EQUITABLE COST-BENEFIT ANALYSIS OF CLIMATE CHANGE

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Abstract

The literature of welfare-maximising greenhouse gas emission reduction strategies pays remarkably little attention to equity. This paper introduces three ways to consider efficiency and equity simultaneously. The first method, inspired by Kant and Rawls, maximises net present welfare, without international cooperation, as if all regions share the fate of the region affected worst by climate change. Optimal emission abatement varies greatly depending on the spatial and temporal resolution, that is, the grid at which ‘maximum impact’ is defined. The second method is inspired by Varian’s no-envy. Emissions are reduced so as to equalise total costs and benefits of climate change over the world and over time. Emission reduction are substantial. This method approximately preserves the inequities that would occur in a world without climate change. The third method uses non-linear aggregations of welfare (the utilitarian default is linear) in a co-operative setting. This method cannot distinguish between sources of inequity. The higher the aversion to inequity, the higher optimal greenhouse gas emission reduction.

Keywords

Climate change, climate economics, greenhouse gas emission reduction, efficiency, equity, Kant, Rawls, no-envy, inequity aversion

JEL Classification

C71, C72, D61, D63, Q25, Q40

Non-technical summary

Choosing a greenhouse gas emission reduction target is a matter of efficiency and equity. On the equity side, the distribution of the costs of emission abatement and the distribution of the impacts of climate change matters. The literature provides surprisingly little guidance to make this trade-off. This paper introduces three alternative methods for doing exactly that.

The first method is based on Kant's "do not to others what you do not want others to do to you". Inspired by Rawls, the 'other' is taken to be the one worst affected by climate change. This method provides little guidance since the answer depends whether one looks at badly hit villages, countries or continents, averaged over a month, a decade, or a century. If one looks at impacts at smaller scales, the greenhouse gas emission reduction advised by this method is large.

The second method equates the total costs and benefits of greenhouse gas emission reduction, so that all regions and times share the same relative burden. Under this emission reduction scenario, the relative wealth of regions is the same as in the situation without climate change. The emission reductions required to achieve this are large.

The third method introduces an aversion to inequalities in income, regardless of whether these are caused by climate change, emission abatement or something else. The higher this inequity aversion, the more substantial the recommended greenhouse gas emission reductions.

1. Introduction

Greenhouse gas emissions and vulnerability to climate change show a strong negative correlation. This is the moral issue at the heart of the climate problem. Yet, little attention has been paid to this in the literature. See Banuri *et al.* (1996) for an overview. The literature on equity issues in climate change is largely confined to the distribution of emission reduction targets. This literature takes the need to reduce greenhouse gas emissions for granted, and takes a parametric approach to the required reductions. On the other hand, the literature that tries to derive how much emission abatement is desirable, largely ducks the equity issue. This paper is an attempt to combine the two problems.

Broadly speaking, there are two approaches to advice on desirable emission abatement. One approach follows the Framework Convention on Climate Change and tries to define a safe, maximum atmospheric concentration of greenhouse gases. The 'safe emission corridor' approach, advocated by RIVM (e.g., Alcamo and Kreileman, 1996), bases its target concentrations on half-baked ecological considerations (e.g., Azar and Rodhe, 1997; Swart and Hootsmans, 1991; Swart *et al.*, 1989). It thus avoids any discussion about equity. The 'tolerable windows' approach, championed by PIK (e.g., Toth *et al.*, 1997), bases its target concentrations on geological considerations of the German Advisory Council on Global Change (1995). This takes the naturalist fallacy to the extreme: The future may not fall outside past experiences, because the past was the best of times. Both approaches ignore that trying to avoid inequities of climate change may invoke more serious inequities of emission abatement.

Other authors simply take a concentration target as given, and derive a cost-effective path towards that concentration (e.g., Ha Duong *et al.*, 1997; Manne and Richels, 1995, 1996, 1998; Peck and Teisberg, 1996; Tol, 1999b,c; Wigley *et al.*, 1996). Cost-effectiveness has an appeal to justice in that it minimises total costs so that, in principle, everyone can be made better off. Rose and Stevens (1993; see also Rose *et al.*, 1998) propose ten different interpretations of an equitable, international sharing of the burden of meeting a particular concentration target. Tol (1998a) complements cost-effectiveness with intertemporal equity. However, these papers all ignore the equity implications of selecting a concentration target.

The other approach to deriving emission and concentration targets includes such trade-offs, at least in principle. However, attempts to derive greenhouse gas emission reductions so as to maximise human welfare are without exception based on a narrow neo-classical interpretation of justice (e.g., Maddison, 1995; Manne *et al.*, 1995; Nordhaus, 1991, 1992, 1993, 1994; Nordhaus and Yang, 1996; Peck and Teisberg, 1991, 1994, 1995; Tol, 1997, 1999a). 'Maximum welfare' is interpreted to mean 'Pareto optimal'. That is, the status quo (no climate policy) is the base situation and climate policy needs to make everybody better off, at least potentially. This is another form of the naturalist fallacy: The world without policy intervention is a pretty good world. The inequities of a 'do nothing' policy have no place in this framework. In fact, the analysis operates under the 'victim pays principle': countries that suffer most from climate change are expected to convince large emittors to abate (Tol, 1997).

Yet, the cost-benefit approach is closer to including equity than is the safe concentration approach. Therefore, I try in this paper to extend welfare maximisation to considering justice. Roemer (1996) and Sen (1982, 1987) champion this at a theoretic level. I take a more pragmatic approach.

Three alternatives are presented, and their results demonstrated with *FUND*, an integrated assessment model (cf. Weyant *et al.*, 1996, for an overview of such models). The first alternative derives from the basic message of Emanuel Kant (do not to others what you do not want them to do to you) with a Rawlsian flavour (the 'other' is the least well-off region). The second alternative is based on the thought that, for all regions for all times, the sum of costs of emission reduction and the costs of climate change should be equal. Thus, the inequities of the no-climate-change scenario are maintained (whereas, in a no-policy-scenario, inequities would deteriorate). Such relative no-envy solutions often prove a pragmatic way out in everyday policy making. In the third alternative, a global welfare function is maximised that explicitly includes a distaste for inequity. This alternative has strong roots in neo-classical economics, but cannot distinguish between inequities of climate change, inequities of emission reduction, and inequities of other causes.

The next section presents the model. Sections 3 to 5 present the results for the three alternatives in the above order. Section 6 concludes.

2. The model

The model used is version 1.6 of the *Climate Framework for Uncertainty, Negotiation and Distribution* (*FUND*) (cf. Tol, 1999b,c). Essentially, *FUND* consists of a set of exogenous scenarios and endogenous perturbations. The model is specified for nine major world-regions: OECD-America (excl. Mexico); OECD-Europe; OECD-Pacific (excl. South Korea);

Central and Eastern Europe and the former Soviet Union; Middle East; Latin America; South and Southeast Asia; Centrally Planned Asia; and Africa. The model runs from 1950 to 2200, in time steps of a year. The prime reason for starting in 1950 is to initialise the climate change impact module. In *FUND*, climate impacts are assumed to depend on the impact of the year before, to reflect the process of adjustment to climate change. Thus, climate impacts (both physical and monetized) are misrepresented in the first decades. This would bias optimal control if the first decades of the simulation coincided with the first decades of emission abatement. Similarly, the period 2100-2200 is there to provide the forward-looking agents in the 21st century with a proper time horizon. The calculated emission reductions in 2100-2200 have little meaning in and of themselves.

The *IMAGE* database (Batjes and Goldewijk, 1994) is the basis for the calibration of the model to the period 1950-1990. Scenarios for the period 2010-2100 are based on the EMF14 Standardised Scenario, which lies between IS92a and IS92f (cf. Leggett *et al.*, 1992). Note that the original EMF14 Standardised Scenario had to be adjusted to fit *FUND*'s nine regions and yearly time-step. The period 1990-2010 is a linear interpolation between observations and the EMF14 Standardised Scenario. The period 2100-2200 is an extrapolation of the EMF14 Standardised Scenario.

The scenarios concern the rate of population growth, urbanisation, economic growth, autonomous energy efficiency improvements, 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.

The scenarios of economic and population growth are perturbed by the impact of climate change. Population falls with climate change deaths, resulting from changes in heat stress, cold stress, malaria, and tropical cyclones. Heat and cold stress are assumed to affect only the elderly, non-reproductive population. The other sources of mortality do affect the number of births. Heat stress only affects urban population. The share of urban in total population is, up to 2025, based on the World Resources Databases; after 2025, urban population slowly converges to 95% of total population (comparable to present day Belgium or Kuwait). Population also changes with climate-induced migration between the regions. Immigrants are assumed to assimilate immediately and completely with the host population.

The tangible impacts of climate change are dead-weight losses to the economy. Consumption and investment are reduced, without changing the saving's rate. Climate change thus reduces long-term economic growth, although at the short term consumption takes a deeper cut. Economic growth is also reduced by carbon dioxide emission abatement.

The energy intensity of the economy and the carbon intensity of the energy supply autonomously decrease over time. This process can be sped up by abatement policies.

The endogenous parts of *FUND* consist of the atmospheric concentrations of carbon dioxide, methane and nitrous oxide, the global mean temperature, the impact of carbon dioxide emission reductions on economy and emissions, and the impact of the damages of climate change on the economy and the population.

Methane and nitrous oxide are taken up in the atmosphere, and then geometrically depleted:

$$C_t = C_{t-1} + \alpha E_t - \beta\left(C_{t-1} - C_{pre}\right) \qquad (1)$$

where C denotes concentration, E emissions, t year, and *pre* pre-industrial. Table 1 displays the parameters for both gases.

Table 1 Parameters of equation (1).

Gas	α[a]	β[b]	pre-industrial concentration
methane (CH_4)	0.3597	1/8.6	790 ppb
nitrous oxide (N_2O)	0.2079	1/120	285 ppb

[a] The parameter α translates emissions (in million metric tonnes of CH_4 or N_2O) into concentrations (in parts per billion by volume).

[b] The parameter β determines how fast concentrations return to their pre-industrial (and assumedly equilibrium) concentrations; $1/\beta$ is the atmospheric life-time (in years) of the gases.

Source: After Schimel *et al.* (1996).

The atmospheric concentration of carbon dioxide follows from a five-box model:

$$Box_{i,t} = \rho_i Box_{i,t} + 0.000471\alpha_i E_t \qquad (2a)$$

with

$$C_t = \sum_{i=1}^{5} \alpha_i Box_{i,t} \qquad (2b)$$

where α_i denotes the fraction of emissions E (in million metric tonnes of carbon) that is allocated to box i (0.13, 0.20, 0.32, 0.25 and 0.10, respectively) and ρ the decay-rate of the boxes (ρ = exp(-1/lifetime), with life-times infinity, 363, 74, 17 and 2 years, respectively). Thus, 13% of total emissions remains forever in the atmosphere, while 10% is—on average—removed in two years (after Hammitt *et al.*, 1992). Carbon dioxide concentrations are measured in parts per million by volume.

Radiative forcing for carbon dioxide, methane and nitrous oxide are based on Shine *et al.* (1990). The global mean temperature T is governed by a geometric build-up to its equilibrium (determined by radiative forcing RF), with a half-time of 50 years. In the base case, global mean temperature rises in equilibrium by 2.5°C for a doubling of carbon dioxide equivalents, so:

$$T_t = \left(1 - \frac{1}{50}\right)T_{t-1} + \frac{1}{50}\frac{2.5}{6.3\ln(2)}RF_t \qquad (3)$$

Global mean sea level is also geometric, with its equilibrium level determined by the temperature and a life-time of 50 years. Temperature and sea level are calibrated to the best guess temperature and sea level for the IS92a scenario of Kattenberg *et al.* (1996).

The climate impact module is based on Tol (1995, 1996). A limited number of categories of the impact of climate change are considered: agriculture, sea level rise, heat and cold stress, malaria, tropical and extratropical storm, river floods, and unmanaged ecosystems. The damage module has two units of measurement: people and money.

People can die (heat stress, malaria, tropical cyclones), not die (cold stress), or migrate. These effects, like all impacts, are monetized. The value of a statistical life is set at $250,000 plus 175 times the per capita income. The value of emigration is set at 3 times the per capita income, the value of immigration at 40% of the per capita income in the host region.

Other impact categories are directly expressed in money, without an intermediate layer of impacts measured in their 'natural' units.

Damage can be due to either the rate of change (benchmarked at 0.04°C/yr) or the level of change (benchmarked at 2.5°C). Benchmark estimates are displayed in Table 2. Damage in the rate of temperature change slowly fades at a speed indicated in Table 3. Damage is calculated through a second-order polynomial in climatic change. Thus, damage D_t in year t is either

$$D_t = \alpha_t W_t + \beta_t W_t^2 \tag{4a}$$

or

$$D_t = \alpha_t \Delta W_t + \beta_t \Delta W_t^2 + \rho D_{t-1} \tag{4b}$$

with W the appropriate climate variable (temperature, sea level, hurricane activity, etc.) and α, β and ρ parameters.

Table 2 Monetized estimates of the impact of global warming (in 10^9 US\$ per year).

Region	species	life	agric.	Sea	extreme	total
level (temperature: +2.5°C; sea level: +50 cm; hurricane activity: +25%; winter precipitation: +10%; extratropical storm intensity: +10%)						
OECD-A	0.0	-1.0	-5.3	0.9	2.5	-2.9
OECD-E	0.0	-1.1	-6.0	0.3	0.3	-6.5
OECD-P	0.0	-0.5	-6.1	1.5	5.5	0.3
CEE&fSU	0.0	3.7	-23.2	0.1	0.2	-19.1
ME	0.0	3.5	3.1	0.1	0.0	6.6
LA	0.0	67.0	7.3	0.2	0.0	74.5
S&SEA	0.0	81.4	15.8	0.2	0.6	98.8
CPA	0.0	58.4	-22.2	0.0	0.1	36.3
AFR	0.0	22.5	5.4	0.1	0.0	28.0
rate (temperature: 0. 04°C/year; other variables follow)						
OECD-A	0.3	0.2	0.3	0.2	0.2	1.2
OECD-E	0.3	0.2	0.0	0.2	0.0	0.7
OECD-P	0.2	0.1	0.0	0.3	0.4	1.0
CEE&fSU	0.1	0.1	0.0	0.0	0.0	0.2
ME	0.0	0.0	0.1	0.0	0.0	0.2
LA	0.0	0.4	0.1	0.1	0.0	0.6
S&SEA	0.0	0.3	0.1	0.1	0.0	0.6
CPA	0.0	0.2	0.3	0.0	0.0	0.5
AFR	0.0	0.0	0.1	0.0	0.0	0.2

Source: Tol (1996).

Table 3 Duration of damage memory per category.[a]

category	years	category	years
species loss	100	immigration	5
agriculture	10	emigration	5
coastal protection	50	wetland (tangible)	10
life loss	15	wetland (intangible)	50
tropical cyclones	5	dryland	50

[a] Damage is assumed to decline geometrically at a rate of 1-1/life-time.

Source: Tol (1996).

Damage is distinguished between tangible (market) and intangible (non-market) effects. Tangible damages affect investment and consumption; through investment, economic growth is affected; through consumption, welfare is affected. Intangible damages affect welfare.

Relative vulnerability to climate change – α and β in (4) – is a function of economic development in many ways. The importance of agriculture falls with economic growth. The share of agriculture in total output changes with per capita income with an elasticity of -0.31, which corresponds to the per capita income elasticity across *FUND*'s 9 regions in 1990. Malaria incidence and the inclination to migrate fall logistically with increases in per capita income. Heat stress increases linearly with urbanisation. The valuation of intangible impacts increases logistically with per capita income.

Emission abatement is restricted to industrial sources of carbon dioxide. The costs of carbon dioxide emission reduction are calibrated to the survey results of Hourcade *et al.* (1996), supplemented with results of Rose and Stevens (1993) for developing countries. Regional and global average cost estimates, and their standard deviations result. Regional relative costs are shrunk to the global average, that is, the weighted average of the regional and global average is taken, with the inverse variances as weights. This reduces the influence of a single study. It particularly influences the developing regions, for which much less information on emission abatement costs is available. Costs are represented by a quadratic function. Table 4 presents the parameters. Roughly, a 1% cut in emissions costs 0.02% of GDP; a 10% cut costs 2%.

Table 4 *Parameters of the CO_2 emission reduction cost function.*[a]

OECD-A	2.0789	CEE&fSU	2.0488	S&SEA	2.1268
OECD-E	2.3153	ME	2.1041	CPA	1.9544
OECD-P	2.2171	LA	2.1253	AFR	2.0931

[a] The proportional loss of GDP C in year t of proportional emission reduction R in year t follows: $C_t = aR_t^2$. The costs to GDP are modelled as a dead-weight loss to the economy. Emission reduction is brought about by a permanent shift in energy- and carbon-intensity.

Source: After Hourcade *et al.* (1996) and Rose and Stevens (1993).

In *FUND*, each region has its own decision maker. *FUND* also distinguishes generations of decision makers. Each decision maker has control over a ten-year period only, but does optimise the net present welfare of her region (in the non-co-operative cases) from the start of the control period up to 2200. In the case of global co-operation, the unweighted sum of the net present regional welfares is maximised. Each decision maker knows the emission reduction efforts of all decision makers in all regions at all times. The equilibrium is found iteratively.

3. Kant

Do not to others what you do not want to happen to you. It is simple, appealing, and restraining. It does take a number of additional considerations, though, to make Kant operational in a climate change context. Firstly, there are costs of emission reduction as well as costs of climate change. However, because of discounting and the slow workings of the climate system, *current* costs of climate change are likely to exceed *current* costs of emission reduction. Therefore, it seems reasonable (and is found to be reasonable in the experiments below) to restrict the attention to the costs of climate change. Secondly, there are a great number of others whose potential discomfort should be internalised. The costs of climate change to various regions are strongly linked, however. If the costs of the most vulnerable are reduced to acceptable levels, the costs of less vulnerable are likely to have fallen (and indeed are in the below experiments) below acceptable levels. Thirdly, the costs of climate change to the most vulnerable regions are not reduced to a pre-ordained level. Instead, less vulnerable regions treat the relative costs of the most vulnerable region as if these were their own, and perform a cost-benefit analysis on that basis. Fourthly, by focusing on the costs to the most vulnerable to climate change, the analysis is sensitive to scale. For instance, in *FUND*, the Maldives and India are grouped in one region. The impact on moderately vulnerable India dominates the impact on the highly vulnerable Maldives. The aggregation in *FUND* is such that little can be done about this. Therefore, the effect is demonstrated by looking at vulnerability per region averaged over time, and vulnerability per region per time-period. Fifthly, optimal emission reductions are calculated in *FUND*'s non-cooperative mode.

Figure 1 displays some results. Using the time-averaged vulnerability adjustment, ' emission abatement reduces concentrations substantially below the business as usual scenario. The common non-cooperative emission abatement policy leads to concentrations which are indistinguishable from the business as usual case. Using the time-specific vulnerability adjustment, 'Kantian' abatement reduces concentrations even further, in fact close to the optimal cooperative solution. The latter may seem strange, since the ' alternative has much higher 'damages'. However, the vulnerability adjustment is based on impacts as a percentage of GDP. An equal percentage impact on, say, the European Union and Africa would still leave the latter worse off in terms of utility. In the '
African impacts on European utility count. In the cooperative case, African impacts on African utility count.

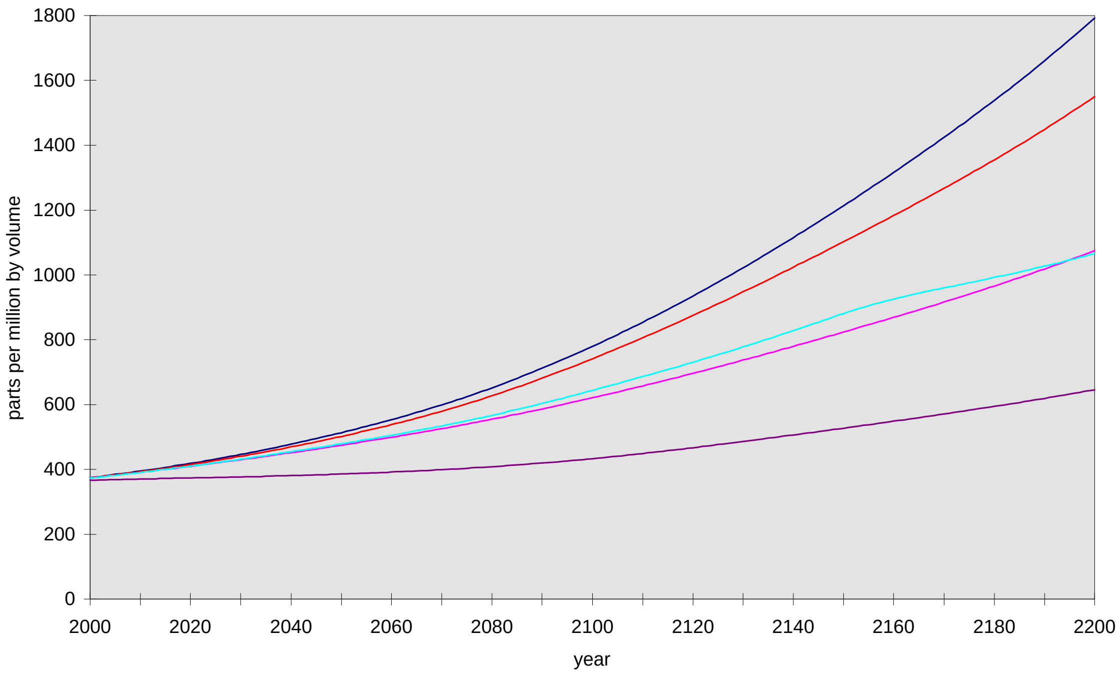

Figure 1. The atmospheric concentration of carbon dioxide for five scenarios, from top to bottom, business as usual (and non-cooperative optimal emission control), non-cooperative average Kantian emission control, non-cooperative maximum Kantian emission control, cooperative optimal emission control, and no-envy emission control.

Although the outcome in terms of concentrations is similar, the distribution of emission reductions over regions and over time is not. Figure 2 displays the regional and temporal distribution of emission reduction for the co-operative optimum, Figure 3 for the average Kant case, and Figure 4 for the maximum Kant case. Average Kantian emission control is generally lower than emission abatement in the other two cases. The main qualitative difference between co-operative and Kantian abatement is for Centrally Planned Asia, which starts poor but is little vulnerable to climate change, and is projected to emit large amounts of carbon dioxide.

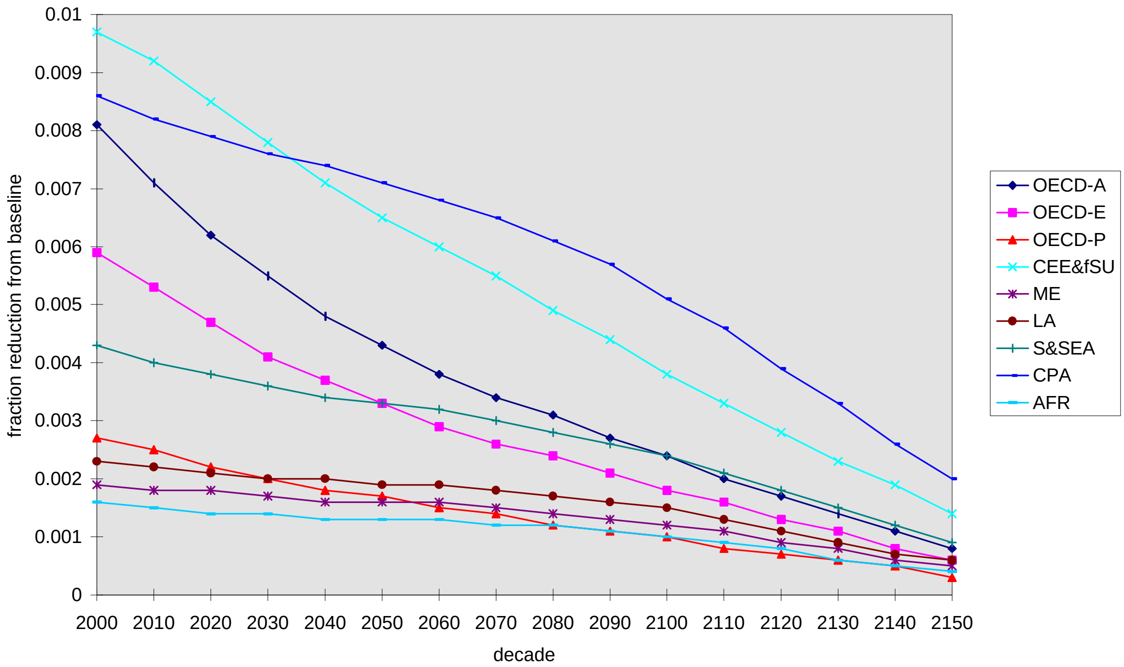

Figure 2. The regional and temporal emission reduction efforts for co-operative optimal control.

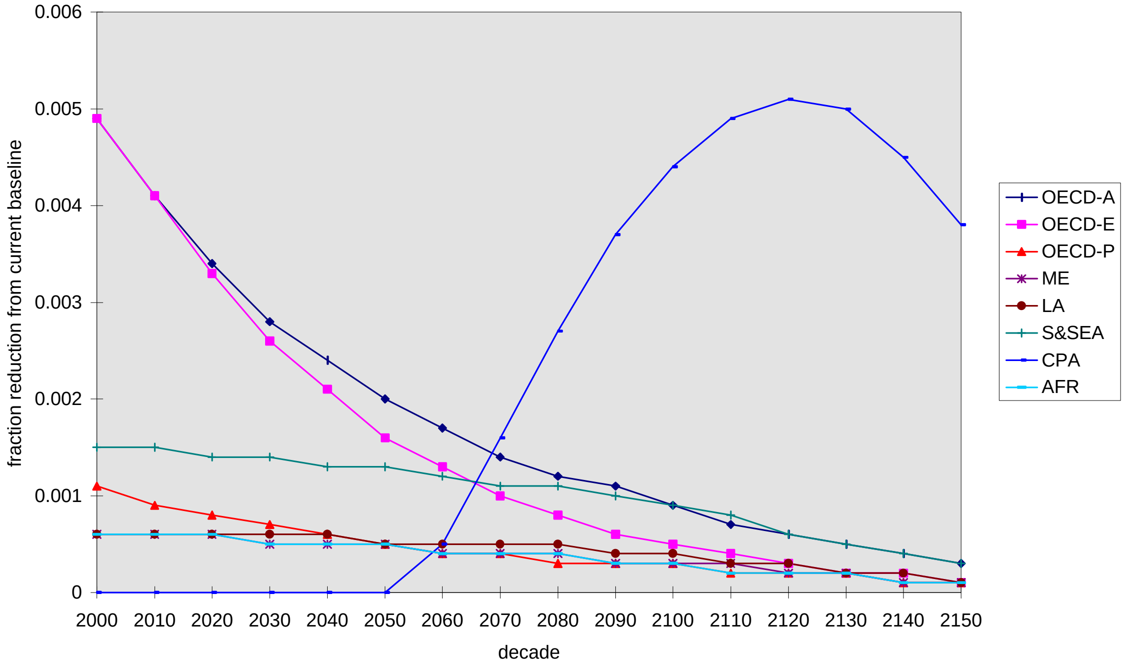

Figure 3. The regional and temporal distribution of emission reduction efforts for the non-cooperative average Kantian emission control case.

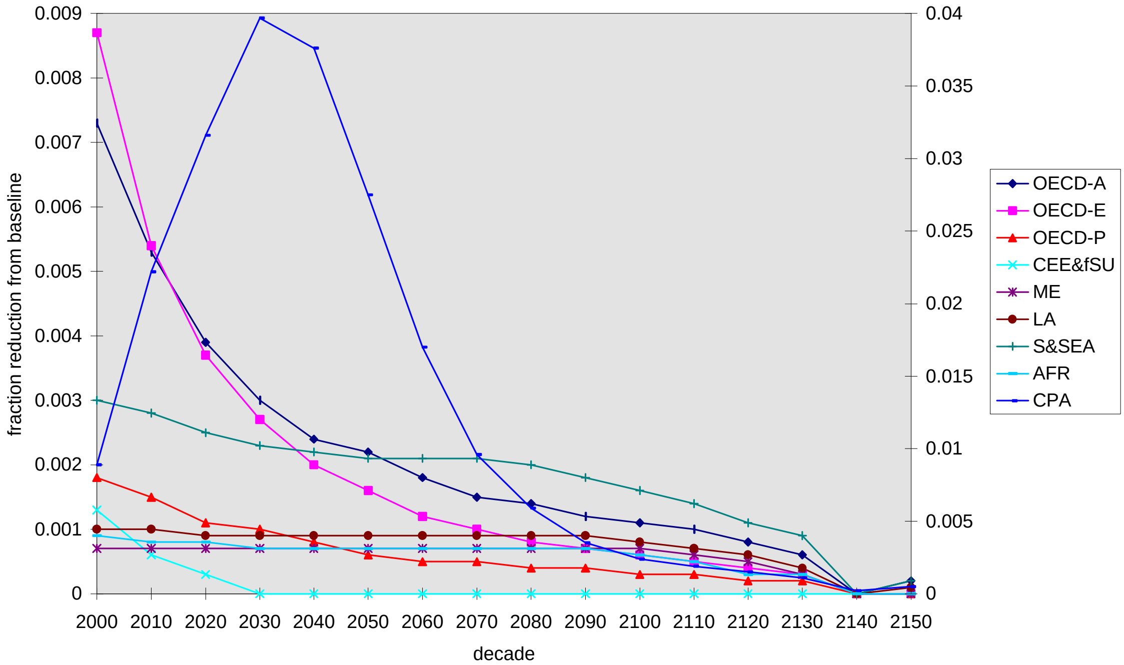

Figure 4. The regional and temporal distribution of emission reduction efforts for the non-cooperative maximum Kantian emission control case. CPA is on the right axis.

4. No-envy

Climate change invokes additional inequities, as its impacts are unevenly distributed and disproportionally affect the poor. Greenhouse gas emission reduction invokes other inequities. Consider the following thought experiment. The leaders of all countries and all generations meet to share the joint burden of climate change and emission reduction. All are committed and no one is inclined to cheat. In real life, such meetings often agree on an equal effort for all (e.g., an equal percentage emission reduction). This is not necessarily equitable, but, if the equal effort is in a proper metric, it does not introduce a lot of new inequities either. The injustice of the status quo is by and large maintained.[1] Varian (1974) coined the term 'no-envy' for such a solution, and explores its implications.

In the hypothetical meeting of countries and generations, however, the situation without climate change is taken as the reference case. The sum of the costs of emission reduction and the costs of climate change, relative to income, is equalised. This implies that the inequities of the no-climate-change scenario are more or less maintained. Greenhouse gas emission reduction policy is used to counteract the inequities of climate change, but no more than that.

Figure 1 displays the results. The business as usual scenario is taken as the starting point. Its climate change impacts are displayed in Figure 5 for four regions. Emissions are reduced so that for each region for each time-period the costs of emission reduction minus the costs of climate change are equal to the average costs of climate change in the no-control scenario. Regions and time with higher than average impacts do not reduce emissions. Resulting emission reductions are fed into *FUND*, new climate change impacts are calculated, and new emission reductions are determined. Convergence is rapid.

The resulting emission reductions are substantial. Atmospheric concentrations of carbon dioxide are kept below 650 ppm. Figure 6 displays emission abatement, expressed as the annual reduction from the current baseline as a fraction of that baseline. The OECD should reduce emissions by about 9% per year, Central and Eastern Europe and the former Soviet Union even more than 10%. Interestingly, China should start reducing emissions immediately, by about 5% per year. China's emission reductions gradually rise to a peak of about 7%, and then fall to zero in the late 22nd century. By the year 2200, these five regions have moved to a almost carbon-free economy. Other regions do not face emission cuts, except the Middle East for a short while.

The costs of this scenario are high. Figure 7 shows the net present consumption losses. These amount to $162 trillion for the world. For comparison, the costs of the Wigley, Richels and Edmonds (1996) trajectory towards a stabilisation of the carbon dioxide concentration at 650 ppm costs only $10 trillion, without international trade in emission permits. The costs of the no-envy scenario can be reduced by allowing international emission permit trade within each period. Costs then fall to $51 trillion. This is in the self-interest of all trading parties.

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[1] This is much like the Pareto criterion, which takes resource endowments as given.

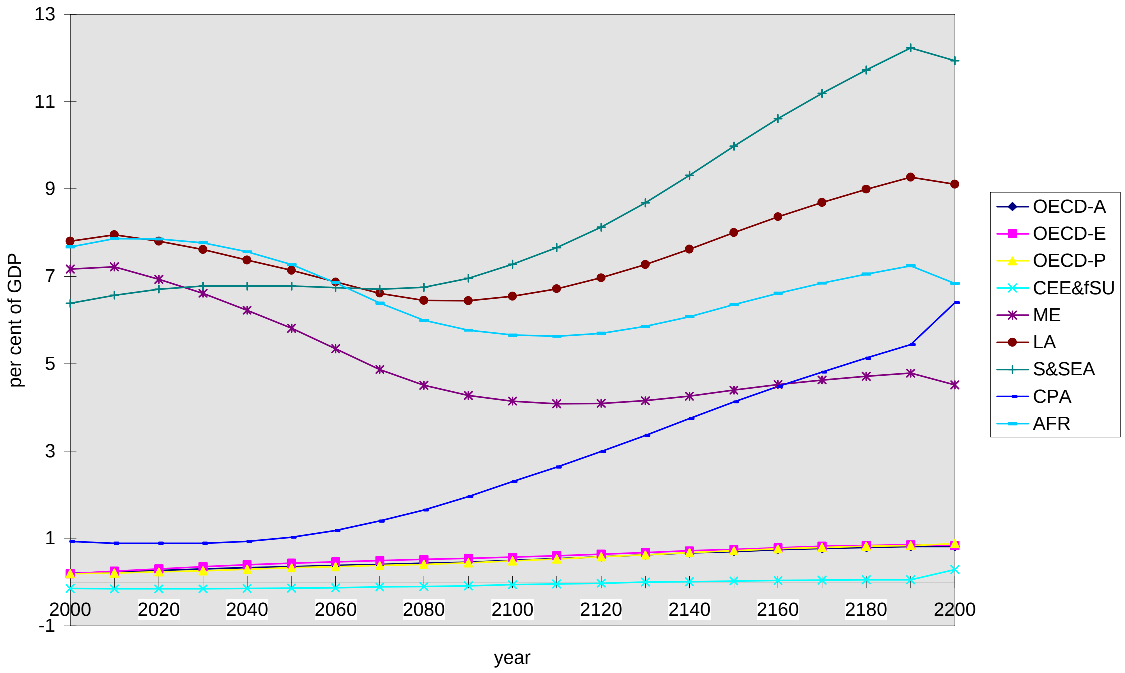

Figure 5. The regional and temporal distribution of the relative impacts of climate change in the business as usual scenario.

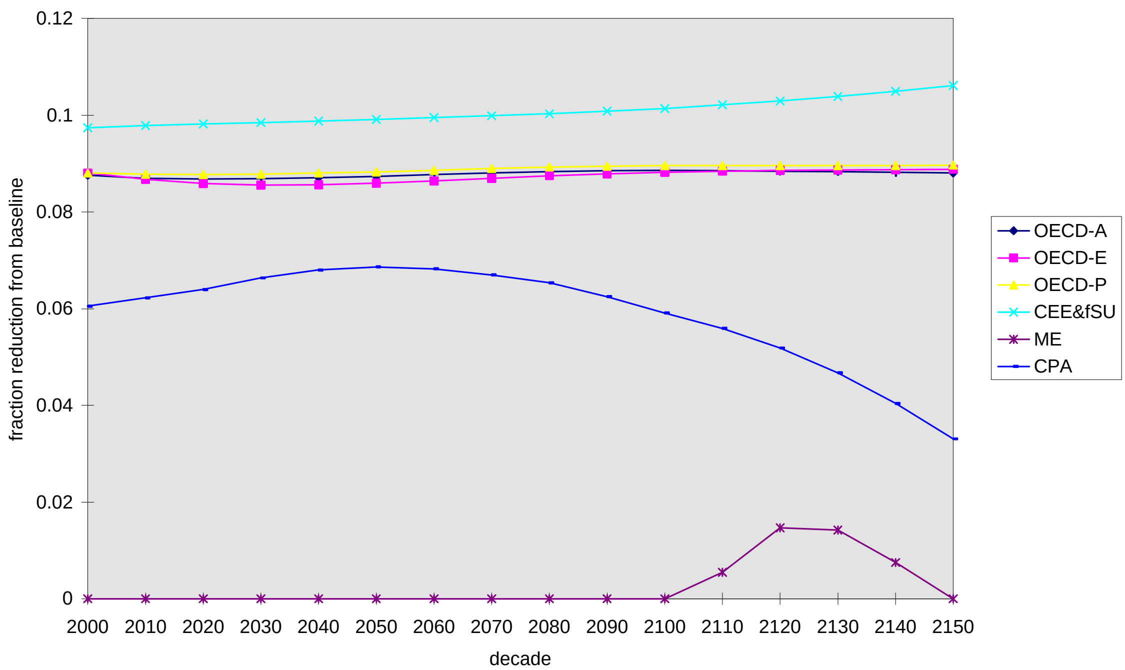

Figure 6. The regional and temporal distribution of emission reduction efforts for the no-envy control case.

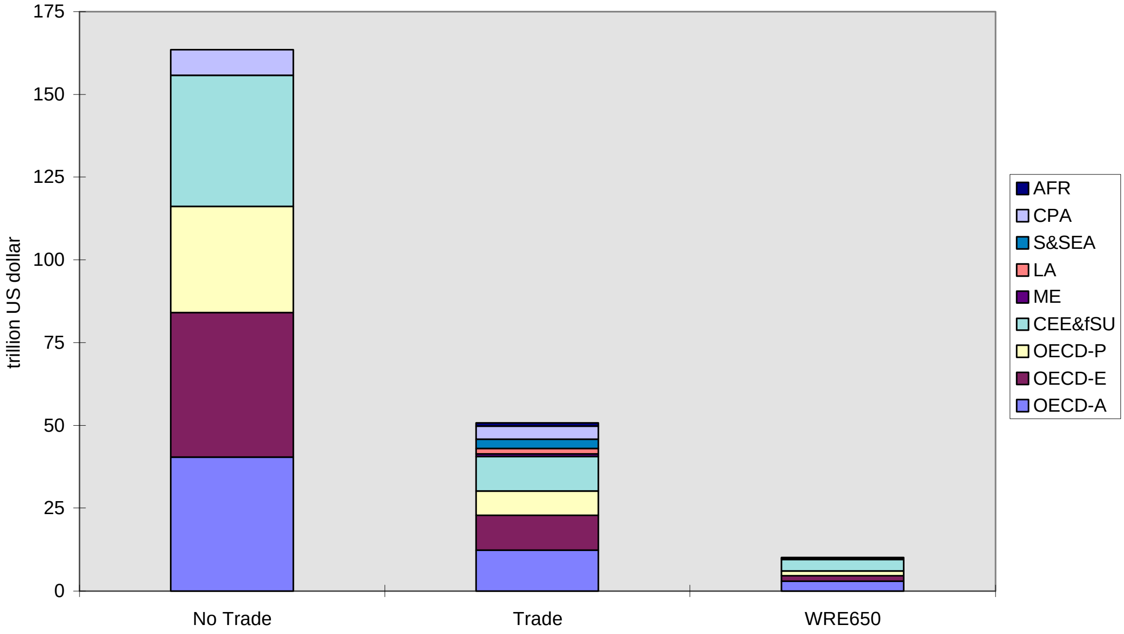

Figure 7. Consumption losses in the period 1990-2200, discounted to 1990 at 5% per year, due to emission reduction for two no-envy emission control scenarios without and with international trade in emission permits and the WRE scenario without international trade $_2$ concentration in the long run.

5. Inequity aversion

Usually, co-operative solutions maximise the sum of the welfares of the actors in the game. There is no reason for this other than convenience. Alternatively, one could maximise

$$W = \sum_r \frac{U_r^{1-g}}{1-g}$$

where U_r denotes the welfare of actor r and g is a parameter, denoting 'inequity aversion'. For g=0, W equals the conventional sum of welfare. The higher g, the more W is determined by the welfare U of the poorer actors. This is easily seen since $g\uparrow\infty$ implies that W=min(U_r) – the Rawlsian maximin approach – and $g\downarrow\infty$ implies that W=max(U_r) – the Nietzschean maximax approach. If g is unity, W is replaced by the – equivalent – product of the actors' welfares, a Bernouilli-Nash type of welfare function (cf. Fankhauser *et al.*, 1997; Tol, 1998b).

Inequity aversion g assumes five different values: 0, 1, 2, 5, and 10. Figure 8 displays the results for the atmospheric concentration of carbon dioxide. Emissions are reduced more for higher inequity aversion. This is because of the implicit wealth transfers of climate change and emission reduction. Co-operative emission control leads to an atmospheric CO_2

concentration of over 1000 ppm in 2200, and rising. If g=10, concentrations are kept below 550 ppm.

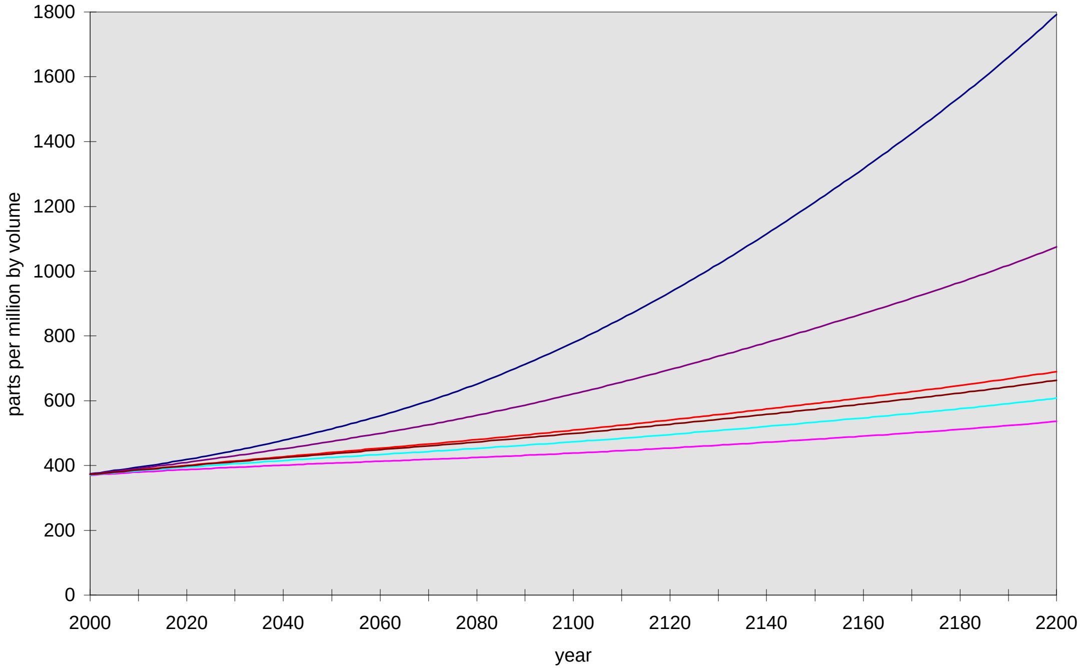

Figure 8. The atmospheric concentration of carbon dioxide for six scenarios, from top to bottom, business as usual, and co-operative optimal emission control with inequity aversion of 0, 1, 2, 5, and 10.

6. Conclusions

This paper explores welfare maximising carbon dioxide emission reductions that better adhere to equity issues than does conventional optimal control. If countries do not co-operate but do act as if the most vulnerable region's relative damage is their own, emissions are not substantially reduced, much less indeed than in the co-operative optimal control case. If, instead, the relative damage of the most vulnerable period of the most vulnerable region is considered, emissions are reduced about as much as in the co-operative optimal control case. This suggests two things. First, like any extremum operator, the Kant-Rawls framework is very sensitive to its temporal and regional resolution. If the grid is refined, emissions are likely to be reduced further. Second, the analysis demonstrates the power of co-operation over non-co-operation. (A similar conclusion can be drawn with respect to discounting (Tol, 1999a) and uncertainty (Tol, 1999d)).

In case the sum of relative carbon dioxide emission reduction costs and relative climate change damage costs is equalised over regions and over time, emission abatement is substantial, keeping CO_2 concentrations below 650 ppm. This no-envy solution, however, is very expensive compared to other strategies aiming at the same concentration target.

If, in a co-operative setting, a premium is put on an equal distribution of per capita income, emission abatement is stricter than in case that premium is naught. For a high aversion of inequity, CO_2 concentrations may even be kept below 550 ppm.

The numbers presented in this paper should be treated with great caution, as they depend on a single parameterisation of a single model. The climate change impact estimates are particularly uncertain, but do drive the numerical results to a substantial extent. The qualitative results are more important. If one takes the climate-change-induced inequities into account, emission abatement should be intensified. International co-operation in emission control is crucial. Strong cuts in emissions may well be justifiable on grounds of equity.

The qualitative results need some caveats as well. Two of the three methods presented here (Kant, inequity aversion) are sensitive to resolution. It does matter whether one looks at groups of countries, countries, or sector or regions within countries. This opens the door to differences of interpretation. All three methods are dependent on the baseline, and on the metric of expressing costs and benefits, both of which are open to dispute.

The main caveat, however, is that it is hard to observe concern for equity issues with the world's governments (Schelling, 1995). The paper presents academic constructs, no descriptions of the real world. These thought experiments may, however, help to inform further thinking about how to handle the enhanced greenhouse effect.

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