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Welfare specifications and optimal control of climate change: an application of fund

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Abstract

The sensitivity of the optimal control of carbon dioxide emissions to the specification of the social welfare function is systematically explored using the FUND model. Increasing risk aversion emphasises climate change damages relative to emission reduction costs, but at the same time increases the discount rate of consumption. Without international co-operation, the discount rate effect dominates so that optimal control decreases with increasing risk aversion. With international co-operation, optimal control first increases then decreases with increasing risk aversion. Since climate change falls heaviest on the poor, optimal control increases with increasing inequity aversion. Full-fledged intergenerational welfare functions on the one hand emphasise climate change damages but on the other hand place more weight on current, poorer generations. In FUND, the two tendencies almost cancel. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Models that seek to estimate the optimal level at which greenhouse gas emissions need to be controlled necessarily assume a functional specification for

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‘welfare’ or ‘utility’, which then needs to be maximised. Examples include Fankhauser (1995); Hasselmann et al. (1997); Maddison (1995), Manne and Richels (1997), Manne et al. (1995), Nordhaus (1994), Nordhaus and Yang (1996), Peck and Teisberg (1991, 1996), Tol (1997, 1999b,c,d,e) and Yohe and Wallace (1996). Obviously, the choice of the welfare function is crucial in such exercises. Although not entirely arbitrary, the welfare function is an assumption, for which little unambiguous empirical or moral guidance exists. It is, therefore, surprising that the literature lacks a systematic discussion of the sensitivity of the optimally controlled emission trajectory to this assumption. In fact, there is hardly any discussion of this topic at all. The theoretical literature does contain substantial discussion on the subject (e.g. Roemer, 1996; Sen, 1987, 1982).

The choice of welfare function obviously reflects views on equity. There is an extensive discussion on equity in the climate change literature (e.g. Banuri et al., 1996; Toth, 1999), but this discussion is largely restricted to the allocation of emission rights given a global emissions cap (e.g. Rose et al., 1998). The welfare and equity implications of choosing a particular cap are ignored. The discussion on intergenerational equity is largely phrased as a discussion on the discount rate (e.g. Arrow et al., 1996; Portney and Weyant, 1999), and thus separated from the wider debate on equity. Schelling (1995) is an exception, but his analysis is qualitative only. This paper looks at the inter- and intragenerational equity and welfare implications of both the global emission reduction target and its allocation to world regions, and does so in a quantitative framework. The analysis here complements that by Kemfert and Tol (2001) and Tol (2001).

Fankhauser et al. (1997) (see also Fankhauser et al., 1998) show that globally aggregated impact estimates of climate change are quite sensitive to the chosen aggregation rule. Such ‘equity weights’ are, in that framework, a corollary of the global welfare function. Generally, impacts increase as one moves away from linear, utilitarian welfare, suggesting a downward bias in the optimal rate of control of greenhouse gases. However, the global welfare function also pertains to the costs of greenhouse gas emissions. Azar and Sterner (1996) extend the equity weights approach to cost–benefit analysis, but their model deviates too much from other models to generalise their findings. Particularly, they reject intergenerational discounting, which in this paper, turns out to be an important counterbalancing factor to inequity aversion. d’Arge et al. (1982) earlier proposed a range of global welfare functions for use in climate change issues, but this paper appeared well before insight into the costs of greenhouse gas emission reduction and climate change was developed. Section 5 uses specifications similar to those of d’Arge et al. (1982).

The paper is organised as follows. Section 2 presents the model used, which is the Climate Framework for Uncertainty, Negotiation and Distribution (FUND), version 1.6 (cf. Tol, 1999a,b,c,d,e). Section 3 discusses the influence of risk aversion on optimal emission control. Section 4 analyses the importance of (current) inequity aversion. Section 5 extends the analysis to global and intergenerational welfare functions. Section 6 concludes.

2. The model

FUND is an integrated assessment model of climate change, combining representations of population, economy, greenhouse gas emissions, carbon cycle, climate and impacts for nine world regions for the period 1950–2200. The period 1950–1990 is used to initialise the climate change impact module, and to give some empirical support to the scenarios used. The period 1990–2100 is used for policy analysis. The period 2100–2200 is used to derive proper final conditions in 2100 (decision-makers in FUND are forward looking).

Essentially, the model revolves around a few driving scenarios (for population, economy and technology potentials) with all other variables calculated endogenously. These scenarios are very close to the EMF Standardised Scenario, which lies somewhere in between IS92a and IS92f (Leggett et al., 1992).

The modules for greenhouse gas concentrations, climate and sea level rise behave like the simple climate models discussed by the IPCC (Harvey et al., 1998). Greenhouse gases are geometrically depleted in the atmosphere, methane and nitrous oxide in a one-box model, carbon dioxide in a five-box model (one box with an infinite lifetime). Other greenhouse gases are omitted. Radiative forcing is taken from Shine et al. (1990). Climate is represented by the global mean surface air temperature. The equilibrium temperature is linear in radiative forcing, with a climate sensitivity of 2.5 °C. Actual temperatures rises geometrically to their equilibrium level, with a half-time of 50 years. Sea level rise is modelled similarly, with a sensitivity of 30 cm/°C and a half-time of 50 years.

Climate impacts follow Tol (1995, 1996). This module is different in structure from most impact modules in integrated assessment models (cf. Tol and Fankhauser, 1998) but this does not lead to substantially different conclusions (cf. Tol, 1997, 1999a,b,c,d,e). Climate impacts are modelled as second-order polynomials in the change and the rate of change of temperature and sea level. Impacts depending on the rate of change fade geometrically, so as to mimic adaptation. Impacts depend also on economy and population, for example: level of urbanisation; share of agriculture in economic output; and per capita income. Impacts are all monetized. Impacts feed back into economy and population, but are not large enough to substantially affect the base scenarios.

Emission reduction is restricted to carbon dioxide from industrial sources. Emission reduction costs are calibrated to the survey of Hourcade et al. (1996). Reduction costs are quadratic in the amount of reduction. Costs differ per region. On average, a reduction of 1% per year (from baseline emissions) costs about 0.02% of economic growth.

Emission reduction is determined from optimising net present welfare. Welfare is driven by the average green consumption per capita. Green consumption equals income minus investments minus the monetary value of the non-market losses due to climate change. The welfare function is standard constant relative risk aversion:

$$W = \begin{cases} \frac{C^e}{1-e} & \text{if } e \neq 1 \\ \ln(C) & \text{if } e = 1 \end{cases} \quad (1)$$

Commonly, regional welfare is assumed to equal the number of people times W in Eq. (1). In FUND, this would imply that climate-change-induced migration from, say, Africa to Europe, would increase European welfare. This effect dominates the negative impacts of climate change, so that Europe would seek to stimulate climate change. This is unrealistic. Blackorby and Donaldson (1984) and Blackorby et al. (1995) show that the choice between average and total welfare is important only in case population growth is endogenous. Apart from climate-change-induced migration, this is not the case in FUND.

The optimal emission reduction of each decade is decided at the start of that decade by optimising the net present welfare. The net present welfare includes the future from the start of the decade until 2200. Carbon dioxide emission reduction is the only instrument available to increase welfare. In the non-co-operative case, each region optimises its own net present welfare. In doing that, each region knows the other regions' emission reduction effort. In the standard co-operative case, the sum of the regional welfares is optimised.² Section 4 and Section 5 employ alternatives. In both the co-operative and non-co-operative case, each generation of decision-makers acts with full knowledge of the other generations' actions.

3. Risk aversion

Commonly, relative risk aversion is assumed to equal 1 (Maddison, 1995; Manne et al., 1995; Nordhaus, 1994; Nordhaus and Yang, 1996; Peck and Teisberg, 1991; Tol, 1997, 1999b,c,d), leading to a logarithmic welfare function. Cline (1992) and Fankhauser (1995) are exceptions, using 1.5. Hasselmann et al. (1997) use 0. Here, values of 0, 1 and 2 are used. At first sight, the implication is that more weight is placed on the negative impacts of climate change, so that optimal emission control increases with increasing risk aversion. This need not be the case, however. In FUND, without international co-operation, optimal emission control decreases with increasing risk aversion (cf. Fig. 1). The reason is that relative risk aversion plays a double role. It enters not only in current welfare, but also in the discount rate, via:

$$r = \rho + e \cdot g \quad (2)$$

where r is the discount rate, ρ is the pure rate of time preference, g is the growth rate of consumption, and e is the negative of the consumption elasticity of marginal utility or relative risk aversion. Higher risk aversion thus implies a higher discount rate. Even with utility discounting, a similar effect holds. Assuming a

² Note that average welfare is used rather than total welfare. The reason is that people migrate because of climate change. Immigration into the OECD hardly affects living standards, but does increase population size. If total welfare is used, the OECD would thus value immigration positively, and may seek to stimulate climate change in order to increase the flow of immigrants. As such an outcome is deemed unrealistic, average welfare is used instead.

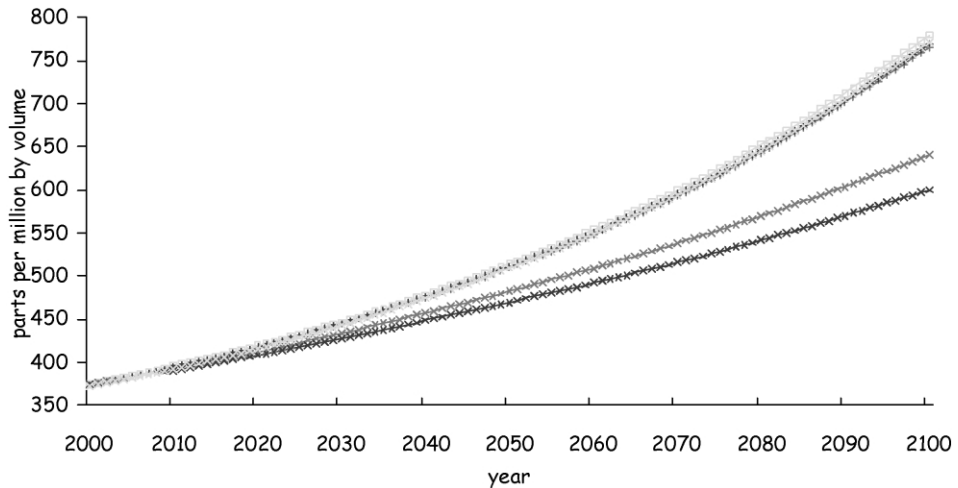


Fig. 1. The atmospheric concentration of carbon dioxide according to six scenarios, from top to bottom: non-co-operative with a risk aversion of two; co-operative with a risk aversion of two; non-co-operative with a risk aversion of one; non-co-operative with a risk aversion of zero; co-operative with a risk aversion of zero; and co-operative with a risk aversion of one. The non-co-operative scenarios with a risk aversion of two equals the business as usual scenario.

growing economy, the utility function is steeper in earlier years than in later. The higher the risk aversion, the more pronounced this effect. This implies that the welfare loss in earlier years (say, due to greenhouse gas emission reduction) is higher than the welfare loss—of an equivalent income loss—in later years (say, due to climate change). In FUND, this effect dominates.

This is an ambiguous finding, however. In the co-operative case, optimising the sum of net present regional welfares, optimal control is highest with a risk aversion of unity, and lowest with a risk aversion of two, with a zero risk aversion in between (cf. Fig. 1). Doubling the climate sensitivity (from 2.5 to 5.0 °C for $2 \times \text{CO}_2$) in the non-co-operative case does not change the relation between risk aversion and emission abatement. The explanation of the different patterns for the co-operative and non-co-operative cases need to be sought in the relative weight of the poorer, more vulnerable regions. This weight increases with the assumed risk aversion. Three factors—valuation of climate impacts, discount rate and weight of poorer regions—thus determine the influence of risk aversion on optimal emission control. As these factors work in different directions, with strength depending on the parameter assumptions, an unambiguous conclusion is impossible.

4. Inequity aversion

In the co-operative analyses above, global welfare is defined as the sum of

regional welfares. A similar assumption is made by Fankhauser (1995); Hasselmann et al. (1997); Maddison (1995), Manne and Richels (1997), Manne et al. (1995), Nordhaus (1994), Nordhaus and Yang (1996), Peck and Teisberg (1991, 1996), Tol (1997, 1999b,c,d) and Yohe and Wallace (1996). A more general global welfare function is:

$$W_{\text{global}} = \begin{cases} \sum_{\text{regions}} \frac{W_{\text{region}}^{\gamma}}{1 - \gamma} & \text{if } \gamma \neq 1 \\ \prod_{\text{regions}} W_{\text{region}} & \text{if } \gamma = 1 \end{cases} \quad (3)$$

where $\gamma = 0$ leads to the simple summation used above. The parameter γ can be interpreted as inequity aversion, since increasing weight is placed on poorer regions with increasing γ . Indeed, if γ approaches infinity, global welfare converges to the extreme egalitarian (Rawlsian) maximin function, $W_{\text{global}} = \min(W_{\text{region}})$. If γ approaches minus infinity, global welfare converges to the extreme elitist (Nietzschean) maximax function, $W_{\text{global}} = \max(W_{\text{region}})$. This analysis is confined to more reasonable choices, viz. $\gamma = 0, 1, 2$. In all cases, risk aversion equals one.³ Note that this approach cannot distinguish between climate-change-induced inequities and inequities from other sources. Tol (2001) presents ways to do so.

The influence of aversion to inequity is unambiguous.⁴ Since climate change affects the poorer regions the most, and since richer regions emit most of the greenhouse gas emissions, emission abatement implies income redistribution from the rich to the poor. This is valued more and more positively as inequity aversion γ increases. Note that FUND excludes international capital transfers, so that redistributive effects of climate change and emission abatement are the only factors.

Fig. 2 shows that the effect of changing inequity aversion can be quite drastic. With an inequity aversion of zero, the atmospheric concentration of carbon dioxide is 640 ppm in 2100 rising to 1107 ppm in 2200. With an inequity aversion of two, the 2100 concentration is 499 and the 2200 concentration 664. Recalling that FUND has a high business as usual scenario lacking any tendency for stabilisation, a tentative conclusion is that including mild inequity aversion in a co-operative cost–benefit analysis leads to optimal CO₂ concentrations compatible with current political interpretations of the Article 2 of the FCCC. To date, cost–benefit analyses have advised emission reductions that are substantially more modest than

³ Note that risk aversion also affects inequity aversion, varying relative utilities for a fixed income distribution. Inequity aversion does not affect risk aversion.

⁴ Note, however, that FUND excludes the effects of emission abatement in one region on other regions through international trade and capital investment (Piggott et al., 1992; Kennedy et al., 1997).

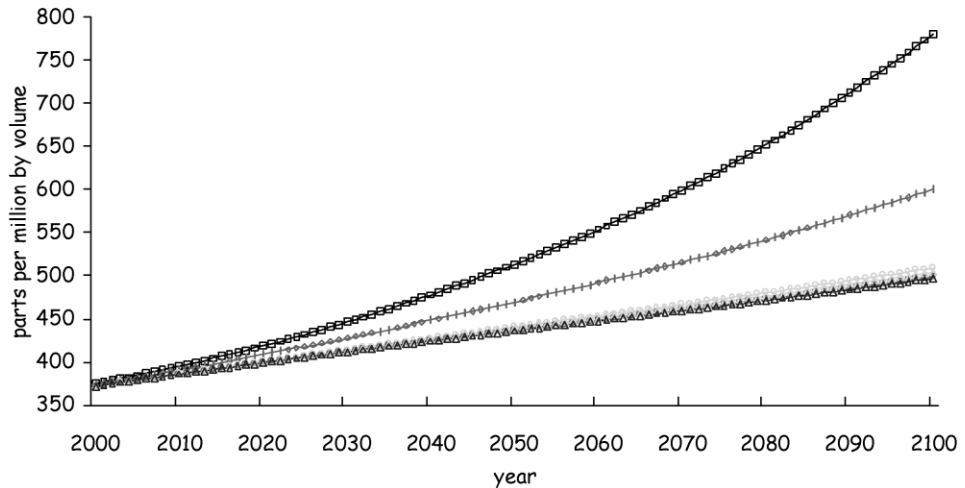


Fig. 2. The atmospheric concentration of carbon dioxide according to six scenarios, from top to bottom: business as usual; an inequity aversion of zero; an inequity aversion of one and sum-discounting; inequity aversion of one and product-discounting; inequity aversion of two and sum-discounting; and inequity aversion of two and squared-sum-discounting. All control scenarios assume full co-operation and a risk aversion of one.

what is on the political agenda (Fankhauser, 1995; Maddison, 1995; Nordhaus, 1994; Nordhaus and Yang, 1996; Peck and Teisberg, 1991).⁵

5. Intergenerational welfare

The global welfare function of Eq. (3) is inconsistent. The well-being of people living at the same time is added, multiplied, or squared and added, depending on the choice for γ . The well-being of people living at different times is added.

In this section, inequity aversion also governs the way people at different times are treated, analogue to Eq. (3). However, weighting with time preference is retained, in order not to skew the discussion. Various tendencies are at work. Climate change affects future generations more heavily so that climate change counts heavier for higher γ . Emission reduction affects current and near-future generations more heavily, and these are assumed to be poorer than future generations. In turn, this effect is counterbalanced by concentrating the effects of emission reduction in the richer regions (while the effects of climate change automatically befall the poorer regions).

⁵ The only serious exception is Manne and Richels (1997), who are optimistic about the costs of renewable energy and pessimistic about the (intangible) impacts of climate change.

Fig. 2 shows that, on balance, the effect is almost nil. Optimal CO₂ concentrations are a little lower than the optimal emissions of the previous section, but at most 6 ppm in 2100.

6. Conclusion

Not surprisingly, the optimal control of greenhouse gas emissions proves to be sensitive to the definition of optimality, that is, the assumed welfare function. Risk aversion is shown to have an ambiguous influence because, while it increases the importance of climate change impacts relative to greenhouse gas abatement costs, it also tilts the discount rate in favour of current poorer generations. In a co-operative context, higher risk aversion works out favourably for poorer regions, increasing optimal control.

Poorer regions are explicitly favoured by introducing inequity aversion. International emission reduction can be targeted at the richer regions. In the absence of spillover effect through international trade or capital investments, optimal emission control increases unambiguously. In FUND, optimal control even comes close to ensuring a stable atmospheric concentration of carbon dioxide at 550 ppm, a level that is often considered as safe. Note that this requires full international co-operation, and a commitment to international equity that is beyond current practice (cf. Schelling, 1995).

Intergenerational welfare is usually represented by a weighted sum, the weights being the pure rate of time preference. More elaborate intergenerational welfare functions introduce ambiguity since functions that place higher weight on climate change impacts automatically place higher weight on current, poorer generations as well.

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