EQUITY, INTERNATIONAL TRADE AND CLIMATE POLICY

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Abstract

The literature of welfare-maximising greenhouse gas emission reduction strategies pays remarkably little attention to equity. This paper introduces various ways to consider efficiency and equity simultaneously. Lower (higher) discount rates lead to higher (lower) emission reduction. Higher (lower) inequity aversion leads to higher (lower) emission abatement, unless one also considers the negative effects of OECD emission reduction on the exports of developing countries; in that case, the effect of inequity aversion is ambiguous. In the absence of international cooperation, higher (lower) risk aversion leads to lower (higher) emission abatement. With international cooperation, the effect of risk aversion is ambiguous because of the higher risk aversion gives more weight to poorer regions and poorer generations. We analyse four ways to introduce compassion in a non-cooperative setting. If observed development aid is a guide, international altruism is small and has little impact on optimal emission control. If countries act as if they 'feel' but not 'physically experience' the climate impact of the most vulnerable country, optimal emission reduction increases, but not substantially so. However, if countries actually have to pay for the damage done, they would prefer to reduce their emissions to much lower levels. Finally, if countries pay as much to emission reduction as other countries suffer from climate change, (that is, if climate policy restores the income distribution to what it would have been without climate change), emissions are rapidly cut to very low levels.

Keywords

Climate change, climate economics, greenhouse gas emission reduction, efficiency, equity, Kant, Rawls, no-envy, inequity aversion, risk aversion, polluter pays principle, altruism

JEL Classification
C71, C72, D61, D63, Q25, Q40

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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, the literature – see Banuri *et al.* (1996) and Toth (1999) for an overview – pays little attention to this, particularly not in a structured or quantitative way. One may argue that equity is an additional reason to abate greenhouse gas emissions. However, emission reduction also has implications for international income distribution. The equity implications of climate change have to be carefully balanced against the equity implications of climate change. This paper is an attempt to do so.

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 (e.g., Alcamo and Kreileman, 1996; Toth *et al.*, 1997). This approach ignores that trying to avoid inequities of climate change may invoke more serious inequities of emission abatement. Substantial attention is given, however, to the equitable, international distribution of the burden imposed by the emission reduction target (Barrett, 1992; Bosello and Roson, 2000; Buonanno *et al.*, 2000; LeCocq *et al.*, 2000; Ridgley, 1996; Rose, 1992; Rose and Stevens, 1993; Rose *et al.*, 1998). Cost-effectiveness is important in this, as it minimises total costs so that, in principle, everyone can be made better off (although this is typically not done). Manne and Richels (1995, 1996, 1998) derive a cost-effective path towards a given concentration target. Tol (1999f) 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, in principle, includes the distributional trade-offs. 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, 1996; 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 (cf. Farrow, 1998). 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, we try in this paper to extend welfare maximisation to considering justice. Roemer (1996) and Sen (1982, 1987) champion this at a theoretic level. We take a more pragmatic approach. This paper builds on Tol (2001c). However, we use a newer version of the model, we extend the number of equitable alternatives to standard cost-benefit analysis, and we add the effects of international trade and investment.

A number of 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’ being 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. The other alternatives have more similarity to conventional economic theory. We first do a sensitivity analysis around the discount rate and risk aversion. In a fourth alternative, a global welfare function is maximised that explicitly includes distaste for inequity. This alternative has roots in neo-classical economics, but cannot distinguish between inequities of climate change, inequities of emission reduction, and inequities of other causes. A further alternative introduces altruism. Again, altruism does not distinguish between sources of inequity. A final alternative is again deeply rooted in neo-classical economics. The polluter pays principle is rigorously implemented.

The next section presents the model. Sections 3 to 7 present the results for the six alternatives, starting with the approaches more in line with neo-classical economics. Section 8 concludes.

2. The model

The model used is version 2.1 of the *Climate Framework for Uncertainty, Negotiation and Distribution* (*FUND*). Version 2.0 of *FUND* is the same as version 1.6, described and applied by Tol (1999a-e), except for the impact module, which is described by Tol (2001a,b).[1] Version 2.1 differs from version 2.0 in that allows for more general utility and welfare functions and international trade effects.

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. Because the starting values in 1950 cannot be approximated very well, climate impacts (both physical and monetized) are misrepresented in the first few decades. This would bias optimal control if the first decades of the simulation coincided with the first decades of emission abatement. Similarly, the 22nd century is included to provide the forward-looking agents in the 21st

[1] The source code of both versions 1.6 and 2.0 the model can be found at http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/fund.html.

century with a long time horizon. The calculated optimal emission reductions in 2100-2200 have little meaning (or policy relevance) 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 scenario for economic growth is displayed in Figure 1. An important feature of this, and all other scenarios for climate change analysis, is the assumed economic convergence between regions. The average income gap between the richest and the poorest region is assumed to fall from the current 50 to about 10.

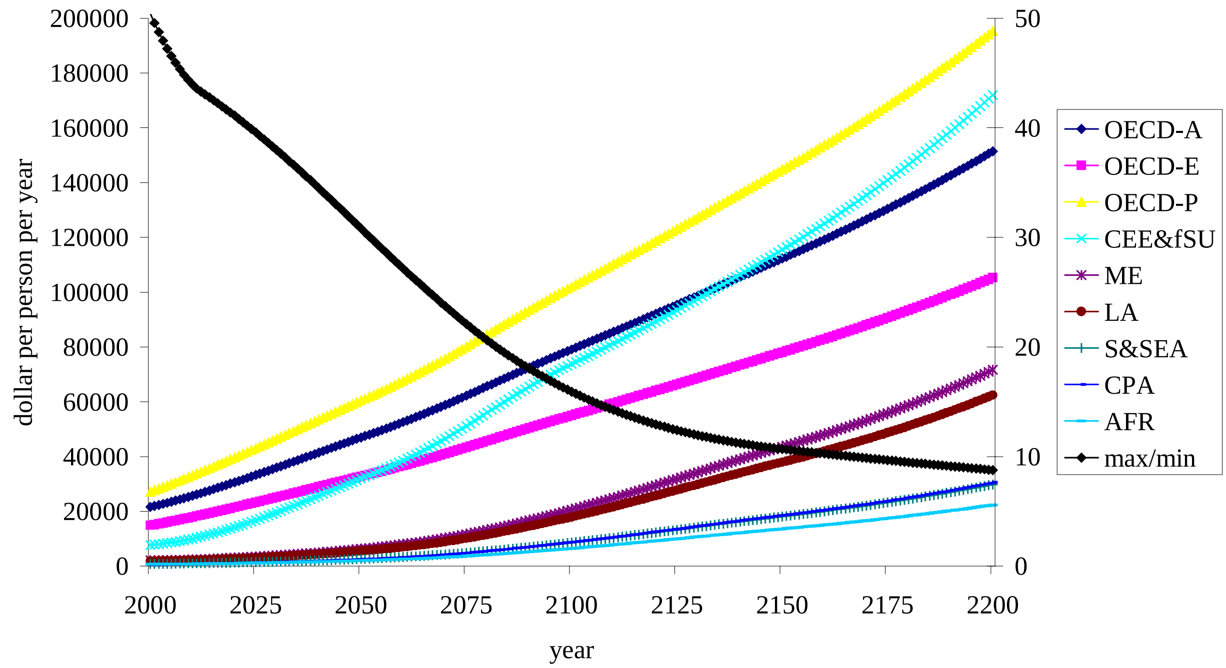

Figure 1. Projected per capita income in *FUND's* nine regions in the case without greenhouse gas emission control and without climate change. Also displayed, on the right axis, is the ratio of average per capita income of the richest and the poorest region.

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:

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

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:

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

with

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

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). The model is due to Meier-Reimer and Hasselmann (1987), its parameters are due to Hammitt *et al.* (1992). Thus, 13% of total emissions remains forever in the atmosphere, while 10% is—on average—removed in two years. 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:

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

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 (2001a,b). A limited number of categories of the impact of climate change are considered: agriculture, forestry sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, energy consumption, water resources, and unmanaged ecosystems.

People can prematurely die (because of temperature stress or vector-borne diseases) or migrate (because of sea level rise). These effects, like all impacts, are monetized. The value of a statistical life is set at 200 times the 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 at 3 times the per capita income (Tol, 1995, 1996), the value of immigration at 40% of the per capita income in the host region (Cline, 1992).

Dryland and wetland loss due to sea level rise are explicitly modelled. Dryland loss is valued at $4 million per square kilometre on average in the OECD in 1990 (cf. Fankhauser, 1994). Dryland value is assumed proportional to GDP per square kilometre. Wetland loss is valued at $2 million per square kilometre on average in the OECD in 1990 (cf. Fankhauser, 1994). Wetland value is assumed to be logistic in per capita income. Coastal protection is based on cost-benefit analysis, including the value of additional wetland lost due to dike building and consequent coastal squeeze.

Other impact categories (agriculture, forestry, energy, water, ecosystems) 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, reflecting adaptation.

Table 2. Estimated impacts of a 1°C increase in the global mean temperature. Standard deviations are given in brackets.

	Billion dollar		percent of GDP	
OECD-A	175	(107)	3.4	(2.1)
OECD-E	203	(118)	3.7	(2.2)
OECD-P	32	(35)	1.0	(1.1)
CEE&fSU	57	(108)	2.0	(3.8)
ME	4	(8)	1.1	(2.2)
LA	-1	(5)	-0.1	(0.6)
S&SEA	-14	(9)	-1.7	(1.1)
CPA	9	(22)	2.1	(5.0)
AFR	-17	(9)	-4.1	(2.2)

Source: Tol (2001a).

Impacts of climate change on energy consumption, agriculture and cardiovascular and respiratory diseases explicitly recognise that there is a climate optimum. A mix of factors, including plant physiology and farmer behaviour, determines the climate optimum. Impacts are positive or negative depending on whether climate is moving to or away from that optimum climate. Impacts are larger if the initial climate is further away from the optimum climate. The optimum climate concerns the potential impacts. Actual impacts lag behind potential impacts, depending on the speed of adaptation. The impacts of not being fully adapted to the new climate are always negative.

Other impacts of climate change, on coastal zones, forestry, unmanaged ecosystems, water resources, malaria, dengue fever and schistosomiasis, are modelled as simple power functions. Impacts are either negative or positive, but do not change sign.

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.

Vulnerability 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 urbanisation) and ecosystems and health (with higher values from 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-borne diseases (with improved health care).

The result of all this is a complex climate change impact profile, a highly non-linear function of climate and society. Figure 2 examplifies this.

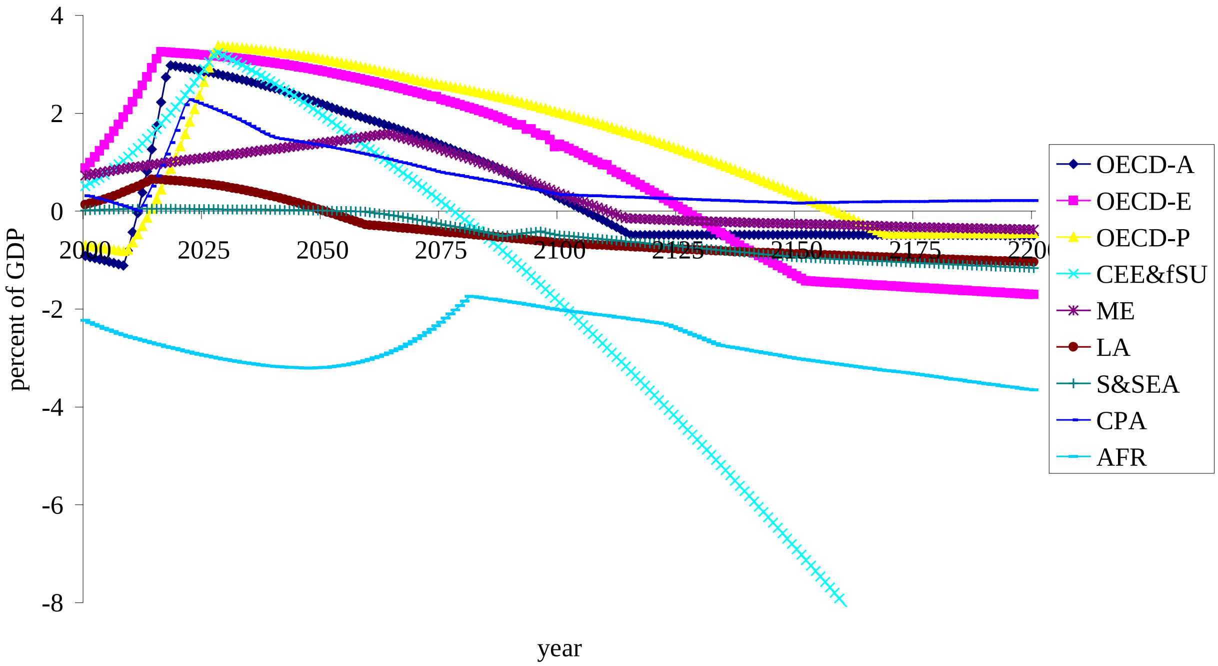

Figure 2. Monetised climate change impacts in *FUND*'s nine region in the scenario without greenhouse gas emission reduction.

Figure 3 displays per capita income without climate policy but with climate change. Comparing Figure 1 and 3, the equity dimension of climate change is very clear. According to *FUND*, climate change will reverse the assumed convergence of per capita income. Climate change impacts will substantially slow economic growth in poor countries, and may even reverse it in some.

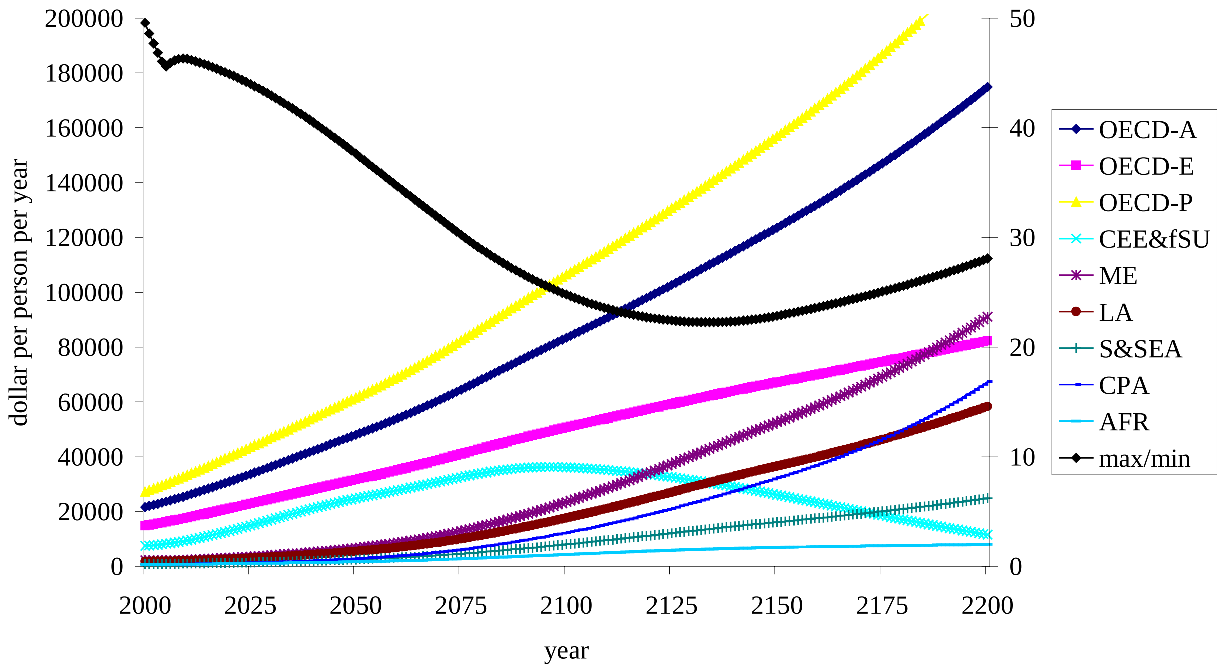

Figure 3. Projected per capita income in *FUND*'s nine regions in the case without greenhouse gas emission control and without climate change. Also displayed, on the right axis, is the ratio of average per capita income of the richest and the poorest region.

Emission abatement is restricted to carbon dioxide originating from industry, utilities, transport and households. Land use change is excluded. 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).

Emission reduction in one region affects economic growth in other regions as well. First of all, the international market in fossil fuels would change, with lower demands and prices for coal and oil. This benefits countries that import fossil fuels and do not reduce emissions. Second, countries with little emission abatement and substantial exports of energy-intensive products would gain competitive advantages over producers of energy-intensive products with substantial emission reduction. Third, overall lower growth would imply overall lower international trade, where exporters of primary commodities are hardest hit. These effects can only be assessed with a computable general equilibrium effects. In this study, we use results from WAGEM (Kemfert 2000). WAGEM is an intertemporal computable general equilibrium and multi regional trade model for the global economy. It considers 11 world regions that are linked through bilateral sectoral trade flows based on GTAP data of 1995. For each region, a representative agent maximises lifetime utility from consumption. This determines the level of savings. Firms choose investment in order to make the most of the present value of their companies. In each region, production of the non-energy macro good is captured by an aggregate production function. The production function characterises technology through transformation possibilities on the output side and substitution possibilities on the input side. In each region, a representative household chooses to allocate lifetime income across consumption in different time periods in order to maximise lifetime utility. In each period, households face the choice between current consumption and future consumption, which can be purchased via savings. The trade-off between current consumption and savings is given by a constant intertemporal elasticity of substitution. Producers invest as long as the marginal return on investment equals the marginal cost of capital formation. The rates of return are determined by a uniform and endogenous world interest rate such that the marginal productivity of a unit of investment and a unit of consumption is equalised within and across countries. Domestic and imported varieties for the non-energy good for all buyers in the domestic market are treated as imperfect substitutes by a CES Armington aggregation function, with a constant elasticity of substitution. Several runs were made with WAGEM, with various emission reduction targets in the OECD. The results of this are used to calibrate *FUND*, where trade effects are assumed to be linear.[2] Emission reduction costs in one region are assumed to lead to a proportional losses of economic growth in other regions, according to the parameters of Table 5. Roughly, a 1% reduction in growth in the OECD would cost other regions between 0.5 and 4.5% of their GDP.

In *FUND*, each region has its own decision maker, nine in total. *FUND* also distinguishes generations of decision makers, twenty in total. Thus, there are 9x20=180 decision makers in the model. Each decision maker has control over a ten-year period only. Each decision maker maximises the net present welfare of her region (in the non-co-operative cases) from the start of the control period up to 2200. Thus, the first decision maker maximise welfare in the period 2000-2200, discounted to 2000, by abating emissions in the period 2000-2009. The second decision maker maximise welfare in the period 2010-

[2] Trade effects are approximately linear in WAGEM.

2200, discounted to 2010, by abating emissions in the period 2010-2019. And so on. Welfare is defined as the natural logarithm of per capita income. The discount rate is one per cent per year. In the case of global co-operation, the unweighted sum of the net present regional welfares is maximised (see Section 5). Each decision maker knows the emission reduction efforts of all decision makers in all regions at all times. The equilibrium is found iteratively. That is, in the first iteration, each decision maker controls emissions so as to maximise net present welfare, assuming that the other decision makers do nothing. In the second iteration, each decision maker acts assuming that the other decision makers do as in the first iteration. And so on, until convergence.

3. Risk aversion and time preference

Figure 4 displays the atmospheric concentration of carbon dioxide according to the business as usual scenario, the non-cooperative optimal control scenario, and the cooperative optimal control scenario. In the optimal control scenarios, all parameters are set to their base values as described in the previous section. If countries do not cooperate, optimal emission reduction is small but greater than zero. If countries cooperate, optimal emission reduction is larger, but not large enough to stabilize atmospheric concentrations of carbon dioxide. These results are well-established.

Figure 7 displays the results for non-cooperative optimal control with and without trade effects. The difference is small (cf. Figure 8), but emission abatement is slightly higher with than without trade effects. In the non-cooperative case, regions do not care about their negative impacts on other regions, but slower growth in less developed regions, particularly China, helps reducing emissions.

In the base case, welfare is defined as the natural logarithm of per capita income. That is, risk aversion is set to unity. A more general welfare function is

(4) $$U_{r,t} = \frac{Y_{r,t}^{1-e}}{1-e}$$

where e denotes risk aversion. Risk aversion determines the curvature of the welfare function, and thus the relative weight placed on a marginal improvement in income of rich and poor. Figure 4 shows optimal atmospheric concentrations of carbon dioxide if risk aversion is set to zero and two. With a risk aversion of two, both cooperative and non-cooperative emission control is zero. The reason is that more weight is placed on the losses of early generations due to emission abatement. Under the scenario assumptions of the model, the current generation is the poorest. With a risk aversion of nought, that is, welfare is linear in income, non-cooperative optimal emission reduction is somewhat higher than in the case with a risk aversion of unity, as more weight is placed on the plight of future generations. However, with a risk aversion of nought, cooperative optimal emission control is lower, as a low risk aversion places little weight on the poorer countries.

In sum, in the non-cooperative case, optimal emission control is decreasing in risk aversion, as higher risk aversion places more weight on the current, poorest generation. In the cooperative case, optimal emission control is first increasing, then decreasing in risk aversion as the relative weights placed on the poorest regions and the poorest generations shift.

A similar effect is observed if we introduce trade effects in cooperative optimal control (see Figure 7). Trade effects increase emission abatement for low risk aversion, and decrease emission abatement for medium risk aversion. With low risk aversion, the negative trade effects carry less weight, and the negative effects of climate change more weight.

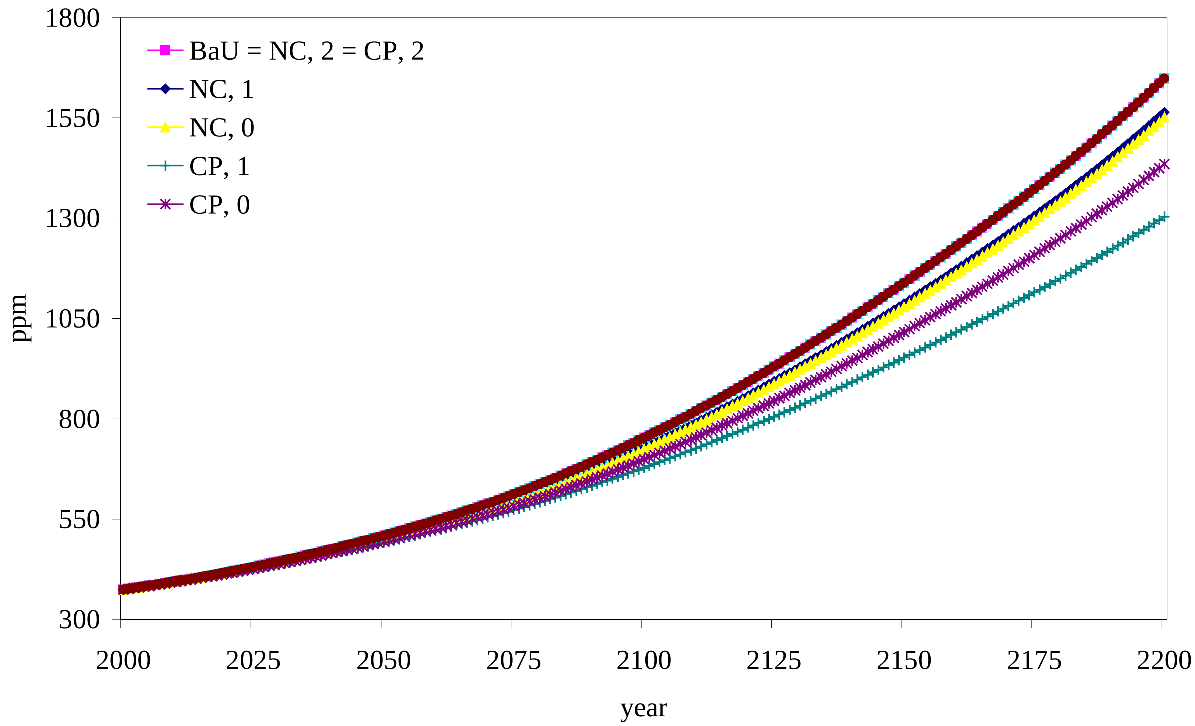

Figure 4. The atmospheric concentration of carbon dioxide according to the business as usual (no control scenario), three non-cooperative optimal emission control scenarios with alternative values for risk aversion, and, three cooperative optimal emission control scenarios with alternative values for risk aversion.

Figure 5 displays the results for different utility discount rates, or pure rates of time preference, ranging from 0.1% to 3% per year. Unsurprisingly, higher (lower) discount rates imply lower (higher) emission abatement, and thus higher (lower) atmospheric concentrations.

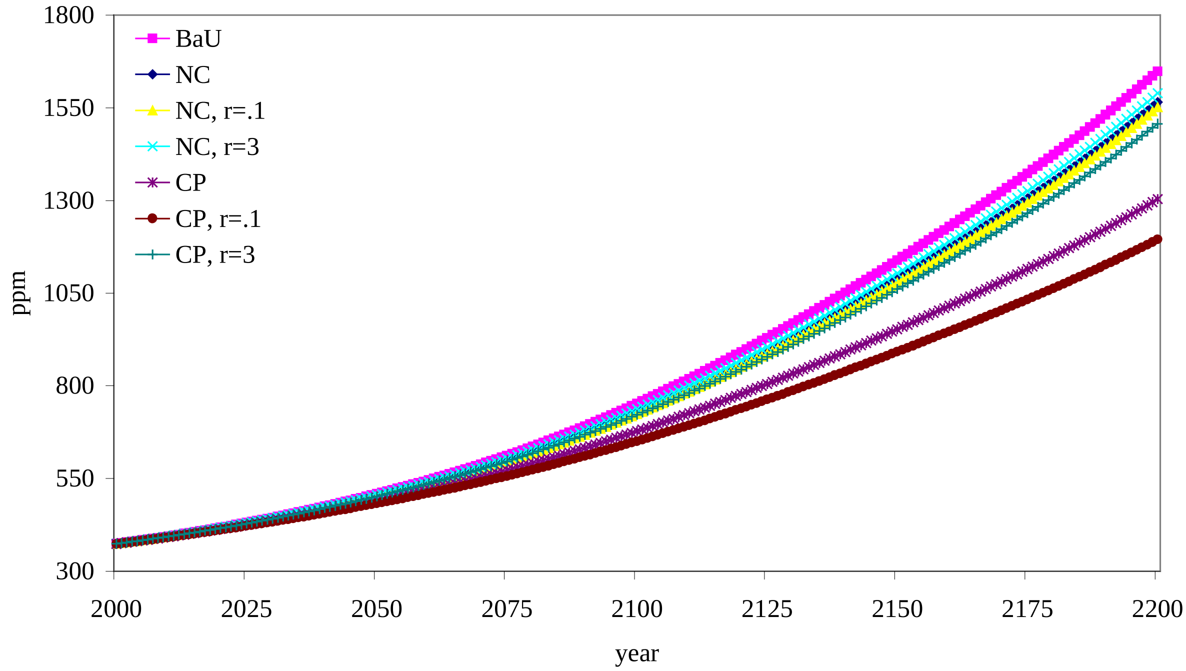

Figure 5. The atmospheric concentration of carbon dioxide according to the business as usual (no control scenario), three non-cooperative optimal emission control scenarios with alternative values for the pure rate of time preference, and, three cooperative optimal emission control scenarios with alternative values for the pure rate of time preference.

Figure 7 compares cooperative optimal emission control with and without trade effects for the alternative discount rates. In the cooperative case, trade effects lead to lower emission reduction, because of the negative impacts of trade. This is more pronounced with a lower than with a higher discount rate, even though the trade effects are concentrated in the next five decades. Their effects on economic growth, however, are felt for a much longer period.

4. Inequity aversion and altruism

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

(5) $$W = \sum_r \frac{U_r^{1-\gamma}}{1-\gamma}$$

where U_r denotes the welfare of actor r and γ is a parameter, denoting 'inequity aversion'. For γ=0, W equals the conventional sum of welfare. The higher γ, the more W is determined by the welfare U of the poorer actors. This is easily seen since $\gamma\uparrow\infty$ implies that W=min(U_r) – the Rawlsian maximin approach – and $\gamma\downarrow\infty$ implies that W=max(U_r) – the Nietzschean maximax approach. If γ is unity, W is replaced by the – equivalent –

product of the actors' welfares, a Bernouilli-Nash type of welfare function. Fankhauser *et al.* (1997) discuss the implications of alternative welfare specifications for the impact of climate change.

The major drawback of this approach is that it cannot distinguish between sources of inequity. Inequities arise from many causes, including climate change. The only policy instrument is greenhouse gas emission reduction. In this specification, the instrument of emission abatement will be used to reduce inequities of any origin, not just from climate change.

In our experiment, inequity aversion γ assumes five different values: 0, 1, 2, 5, and 10. Figure 6 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 transfer of climate change and emission reduction. That is, the costs of greenhouse gas emission reduction by the richer regions counts less and less for higher γ, while the avoided damages of climate change to the poorer regions count more and more. Poorer regions are thought to be more vulnerable to climate change, while welfare maximisation concentrates emission reductions in the richer regions. Thus, emission control in the richer regions implies a welfare transfer to the poor. Emission control increases with inequity aversion, but even strong inequity aversion is not enough to stabilize atmospheric concentrations below 1000 ppm.

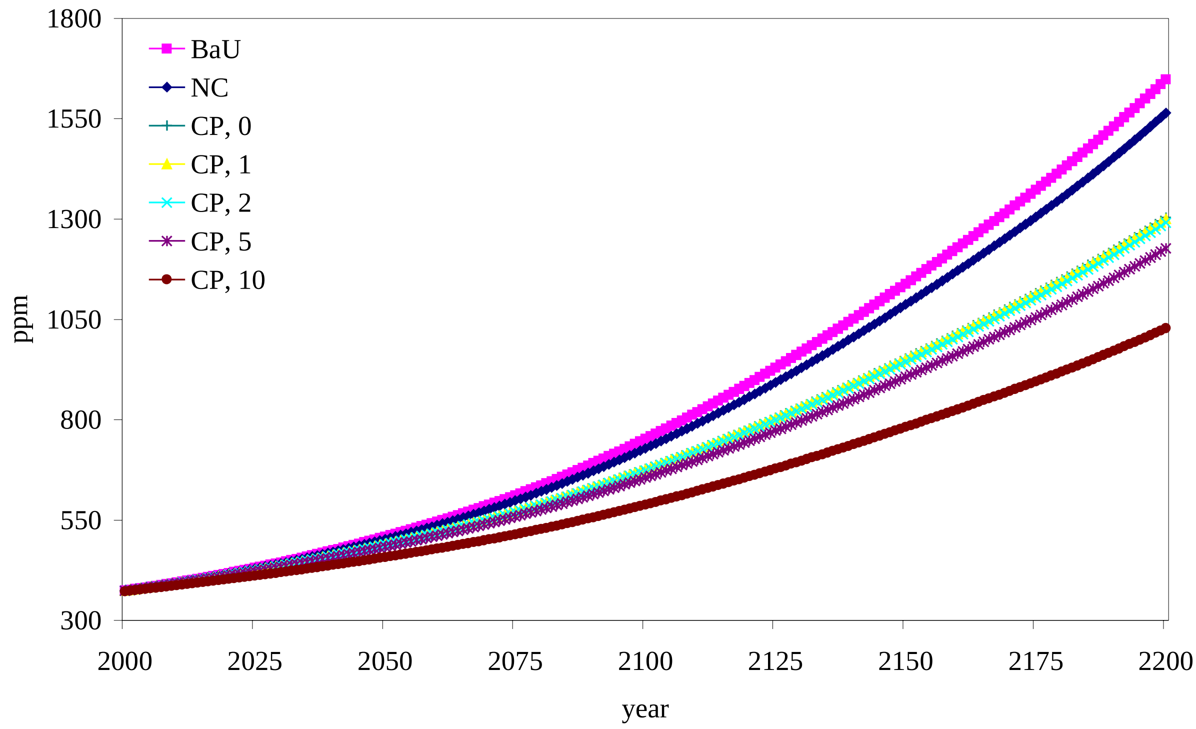

Figure 6. The atmospheric concentration of carbon dioxide according to the business as usual (no control scenario), the base non-cooperative optimal emission control scenarios, and five cooperative optimal emission control scenarios with alternative values for inequity aversion.

Figure 7 displays the differences in results with and without trade effects for a variety of scenarios. Trade effects are most pronounced in case on inequity aversion. In the standard cooperative case, that is, with an inequity aversion of zero, emission control is lower with than without trade effects. That is, the negative effects of trade on growth in less developed regions is a reason to abate less. This is more pronounced with inequity aversions of 1 and 10, but the situation is reversed for intermediate inequity aversion. The explanation lies in the diversity of the poorer regions. Different values of inequity aversion attach different weights to different regions and time periods. The negative trade effects not only hurt growth, but they also cut emissions, particularly in China, and this is valued positively, particularly in Africa and South and Southeast Asia. In principle, one would expect the effect of trade on optimal emission control to be ambiguous, and this is what the numerical analysis demonstrates.

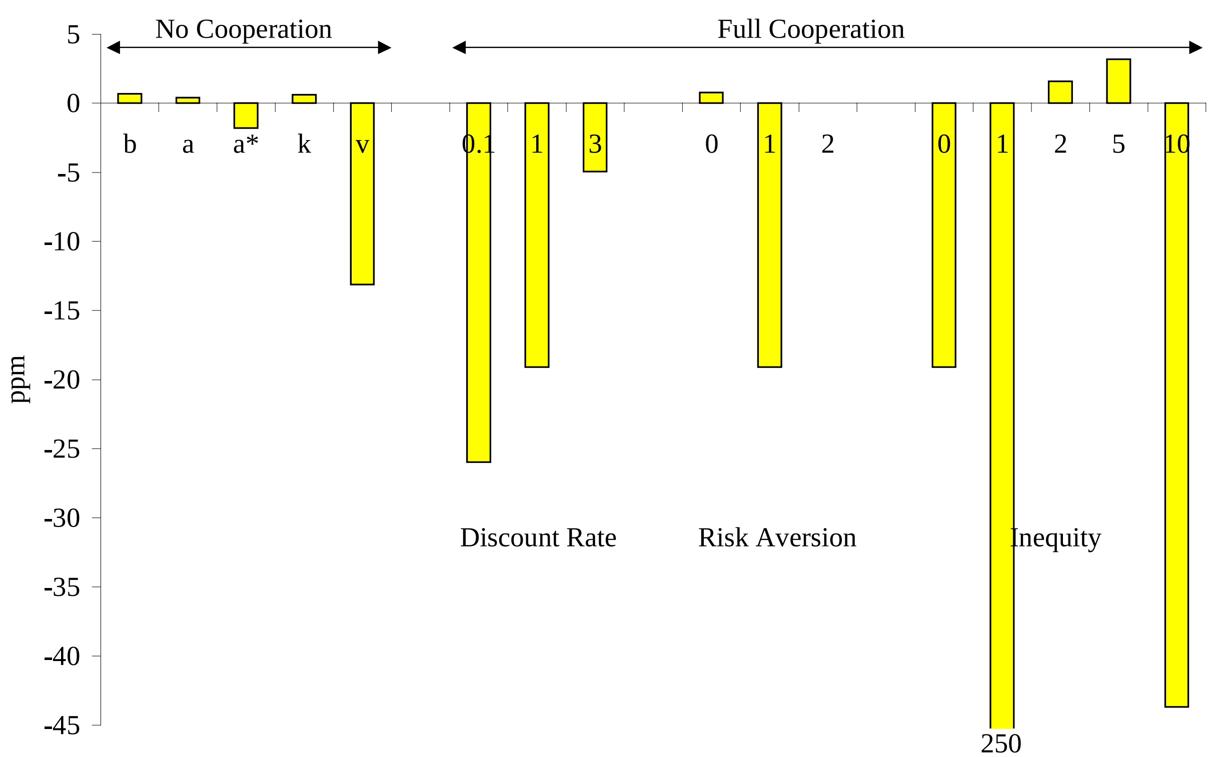

Figure 7. The impact of trade effects on the optimal 2200 atmospheric concentration of carbon dioxide, according to five non-cooperative emission control scenarios (b: base case; a: altruism; a*: altruism x 10; k: Kant-Rawls; v: Varian) and nine cooperative emission control scenarios, varying the discount rate (0.1, 1, 3%), risk aversion (0, 1, 2) and inequity aversion (0, 1, 2, 5, 10); displayed are the concentrations with trade minus the concentrations without trade.

The non-cooperative variant of inequity aversion is altruism, that is, one region's welfare is a function of other regions' welfare as well. One representation is

(6) $$U_i^* = U_i + \alpha U_j$$

where U denotes selfish welfare and U^* altruistic welfare. The parameter α measures the extent of altruism. Let us assume that governments in the OECD maximise (6), and that selfish welfare is measured according to classical utilitarianism. Then (6) turns into

(6') $$\max_A P_i \ln\left(\frac{Y_i - A}{P_i}\right) + \alpha P_j \ln\left(\frac{Y_j + A}{P_j}\right) \Rightarrow \alpha = \frac{P_i^2 (C_j + A)}{P_j^2 (C_i + A)}$$

Let us further assume that populations and incomes are as in 1990, and that OECD give 1% of their income to development aid. Then, α=0.004. If, instead, we assume that welfare depends on per capita income only, α=0.04. We use the higher value.

Figure 8 shows the optimal atmospheric concentration of carbon dioxide. Altruism slightly increases emission reduction, but the impact on the atmosphere is hardly noticeable. This is not surprising, as altruism is so small, Even if we set α=0.4, emission abatement is largely unchanged. The reason is that some regions towards the OECD displays altruistic feelings actually benefit from climate change.

Figure 7 compares the results with and without international trade. With a little altruism, optimal emission reduction increases. With more altruism, optimal emission abatement decreases. The reasons for this ambiguity are the same as for the ambiguity with inequity aversion.

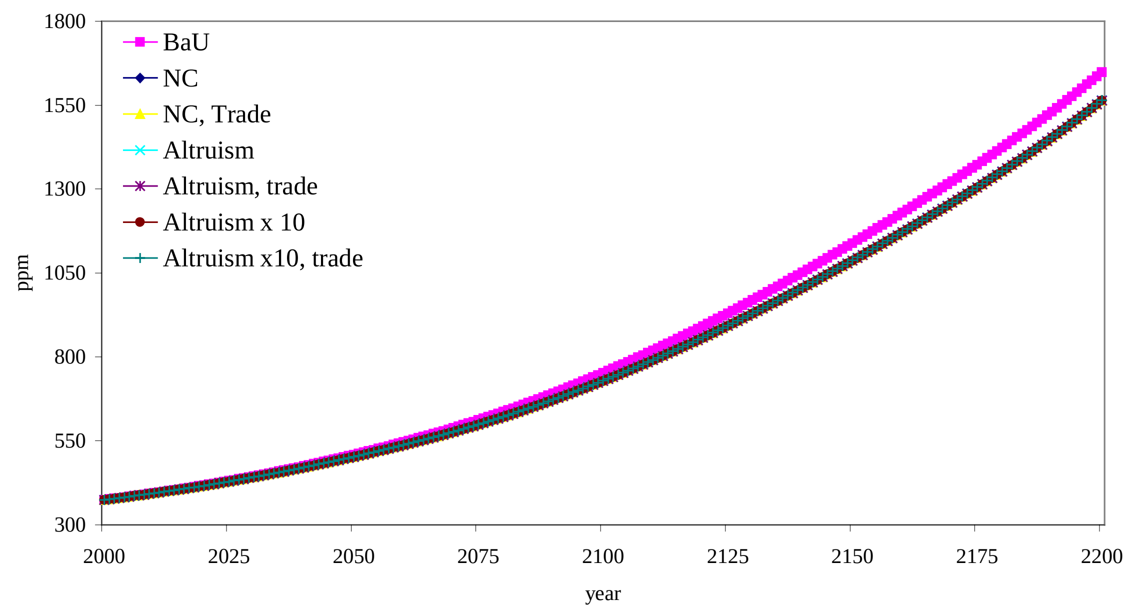

Figure 8. The atmospheric concentration of carbon dioxide according to the business as usual (no control scenario), the non-cooperative optimal emission control scenarios with and without trade effects, and two non-cooperative optimal emission control scenarios with alternative values for altruism and with and without trade effects.

5. The polluter pays principle and historical responsibility

An alternative way to internalise climate change impacts on other regions is through the polluter pays principle. Simply put, those that emit pollution compensate those that suffer the consequences. In reality, it is hard to assess cause and effect, and to determine adequate compensation. In a model, this is much easier. We aggregate all climate change impacts, valued at regionally specific values. Aggregate world damage is then allocated to the regions according to their historical contribution to the enhanced greenhouse effect. Gruebler and Nakicenovic (1996) estimate accumulated carbon dioxide emissions for the period 1850-1950. From 1950 onwards, *FUND* generates emissions. Figure 9 displays cumulative emissions per region as a fraction of total cumulative emissions. The OECD is clearly the largest contributor to climatic change in 2000, but its share gradually declines over time.

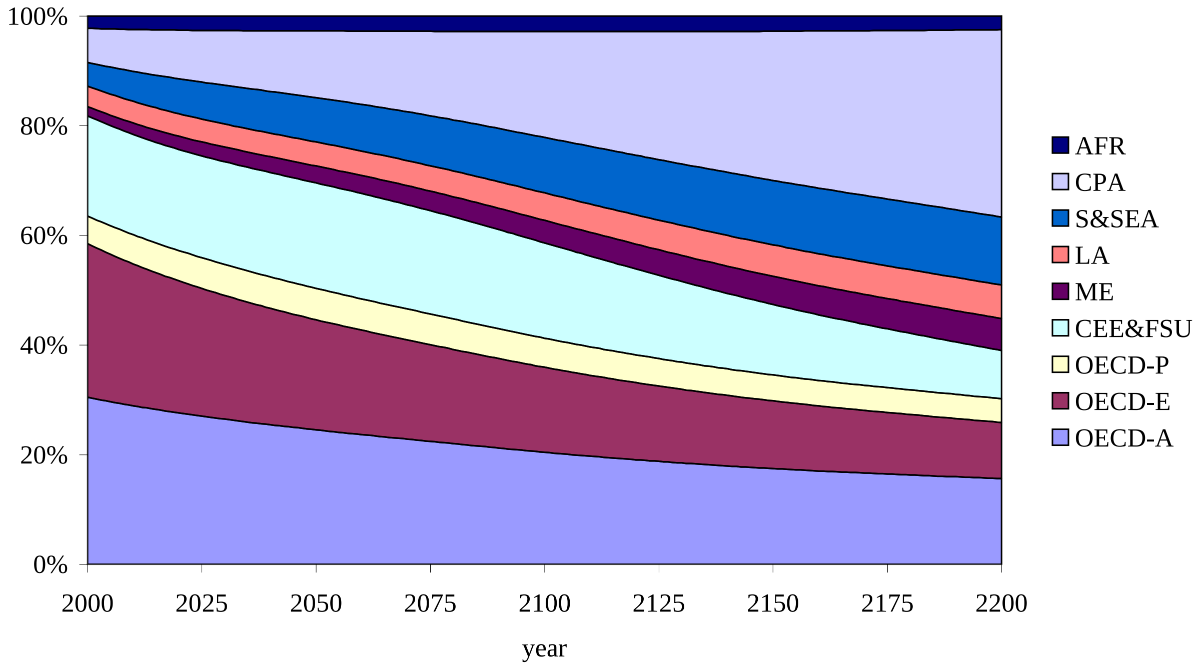

Figure 9. The share of regional cumulative carbon dioxide emissions from fossil fuel combustion in global cumulative emissions, according to the business as usual scenario without compensation.

Figure 10 displays business as usual concentrations of carbon dioxide with and without compensation. The OECD pays so much in compensation that its economies and emissions decline. Other regions grow faster as a result, but the additional emissions do not make up for the loss of OECD emissions. Consequently, business as usual concentrations are lower with than without compensation. This result is model and scenario dependent.

Figure 10 also displays non-cooperative optimal emission control with compensation. The polluter pays principle induces OECD regions, in particular, to abate more emissions. If trade effects are introduced, optimal emission control slightly falls, because growth in the less developed regions is slowed and their total impact reduced, so that less compensation needs to be paid.

Trade effects are again small, although less so than in the earlier non-cooperative control cases. In contrast, trade effects now decrease non-cooperative optimal control. The reason is that trade effects reduce growth in the poorest countries, thus increasing their vulnerability and so the amount of compensation that needs to be paid.

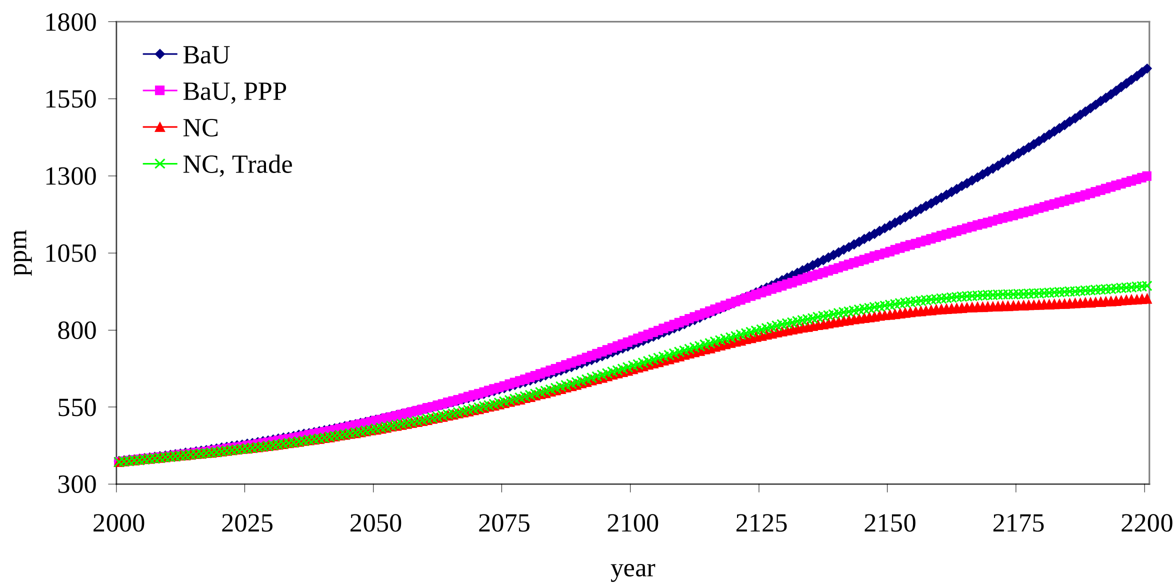

Figure 10. The atmospheric concentration of carbon dioxide according to the business as usual (no control scenario) with (PPP) and without compensation, and two non-cooperative optimal emission control scenarios with and without trade effects.

6. 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.[3] 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, the *maximum current* costs of climate change are likely to exceed the *maximum current* costs of emission reduction, and indeed do so in the experiments reported below. Therefore, we restrict our attention to the costs of climate change.

3 Barrett (1992) explores a Kantian burden sharing rule for greenhouse gas emission reduction.

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. That is, the climate change impacts of each region in each decade is multiplied by a factor $A_{t,r} = \left(\max_r I_{t,r}\right) \big/ I_{t,r}$, where $I_{t,r}$ denotes the impact at time t in region r. 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. Fifthly, optimal emission reductions are calculated in *FUND*'s non-cooperative mode.

Figure 11 displays some results. The non-cooperative optimal control scenario and the Kant-Rawls optimal control scenario are very close together, with a latter one leading to slightly lower concentrations. This is surprising. The reason is as follows. Emission control is non-cooperative, also in the Kant-Rawls case, so only a fraction of the climate change damage is internalised. Also, the Kant-Rawls damage is modelled as a loss of welfare, not affecting economic growth. Thus, even if richer regions experience current impacts on poor countries, the richer regions do not suffer the dynamic consequences.

Trade effects lead to a slight increase in emission control (Figure 7). The earlier result for non-cooperative emission reduction also holds in this case: Trade effects reduce growth and emissions. As growth is also reduced in the region with the highest impact, the effect is less pronounced the Kant-Rawls than in the standard case.

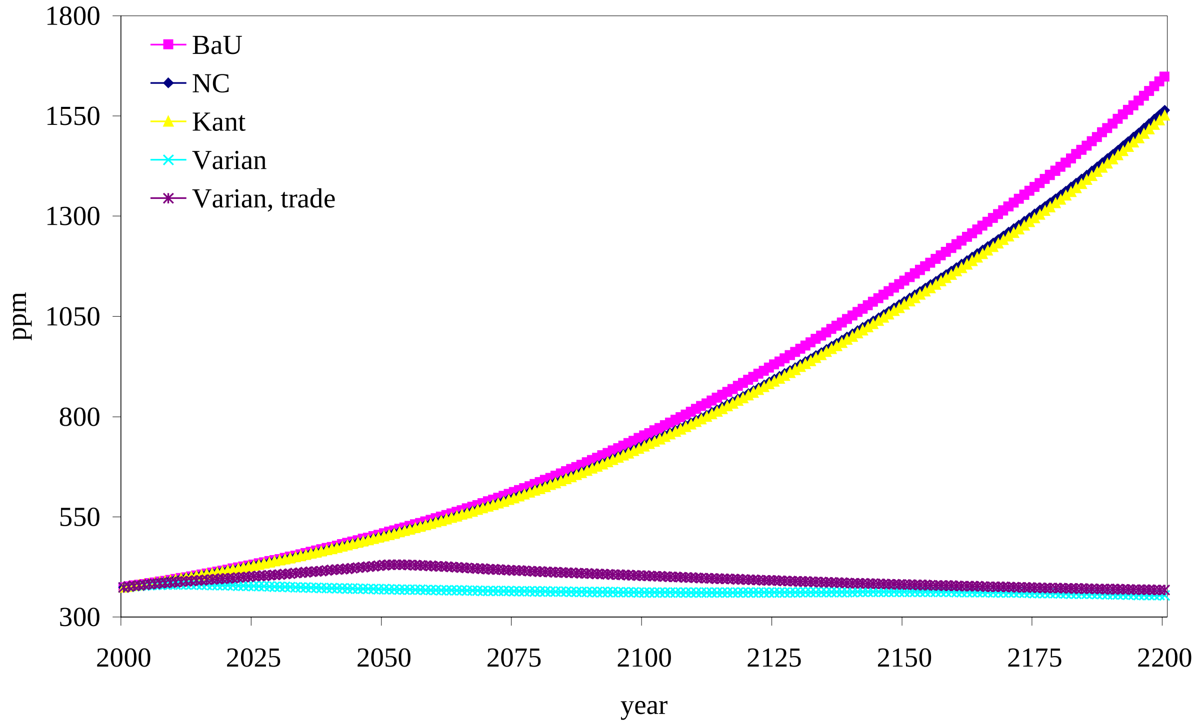

Figure 11. The atmospheric concentration of carbon dioxide according to the business as usual (no control scenario) with (PPP), and the base non-cooperative optimal emission control scenario, the Kant-Rawls non-cooperative optimal emission control scenario, and the Varian optimal control scenario with and without trade effects.

7. 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[4]). 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.[5] 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

[4] Note that this is not necessarily equitable or equity neutral (see Rose *et al.*, 1998).

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

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 11 displays the results. Climate change impacts in some regions are already so high in the early 21st century that other regions have to spend considerable amounts on emission reduction. As a result, emissions fall dramatically, almost immediately stabilizing atmospheric concentrations.

If we introduce trade effects, than non-enviable emission reduction is impossible. For, if an OECD region want to spend as much on emission reduction as a non-OECD suffers from climate change consequences, then non-OECD damage only increases. Therefore, in this case, emission reduction is set to zero for the periods in which we assumed trade effects. The result is an obvious increase in atmospheric concentrations (Figures 7 and 11).

8. Conclusions

This paper explores welfare maximising carbon dioxide emission reductions that better adhere to equity issues than does conventional optimal control. Non-cooperative emission control does not lead to strong cuts of emissions, even if the regions are altruistic or adopt a Kantian attitude. The reasons are that global externalities are only partially internalised, and some regions are less vulnerable to climate change than are others. Some regions may even benefit from climate change, and denying them this benefit would be very unjust. Trade effects, harmful to poor regions, only complicate the matter without, however, changing the numerical outcomes very much. The only exception to this is the case in which compensation is paid for climate change impacts according to historical responsibility. The polluter pays principle, taken literally, a good deterrent for greenhouse gas emissions.

If climate policy aims to restore the income distribution that would have prevailed had there been no climate change, emission reduction should be high. In fact, in this case, atmospheric concentrations should be stabilized immediately.

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.

Risk aversion has an ambiguous impact on optimal emission control. On the one hand, a higher risk aversion implies a higher weight on the poorer regions. On the other hand, a higher risk aversion places a higher weight on the short run.

International trade effects are similarly ambiguous. Trade effects hurt growth in poorer countries, but they also cut emissions. In the majority of cases, the growth and associated welfare impact matters most, but there are also exceptions.

The numbers presented in this paper should be treated with great caution, as they depend on a single parameterisation of a single model.[6] 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, and if one wants to manage them through greenhouse gas emission control, emission abatement should be intensified.[7] 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. A number of the methods presented here (e.g., 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 presented 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, other than rhetorical, 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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6 The results here are roughly in line with those of Tol (2001c), but that paper uses a different version of the same model.

7 Alternatively, induced inequities can be reduced by sponsoring adaptation. This is not pursued any further here.

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