **Working Paper 140**.

Cline, W.R. (1992), *The Economics of Global Warming* Institute for International Economics, Washington, D.C.

Fankhauser, S., R.S.J.Tol, and D.W.Pearce (1998), 'Extensions and Alternatives to Climate Change Impact Valuation: On the Critique of IPCC Working Group III's Impact Estimates', *Environment and Development Economics*, **3**, 59-81.

Fankhauser, S. and R.S.J.Tol (2005), 'On climate change and economic growth', *Resource and Energy Economics*, **27**, 1-17.

Fankhauser, S. (1994), 'Protection vs. Retreat -- The Economic Costs of Sea Level Rise', *Environment and Planning A*, **27**, 299-319.

Fankhauser, S., R.S.J.Tol, and D.W.Pearce (1997), 'The Aggregation of Climate Change Damages: A Welfare Theoretic Approach', *Environmental and Resource Economics*, **10**, 249-266.

Gruebler, A., N.Nakicenovic, J.Alcamo, G.Davis, J.Fenhann, B.Hare, S.Mori, B.Pepper, H.M.Pitcher, K.Riahi, H.-H.Rogner, E.Lebre la Rovere, A.Sankovski, M.E.Schlesinger, P.R.Shukla, R.J.Swart, N.Victor, and T.Y.Jung (2004), 'Emissions Scenarios: A Final Response', *Energy & Environment*, **15**, (1), 11-24.

Hammitt, J.K., R.J.Lempert, and M.E.Schlesinger (1992), 'A Sequential-Decision Strategy for Abating Climate Change', *Nature*, **357**, 315-318.

Helm, C. (2002), 'International Emissions Trading with Endogenous Allowance Choices', *Journal of Public Economics* (in press).

Kattenberg, A., F.Giorgi, H.Grassl, G.A.Meehl, J.F.B.Mitchell, R.J.Stouffer, T.Tokioka, A.J.Weaver, and T.M.L.Wigley (1996), 'Climate Models - Projections of Future Climate', in *Climate Change 1995: The Science of Climate Change -- Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, 1 edn, J.T. Houghton et al. (eds.), Cambridge University Press, Cambridge, pp. 285-357.

Leggett, J., W.J.Pepper, and R.J.Swart (1992), 'Emissions Scenarios for the IPCC: An Update', in *Climate Change 1992 - The Supplementary Report to the IPCC Scientific Assessment*, 1 edn, vol. 1 J.T. Houghton, B.A. Callander, and S.K. Varney (eds.), Cambridge University Press, Cambridge, pp. 71-95.

Link, P.M. and R.S.J.Tol (2006), 'Economic impacts of changes in the population dynamics of fish on the fisheries of the Barents Sea', *ICES Journal of Marine Science*, **63**, 611-625.

Maier-Reimer, E. and K.Hasselmann (1987), 'Transport and Storage of Carbon Dioxide in the Ocean: An Inorganic Ocean Circulation Carbon Cycle Model', *Climate Dynamics*, **2**, 63-90.

Mendelsohn, R.O., M.E.Schlesinger, and L.J.Williams (2000), 'Comparing Impacts across Climate Models', *Integrated Assessment*, **1**, 37-48.

Pearce, D.W. (2003), 'The Social Cost of Carbon and its Policy Implications', *Oxford Review of Economic Policy*, **19**, (3), 1-32.

Ramaswamy, V., O.Boucher, J.Haigh, D.Hauglustaine, J.Haywood, G.Myhre, T.Nakajima, G.Y.Shi, and S.Solomon (2001), 'Radiative Forcing of Climate Change', in *Climate Change 2001: The Scientific Basis -- Contribution of Working Group I to the*

Third Assessment Report of the Intergovernmental Panel on Climate Change, J.T. Houghton and Y. Ding (eds.), Cambridge University Press, Cambridge, pp. 349-416.

Rehdanz, K. and R.S.J.Tol (2005), 'Unilateral regulation of bilateral trade in greenhouse gas emission permits', *Ecological Economics*, **54**, 397-416.

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

Tol, R.S.J. (2001), 'Equitable Cost-Benefit Analysis of Climate Change', *Ecological Economics*, **36**, (1), 71-85.

Tol, R.S.J. (1999), 'The Marginal Costs of Greenhouse Gas Emissions', *Energy Journal*, **20**, (1), 61-81.

Tol, R.S.J. (2002a), 'Welfare specifications and optimal control of climate change: an application of fund', *Energy Economics*, **24**, 367-376.

Tol, R.S.J. (2005), 'The marginal damage costs of carbon dioxide emissions: an assessment of the uncertainties', *Energy Policy*, **33**, 2064-2074.

Tol, R.S.J. (2002b), 'Estimates of the Damage Costs of Climate Change - Part 1: Benchmark Estimates', *Environmental and Resource Economics*, **21**, 47-73.

Tol, R.S.J. (2002c), 'Estimates of the Damage Costs of Climate Change - Part II: Dynamic Estimates', *Environmental and Resource Economics*, **21**, 135-160.

Tol, R.S.J. (2006a), 'Multi-Gas Emission Reduction for Climate Change Policy: An Application of FUND', *Energy Journal* (Multi-Greenhouse Gas Mitigation and Climate Policy Special Issue), 235-250.

Tol, R.S.J. (2006b), 'Exchange Rates and Climate Change: An Application of FUND', *Climatic Change*, **75**, 59-80.

Tol, R.S.J. (2006c), *The Polluter Pays Principle and Cost-Benefit Analysis of Climate Change: An Application of* FUND, Research unit Sustainability and Global Change **FNU-98**, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg. Also: Nota di Lavoro **88.06**, Fondazione Eni Enrico Mattei, Milan.

Table 1. Alternative positions on impacts abroad; see Equation (18); h = home, f = foreign, w = world.

	Weight of welfare abroad	Equity weight	Discount rate
Sovereignty	$\varphi=0$	-	-
Altruism	$0<\varphi<1$	$\omega_f = \left(\frac{C_{0,h}}{C_{0,f}}\right)^{\varepsilon}$	$R=1+\rho+\varepsilon g_f$
Good neighbour	$\varphi=1$	$\omega_f = \left(\frac{C_{0,h}}{C_{0,f}}\right)^{\varepsilon}$	$R=1+\rho+\varepsilon g_f$
Cooperation	$\varphi=1$	$\omega_f= 1$	$r=1+\rho+\varepsilon g_f$
Equity weighing	$\varphi=1$	$\omega_f = \left(\frac{C_{0,w}}{C_{0,f}}\right)^{\varepsilon}$	$r=1+\rho+\varepsilon g_f$
No sense	$\varphi=1$	$\omega_f = \left(\frac{C_{0,h}}{C_{0,f}}\right)^{\varepsilon}$	$r=1+\rho+\varepsilon g_h$
Compensation	$\varphi=1$	$\omega_f= 1$	$r=1+\rho+\varepsilon g_h$

Table 2. Regional characteristics.

	Population		Income		Impact
	(millions)		(PPP $/cap)	(-)	(% GDP)
	2000	2100	2000	2100/2000	2100
USA	278	298	37,317	3.7	-0.51
CAN	31	34	25,498	3.8	-0.14
WEU	388	396	30,312	3.9	-0.91
JPK	171	223	42,872	4.4	0.19
ANZ	20	28	21,437	3.8	0.47
EEU	125	126	5,394	6.0	-0.64
FSU	293	292	4,493	5.2	-4.04
MDE	241	553	3,397	7.7	1.05
CAM	137	216	6,783	5.4	-0.12
SAM	346	537	7,920	5.4	-0.41
SAS	1,366	2,630	1,984	5.9	-0.45
SEA	630	1,197	4,588	5.9	-1.49
CHI	1,315	1,712	5,509	8.1	-0.41
NAF	143	401	2,248	6.2	-4.40
SSA	639	1,831	1,198	5.2	-1.99
SIS	43	66	1,545	9.3	0.29
World	6,168	10,541	8,580	3.9	-0.63

Table 3. The regional marginal damage costs of carbon dioxide (in \$/tC), for a pure rate of time preference of 1% per year and a constant relative rate of risk aversion of 1.

	Sovereign	Altruism	Compensation	Good neighbour
USA	0.91	13.35	33.76	125.27
CAN	0.07	8.62	33.28	85.60
WEU	1.54	11.56	32.35	101.76
JPK	0.30	14.66	27.95	143.92
ANZ	0.06	7.25	33.15	71.97
EEU	0.12	1.92	17.89	18.11
FSU	0.80	2.23	24.32	15.08
MDE	0.38	1.49	9.82	11.40
CAM	0.26	2.51	17.28	22.77
SAM	0.23	2.86	15.11	26.59
SAS	1.07	1.63	17.28	6.66
SEA	1.27	2.68	16.42	15.40
CHI	7.49	8.59	12.70	18.49
NAF	0.43	1.14	13.39	7.55
SSA	0.57	0.92	18.85	4.02
SIS	0.07	0.58	8.54	5.19
Cooperation	15.56			
Equity weights	27.86			

Table 4. The regional marginal damage costs of carbon dioxide (in \$/tC), for a pure rate of time preference of 0% per year and a constant relative rate of risk aversion of 1.

	Sovereign	Altruism	Compensation	Good neighbour
USA	5.06	86.45	230.66	818.93
CAN	0.39	56.31	227.44	559.58
WEU	9.33	74.91	222.08	665.21
JPK	2.42	96.26	189.33	940.86
ANZ	0.39	47.40	226.58	470.45
EEU	0.83	12.58	117.34	118.37
FSU	4.99	14.35	164.83	98.61
MDE	2.70	9.88	61.17	74.55
CAM	1.83	16.53	109.59	148.86
SAM	1.40	18.64	94.04	173.81
SAS	7.31	10.93	114.78	43.54
SEA	8.08	17.34	105.49	100.69
CHI	50.30	57.36	84.13	120.90
NAF	2.51	7.19	85.88	49.34
SSA	3.49	5.77	121.86	26.29
SIS	0.48	3.82	54.38	33.91
Cooperation	101.49			
Equity weights	182.12			

Table 5. The regional marginal damage costs of carbon dioxide (in \$/tC), for a pure rate of time preference of 3% per year and a constant relative rate of risk aversion of 1.

	Sovereign	Altruism	Compensation	Good neighbour
USA	0.05	0.57	1.33	5.22
CAN	0.00	0.36	1.31	3.57
WEU	0.08	0.49	1.27	4.24
JPK	0.00	0.60	1.12	6.00
ANZ	0.00	0.30	1.31	3.00
EEU	0.00	0.08	0.75	0.75
FSU	0.04	0.10	0.98	0.63
MDE	0.01	0.06	0.44	0.48
CAM	0.01	0.10	0.75	0.95
SAM	0.01	0.12	0.68	1.11
SAS	0.04	0.06	0.71	0.28
SEA	0.05	0.11	0.70	0.64
CHI	0.31	0.35	0.53	0.77
NAF	0.02	0.05	0.58	0.31
SSA	0.03	0.04	0.80	0.17
SIS	0.00	0.02	0.37	0.22
Cooperation	0.66			
Equity weights	1.16			

Table 6. The regional marginal damage costs of carbon dioxide (in \$/tC), for a pure rate of time preference of 1% per year and a constant relative rate of risk aversion of 0.5.

	Sovereign	Altruism	Compensation	Good neighbour
USA	2.13	17.14	84.22	152.17
CAN	0.16	12.72	83.62	125.78
WEU	3.80	17.13	82.48	137.14
JPK	0.87	17.10	76.49	163.10
ANZ	0.14	11.66	83.46	115.33
EEU	0.42	6.17	60.85	57.85
FSU	2.28	7.34	71.29	52.80
MDE	1.86	6.27	44.57	45.91
CAM	0.94	7.33	59.45	64.88
SAM	0.83	7.76	55.35	70.10
SAS	3.77	6.90	59.94	35.09
SEA	4.48	9.37	58.09	53.36
CHI	30.36	33.17	51.30	58.47
NAF	1.60	5.18	52.39	37.35
SSA	1.85	4.39	62.35	27.27
SIS	0.35	3.42	41.72	30.96
Cooperation	55.87			
Equity weights	71.76			

Table 7. The regional marginal damage costs of carbon dioxide (in \$/tC), for a pure rate of time preference of 1% per year and a constant relative rate of risk aversion of 0.5; risk aversion does not affect the money discount rate.

	Sovereign	Altruism	Compensation	Good neighbour
USA	0.91	4.93	33.76	41.08
CAN	0.07	3.46	33.28	33.96
WEU	1.54	5.09	32.35	37.03
JPK	0.30	4.67	27.95	44.03
ANZ	0.06	3.16	33.15	31.14
EEU	0.12	1.67	17.89	15.62
FSU	0.80	2.15	24.32	14.26
MDE	0.38	1.59	9.82	12.40
CAM	0.26	1.98	17.28	17.52
SAM	0.23	2.10	15.11	18.93
SAS	1.07	1.91	17.28	9.47
SEA	1.27	2.58	16.42	14.40
CHI	7.49	8.32	12.70	15.78
NAF	0.43	1.39	13.39	10.08
SSA	0.57	1.25	18.85	7.36
SIS	0.07	0.90	8.54	8.36
Cooperation	15.56			
Equity weights	19.37			

Table 8. The regional marginal damage costs of carbon dioxide (in \$/tC), for a pure rate of time preference of 1% per year and a constant relative rate of risk aversion of 1.5.

	Sovereign	Altruism	Compensation	Good neighbour
USA	0.40	12.70	13.84	123.46
CAN	0.03	7.00	13.55	69.73
WEU	0.64	9.61	12.97	90.38
JPK	0.10	15.29	10.49	152.03
ANZ	0.02	5.40	13.47	53.76
EEU	0.04	0.71	5.46	6.78
FSU	0.29	0.77	8.53	5.16
MDE	0.08	0.41	2.29	3.39
CAM	0.07	1.02	5.25	9.57
SAM	0.07	1.27	4.36	12.07
SAS	0.31	0.43	5.15	1.51
SEA	0.37	0.87	4.84	5.32
CHI	1.91	2.42	3.26	7.00
NAF	0.12	0.29	3.58	1.83
SSA	0.18	0.24	5.93	0.71
SIS	0.01	0.12	1.84	1.04
Cooperation	4.65			
Equity weights	12.95			

Table 9. The regional marginal damage costs of carbon dioxide (in \$/tC), for a pure rate of time preference of 1% per year and a constant relative rate of risk aversion of 1.5; risk aversion does not affect the money discount rate.

	Sovereign	Altruism	Compensation	Good neighbour
USA	0.91	43.83	33.76	430.14
CAN	0.07	24.36	33.28	242.95
WEU	1.54	32.88	32.35	314.90
JPK	0.30	53.23	27.95	529.68
ANZ	0.06	18.78	33.15	187.29
EEU	0.12	2.47	17.89	23.64
FSU	0.80	2.52	24.32	17.97
MDE	0.38	1.53	9.82	11.81
CAM	0.26	3.57	17.28	33.34
SAM	0.23	4.41	15.11	42.06
SAS	1.07	1.49	17.28	5.27
SEA	1.27	2.99	16.42	18.54
CHI	7.49	9.18	12.70	24.40
NAF	0.43	1.02	13.39	6.36
SSA	0.57	0.76	18.85	2.47
SIS	0.07	0.43	8.54	3.62
Cooperation	15.56			
Equity weights	45.11			

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Lau, M.A. (2006), *An analysis of the travel motivation of tourists from the People's Republic of China,* **FNU-108** (submitted).

Lau, M.A. and R.S.J. Tol (2006), *The Chinese are coming – An analysis of the preferences of Chinese holiday makers at home and abroad*, **FNU-107** (submitted, *Tourism Management*).

Röckmann, C., R.S.J. Tol, U.A. Schneider, and M.A. St.John (2006), *Rebuilding the Eastern Baltic cod stock under environmental change - Part II: The economic viability of a marine protected area.* **FNU-106** (submitted)

Ronneberger, K., M. Berrittella, F. Bosello and R.S.J. Tol (2006), *KLUM@GTAP: Introducing biophysical aspects of land-use decisions into a general equilibrium model. A coupling experiment,* **FNU-105** (submitted).

Link, P.M. and Tol, R.S.J. (2006), *Economic impacts on key Barents Sea fisheries arising from changes in the strength of the Atlantic thermohaline circulation*, **FNU-104** (submitted).

Link, P.M. and Tol, R.S.J. (2006), *The economic impact of a shutdown of the Thermohaline Circulation: an application of FUND*, **FNU-103** (submitted).

Tol, R.S.J. (2006), *Integrated Assessment Modelling*, **FNU-102** (submitted).

Tol, R.S.J. (2006), *Carbon Dioxide Emission Scenarios for the USA*, **FNU-101** (submitted, *Energy Policy*).

Tol, R.S.J., S.W. Pacala and R.H. Socolow (2006), *Understanding Long-Term Energy Use and Carbon Dioxide Emissions in the USA*, **FNU-100** (submitted).

Sesabo, J.K, H. Lang and R.S.J. Tol (2006), *Perceived Attitude and Marine Protected Areas (MPAs) establishment: Why households' characteristics matters in Coastal resources conservation initiatives in Tanzania*, **FNU-99** (submitted).

Tol, R.S.J. (2006), *The Polluter Pays Principle and Cost-Benefit Analysis of Climate Change: An Application of* FUND, **FNU-98** (submitted, *Environmental and Resource Economics*)

Tol, R.S.J. and G.W. Yohe (2006), *The Weakest Link Hypothesis for Adaptive Capacity: An Empirical Test*, **FNU-97** (forthcoming, *Global Environmental Change*)

Berrittella, M., K. Rehdanz, R.Roson and R.S.J. Tol (2005), *The Economic Impact of Water Pricing: A Computable General Equilibrium Analysis*, **FNU-96** (submitted)

Sesabo, J.K. and R. S. J. Tol (2005), *Technical Efficiency and Small-scale Fishing Households in Tanzanian coastal Villages: An Empirical Analysis*, **FNU-95** (submitted)

Lau, M.A. (2005), *Adaptation to Sea-level Rise in the People's Republic of China – Assessing the Institutional Dimension of Alternative Organisational Frameworks*, **FNU-94** (submitted)

Berrittella, M., A.Y. Hoekstra, K. Rehdanz, R. Roson and R.S.J. Tol (2005), *The Economic Impact of Restricted Water Supply: A Computable General Equilibrium Analysis*, **FNU-93** (forthcoming, *Water Research*)

Tol, R.S.J. (2005), *Europe's Long Term Climate Target: A Critical Evaluation*, **FNU-92** (*Energy Policy*, **35** (1), 424-434)

Hamilton, J.M. (2005), *Coastal Landscape and the Hedonic Price of Accommodation*, **FNU-91** (submitted)

Hamilton, J.M., D.J. Maddison and R.S.J. Tol (2005), *Climate Preferences and Destination Choice: A Segmentation Approach*, **FNU-90** (submitted)

Zhou, Y. and R.S.J. Tol (2005), *Valuing the Health Impacts from Particulate Air Pollution in Tianjin*, **FNU-89** (submitted)

Röckmann, C. (2005), *International Cooperation for Sustainable Fisheries in the Baltic Sea,* **FNU-88** (forthcoming, in Ehlers,P./Lagoni,R. (Eds.): *International Maritime Organisations and their Contribution towards a Sustainable Marine Development*.)

Ceronsky, M., D. Anthoff, C. Hepburn and R.S.J. Tol (2005), *Checking the price tag on catastrophe: The social cost of carbon under non-linear climate response* **FNU-87** (submitted, *Climatic Change*)

Zandersen, M. and R.S.J. Tol (2005), *A Meta-analysis of Forest Recreation Values in Europe,* **FNU-86** (submitted, *Journal of Environmental Management*)

Heinzow, T., R.S.J. Tol and B. Brümmer (2005), Offshore-Windstromerzeugung in der Nordsee -eine ökonomische und ökologische Sackgasse? **FNU-85** (*Energiewirtschaftliche Tagesfragen*, **56** (3), 68-73)

Röckmann, C., U.A. Schneider, M.A. St.John, and R.S.J. Tol (2005), *Rebuilding the Eastern Baltic cod stock under environmental change - a preliminary approach using stock, environmental, and management constraints,* **FNU-84** (forthcoming, *Natural Resource Modeling*)

Tol, R.S.J. and G.W. Yohe (2005), *Infinite uncertainty, forgotten feedbacks, and cost-benefit analysis of climate policy,* **FNU-83** (submitted, *Climatic Change*)

Osmani, D. and R.S.J. Tol (2005), *The case of two self-enforcing international agreements for environmental protection*, **FNU-82** (submitted)

Schneider, U.A. and B.A. McCarl, (2005), *Appraising Agricultural Greenhouse Gas Mitigation Potentials: Effects of Alternative Assumptions*, **FNU-81** (submitted)

Zandersen, M., M. Termansen, and F.S. Jensen, (2005), *Valuing new forest sites over time: the case of afforestation and recreation in Denmark,* **FNU-80** (submitted)

Guillerminet, M.-L. and R.S.J. Tol (2005), *Decision making under catastrophic risk and learning: the case of the possible collapse of the West Antarctic Ice Sheet*, **FNU-79** (submitted, *Climatic Change*)

Nicholls, R.J., R.S.J. Tol and A.T. Vafeidis (2005), *Global estimates of the impact of a collapse of the West Antarctic Ice Sheet: An application of FUND,* **FNU-78** (submitted, *Climatic Change*)

Lonsdale, K., T.E. Downing, R.J. Nicholls, D. Parker, A.T. Vafeidis, R. Dawson and J.W. Hall (2005), *Plausible responses to the threat of rapid sea-level rise for the Thames Estuary,* **FNU-77** (submitted, *Climatic Change*)

Poumadère, M., C. Mays, G. Pfeifle with A.T. Vafeidis (2005), *Worst Case Scenario and Stakeholder Group Decision: A 5-6 Meter Sea Level Rise in the Rhone Delta, France,* **FNU-76** (submitted, *Climatic Change*)

Olsthoorn, A.A., P.E. van der Werff, L.M. Bouwer and D. Huitema (2005), *Neo-Atlantis: Dutch Responses to Five Meter Sea Level Rise,* **FNU-75** (submitted, *Climatic Change*)

Toth, F.L. and E. Hizsnyik (2005), *Managing the inconceivable: Participatory assessments of impacts and responses to extreme climate change*, **FNU-74** (submitted, *Climatic Change*)

Kasperson, R.E. M.T. Bohn and R. Goble (2005), *Assessing the risks of a future rapid large sea level rise: A review,* **FNU-73** (submitted, *Climatic Change*)

Schleupner, C. (2005), *Evaluation of coastal squeeze and beach reduction and its consequences for the Caribbean island Martinique,* **FNU-72** (submitted)

Schleupner, C. (2005), *Spatial Analysis As Tool for Sensitivity Assessment of Sea Level Rise Impacts on Martinique,* **FNU-71** (submitted)

Sesabo, J.K. and R.S.J. Tol (2005), *Factors affecting Income Strategies among households in Tanzanian Coastal Villages: Implication for Development-Conservation Initiatives,* **FNU-70** (submitted)

Fisher, B.S., G. Jakeman, H.M. Pant, M. Schwoon. and R.S.J. Tol (2005), *CHIMP: A Simple Population Model for Use in Integrated Assessment of Global Environmental Change*, **FNU-69** (*Integrated Assessment Journal*, **6** (3), 1-33)

Rehdanz, K. and R.S.J. Tol (2005), *A No Cap But Trade Proposal for Greenhouse Gas Emission Reduction Targets for Brazil, China and India*, **FNU-68** (submitted, *Climate Policy*)

Zhou, Y. and R.S.J. Tol (2005), *Water Use in China's Domestic, Industrial and Agricultural Sectors: An Empirical Analysis*, **FNU-67** (*Water Science and Technoloy: Water Supply*, **5** (6), 85-93)

Rehdanz, K. (2005), *Determinants of Residential Space Heating Expenditures in Germany*, **FNU-66** (forthcoming, *Energy Economics*)

Ronneberger, K., R.S.J. Tol and U.A. Schneider (2005), *KLUM: A Simple Model of Global Agricultural Land Use as a Coupling Tool of Economy and Vegetation,* **FNU-65** (submitted, *Climatic Change*)

Tol, R.S.J. (2005), *The Benefits of Greenhouse Gas Emission Reduction: An Application of* FUND, **FNU-64** (submitted, *Global Environmental Change*)

Röckmann, C., M.A. St.John, U.A. Schneider, F.W. Köster, F.W. and R.S.J. Tol (2006), *Testing the implications of a permanent or seasonal marine reserve on the population dynamics of Eastern Baltic cod under varying environmental conditions,* **FNU-63-revised** (submitted)

Letsoalo, A., J. Blignaut, T. de Wet, M. de Wit, S. Hess, R.S.J. Tol and J. van Heerden (2005), *Triple Dividends of Water Consumption Charges in South Africa*, **FNU-62** (forthcoming, *Water Resources Research*)

Zandersen, M., Termansen, M., Jensen,F.S. (2005), *Benefit Transfer over Time of Ecosystem Values: the Case of Forest Recreation,* **FNU-61** (submitted)

Rehdanz, K., Jung, M., Tol, R.S.J. and Wetzel, P. (2005), *Ocean Carbon Sinks and International Climate Policy*, **FNU-60** (*Energy Policy*, **34**, 3516-3526)

Schwoon, M. (2005), *Simulating the Adoption of Fuel Cell Vehicles*, **FNU-59** (submitted)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2005), *The Impact of Climate Change on Domestic and International Tourism: A Simulation Study*, **FNU-58** (submitted)

Bosello, F., R. Roson and R.S.J. Tol (2004), *Economy-wide estimates of the implications of climate change: Human health*, **FNU-57** (*Ecological Economics,* **58**, 579-591)

Hamilton, J.M. and M.A. Lau (2004) *The role of climate information in tourist destination choice decision-making,* **FNU-56** (forthcoming, Gössling, S. and C.M. Hall (eds.), Tourism and Global Environmental Change. London: Routledge)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2004), *The impact of climate on holiday destination choice*, **FNU-55** (*Climatic Change*, **76** (3-4), 389-406)

Bigano, A., J.M. Hamilton, M. Lau, R.S.J. Tol and Y. Zhou (2004), *A global database of domestic and international tourist numbers at national and subnational level*, **FNU-54** (forthcoming, *International Journal of Tourism Research*)

Susandi, A. and R.S.J. Tol (2004), *Impact of international emission reduction on energy and forestry sector of Indonesia*, **FNU-53** (submitted)

Hamilton, J.M. and R.S.J. Tol (2004), *The Impact of Climate Change on Tourism and Recreation*, **FNU-52** (forthcoming, Schlesinger et al. (eds.), Cambridge University Press)

Schneider, U.A. (2004), *Land Use Decision Modelling with Soil Status Dependent Emission Rates*, **FNU-51** (submitted)

Link, P.M., U.A. Schneider and R.S.J. Tol (2004), *Economic impacts of changes in fish population dynamics: the role of the fishermen's harvesting strategies*, **FNU-50** (submitted)

Berritella, M., A. Bigano, R. Roson and R.S.J. Tol (2004), *A General Equilibrium Analysis of Climate Change Impacts on Tourism*, **FNU-49** (*Tourism Management*, **27** (5), 913-924)

Tol, R.S.J. (2004), *The Double Trade-Off between Adaptation and Mitigation for Sea Level Rise: An Application of* FUND, **FNU-48** (forthcoming, *Mitigation and Adaptation Strategies for Global Change*)

Erdil, E. and Yetkiner, I.H. (2004), *A Panel Data Approach for Income-Health Causality,* **FNU-47**

Tol, R.S.J. (2004), *Multi-Gas Emission Reduction for Climate Change Policy: An Application of* FUND, **FNU-46** (forthcoming, *Energy Journal*)

Tol, R.S.J. (2004), *Exchange Rates and Climate Change: An Application of* FUND*,* **FNU-45** (*Climatic Change*, **75**, 59-80)

Gaitan, B., Tol, R.S.J, and Yetkiner, I. Hakan (2004), *The Hotelling's Rule Revisited in a Dynamic General Equilibrium Model*, **FNU-44** (submitted)

Rehdanz, K. and Tol, R.S.J (2004), *On Multi-Period Allocation of Tradable Emission Permits*, **FNU-43** (submitted)

Link, P.M. and Tol, R.S.J. (2004), *Possible Economic Impacts of a Shutdown of the Thermohaline Circulation: An Application of* FUND, **FNU-42** (*Portuguese Economic Journal*, **3**, 99-114)

Zhou, Y. and Tol, R.S.J. (2004), *Evaluating the costs of desalination and water transport,* **FNU-41** (*Water Resources Research,* **41** (3), W03003)

Lau, M. (2004), *Küstenzonenmanagement in der Volksrepublik China und Anpassungsstrategien an den Meeresspiegelanstieg,***FNU-40** (*Coastline Reports*, Issue 1, pp.213-224.)

Rehdanz, K. and Maddison, D. (2004), *The Amenity Value of Climate to German Households*, **FNU-39** (submitted)

Bosello, F., Lazzarin, M., Roson, R. and Tol, R.S.J. (2004), *Economy-wide Estimates of the Implications of Climate Change: Sea Level Rise*, **FNU-38** (submitted, *Environmental and Resource Economics*)

Schwoon, M. and Tol, R.S.J. (2004), *Optimal CO_2-abatement with socio-economic inertia and induced technological change*, **FNU-37** (submitted, *Energy Journal*)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2004), *The Effects of Climate Change on International Tourism,* **FNU-36** (*Climate Research*, **29**, 255-268)

Hansen, O. and R.S.J. Tol (2003), *A Refined Inglehart Index of Materialism and Postmaterialism*, **FNU-35** (submitted)

Heinzow, T. and R.S.J. Tol (2003), *Prediction of Crop Yields across four Climate Zones in Germany: An Artificial Neural Network Approach,* **FNU-34** (submitted, *Climate Research*)

Tol, R.S.J. (2003), *Adaptation and Mitigation: Trade-offs in Substance and Methods,* **FNU-33** (*Environmental Science and Policy*, **8** (6), 572-578)

Tol, R.S.J. and T. Heinzow (2003), *Estimates of the External and Sustainability Costs of Climate Change*, **FNU-32** (submitted)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2003), *Climate change and international tourism: a simulation study,* **FNU-31** (*Global Environmental Change,* **15** (3), 253-266)

Link, P.M. and R.S.J. Tol (2003), *Economic impacts of changes in population dynamics of fish on the fisheries in the Barents Sea*, **FNU-30** (*ICES Journal of Marine Science*, **63** (4), 611-625)

Link, P.M. (2003), *Auswirkungen populationsdynamischer Veränderungen in Fischbeständen auf die Fischereiwirtschaft in der Barentssee*, **FNU-29** (*Essener Geographische Arbeiten*, **35**, 179-202)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China – An Assessment of Structural Impacts on Decision-making Processes*, **FNU-28** (*Ocean & Coastal Management*, No. 48 (2005), pp. 115-159.)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China – A Unique Approach?*, **FNU-27** (*China Environment Series,* Issue 6, pp. 120-124; http://www.wilsoncenter.org/topics/pubs/7-commentaries.pdf)

Roson, R. and R.S.J. Tol (2003), *An Integrated Assessment Model of Economy-Energy-Climate – The Model Wiagem: A Comment*, **FNU-26** (*Integrated Assessment,* **6** (1), 75-82)

Yetkiner, I.H. (2003), *Is There An Indispensable Role For Government During Recovery From An Earthquake? A Theoretical Elaboration*, **FNU-25**

Yetkiner, I.H. (2003), *A Short Note On The Solution Procedure Of Barro And Sala-i-Martin for Restoring Constancy Conditions*, **FNU-24**

Schneider, U.A. and B.A. McCarl (2003), *Measuring Abatement Potentials When Multiple Change is Present: The Case of Greenhouse Gas Mitigation in U.S. Agriculture and Forestry*, **FNU-23** (submitted)

Zhou, Y. and Tol, R.S.J. (2003), *The Implications of Desalination to Water Resources in China - an Economic Perspective*, **FNU-22** (*Desalination*, **163** (4), 225-240)

Yetkiner, I.H., de Vaal, A., and van Zon, A. (2003), *The Cyclical Advancement of Drastic Technologies*, **FNU-21**

Rehdanz, K. and Maddison, D. (2003) *Climate and Happiness*, **FNU-20** (*Ecological Economics,* **52** 111-125)

Tol, R.S.J., (2003), *The Marginal Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties*, **FNU-19** (*Energy Policy,* **33** (16), 2064-2074).

Lee, H.C., B.A. McCarl, U.A. Schneider, and C.C. Chen (2003), *Leakage and Comparative Advantage Implications of Agricultural Participation in Greenhouse Gas Emission Mitigation*, **FNU-18** (submitted).

Schneider, U.A. and B.A. McCarl (2003), *Implications of a Carbon Based Energy Tax for U.S. Agriculture*, **FNU-17** (submitted).

Tol, R.S.J. (2002), *Climate, Development, and Malaria: An Application of* FUND, **FNU-16** (forthcoming, *Climatic Change*).

Hamilton, J.M. (2003), *Climate and the Destination Choice of German Tourists,* **FNU-15** (revised and submitted).

Tol, R.S.J. (2002), *Technology Protocols for Climate Change: An Application of* FUND, **FNU-14** (*Climate Policy,* **4**, 269-287).

Rehdanz, K (2002), *Hedonic Pricing of Climate Change Impacts to Households in Great Britain*, **FNU-13** (forthcoming, *Climatic Change*).

Tol, R.S.J. (2002), *Emission Abatement Versus Development As Strategies To Reduce Vulnerability To Climate Change: An Application Of* FUND, **FNU-12** (forthcoming, *Environment and Development Economics*).

Rehdanz, K. and Tol, R.S.J. (2002), *On National and International Trade in Greenhouse Gas Emission Permits*, **FNU-11** (*Ecological Economics*, **54**, 397-416).

Fankhauser, S. and Tol, R.S.J. (2001), *On Climate Change and Growth*, **FNU-10** (*Resource and Energy Economics*, **27**, 1-17).

Tol, R.S.J.and Verheyen, R. (2001), *Liability and Compensation for Climate Change Damages – A Legal and Economic Assessment*, **FNU-9** (*Energy Policy*, **32** (9), 1109-1130).

Yohe, G. and R.S.J. Tol (2001), *Indicators for Social and Economic Coping Capacity – Moving Toward a Working Definition of Adaptive Capacity*, **FNU-8** (*Global Environmental Change*, **12** (1), 25-40).

Kemfert, C., W. Lise and R.S.J. Tol (2001), *Games of Climate Change with International Trade*, **FNU-7** (*Environmental and Resource Economics*, **28**, 209-232).

Tol, R.S.J., W. Lise, B. Morel and B.C.C. van der Zwaan (2001), *Technology Development and Diffusion and Incentives to Abate Greenhouse Gas Emissions*, **FNU-6** (submitted).

Kemfert, C. and R.S.J. Tol (2001), *Equity, International Trade and Climate Policy*, **FNU-5** (*International Environmental Agreements*, **2**, 23-48).

Tol, R.S.J., Downing T.E., Fankhauser S., Richels R.G. and Smith J.B. (2001), *Progress in Estimating the Marginal Costs of Greenhouse Gas Emissions*, **FNU-4**. (*Pollution Atmosphérique – Numéro Spécial: Combien Vaut l'Air Propre?*, 155-179).

Tol, R.S.J. (2000), *How Large is the Uncertainty about Climate Change?*, **FNU-3** (*Climatic Change*, **56** (3), 265-289).

Tol, R.S.J., S. Fankhauser, R.G. Richels and J.B. Smith (2000), *How Much Damage Will Climate Change Do? Recent Estimates*, **FNU-2** (*World Economics,* **1** (4), 179-206)

Lise, W. and R.S.J. Tol (2000), *Impact of Climate on Tourism Demand*, **FNU-1** (*Climatic Change*, **55** (4), 429-449).