# EXCHANGE RATES AND CLIMATE CHANGE: AN APPLICATION OF *FUND*

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## Abstract

As economic and emissions scenarios assume convergence of per capita incomes, they are sensitivity to the exchange rate used for international comparison. Particularly, developing countries grow slower with a purchasing power exchange rate than with a market exchange rate. Different exchange rates may lead to scenarios with very different per capita income. However, these scenarios also assume convergence of energy intensities, which at least partly offsets the income effect, so that scenarios with different exchange rates would differ less in greenhouse gas emissions. Differences become smaller still if atmospheric concentrations and global warming is considered. However, differences become larger again if one considers the costs of meeting a certain stabilisation target, as the gap between baseline and target is more sensitive to the exchange rate used than the baseline itself. Differences also grow larger if one looks at climate change impacts, which are determined not just by climate change but also by development. The sensitivity to the exchange rate is purely due to imperfect data, imperfect statistical analysis of data, a crude spatial resolution, and imperfect models.

## Key words

Climate change, emissions scenarios, purchasing power parity, market exchange rate

## JEL Classification

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## 1. Introduction

Recently, the IPCC SRES scenarios have been severely criticised (Castles and Hendersen, 2003a,b; Castles, 2004). The data underlying the SRES scenarios are largely based on market exchange rates (MER) for converting national currencies into US dollars. Castles and Henderson argue that the appropriate conversion should be based on purchasing power parity exchange rates (PPP). Under PPP, the gap between rich and poor countries is smaller. Castles and Henderson argue that therefore the economic growth rate and hence the emissions growth rate would have been smaller had the SRES scenarios been based on PPP. Climate change would be much less of a problem. This conclusion and the ensuing debate, commenced by the defensive attitude of the IPCC (IPCC, 2003; Nakicenovic *et al.*, 2003), attracted the attention of climate change policy makers, the press (Economist, 2003a,b, 2004), and the sceptics (WCP, 2003).[1] The IPCC's defence largely rests on Manne and Richels (2004), who use the MERGE model to show that the choice between PPP and MER indeed alters carbon dioxide emissions, but that the differences are small compared to other uncertainties, and that the differences get smaller if one moves from emissions to concentrations to temperatures. This paper complements Manne and Richels (2004) by, first, repeating their analysis with a different model and then looking into the implications of climate change damages and emission reduction costs. Alfsen *et al.* (2003) and Holtsmark and Alfsen (2004) make essentially the same contribution as do Manne and Richels (2004), but with a less specific model.

Before turning to the main analyses, a few words are in place on the context of this research. Market exchange rates largely reflect the price of money, a combination of the expected rate of return on capital invested in different countries and expected changes in the exchange rate. Therefore, differences in per capita income measured in market exchange rates do not necessarily accurately reflect differences in living standards. This is particularly the case for countries that are not well integrated in the international market for goods and capital. PPP exchange rates, on the other hand, measures the relative cost of buying a standard basket of goods in different countries and therefore measure differences in living standards, provided that the basket of goods is representative. PPP is thus a better basis for international welfare comparison than is MER. However, PPP is harder to measure, and data coverage is less. Besides, PPP is harder to explain to non-economists. For those reasons, the economic literature on climate change is largely based on MER. An overlooked alternative to MER and PPP is the real exchange rate (RER), or the barter rate of exchange. Like PPP, RER measures the differences in living standards; however, RER is based on all traded goods, rather than on an arbitrarily selected basket of goods. Although RER is the theoretically preferred concept (Pant and Fisher, 2004) and the Penn World Tables (Heston *et al.*, 2002) report it, it is hardly used in practice.

Per capita income in poor countries tends to be higher when measured in PPP (or RER) than when measured in MER. Castles and Henderson (2003a,b) deduce from this that developing country growth in the future would be slower under PPP than under MER. This implicitly assumes convergence of per capita income. The SRES scenarios and most economic models used for climate change policy analysis (including the ones used in this paper) indeed assume convergence, so the critique by Castles and Henderson is valid. However, absolute convergence of per capita income is supported by neither observations nor by state of the art growth theory (Barro and Sala-i-Martin, 1995). Nonetheless, in line with the climate change literature, we assume convergence.

The paper proceeds as follows. Section 2 presents the model used, FUND2.7. Section 3 discusses scenarios of climate change, essentially reproducing Alfsen et al. (2003), Holtsmark and Alfsen (2004) and Manne and Richels (2004). Section 4 looks at the implications for the impacts of climate change. Section 5 turns to emission reduction costs. Section 6 concludes.

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[1] After the Second Assessment Report of the IPCC, there was also a flap about, *inter alia*, PPP exchange rates; see Bruce (1995, 1996), Courtney (1996), Fankhauser and Tol (1995, 1996, 1997), Grubb (1996), Masood (1995), Masood and Ochert (1995), Meyer (1995a,b), Meyer and Cooper (1995), Nature (1995), O'Riordan (1997), D. Pearce (1995), F. Pearce (1995a,b), Sundaraman (1995), and Tol (1997).

## 2. The model

The model used is version 2.7 of the *Climate Framework for Uncertainty, Negotiation and Distribution (FUND)*. Version 2.7 of *FUND* corresponds to version 1.6, described and applied by Tol (1999a-e, 2001, 2002a), except for the impact module, which is described by Tol (2002b,c) and updated by Tol (2002d). A further difference is that the current version of the model distinguishes 16 instead of 9 regions. The current version of the model also includes emission reduction for nitrous oxide ($N_2O$), not incorporated in earlier versions of *FUND*, as well as a new formulation of methane ($CH_4$) emission reduction.

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 2200 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 century is included to make sure that climate policies aimed at stabilizing concentrations indeed achieve that goal.

The period of 1950-1990 is used for the calibration of the model which is based on the *IMAGE* 100-year database (Batjes & Goldewijk, 1994). The climate scenarios for the period 2010-2200 are based on the EMF14 Standardized Scenario, which lies somewhere in between IS92a and IS92f (Leggett *et al.*, 1992).

The scenarios concern the rate of population growth, 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 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 (WRI, 2000). 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 cause 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. Consumption and investment are reduced without changing the savings rate. Thus, climate change reduces the long-term economic growth, although for the short term the consumption is particularly affected. 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.

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 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:

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

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

The atmospheric concentration of carbon dioxide, measured in parts per million by volume, is derived from a five-box model:

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

where

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

Here $\alpha_i$ denotes the fraction of emissions *E* (in million metric tons of carbon) that is allocated to box *i* (0.13, 0.20, 0.32, 0.25 and 0.10 respectively) and $\rho$ the rate of decay of the boxes ($\rho = \exp(-1 / \text{life time})$. The life times in the boxes are $\infty$, 363, 74, 17, and 2 years respectively. This model is based on Maier-Reimer and Hasselmann (1987). Its parameters are taken from Hammitt *et al.* (1992). According to this model, 13 per cent of total emissions remain in the atmosphere indefinitely, while 10 per cent are removed within an average time period of two years.

The radiative forcing of carbon dioxide, methane and nitrous oxide is determined based on Shine *et al.* (1990). 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, so:

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

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 is based on Tol (2002b,c). The following impact categories of climate change are considered: agriculture, forestry, sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, diarrhea, energy consumption, water resources, and unmanaged ecosystems.

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, 1996), 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 modeled explicitly. The monetary value of a loss of one square kilometer 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 kilometer. Wetland losses are valued at $2 million per square kilometer 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).

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).

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 behavior 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, malaria, dengue fever, and schistosomiasis are modeled as simple power functions. Impacts are either negative or positive, and 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).

Carbon dioxide emissions are calculated on the basis of the Kaya identity. Emissions can be modified by policy measures, e.g. a carbon tax. The costs of emission reduction are subject to learning by doing, so that emission abatement in early time periods of the simulations reduces the costs of emission abatement in subsequent periods. The exact specification is given by Tol (2002e).

## 3. Climate change scenarios

The basic scenario described above is based on market exchange rates. Figure 1 presents the natural logarithm of the ratio of per capita income in PPP (RER) and MER as a function of the natural logarithm of per capita income measured in MER. The data are for 1995. Clearly, as countries grow richer, the difference between PPP (RER) and MER disappears. Based on the data displayed in Figure 1, a MER income elasticity of PPP (RER) of –0.28 (-0.31) is estimated. That is, a 1% growth in MER income would result in a 0.72% (0.69%) reduction of the PPP/MER (RER/MER) ratio. If we assume that the MER income growth assumed in the scenario is correct, this implies that the PPP (RER) income growth is lower by the same amount as the reduction in the PPP/MER (RER/MER) ratio. This is the basis of the PPP (RER) income scenario.[2] Figure 2 displays the per capita income for two regions, China and Subsaharan Africa. In the MER scenario, the income is lower at the start but rises faster. Growth is slightly slower using RER rather than PPP.

The other main difference between the MER and PPP (RER) scenarios are the assumptions on technological progress in the energy sector. Castles and Henderson (2003a,b) seem to base their critique on the assumption that the rate of energy efficiency improvement and decarbonisation is independent of the growth rate of per capita income. McKibbin *et al.* (2004) adopt the same position, and duly find much higher emissions under MER than under PPP. However, one could also argue that the SRES and other climate scenarios assume a high rate of technological progress in poor countries based on the observation that their carbon intensity, that is, the amount of carbon dioxide emitted per dollar of income earned, is much higher than in rich countries. Indeed, Nakicenovic (2004), Van Vuuren (2004), Alfsen *et al.* (2003) and Holtsmark and Alfsen (2004) argue that this would largely offset the different economic growth rate. This deliberation leads to our two extreme PPP scenario, named CAH and NVV. In the CAH scenario, energy efficiency improvements and decarbonisation are as in the MER scenario. In the NVV scenario, we alter the exogenous assumptions on energy efficiency improvements and decarbonisation so that emissions are as in the MER scenario. In the third PPP scenario (so named), the change in energy efficiency improvement and decarbonisation is exactly halfway between the NVV and CAH scenarios. For RER, we only use the two extreme emissions scenarios; energy efficiency and decarbonisation in CAH' equal those in CAH (this scenario is used in only a limited way); energy efficiency and decarbonisation in the RER scenario are such that they offset the change in economic growth. Table 2 shows the six scenarios. Three scenarios, viz. MER, NVV and RER, share the same climate change but have different economic growth; also, three scenarios, viz. NVV, PPP and CAH, share the same economic growth but have different climate change.

Figure 3 shows the regional carbon dioxide emissions from fossil fuel combustions for the six scenarios. The MER, RER and NVV have almost exactly the same emissions; the differences are induced by the feedbacks in the model. The CAH scenarios have substantially lower emissions, and the PPP scenario lies somewhere in between (see also Table 3); the CAH' scenario has lowest emissions as well as lowest economic growth. Interestingly, the change in emissions is primarily in Asia. African and Latin American emissions change too, but not as dramatically as Asian emissions. The reasons are that Asian emissions are larger than those of the other developing continents, but more importantly that the difference between PPP (RER) and MER incomes is largest in Asia. So, the different scenarios do not only have different total emissions, the regional distribution of emissions is also very different; in fact, under PPP (RER), developing countries contribute substantially less than do developed countries, with drastic implications for the discussion on appropriate burden sharing for greenhouse gas emission reduction.

Figure 4 shows global carbon dioxide emissions for 5 scenarios.[3] Figure 5 shows the resulting concentrations, and Figure 6 the corresponding global mean temperatures. Like Manne and Richels (2003), we find that the difference in emissions is larger than the difference in concentrations, which in turn is larger than the difference in temperatures. This does not imply, however, that climate change is less of a problem under PPP (RER) than under MER

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[2] Note that three *FUND* regions, viz. Australia and New Zealand, Canada, and Japan and South Korea, have a PPP that is *lower* than the MER. For these regions, a linearly force the PPP/MER ratio to unity by 2020. The same procedure was used for RER, but not for Canada as its RER/MER exceeds unity.

[3] The CAH' scenario is omitted from here onwards to simplify the exposition.

(cf. Section 4); nor that the difference between PPP (RER) and MER gets smaller if one moves to indicators that matter more to policy (cf. Section 5).

## 4. Impact and vulnerability

Switching from MER to PPP (RER) would change our assumptions about future economic growth in developing countries and may change our assumptions about future emissions. Climate change impacts would therefore be different too. Impacts do not just depend on climate change (exposure) but also on development (which largely determines vulnerability).

*FUND* is unique among the current generation of integrated assessment models in the attention it pays to climate change impacts and how development affects vulnerability; this was already the case in the survey of Tol and Fankhauser (1998), but the difference has grown larger. This feature allows us to investigate how a shift from MER based to PPP (RER) based scenarios alters climate change impacts, which presumably matters more than climate change itself.

A few changes need to made to the model, however. A switch from MER to PPP (RER) would lead us to believe that the income gap between rich and poor is smaller, and that therefore convergence would be slower as well. On the other hand, it would lead us to believe that poverty-related phenomena, such as a high share of GDP in agriculture or the prevalence of infectious diseases, would persist at higher levels of development. In *FUND*, vulnerability changes with per capita income. This change is governed by sector-specific income elasticities, which are estimated on a cross-section of country data. If we re-estimate these income elasticities on PPP (RER) income data, their absolute value would fall. This adjustment was made for water resources, agriculture, forestry, energy consumption, and cardiovascular diseases. For vector-borne diseases, there is an income threshold above which these diseases are not assumed to occur. This was adjusted for PPP (RER) as well.

Figure 7 shows the impacts of climate change for China. The CAH, PPP and NVV scenarios share the same development, but have a different climate. The market and non-market impacts increase as climate change gets worse. The MER, NVV and RER scenario share the same climate, but have different development. The market impacts are generally higher under MER, except in the first decades. The impacts of climate change on Chinese agriculture are positive, and agriculture is a larger part of the Chinese economy under MER than under NVV (RER). In later years, the additional energy demand for air conditioning becomes more important. As per capita income is greater under MER than under NVV (RER), demand for air-conditioning is as well. However, energy efficiency is lower under NVV and hence the costs of meeting the air conditioning demand higher; this effect dominates, explaining why market impacts under NVV (RER) again exceed those under MER in the later decades, and why eventually markets impacts under RER are higher than under NVV (these two scenarios being largely indistinguishable prior to 2150). The non-market impacts are lower under MER than under NVV (RER) in the 21st century, which reflects the value of the impacts rather than the impacts themselves. In the 22nd century, the difference between MER and NVV (RER) impacts falls, for the same reason; cf. Figure 2 which shows that Chinese MER income exceeds its NVV (RER) income in the long run. The difference in non-market damage between NVV and RER is minimal, as is the difference between per capita income.

Figure 8 shows the impacts of climate change for Sub-Saharan Africa. The CAH, PPP and NVV scenarios share the same development, but have a different climate. The market and non-market impacts increase as climate change gets worse. The MER, RER and NVV scenario share the same climate, but have different development. The market impacts are generally higher under MER, as people are poorer and therefore more vulnerable. Market impacts are not strictly decreasing in per capita income, however, as is shown by the changes in position of NVV and RER; see the explanation for China's market impacts above. The non-market impacts are initially higher under MER than under CAH, which reflects the greater incidence of vector-borne diseases, particularly malaria. However, because growth is faster under MER, malaria is eradicated earlier under that scenario, so that MER impacts fall below CAH. Growth is slowest under RER; even though RER per capita income is higher than MER per capita income in 2000, the RER income threshold is also higher; as a result, malaria eradicated later under RER than under CAH and MER, and non-market impacts remain high for a longer period.

Table 4 shows the marginal damage costs of carbon dioxide emissions for the five scenarios, for three alternative pure rates of time preference (0, 1 and 3%), and with and without equity weighting (cf. Fankhauser *et al.*, 1997, 1998). Comparison of the CAH, PPP and NVV scenarios shows that marginal impacts, like total impacts, get worse if climate change is more severe and development is the same. Comparison of MER on the one hand and NVV and RER on the other hand shows the same ambiguity as seen in the market impacts of China and the non-market impacts of Africa. In the short run, overall vulnerability is higher under MER than under NVV and RER (see the results for a 3% PRTP), but in the long run this is reversed. This ambiguity is enhanced by the fact that, although the pure rate of time preference is equal, the social rate of discount is not. The social rate of discount is used to discount current marginal damage costs to the net present marginal damage costs shown in Table 4. The social rate of discount equals the pure rate of time preference plus (the elasticity of marginal utility with respect to consumption, which is unity, times) the growth rate of per capita consumption. The latter is lowest under RER, followed by PPP and MER.

Furthermore, the global marginal damage costs cannot be directly compared, as exchange rates are different. Table 5 shows the marginal damage costs for a 1% PRTP and simple summation; Table 3 reproduces the key results. In Table 5, the regional marginal damage costs are computed for the five scenarios, converted to MER/PPP/RER at 2000 exchange rates, and then added up. The patterns in Table 5 are clearer than in Table 4. The same development, but worse climate change leads to higher marginal damage costs. The same climate change, but lower development leads to higher marginal damage costs. An exchange rate that makes developing economics take a greater share in the global economy leads to higher marginal damage costs.

## 5. Emission reduction costs

The costs of emission reduction also differ between the different scenarios and assumptions on the appropriate exchange rate. The first reason is straightforward. If the aim is to keep carbon dioxide concentrations under 750 ppm, then this would take some effort in the MER, RER and NVV scenarios, but less in the PPP scenario, while in the CAH scenario concentrations do not exceed 750 ppm at all. The other reasons are less straightforward. Many policy proposals assume that, in one way or another, the responsibility for emission reduction reflects relative emissions. Under the PPP and CAH scenarios, developing countries contribute much less to climate change, and could therefore expect to carry less of the burden of emission reduction. Many policy proposals foresee, in one way or another, where-flexibility, allowing actual emission reduction to occur where that is cheapest. Exchange rates play two roles here. Firstly, the marginal costs of emission reduction in, say, China is higher if measured with a PPP exchange rate than with an MER exchange rate. Secondly, most models, including the one used in this paper, assume, implicitly or explicitly, that emission reduction is cheap (expensive) if emission intensity is high (low). The choice of exchange rate also affects the measured emission intensity. The implication of all this is that the choice of exchange rate affects the severity of the target, the distribution of responsibility, the distribution of the efforts, and the costs of emission abatement. The upshot is that little can be said in general about the difference in costs of emission reduction between the different scenarios.

For specific targets and implementation architectures, comparisons can of course be made. We assume that carbon dioxide concentrations need to stay below 550 ppm. We assume that emission reduction is implemented with full where and when flexibility. As a result, marginal costs of emission reduction are equal for all regions, and increase over time at the same rate as the rate of discount. (We ignore the issue of who pays for emission reduction, but in a scenario like this, the amounts paid would not substantially affect the economic growth path.)

Table 3 shows the net present value of the loss in consumption for Annex I and other countries. MER, NVV and RER have the same global emission reduction. Yet, costs are higher under NVV and RER than under MER because emission reduction in developing countries is less cheap; there is a marked shift of emission reduction to Annex I countries under NVV or RER relative to MER. NVV, PPP and CAH have the same economic scenario, but different emissions and thus different emission reduction targets. As baseline emissions get lower, emission reduction costs fall.

## 6. Discussion and conclusion

An important thing to keep in mind is that the exchange rate used only affects economic and emissions scenarios because the modelling approach commonly used for scenario analysis compounds a series of imperfections. If we were to model the development of each country separately based on the fundamental drivers of growth of that country, without explicit or implicit assumptions about income or technology convergence, and with price, income and substitution elasticities estimated separately for that country, then the exchange rate would not affect the outcomes of the model; it would only affect cross-country comparisons and regional aggregations of the model results. The scenarios are only sensitive to the choice of exchange rate because the scenarios assume per capita and technology income convergence; because elasticities are estimated from international cross-sections; and because countries are aggregated to regions.

The results shown here partly confirm those of Manne and Richels (2004) and Holtsmark and Alfsen (2004). The choice of exchange rate may affect carbon dioxide emissions, but the effect on carbon dioxide concentrations would be smaller, and the effect on climate smaller still. However, when we turn to the impacts of climate change or the costs of emission reduction, differences may become larger again. This contradicts Manne and Richels' (2004) and Holtsmark and Alfsen's (2004) conclusion that the choice of exchange rate does not really matter, but then their analysis does not extend as far as this one.

Two main conclusions result from the analysis. Firstly, the choice of exchange rate matters for climate change policy analysis. Unfortunately, it is not obvious which exchange rate should be used. The market exchange rate is more appropriate for that part of the analysis that deals with market transactions, and the real exchange rate is more appropriate for welfare comparisons. The choice of exchange rate thus depends on the aim of the analysis, but most analyses would be served best by presenting a sensitivity analysis around the exchange rate. Secondly, the choice of exchange rate should not matter as much as it does. The models used for climate change policy analysis should be improved.

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**Table 1:** Parameters of equation (1) (based on Schimel *et al*., 1996)

| Gas | $\alpha$[a] | $\beta$[b] | pre-industrial concentration |
|---|---|---|---|
| methane ($CH_4$) | 0.3597 | 1/8.6 | 790 ppbv |
| nitrous oxide ($N_2O$) | 0.2079 | 1/120 | 285 ppbv |

[a] The parameter $\alpha$ translates emissions in millions of metric tons of $CH_4$ or $N_2O$ into concentrations in parts per billion by volume.

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

Table 2. Scenarios

| | Same climate scenario | | |
|---|---|---|---|
| Same economic scenario | MER | NVV | RER |
| | | PPP | |
| | | CAH | CAH’ |

Table 3. Scenario characteristics for the MER, NVV, PPP, CAH and RER scenarios, and fraction of the MER scenario. Displayed are the carbon dioxide emissions in 2100 (MMTC) for the world and the non-Annex I countries; the carbon dioxide concentration in 2100 (ppm); the global mean temperature in 2100 (degree centigrade); the marginal damage costs of carbon dioxide emissions in the current decade; carbon dioxide emission reduction in 2050 (fraction of baseline) for the Annex I and non-Annex I countries; and the net present value of the carbon dioxide abatement costs (trillion US dollar, consumption loss, discounted at 5%).

| | Emissions | | Concen- | Tempe- | Marginal | Emission | reduction | Abatement | costs |
|---|---|---|---|---|---|---|---|---|---|
| | World | Non-Annex I | tration | rature | cost | Annex I | non-Annex I | Annex I | non-Annex I |
| MER | 36031 | 23333 | 871 | 3.24 | 7.2 | 0.41 | 0.54 | 2.80 | 5.65 |
| RER | 35754 | 22690 | 865 | 3.22 | 10.5 | 0.44 | 0.41 | 4.46 | 5.81 |
| NVV | 35270 | 22270 | 858 | 3.20 | 8.9 | 0.46 | 0.41 | 4.03 | 5.27 |
| PPP | 27117 | 15005 | 772 | 3.03 | 5.7 | 0.43 | 0.37 | 4.01 | 4.18 |
| CAH | 21772 | 10249 | 712 | 2.90 | 3.0 | 0.40 | 0.32 | 3.91 | 3.24 |
| | | | | | | | | | |
| RER | 0.99 | 0.97 | 0.99 | 0.99 | 1.46 | 1.09 | 0.76 | 1.59 | 1.03 |
| NVV | 0.98 | 0.95 | 0.99 | 0.99 | 1.24 | 1.12 | 0.76 | 1.44 | 0.93 |
| PPP | 0.75 | 0.64 | 0.89 | 0.94 | 0.80 | 1.05 | 0.67 | 1.43 | 0.74 |
| CAH | 0.60 | 0.44 | 0.82 | 0.90 | 0.43 | 0.97 | 0.59 | 1.40 | 0.57 |

Table 4. Marginal damage costs of carbon dioxide emissions ($/tC).

| PRTP | 0% | | 1% | | 3% | |
|---|---|---|---|---|---|---|
| | SS | EW | SS | EW | SS | EW |
| MER | 36.4 | 38.6 | 7.2 | 7.5 | -3.2 | -5.4 |
| CAH | 52.8 | 58.3 | 3.0 | 5.2 | -10.3 | -11.4 |
| PPP | 60.5 | 67.4 | 5.7 | 8.5 | -9.8 | -10.7 |
| NVV | 69.3 | 77.8 | 8.9 | 12.4 | -9.1 | -9.8 |
| RER | 79.3 | 91.5 | 10.5 | 15.7 | -9.9 | -9.9 |

Table 5. Marginal damage costs of carbon dioxide emissions (\$/tC) at a 1% pure rate of time preference, simple sum.

| | at MER | at PPP | at RER |
|---|---|---|---|
| MER | 7.2 | 14.2 | 17.1 |
| CAH | 1.1 | 3.0 | 4.6 |
| PPP | 2.3 | 5.7 | 7.6 |
| NVV | 3.6 | 8.9 | 11.2 |
| RER | 3.2 | 8.4 | 10.5 |

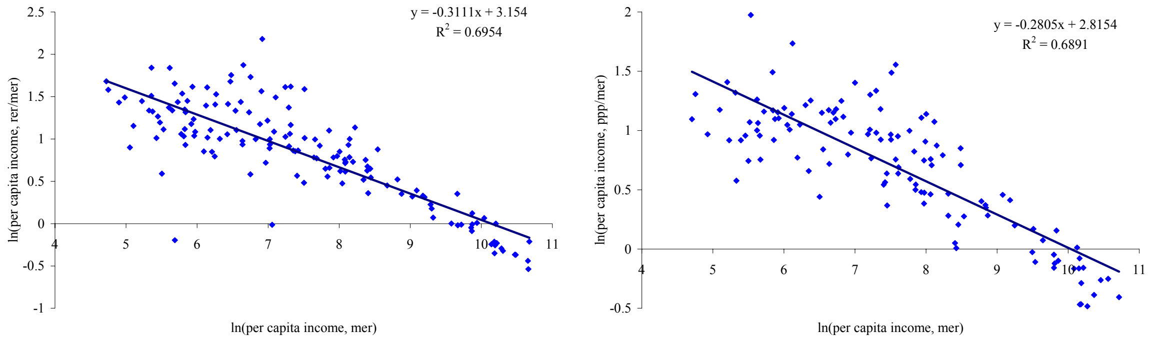


Figure 1. The ratio of per capita income measured PPP and MER as a function of per capita income in MER in 1995 (left panel) and the same for RER and MER (right panel). Source: WRI (200x), Penn World Tables.

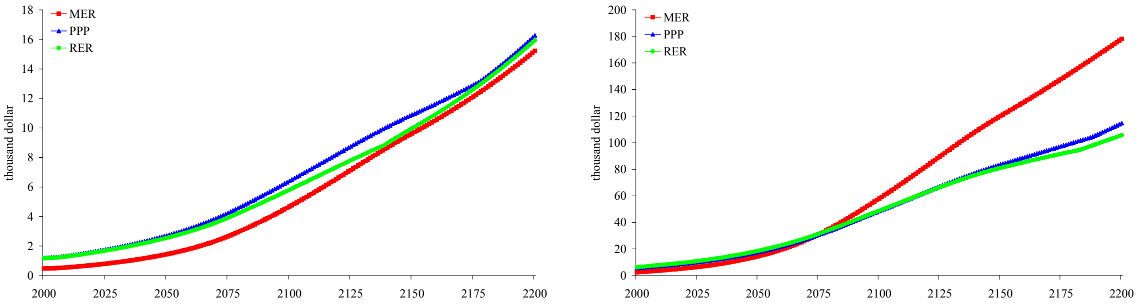


Figure 2. Per capita income in Subsaharan Africa (left panel) and China (right panel) for the MER, PPP and RER scenarios.

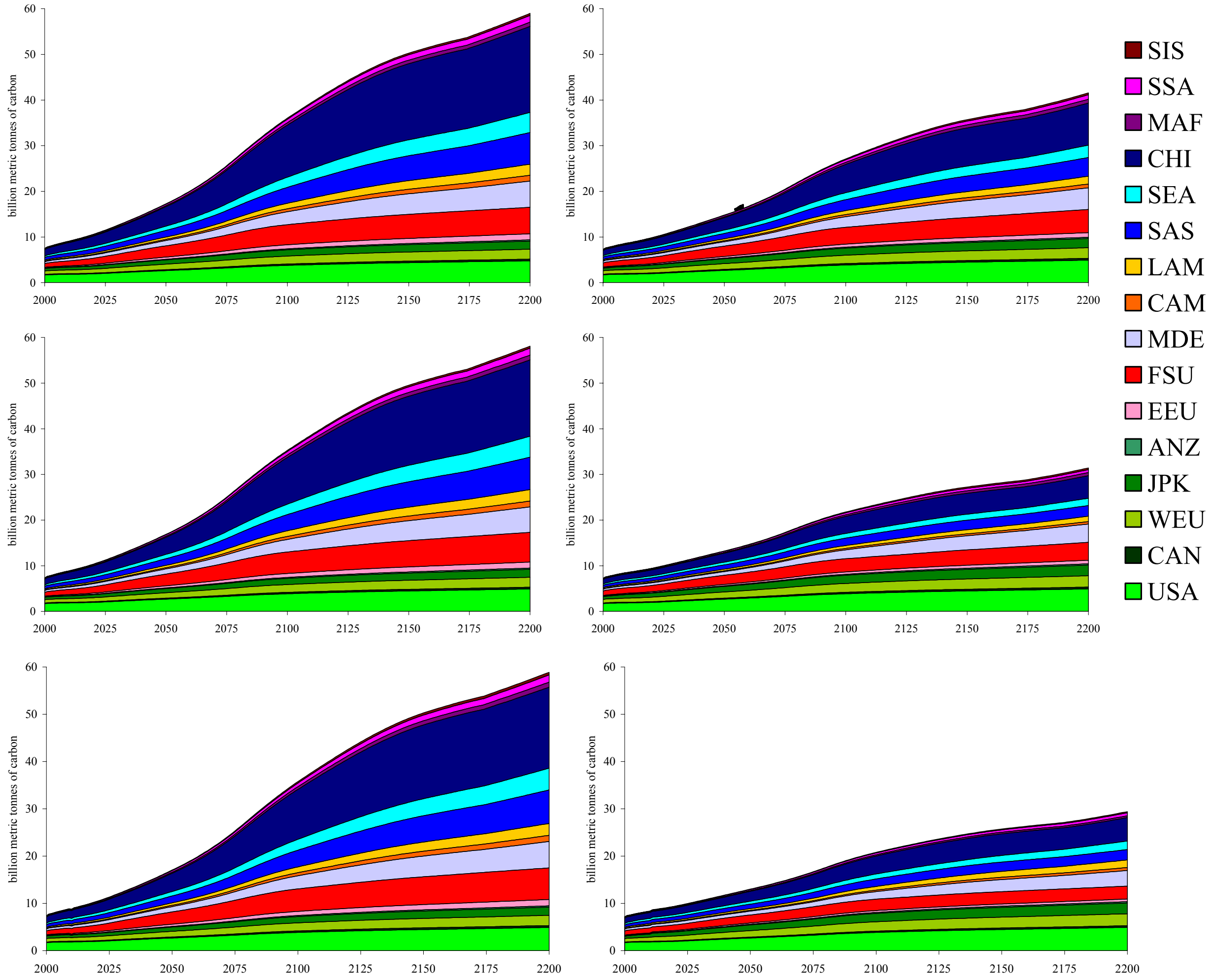


Figure 3. The regional carbon dioxide emissions from fossil fuel combustion (in billion metric tonnes of carbon) according to the MER scenario (top left), the NVV scenario (middle left), the RER scenario (middle bottom), the PPP scenario (top right), the CAH scenario (middle right) and the CAH' scenario (bottom right).

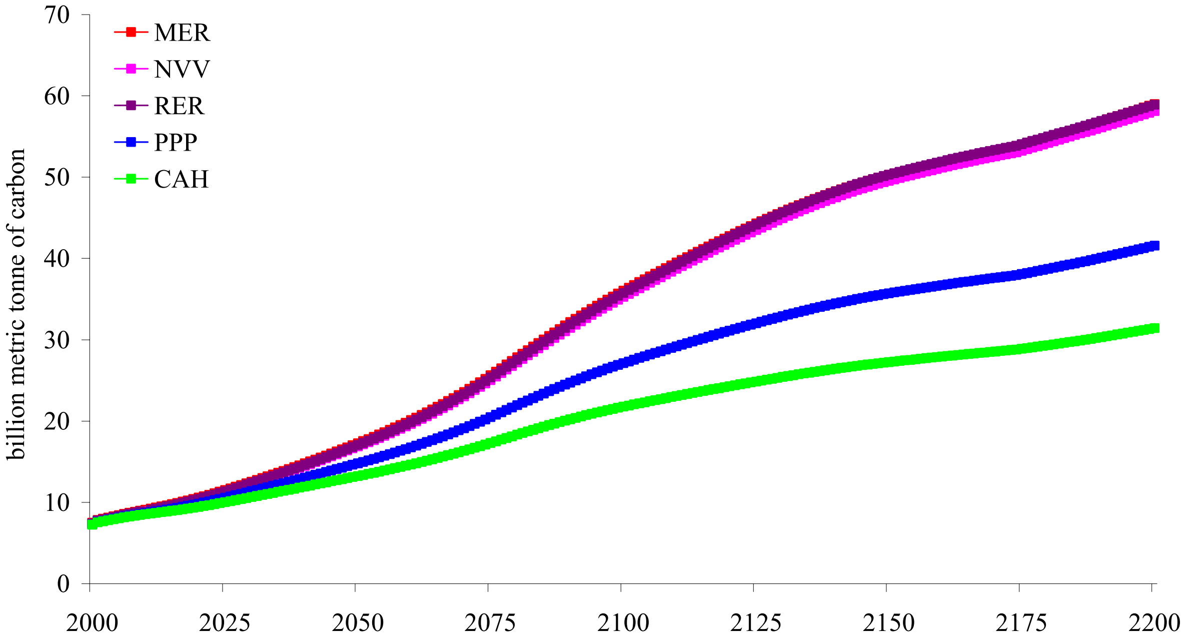
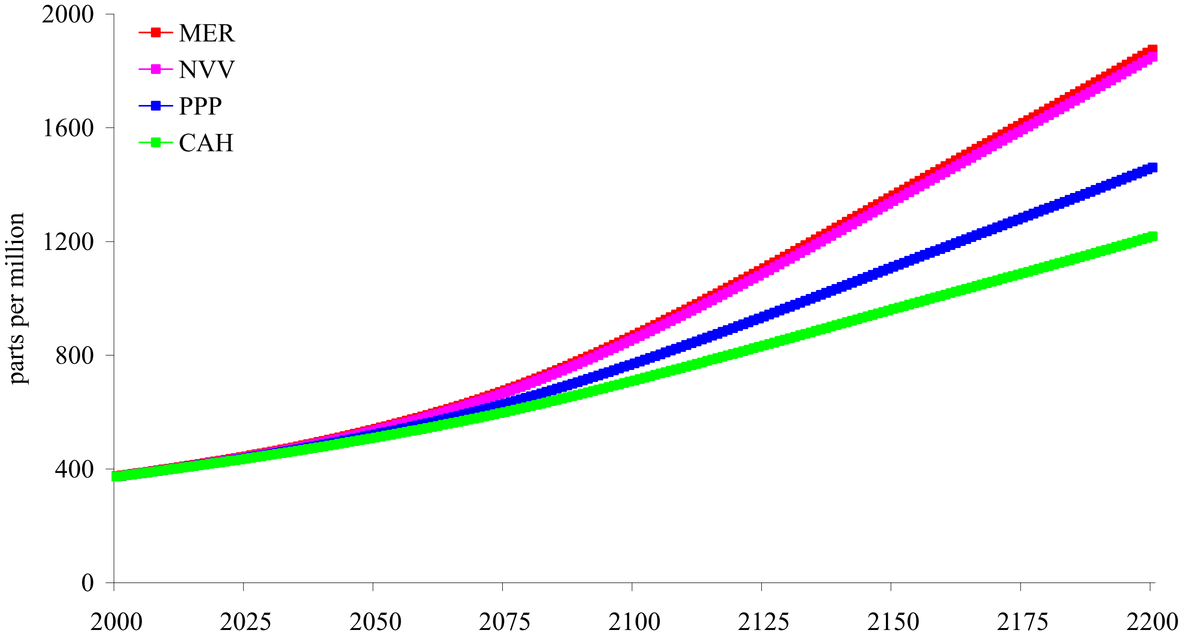


Figure 4. Global carbon dioxide emissions from fossil fuel combustion according to the five scenarios, from top to bottom MER, NVV, RER, PPP and CAH. Note that MER, RER and NVV are almost indistinguishable.



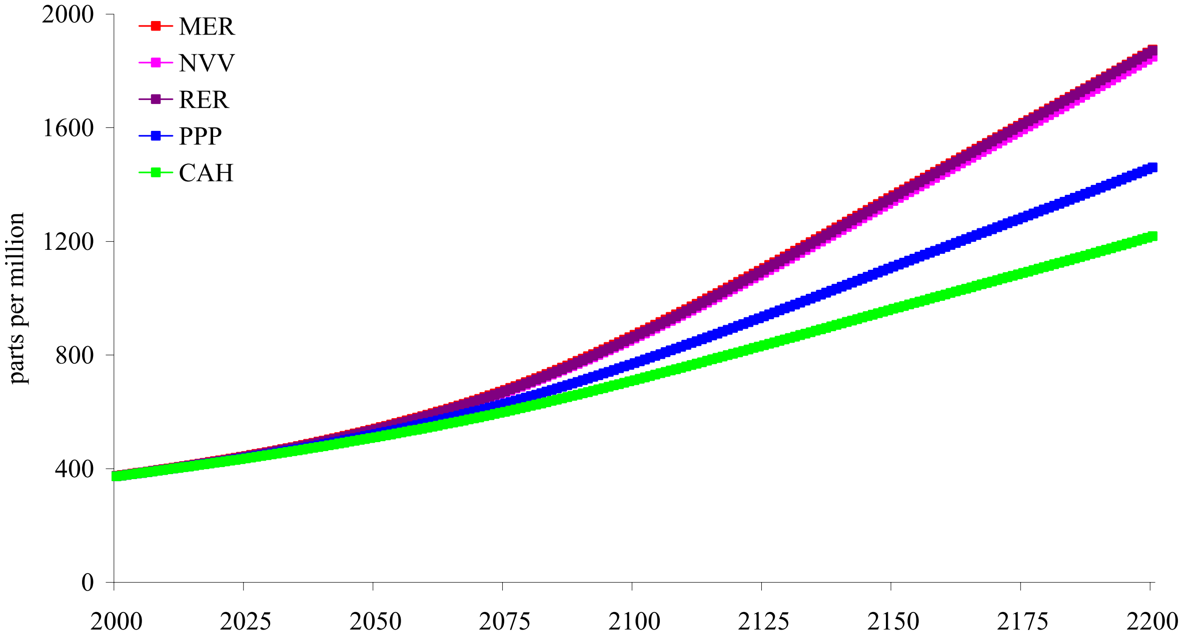


Figure 5. Carbon dioxide concentrations according to the four scenarios, from top to bottom MER, NVV, PPP and CAH. Note that MER and NVV are almost indistinguishable.

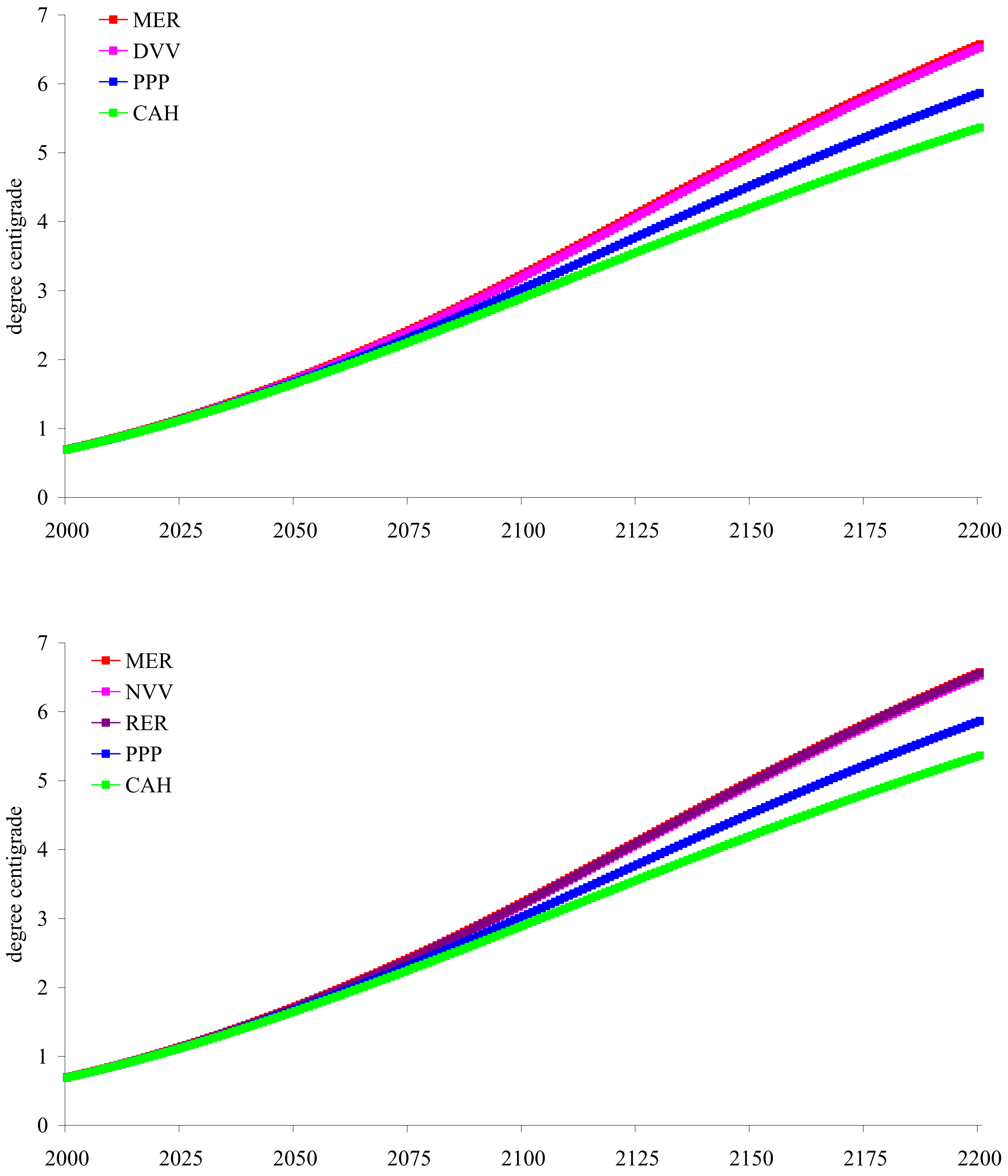


Figure 6. Carbon dioxide concentrations according to the fiver scenarios, from top to bottom MER, NVV, RER, PPP and CAH. Note that MER, RER and NVV are almost indistinguishable.

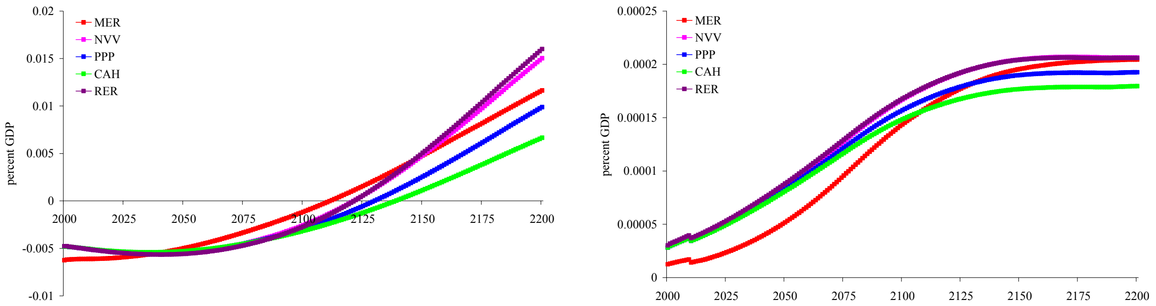


Figure 7. The market (left panel) and non-market (right panel) impacts of climate change on China according to the four scenarios, viz. MER, RER, NVV, PPP and CAH.

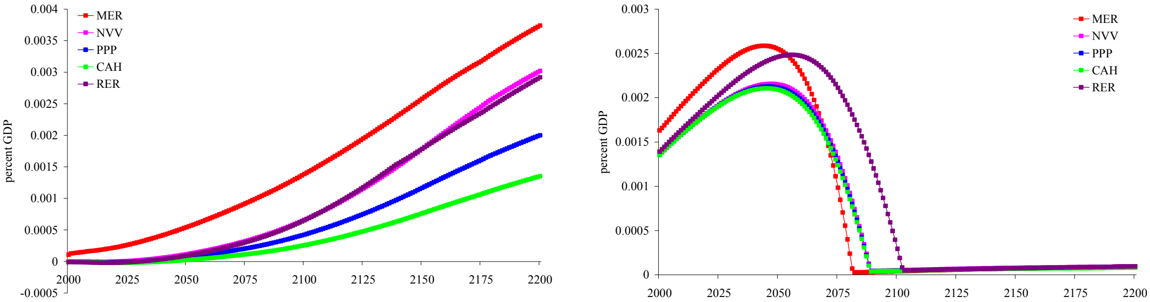


Figure 8. The market (left panel) and non-market (right panel) impacts of climate change on Subsaharan Africa according to the four scenarios, viz. MER, RER, NVV, PPP and CAH.

# Working Papers

## Research Unit Sustainability and Global Change

## Hamburg University and Centre for Marine and Atmospheric Science

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

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

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** (submitted)

Zhou, Y. and Tol, R.S.J. (2004), *Evaluating the costs of desalination and water transport,* **FNU-41** (submitted)

Lau, M. (2004), *Küstenzonenmanagement in der Volksrepublik China und Anpassungsstrategien an den Meeresspiegelanstieg,***FNU-40** (submitted to *Coastline Reports*)

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)

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

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

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 to *Climate Research*)

Tol, R.S.J. (2003), *Adaptation and Mitigation: Trade-offs in Substance and Methods,* **FNU-33** (submitted)

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** (submitted)

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** (submitted)

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** (submitted)

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** (forthcoming in *Integrated Assessment*)

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

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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)

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Rehdanz, K. and Maddison, D. (2003) *Climate and Happiness*, **FNU 20** (submitted to *Ecological Economics*)

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

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

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

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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).

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