DEPARTMENT OF ECONOMICS

Working Paper

Distributional biases in the analysis of climate change

By

Peter Skott
Leila Davis

Working Paper 2011-22
(Revised February 2012)

UNIVERSITY OF MASSACHUSETTS
AMHERST

Distributional biases in the analysis of climate change[*]

Peter Skott[†] and Leila Davis[‡]

14th February 2012

Abstract

The economic analysis of global warming is dominated by models based on optimal growth theory. These representative-agent models have an intrinsic distributional bias in favor of the rich. The bias is compounded by the use of 'revenue-neutrality' in the allocation of emission permits. The result is mitigation recommendations that are biased downwards.

JEL classification: Q13, I3, E1
Key words: representative agent, welfare, global warming, inequality.

---

[*] An earlier version of this paper was presented at the Analytical Political Economy Workshop, Queen Mary University of London, May 2011, and at the Adam Smith Seminar, University of Hamburg. We thank the participants and Frank Ackerman, Jim Boyce and Liz Stanton for helpful comments and suggestions. We are grateful also to three anonymous referees. Their constructive comments led to significant improvements in this version of the paper.

[†] Department of Economics, University of Massachusetts Amherst; pskott@econs.umass.edu

[‡] Department of Economics, University of Massachusetts Amherst; leila.davis1@gmail.com

1 Introduction

Climate change has strong distributional effects. The expected consequences for potential crop yields and the likelihood of flooding or droughts differ across regions, and the most detrimental effects are expected to occur in poorer regions. Negative health and mortality effects also affect developing countries disproportionately. Thus, the Intergovernmental Panel on Climate Change concludes, "The effects of climate change are expected to be greatest in developing countries in terms of loss of life and relative effects on investment and the economy" (IPCC, 2001, p. 8). The severity of these negative effects of climate change in poor regions is compounded by the fact that "The ability of human systems to adapt to and cope with climate change depends on such factors as wealth, technology, education, information, skills, infrastructure, access to resources, and management capabilities." Because endowments of these factors are typically lower in developing countries, poorer regions also "have lesser capacity to adapt and are, therefore, more vulnerable to climate change damages" (p. 8).

The uneven distribution of costs and benefits is not unique to environmental change and environmental policy. Policy generally benefits some people while others are hurt, and Pareto rankings of the outcomes are typically not available. Instead, decisions have to be based on social welfare evaluations that make (implicit or explicit) interpersonal comparisons, weighing up costs and benefits so as to arrive at a net result. A standard approach in the economic literature uses the utility function of a 'representative agent' as a social welfare function.

In the climate literature, the main debates have centered on the choice of discount rates.[1] The Stern Review (Stern 2006) adopted a 'prescriptive' approach and argued that on ethical grounds the pure discount rate in the welfare function should be close to zero. Nordhaus (2008) and most other studies by contrast use a 'descriptive' approach in which the welfare function of the representative agent has to be calibrated to fit empirical observations.[2] This approach, Nordhaus argues, "does not make a case for the social desirability of the distribution of incomes over space or time under existing conditions". Instead, using the descriptive approach

> The calculations of changes in world welfare arising from efficient climate-change policies examine potential improvements within the context of the existing distribution of income and investments across space and time. (Nordhaus, 2008, p. 174-175)

Assuming that aggregate outcomes can be described consistently by a representative agent, it may seem reasonable to use this agent's preferences to measure social welfare. This approach has the appearance of neutrality and objectivity. The analyst does not impose her own preferences but merely takes

---

[1] E.g. Chichilnisky (1996), Dasgupta (2011), Davis and Skott (2011), Rezai et al. (2011), Roemer (2011), Stern (2008), Weitzman (2009).

[2] The 'prescriptive'/'descriptive' terminology is used by Arrow at al. (IPCC chapter 4, 1996).

as given the revealed preferences of the population. Weitzman makes this argument explicitly. Like Nordhaus, he rejects the prescriptive approach of the Stern Review, arguing that:

> economists understand the difference between their own personal preferences for apples over oranges and the preferences of others for apples over oranges. Inferring society's revealed preference ... is not an easy task in any event ... but at least a good-faith effort at such an inference might have gone some way towards convincing the public that the economists doing the studies are not drawing conclusions primarily from imposing their own value judgments on the rest of the world. (Weitzman 2007, p. 712)

According to Weitzman, Nordhaus's "careful pragmatic modeling throughout his DICE series of IAMs has long set the standard in this area" (p. 713).[3]

The use of descriptive representative-agent models is not confined to the climate literature. Models of this kind have been the workhorses of macroeconomics since the Lucas revolution of the late 1970s. The explicit welfare criterion is seen as a strength of the models. Woodford (2003, p. 12; emphasis added), for instance, suggests that the utility function of the representative agent "provides a *natural objective* in terms of which alternative policies should be evaluated", while, according to Blanchard (2008, p. 9, emphasis added), contemporary macro models with formal optimization enable one "to derive optimal policy based on the *correct* (within the model) welfare criterion". Most tellingly, perhaps, the evaluation of outcomes based on the stipulated utility function of the representative agent is usually presented without any argument or caveat.

Although widespread and well-established, there is nothing objective about this approach to welfare analysis. There is no justification for the implicit claim that the same function which describes the representative agent can do double duty as a measure of social welfare. The representative agent is designed to explain average behavior and, loosely speaking, this average is determined using the economic resources of individual agents as weights. Because a rich agent influences aggregate consumption patterns more strongly than a poor agent, the preferences of the rich agent are given greater weight in the construction of the representative agent and hence also in the evaluation of social welfare. In the climate literature the biases can affect the abatement recommendations from representative-agent models.

At a general level the problems are well known. There is a big literature on cost-benefit analysis and the issues are similar.[4] Our main contribution in this paper is to provide simple examples that illustrate the problems and relate

---

[3] Despite his endorsement of Nordhaus's descriptive approach, Weitzman's conclusions are similar to those of Stern: his analysis of risk and the possibility of catastrophic change implies a low discount rate. In Weitzman's words, the Stern report may have been "right for the wrong reasons" (2007, p. 724).

[4] See Ackerman and Heinzerling (2005), Baum (2009), Sen (2000), Stanton (2010) and Stern (2006) for recent discussions with reference to climate change.

them to existing IAMs, especially the DICE and RICE models (Nordhaus 2008, Nordhaus and Boyer 2000). We focus on distributional issues that are unrelated to discounting and other intertemporal questions. Given this purpose, little is lost by ignoring the time dimension. Thus, we consider a static setting and assume that all costs and benefits occur in the same period.

Section 2 examines policy decisions in models with a well-defined representative agent. The models are highly stylized. There are two types of agents and we assume, in particular, that one good is consumed exclusively by one of the types and another good exclusively by the other type. This assumption may seem restrictive but the goods need not be ordinary goods: they can represent the non-market outcomes in two different regions. This interpretation and the relevance of the examples is discussed more fully at the end of the section.

The examples in Section 2 describe exchange economies without any production. Production is introduced in Section 3. The setting is similar to that of the RICE model. The economy is regionally disaggregated, there is inequality across regions, and the damages from climate change can be calculated in different ways, with or without some kind of 'equity weighting'. However, a unique, optimal level of emissions can be determined independently of distribution if two assumptions are satisfied: there is a single, homogeneous consumption good and this good can be transferred between regions. The crucial role of the first assumption (a single 'generalized consumption good') is illustrated by the examples in Section 2: in these examples the separation between efficiency and distribution breaks down and policies that maximize a standard measure of real output have a strong regressive bias.

The transfer assumption is the focus of Section 4 which develops a three good example. The example builds on Sections 2-3. There is one produced good and two non-produced environmental goods. The produced good is tradable and consumed in all regions; the two environmental goods are non-traded and cannot be transferred. An (extremely restrictive) assumption of perfect substitution means that the 'efficient' level of emissions will be uniquely defined, despite the existence of three goods, and the distributional outcome is determined by transfers (the allocation of emission permits across regions). The section analyzes how different allocation schemes can have adverse distributional consequences: the efficient solution with a reasonable-looking allocation scheme can produce a (utilitarian) welfare loss. Section 5 offers a few concluding remarks.

2 Some simple examples with a well-defined representative agent

Well-behaved preferences at the agent level do not imply that aggregate outcomes behave as if they were generated by an optimizing representative agent.[5]

---

[5] This result, which has been well-known since the work of Debreu (1974), Mantel (1976) and Sonnenschein (1972), undermines the claims of modern macro to be built on microeconomic foundations (Kirman 1992).

In some cases, however, a well-defined representative agent does exist, and these are clearly the cases that are most favorable to the representative-agent approach. Our examples focus on cases of this kind. The examples show that, even in these cases, the use of the representative agent for welfare analysis is highly questionable.[6]

2.1 A two-good example

Consider an economy with two types of agents, $A-$types who consume only good 1 and B-types who consume only good 2. The total endowment of the two goods is $\bar{q}_1$ and $\bar{q}_2$, and all agents have endowment compositions that mirror the aggregate composition (changes in relative prices therefore have no distributional effects). These assumptions imply that the share of good 1 in total expenditure is equal to the share of A-agents in total income (= their share in endowments). If α is the income share of A-agents, aggregate excess demands in this economy can be derived from the maximization of a Cobb-Douglas utility function,

$$U = q_1^{\alpha} q_2^{1-\alpha} \tag{1}$$

subject to the aggregate budget constraint $p_1 q_1 + p_2 q_2 = p_1 \bar{q}_1 + p_2 \bar{q}_2$. Thus, equation (1) represents the preferences of a representative agent for this economy.

Assume that initially $\bar{q}_1 = \bar{q}_2 = \bar{q}$ and that an opportunity now arises which would raise $\bar{q}_1$ marginally but reduce $\bar{q}_2$ by the same amount. Is social welfare increased by moving from the endowment bundle $(\bar{q}, \bar{q})$ to the new bundle $(\bar{q} + \Delta, \bar{q} - \Delta)$? Using the utility function (1) as the yardstick, the change in welfare is given by

$$dU = (\frac{\bar{q}_2}{\bar{q}_1})^{-\alpha}[\alpha \frac{\bar{q}_2}{\bar{q}_1} - (1-\alpha)]\Delta = (2\alpha - 1)\Delta \tag{2}$$

Hence, the analyst must conclude in favor of the policy if – collectively – $A-$agents have more than 50 percent of the resources. The conclusion does not depend on whether a high α reflects a large share of $A-$agents in the population (with all agents having the same endowment) or a large endowment for each $A-$agent (with the same number of A and B agents). In this sense the welfare criterion is independent of distribution. In general, however, the policy implications are highly regressive. Consider two economies: they have the same proportion of A and B agents, but A agents are richer than B agents in one economy while B agents are richer in the other economy. Representative-agent evaluations will give different conclusions: the analyst will recommend the policy – which favors A agents – in the economy with rich A agents but reject the policy when A agents are poor.

This two-good example is one of pure conflict. A and B agents consume different goods. Any change in the overall composition of the goods must

---

[6] According to Kirman (1992), there are cases in which a policy change raises the utility of all agents but reduces the utility of the representative agent. His argument for this proposition seems unclear, however, and arguably the case with conflicting interests (which Kirman does not discuss) is both more interesting and empirically more relevant.

benefit one type and hurt the other. Compensation is impossible, and there are no Pareto improving changes in the composition of the endowments. The representative-agent approach glosses over this conflict. It gives a clear and unambiguous policy recommendation: do what is good for the rich. There is an intrinsic bias in favor of the rich.

2.2 A three-good example

Empirically, the consumption sets of the rich and the poor are not completely disjoint. Some goods are valued by all agents and this opens up the possibility of compensation and Pareto improving changes. We examine this case using an extended model with three goods.

As in the two-good example, there are two types of agent, A and B, and all agents have the same endowment composition. The new element is the introduction of a good that is valued and consumed by both types of agent. The preferences of the agents are given by Cobb-Douglas utility functions

$$U^A = q_{1A}^{\beta} q_{3A}^{1-\beta} \tag{3}$$

$$U^B = q_{2B}^{\beta} q_{3B}^{1-\beta} \tag{4}$$

where q_{ij} is the consumption of good i by agent j. As in Section 2.1, we let α denote the share of A-agents in total income ($Y_A = \alpha Y,\ Y_B = (1-\alpha)Y$).

With this combination of preferences and endowments, the consumption patterns of the two agents satisfy

$$p_1 q_{1A} = \beta Y_A, \quad p_2 q_{2A} = 0, \quad p_3 q_{3A} = (1-\beta) Y_A \tag{5}$$

$$p_1 q_{1B} = 0, \quad p_2 q_{2B} = \beta Y_B, \quad p_3 q_{3B} = (1-\beta) Y_B \tag{6}$$

Thus, the aggregate demands ($q_1 = q_{1A} + q_{1B}, q_2 = q_{2A} + q_{2B}, q_3 = q_{3A} + q_{3B}$) for the three goods are given by the following equations:

$$p_1 q_1 = \alpha\beta Y \tag{7}$$

$$p_2 q_2 = (1-\alpha)\beta Y \tag{8}$$

$$p_3 q_3 = (1-\beta) Y \tag{9}$$

The demand structure in equations (7)-(9) can be derived from the optimizing behavior of a single representative agent with utility function

$$U = q_1^{\alpha\beta} q_2^{(1-\alpha)\beta} q_3^{1-\beta} \tag{10}$$

and budget constraint $p_1 q_1 + p_2 q_2 + p_3 q_3 = p_1 \bar{q}_1 + p_2 \bar{q}_2 + p_3 \bar{q}_3 = Y$.

2.2.1 Marginal changes

Consider the same policy question as in Section 2.1. Should we increase the supply of good 1 at the expense of a reduction in the supply of good 2? With a one-for-one tradeoff and supplies of the two goods that are equal initially, a marginal change of this kind would have a welfare effect given by

$$dU = \beta(\frac{\bar{q}_3}{\bar{q}})^{1-\beta}[2\alpha - 1] \tag{11}$$

where $\bar{q} = \bar{q}_1 = \bar{q}_2$ is the initial supply of the goods 1 and 2. The conclusion is similar to the earlier example: implement the policy if $\alpha > 0.5$.

Unlike in the two-good example, the policy decision does not directly prejudice the distributional outcome. $A-$agents are the direct beneficiaries of the policy but the B-agents could be compensated by raising their share of the consumption of good 3. Having the third good means that Pareto improvements become possible.

There are two extreme cases of Pareto improvements: one in which all the improvements go to $A-$agents and one in which only $B-$agents benefit. Keeping U^B unchanged following a marginal increase in q_1 (and an equal marginal decrease in q_2) requires

$$0 = dU^B = \beta\frac{U^B}{q_{2B}}dq_{2B} + (1-\beta)\frac{U^B}{q_{3B}}dq_{3B} \tag{12}$$

or

$$\frac{dq_{3B}}{d\bar{q}_1} = \frac{\beta}{1-\beta}\frac{q_{3B}}{q_{2B}} = \frac{\beta}{1-\beta}\frac{(1-\alpha)\bar{q}_3}{\bar{q}_1} \tag{13}$$

where we have used $d\bar{q}_2 = -d\bar{q}_1$ (by assumption this is the tradeoff) and $q_{3B} = (1-\alpha)\bar{q}_3$, $q_{2B} = \bar{q}_2 = \bar{q}_1$ at the initial position (these equilibrium conditions follow from (5)-(6)). Since $dq_{3B} = -dq_{3A}$, we can now derive the gain to the A-agents in the case where $dU^B = 0:$

$$dU^A = \alpha^{-\beta}\beta(\frac{\bar{q}_3}{\bar{q}_1})^{1-\beta}[2\alpha - 1]d\bar{q}_1 \tag{14}$$

Analogously, setting $dU^A = 0$, the increase in q_{3B} and the marginal increase in the utility of $B-$agents can be found:

$$\frac{dq_{3B}}{d\bar{q}_1} = \frac{\beta}{1-\beta}\frac{q_{3A}}{q_{1A}} = \frac{\beta}{1-\beta}\frac{\alpha\bar{q}_3}{\bar{q}_1} \tag{15}$$

$$dU^B = (1-\alpha)^{-\beta}\beta(\frac{\bar{q}_3}{\bar{q}_1})^{1-\beta}[2\alpha - 1]d\bar{q}_1 \tag{16}$$

The largest improvement in aggregate utility, $U^A + U^B$, comes when all the net gains are given to the poor $B-$agents: the symmetric specifications of the utility functions in equations (3)-(4) imply that poor agents have a higher marginal utility. If one rejects cardinality of the utility function, however, no significance attaches to the magnitudes of the expressions in equations (14) and (16), and interpersonal comparisons of utility gains become meaningless. But the expressions in (13) and (15) still hold without cardinality, and the policy generates a Pareto improvement if the compensating change $dq_{3B}/d\bar{q}_1$ falls in the interval between the expressions on the right-hand-sides of (13) and (15).

2.2.2 Non-marginal change

The analysis in Section 2.2.1 analyzed marginal changes. One can also look for the optimal amount of good 2 to convert (one-for-one) into good 1. We consider four different approaches to this question.

Case I: A 'generalized consumption good' The initial equilibrium can be used to define a generalized consumption good. Using p_3 as the numeraire, the demand equations (7)-(9) can be combined with the initial supplies ($\bar{q}_1 = \bar{q}_2 = \bar{q}, \bar{q}_3$) to give the pre-policy equilibrium prices

$$\bar{p}_1 = \frac{\alpha\beta}{1-\beta}\frac{\bar{q}_3}{\bar{q}} \tag{17}$$

$$\bar{p}_2 = \frac{(1-\alpha)\beta}{1-\beta}\frac{\bar{q}_3}{\bar{q}} \tag{18}$$

$$\bar{p}_3 = 1 \tag{19}$$

A generalized good can be defined using these weights,

$$c = \bar{p}_1 q_1 + \bar{p}_2 q_2 + q_3 \tag{20}$$

If the utility of the representative agent is taken to be an increasing function of the consumption of this generalized good, policy should aim to maximize $\bar{c} = \bar{p}_1\bar{q}_1 + \bar{p}_2\bar{q}_2 + \bar{q}_3$. By assumption, there is a one–for-one transformation between goods 1 and 2. The prices of the two goods are different, however, and using this criterion the policy-maker should convert all existing supplies of good 2 into good 1 if $\alpha > 0.5$.

Case II: Using the utility function of the representative agent The answer in this case is found by maximizing (10) subject to the conditions

$$q_1 + q_2 = \bar{q}_1 + \bar{q}_2 \tag{21}$$

$$q_3 = \bar{q}_3 \tag{22}$$

The result is

$$(\frac{q_2}{q_1})^{*,rep} = \frac{1-\alpha}{\alpha} \tag{23}$$

Case III: Maximizing U^A subject to $dU^B = 0$ Straightforward calculations yield (see the appendix)

$$(\frac{q_2}{q_1})^{*,\max A} = \frac{[2(1-\alpha)]^{1-\beta}}{2-[2(1-\alpha)]^{1-\beta}} = \frac{(1-\alpha)}{[2(1-\alpha)]^{\beta}-1+\alpha} \tag{24}$$

Case IV: Maximizing U^B subject to $dU^A = 0$ The optimal ratio in this case becomes

$$(\frac{q_2}{q_1})^{*,\max B} = \frac{2-(2\alpha)^{1-\beta}}{(2\alpha)^{1-\beta}} = \frac{(2\alpha)^{\beta}-\alpha}{\alpha} \tag{25}$$

Case I extends the marginal analysis to a non-marginal question. Using the equilibrium prices that apply at the initial state, this approach generates a policy recommendation that wipes out all of the consumption good that is specific to the poor. Given the specification of the utility functions, the poor cannot be compensated for this by a redistribution of good 3: with $q_{2B} = 0$, their utility is identically equal to zero.[7] It follows, in particular, that having chosen $\bar{q}_2 = 0$, a Pareto improvement can now be obtained by setting $q_{3B} = 0$ and $q_{3A} = \bar{q}_3$.

Eschewing the use of prices and local approximations, cases II-IV base the policy recommendation on utility functions and – in cases III and IV – distributional requirements. The results are quite different in the three cases. It can be seen that for $\alpha > 0.5$, we have[8]

$$(\frac{q_2}{q_1})^{*,\max B} > (\frac{q_2}{q_1})^{*,\max A} > (\frac{q_2}{q_1})^{*,rep} \tag{26}$$

Comparing cases III and IV, it is intuitively obvious that $B-$agents will do better when they get all the net benefits from the change. This intuition is reflected in a larger ratio of their preferred good: the ratio q_2/q_1 is higher in the case that favors $B-$agents (the first inequality in (26)).

Case II, which uses the utility function of the representative agent, reduces the ratio q_2/q_1 compared to cases III and IV (the last inequality in (26)).[9]

---

[7] The extreme outcome with $q_{2B} = 0$ no longer holds – even with fixed prices – if the technical transformation of good 2 into good 1 were subject to diminishing returns. But using the initial equilibrium prices as weights still amplifies the magnitude of the recommended change.

[8] The second inequality follows directly from the observation that $[2(1-\alpha)]^{\beta} - 1 < 0$ for $\alpha > 0.5$. The first inequality can be derived by noting that

$$\frac{(2\alpha)^{\beta}-\alpha}{\alpha} > \frac{(1-\alpha)}{[2(1-\alpha)]^{\beta}-1+\alpha}$$

$\iff$

$$[2^{\beta}\alpha^{\beta-1}-1][2^{\beta}(1-\alpha)^{\beta-1}-1] > 1$$

$\iff$

$$2^{\beta} > \alpha^{1-\beta} + (1-\alpha)^{1-\beta}$$

The expression on the right-hand-side of the latter inequality has a maximum at $\alpha = 0.5$ with the maximum value equal to 2^{β}.

[9] The magnitude of the difference between the three solutions for q_2/q_1 depends on the value of β. The non-market goods are important if β is large. In this case, any change in the relative supplies of goods 1 and 2 will have a big impact on the compensation that is required to avoid a decline in the utility of the poor. As a result, only a small range of changes in relative supply can produce a Pareto improvement: in the limit we have $\lim_{\beta\to 1}(q_2/q_1)^{*,B\max} = \lim_{\beta\to 1}(q_2/q_1)^{*,A\max} = 1$. Conversely, a small value of β implies that cases II-IV yield similar results. Thus, we have $\lim_{\beta\to 0}(q_2/q_1)^{*,B\max} = \lim_{\beta\to 0}(q_2/q_1)^{*,A\max} = (q_2/q_1)^{*,rep} = (1-\alpha)/\alpha$.

The poor $B-$agents are hurt by this reduction. In principle, they could be compensated by an increase in their share of good 3. *If the post-policy outcome is to be Pareto efficient, however, there can be no such compensating increase.* To see this, note that the composition of goods 1 and 2 is chosen so as to match the initial equilibrium outcome for q_{3B}/q_{3A}.[10] Pareto efficiency requires that $q_2/q_1 = q_{3B}/q_{3A}$, and it follows that – having set the supply ratio $\bar{q}_2/\bar{q}_1$ equal to the initial consumption ratio for good 3 – this initial equilibrium composition of good-3 consumption must be maintained if the new allocation is to be efficient. Policies that combine the case-II value of q_2/q_1 with redistribution of good 3 may achieve a Pareto improvement, but they will not be Pareto efficient.

In short, in this example the representative-agent analysis leads to an outcome that is either inefficient or distributionally regressive. This conclusion is related to the dependence of the descriptive representative agent on the distribution of income. If we change the distribution of income in order to compensate the poor in region B for a decline in their consumption of the non-market good then the appropriate definition of the representative agent is affected: the share of A-agents (α) is a parameter in the representative agent's utility function, equation (10). This result illustrates one of the problems with the Lucas-inspired program of 'micro-founded' macroeconomics. The microeconomic foundations for macroeconomics were needed, Lucas argued, because the preferences of individual agents could be taken as invariant to changes in economic policy. But as shown by the example, distributional changes (a change in the share of the A-agents) imply that the representative agent has to be re-defined. Real-world policy changes invariably have distributional consequences. Hence, contemporary macro is itself subject to a 'Lucas critique': the preferences of the representative agent are not structurally invariant.

2.3 Discussion

The two- and three-good examples in Sections 2.1-2.2 have well-defined representative agents. Changes in relative prices have no distributional effects, but this does not eliminate distributional conflicts. The preferences and the composition of the consumption bundles differ across agents, and there are potential conflicts over both the distribution and composition of the endowment bundles.

The examples are simple and abstract, and they may seem far removed from the climate debate. The assumption that good 1 is consumed only by A-types and good 2 only by B-types may appear particularly restrictive. This concern would be reasonable if the goods were thought of as ordinary, traded goods. But another interpretation is possible. Many of the important effects of climate change are outside the market sphere. Health and mortality effects are obvious examples, but broader social implications (including migration and the possibility of wars and other upheavals in the wake of strong regional effects) fall in this category too. The non-market effects of climate change are unevenly

---

[10] This happens because both the parameters of the representative agent's utility function and the consumption ratio q_{3B}/q_{3A} are determined by the distribution of income.

distributed, and goods 1 and 2 can be interpreted as the non-market outcomes in two different regions, a rich A region and a poor B region.

An interpretation which has good 1 representing the health of people in region A and good 2 the health of people in region B may seem inconsistent with the assumption that all agents receive endowment bundles with the same composition. The utility functions, however, mean that A-agents get no utility from the consumption of good 2 and B-agents no utility from good 1. With this specification of preferences, the outcome of an economy in which all three goods are traded and the initial compositions are the same across agents is isomorphic to the outcome in an economy in which all good-1 endowments are given to A agents, all good-2 endowments are given to the B-agents, and only good 3 is tradable. Neither economy will see any trade in good 3, and both economies will have A-agents consume the total supply of good 1 and B-agents the total supply of good 2.

The damages of climate change fall disproportionately on poor regions while the benefits from continued greenhouse gas emissions accrue more strongly to richer regions. A stylized version of this distributional pattern can be captured in the 3-good example by associating an increase in emissions with an increase in the supply of good 1 at the expense of good 2.

3 Integrated assessment models

3.1 The setting

Building on a number of earlier contributions, Nordhaus (1992, 1994) presented the first version of the DICE model. Since then the model has gone through several iterations, and the analysis has been extended in many ways. From our perspective the most interesting extension is the explicit incorporation of regional disaggregation in the RICE versions of the model.

Nordhaus and Boyer (2000) disaggregate the analysis by looking at 8 different regions. Each region is assumed to maximize a social welfare function. The argument of the welfare function is the level of per-capita 'generalized consumption', which includes both market and non-market effects of climate change.[11] A logarithmic specification of instantaneous per capita utility is used,

$$u(c_j) = \log c_j \tag{27}$$

where c_j is the per-capita consumption in region j.

Regional consumption is equal to output minus investment, and output is given by a Cobb-Douglas production function (p. 17-18)

$$Q_j = \Omega_j (A_j K_j^{\gamma} L_j^{1-\beta-\gamma} E_j^{\beta} - m_j E_j) \tag{28}$$

---

[11] In general, the weights used to calculate a generalized consumption good will be changing in response to changes in the consumption bundle. Hoel and Sterner (2007) examine the effects of these changes on the relevant discount rates in an optimal growth model with two goods: a slow growing environmental good and a fast-growing standard consumption good.

where E is carbon-energy and m is the cost of this intermediate input; Q is output, K and L are capital and labor, and A represents the level of technology. The regional estimate of Ω represents the proportional loss of regional output from climate change. This loss depends on the average temperature, and temperatures in turn are related to emissions.

The regional loss varies significantly across regions. A rise of 2.5 degree Celsius in average temperatures produces an estimated output loss of 0.45 percent in the US, while the estimated loss of output in the group of low-income countries amounts to 2.64 percent.

The global loss can be found as a weighted average of the regional losses, and two distinct measures are presented: one using output weights and one using population weights.

Output loss Output is treated as homogeneous in the model. Generalized output (and consumption) in region i can be transformed one-for-one into generalized output in region j. Thus, aggregate output is given by

$$Q = \sum Q_j \tag{29}$$

and the first measure of global damages is a standard expression for the proportional output loss:

$$\frac{dQ}{Q} = \sum \frac{dQ_j}{Q} = \sum \frac{Q_j}{Q} \frac{dQ_j}{Q_j} = \sum \frac{Q_j}{Q} \frac{d\Omega_j}{\Omega_j} \tag{30}$$

Welfare loss An indicator of output loss does not give an accurate picture of the welfare implications. Equation (27) implies that marginal utility is declining in consumption, and an additional unit of consumption does not provide the same utility gain to a rich person as to a poor person. Population weights can be seen as a way of adjusting for this.

Nordhaus and Boyer do not discuss the population weights in any detail, but the population-weighted output loss approximates the welfare implications of the damages when the utility function is logarithmic. A utilitarian approach defines total welfare as the population weighted average of regional welfare,

$$W = \sum \frac{N_j}{N} u(c_j) \tag{31}$$

where N_j and N denote regional and global population. With a logarithmic utility function it follows that the change in welfare can be written

$$dW = \sum \frac{N_j}{N} u'(c_j) dc_j = \sum \frac{N_j}{N} \frac{dc_j}{c_j} = \sum \frac{N_j}{N} \frac{d\Omega_j}{\Omega_j} \tag{32}$$

where the last equality follows from an assumption of proportionality between output and consumption (and from the calculation of the loss for given values of A, K, L, E).

Because damages are higher and consumption is lower in poor regions, population weighted measures produce higher estimates of aggregate damages. Thus, in Nordhaus and Boyer's model, the use of population weights increases estimates of the damages resulting from a five degree Celsius increase in global mean temperature from six percent to eight percent of GDP. Similarly, Tol (2002) finds that 'equity-weighted' estimates lead to a doubling of projected damages associated with a 5 degree increase in temperatures. In general, there is widespread agreement among economists that some kind of weighting can be used to capture the welfare effects of an uneven distribution of damages; as an example, the Stern review seems to endorse this approach (Stern, 2006, pp. 148-149).

Discussion The utilitarian approach to welfare is controversial and raises issues that are beyond the scope of this paper. Staying within the standard optimal-growth framework, there is no consensus on the definition of 'equity'. The Nordhaus and Boyer adjustment invites two obvious (and well-known) points. The disaggregation, first, is not taken very far. Increasing the number of regions will almost certainly raise the population weighted estimate of damages. Moreover, within each region the damages are likely to affect the poor more strongly than the rich which – if taken into account – would raise the estimates even further.[12]

The second problem is more technical. The population weighting provides a good (local) approximation of welfare changes if the utility function $u(c_j)$ is logarithmic. The logarithmic specification is the limiting case of a general CRRA utility function, $u(c_j) = (c_j^{1-\theta} - 1)/(1-\theta)$, with $\theta \to 1$. It is widely suggested, however, that a specification with $\theta > 1$ gives a better fit for the preferences of the representative agent, and a higher value of θ implies that marginal utility falls off more rapidly as consumption increases.[13] As a result, the outcomes for the poor need to be given even greater weight in order to get an estimate of the total welfare loss. Formally, if $u(c_j) = (c_j^{1-\theta} - 1)/(1-\theta)$,

$$dW = \sum \frac{N_j}{N} u'(c_j) dc_j = \sum \frac{N_j}{N} c_j^{-\theta} dc_j = \sum \frac{N_j}{N} c_j^{-\theta+1} \frac{dc_j}{c_j} = \sum \frac{N_j}{N} c_j^{-\theta+1} \frac{d\Omega_j}{\Omega_j} \tag{33}$$

As an example, consider a three-region case: a rich region with income at 2 and damages at 1 percent, a middle income region with income at 1 and damages at 2 percent, and a poor region with income at 0.5 and damages at 3 percent, and assume that population is evenly divided across the three regions. The income weighted output loss is 1.57 percent (equation (30)); the welfare loss, however, is 2 percent if the utility function is logarithmic (in which case the welfare loss equals the population weighted output loss, equation (32)) and 2.83 percent if $\theta = 2$ (equation (33)).[14]

---

[12] See Anthoff et al. (2010) for a recent discussion.

[13] Nordhaus (2008) assumes $\theta = 2$.

[14] One may note also that if $\theta > 1$, the welfare loss will depend on the degree of inequality,

Azar and Sterner (1996) discuss the effects of disaggregation on the welfare loss; see also Anthoff et al. (2009). Nordhaus and Boyer, however, do not pursue these issues, and there is no need for them to do this. Their approach implies that equity weighting becomes largely irrelevant for the calculation of the efficient level of mitigation.

3.2 The 'optimal solution'

Consider a true one-good world in which the utility of individuals depends exclusively on their consumption of this good. In this world efficiency requires that the amount of the good be made as large as possible; in general this condition also determines where the production (and emissions) should take place. Once total consumption has been maximized, the outcome will be Pareto efficient no matter how the good is distributed among regions and individuals. Thus, the optimal amount of mitigation can be found without any reference to distribution. This independence of efficiency from distribution does not imply that distribution is unimportant from a welfare perspective. But in a one-good world, equity concerns are separate from efficiency. Equity-weighted damages can be calculated to illustrate the differential impact of global warming, but they play no role in the derivation of the optimal level of emissions.[15]

The Nordhaus-Boyer model reduces all outcomes to a single good, 'generalized consumption'. But their model does not describe a true one-good world. The generalized consumption good is constructed using relative prices associated with an initial equilibrium. In this respect the Nordhaus-Boyer argument fits case I in Section 2.2.

As shown in Section 2.2, the maximization of the total supply of generalized consumption shifts the policy recommendations further in the interest of the rich regions than would be justified by a representative-agent analysis which itself is biased in favor of the rich. Moreover, efficiency cannot be separated from distribution if the one-good assumption is abandoned. The examples in section 2.2 illustrate this general point: the representative-agent analysis in case II led to a recommendation that was only efficient for a particular distribution of income.

---

even if all regions suffer the same proportional damage. Thus, if $d\Omega_j/\Omega_j = d\Omega/\Omega$

$$dW = \sum \frac{N_j}{N} c_j^{-\theta+1} \frac{d\Omega_j}{\Omega_j} = \frac{d\Omega}{\Omega} \sum \frac{N_j}{N} c_j^{-\theta+1} \le \frac{d\Omega}{\Omega} c^{-\theta+1}$$

with equality iff $c_j = c$ for all j.

[15] Assuming that the consumption good can be transferred. See Chichilnisky and Heal (1993) for an analysis of cases where no such transfer is possible.

4 The case of perfect substitution

4.1 Compensation

The Nordhaus-Boyer approach is theoretically valid in the special case of perfect substitution between goods 1 and 3 for A-agents and between goods 2 and 3 for B-agents (this special case effectively means that we have a true one-good world). The assumption of perfect substitution is extremely restrictive and has no empirical support, but let us accept it for the sake of the argument.

Having found the optimal level of emissions, the distribution of the available amount of generalized consumption across regions has to be determined. A radical utilitarian approach would maximize the sum of utility. Using the same (cardinal) utility functions for rich and poor agents, the distributional consequences would be immense. If global mitigation efforts are linked strongly with dramatic redistribution, however, it may be difficult to get the rich countries to participate. Recognizing this, Ackerman et al. (2010) – who adopt a utilitarian approach – temper their recommendations by including several constraints, one of them that consumption in the rich countries must not decline in absolute terms.

A focus on Pareto improvements would seem to be in line with Nordhaus's stated objective to "examine potential improvements within the existing distribution of income" (cf. above p. 1). In terms of our examples in Section 2, the relevant outcomes then fall in the range between those of cases III and IV, with equity concerns presumably tilting the choice towards case IV which favors the poor.[16]

Nordhaus and Boyer do not discuss the compensation issue in any detail. Implicitly, however, their position on distribution is reflected in the allocation of emission permits. Emissions can be controlled through tradable permits, and the total number of permits is determined by the efficiency requirement. But the initial allocation of these permits has distributional effects.[17] The issues can be illustrated using an extended version of the models in Section 2.

4.2 3-good example with production

Building on the 3-good example in Section 2, we define the regional welfare as a function of the consumption of goods 1 and 3 in region A and goods 2 and 3 in region B. Unlike in Section 2, however, it is assumed that there is perfect substitution. A-agents are willing to substitute one-for-one between goods 1 and 3 and their utility is determined by the sum of their consumption of goods 1 and 3; B-agents' utility, analogously, is determined by the sum of their consumption

---

[16] IPCC (1996, chapter 3) surveys the literature on equity in the distribution of emissions and abatement costs.

[17] Note that these distributional effects occur both within and across countries; see, for example, Brenner et al 2007 for a discussion of distributional effects within China.

of goods 2 and 3. Thus,

$$U^A = U(c_{1A}, c_{3A}) = u(c_1 + c_{3A}) = u(c^A) \tag{34}$$

$$U^B = U(c_{2B}, c_{3B}) = u(c_2 + c_{3B}) = u(c^B) \tag{35}$$

where $c^A = c_1 + c_{3A}$ and $c^B = c_2 + c_{3B}$ are the levels of consumption in the two regions.

Instead of given endowments, the three goods are now produced. The non-market goods, c_1 and c_2, are the result of global warming and their amounts depend on the total emissions ($\bar{E} = \bar{E}_A + \bar{E}_B$ with $\bar{E}_i$ representing aggregate emissions in region i) :

$$c_1 = H^A(\bar{E}) \tag{36}$$

$$c_2 = H^B(\bar{E}) \tag{37}$$

The production of the market good – good 3 – in the two regions is a function of emissions. Algebraically,

$$c_{3A} = Y_{3A} = F^A(E_A, \bar{E}); \qquad F_2 \leq 0 \tag{38}$$

$$c_{3B} = Y_{3B} = \lambda F^B(E_B, \bar{E}); \qquad F_2 \leq 0 \tag{39}$$

Individual producers of good 3 take the aggregate emissions $\bar{E}$ as exogenously given. The effect of E_i on c_{3i}, by contrast, expresses a firm-level relation between emissions and output. For simplicity, only emissions are included explicitly in the production functions for good 3 (equations (38)-(39)). Other factors, including labor and capital, are taken to be in fixed supply.

Using linear and quadratic versions of (35)-(39), let

$$c_1 = H^A(\bar{E}) = C_0 - \nu_A \bar{E} \tag{40}$$

$$c_2 = H^B(\bar{E}) = \lambda[C_0 - \nu_B \bar{E}] \tag{41}$$

$$Y_{3A} = Y_0 + E_A - \frac{\rho}{2} E_A^2 - \mu_A \bar{E} \tag{42}$$

$$Y_{3B} = \lambda[Y_0 + E_B - \frac{\rho}{2} E_B^2 - \mu_B \bar{E}] \tag{43}$$

where $\lambda < 1$ and where the constants (C_0, Y_0) and $(\lambda C_0, \lambda Y_0)$ represent the available supplies of non-market and market goods in the two regions when there are no emissions. The technology in the poor B region is less advanced ($\lambda < 1$).[18] Emission damages may also be assessed differently in the two regions,

---

[18] It may seem unreasonable to scale the poor region's supply of the non-market good by the 'technology factor' λ. The scaling, however, roughly reflects the standard valuations of non-market effects. The willingness to pay – which forms the basis for the valuations – depends strongly on ability to pay. The calculations of damages resulting from climate change therefore use a higher statistical value of human life in rich areas than in poor areas. In Tol's (1995) analysis, for example, the value of a statistical life is "assumed to equal $250,000 + 175 times the average income per capita" (p. 369). Analogously, in their regional model, Nordhaus and Boyer (2000, p. 82) value a "year of life lost" at two years of per capita income, again giving a lower value to lives in low income regions.

both because of direct climate effects on traditional production ($\mu_A \gtrless \mu_B$) and because of differences in the valuation of non-market damages ($\nu_A \gtrless \nu_B$).

Treating aggregate emissions as exogenous, a *laissez-faire solution* implies that

$$E_A^{market} = \frac{1}{\rho}, \qquad E_B^{market} = \frac{1}{\rho} \tag{44}$$

Efficient regional intervention has each region maximize its own welfare, taking as given the emissions from the other region.[19] The result in this case is given by

$$E_A^{reg} = \frac{1 - \mu_A - \nu_A}{\rho}, \qquad E_B^{reg} = \frac{1 - \mu_B - \nu_B}{\rho} \tag{45}$$

The *globally efficient outcome* – which takes into account the global externality – reduces the emissions further:

$$E_A^{eff} = \frac{1 - \mu_A - \nu_A - \lambda\mu_B - \lambda\nu_B}{\rho}, \qquad E_B^{eff} = \frac{\lambda - \mu_A - \nu_A - \lambda\mu_B - \lambda\nu_B}{\lambda\rho} \tag{46}$$

The RICE model finds the globally efficient solution and thus the number of emission permits to be issued. The price of these permits will be equal to the marginal damage from emissions:

$$p^{permit} = \mu_A + \nu_A + \lambda\mu_B + \lambda\nu_B \tag{47}$$

4.3 Permit allocation

4.3.1 Revenue neutrality

Nordhaus and Boyer suggest that the permits be allocated "in a revenue-neutral way across countries" where "a revenue-neutral permit allocation grants each region permits equal to its emissions at the equilibrium carbon tax" (p. 25).[20] This allocation implies that region A is given E_A^{eff} permits while region B gets E_B^{eff}. As a result there is trade in neither permits nor the tradable good 3. The absence of trade holds also for the laissez-faire and regional-intervention regimes. Thus, in all three regimes, the consumption pattern for generalized consumption can be found by substituting the levels of emissions into :

$$c_A^* = c_1 + Y_{3A} = C_0 - \nu_A\bar{E} + Y_0 + E_A - \frac{\rho}{2}E_A^2 - \mu_A\bar{E} \tag{48}$$

$$c_B^* = \lambda[C_0 - \nu_B\bar{E}] + \lambda[Y_0 + E_B - \frac{\rho}{2}E_B^2 - \mu_B\bar{E}] \tag{49}$$

By construction the globally efficient solution raises aggregate consumption, but the efficient regime with revenue neutrality need not produce a Pareto improvement. This possibility is illustrated by the following numerical example.

---

[19] The implementation of this outcome requires policy intervention, whether in the form of emission permits or taxes.

[20] If emissions are controlled by a tax then the equilibrium carbon tax is equal to the price of permits in (47).

Example 1 $\lambda = 1/3, \rho = 0.1, \mu_A = \mu_B = \nu_A = \nu_B = 0.05$

With these parameter values the income of the poor region declines in the efficient solution compared to both laissez-faire and regional intervention (see Table 1). A revenue neutral allocation of permits means that no compensation will take place, and if the utility functions are sufficiently concave the overall effect on social welfare will be negative (assuming a utilitarian measure of social welfare). The increase in efficiency has produced greater inequality and a decline in aggregate welfare.

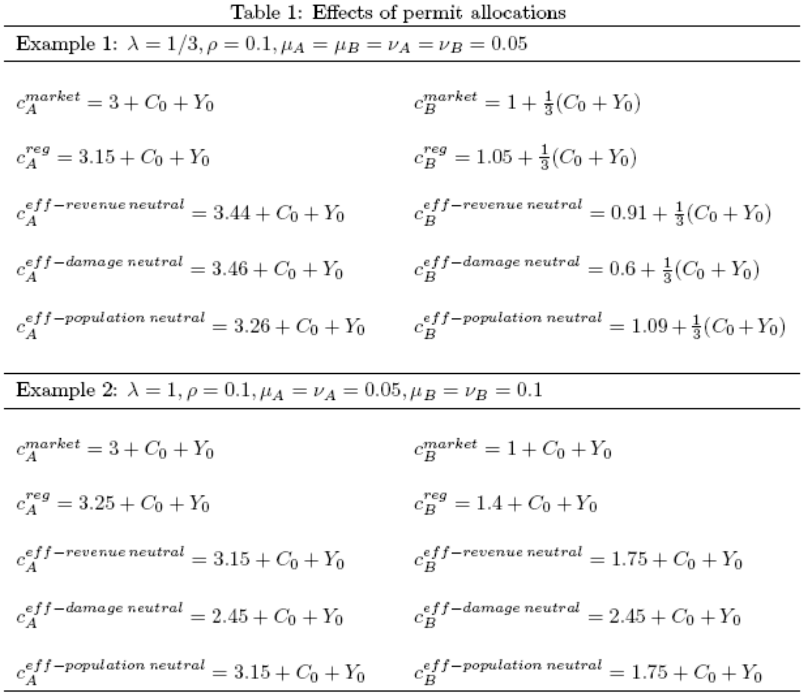

Table 1: Effects of permit allocations

Example 1: $\lambda = 1/3, \rho = 0.1, \mu_A = \mu_B = \nu_A = \nu_B = 0.05$	
$c_A^{market} = 3 + C_0 + Y_0$	$c_B^{market} = 1 + \frac{1}{3}(C_0 + Y_0)$
$c_A^{reg} = 3.15 + C_0 + Y_0$	$c_B^{reg} = 1.05 + \frac{1}{3}(C_0 + Y_0)$
$c_A^{eff-revenue\,neutral} = 3.44 + C_0 + Y_0$	$c_B^{eff-revenue\,neutral} = 0.91 + \frac{1}{3}(C_0 + Y_0)$
$c_A^{eff-damage\,neutral} = 3.46 + C_0 + Y_0$	$c_B^{eff-damage\,neutral} = 0.6 + \frac{1}{3}(C_0 + Y_0)$
$c_A^{eff-population\,neutral} = 3.26 + C_0 + Y_0$	$c_B^{eff-population\,neutral} = 1.09 + \frac{1}{3}(C_0 + Y_0)$
Example 2: $\lambda = 1, \rho = 0.1, \mu_A = \nu_A = 0.05, \mu_B = \nu_B = 0.1$	
$c_A^{market} = 3 + C_0 + Y_0$	$c_B^{market} = 1 + C_0 + Y_0$
$c_A^{reg} = 3.25 + C_0 + Y_0$	$c_B^{reg} = 1.4 + C_0 + Y_0$
$c_A^{eff-revenue\,neutral} = 3.15 + C_0 + Y_0$	$c_B^{eff-revenue\,neutral} = 1.75 + C_0 + Y_0$
$c_A^{eff-damage\,neutral} = 2.45 + C_0 + Y_0$	$c_B^{eff-damage\,neutral} = 2.45 + C_0 + Y_0$
$c_A^{eff-population\,neutral} = 3.15 + C_0 + Y_0$	$c_B^{eff-population\,neutral} = 1.75 + C_0 + Y_0$

The intuition behind the outcome in example 1 is straightforward. The rich countries may have large emissions, but they are also likely to be efficient producers (they have gained this energy efficiency partly through past learning-by-doing which itself involved emissions). Hence, it becomes efficient to locate production in the rich countries, and revenue neutrality means that there is no compensation to the rest of the world, as long as the rich-country emissions do not exceed the efficient level. In fact, revenue neutrality means that one can have the paradoxical outcome in which a poor region that has low emissions and inflicts little damage is required to compensate the rich simply because it may have failed to reduce its (low) emissions to the efficient level (which is even lower because the region is poor).

Example 1 assumes symmetry in damages. The benefits to the poor from reducing emissions increase if the damages fall more heavily on the poor. This is illustrated by example 2 which assumes symmetry in productivity ($\lambda = 1$)

but differences in damages ($\mu_A < \mu_B, \nu_A < \nu_B$). The example is calibrated to give the same relative consumption as example 1 in the laissez-faire case.

Example 2 $\lambda = 1, \rho = 0.1, \mu_A = \nu_A = 0.05, \mu_B = \nu_B = 0.1$

This parameter constellation implies that the income of the poor region increases in the efficient scenario relative to the scenario with regional efficiency and a fortiori relative to laissez faire (Table 1). Most of the benefits in this example accrue to the poor region.

4.3.2 Damage neutrality

Revenue neutrality can produce outcomes that are distinctly non-neutral. The underlying principle also seems peculiar: why not give the permits to the regions that suffer the damage rather than to those that inflict the damage? Following a rights-based line of reasoning, the net compensation from one region to the rest of the world could be calculated as the difference between (i) the estimated global damages from the region's emissions and (ii) the estimated damage from global emissions on the regions own net output.[21]

In a damage-neutral scheme the permits are allocated to the regions in proportion to the damages that they suffer. In terms of the two numerical examples, a damage neutral allocation implies the following net transfer from A to B:

$$\begin{aligned}\Pi &= p^{permit}[E_A - \frac{\mu_A + \nu_A}{\mu_A + \nu_A + \lambda(\mu_B + \nu_B)}(E_A + E_B)] \\ &= \lambda(\mu_B + \nu_B)E_A - (\mu_A + \nu_A)E_B \qquad (50)\end{aligned}$$

These damage neutral transfers benefit the poor region when the parameters are as in example 2 (see Table 1). With the parameters from example 1, however, the poor region does worse than under revenue neutrality (Table 1). This deterioration of the outcome for the poor region illustrates an important point: the fairness of a damage neutral allocation depends on the calculation of the damages. The allocation can be very unfair if market prices and willingness to pay are used to estimate damages. Suppose for instance that (i) the only damages are loss of life, (ii) the same number of lives is lost in each of two regions, and (iii) the regions produce roughly the same level of emissions. Under these circumstances, the poor region will be required to compensate the rich since lives are valued more highly in the rich region.

4.3.3 Population neutrality

As a parallel to Nordhaus and Boyer's use of population weights in the calculation of equity-weighted damages, a population-neutral allocation of permits distribute the permits in proportion to population.[22] In our simple model, if the A and B regions have the same size population, transfers based on this principle

---

[21] Damage-neutrality corresponds to the 'compensation' case in Anthoff and Tol (2010).

[22] For advocacy and discussion of 'population neutrality', see Narain and Riddle (2007).

benefit the poor when the parameters are as in example 1; using example-2 parameters, however, the poor do no better than under revenue neutrality (Table 1).

4.4 Discussion

The numerical examples in this section consider three different permit allocations. All three allocations can be considered 'neutral' in some sense.[23] Their implications, however, are very different. The examples are stylized but they serve to illustrate why efficient allocations may fail to produce Pareto improvements, even when paired with seemingly reasonable principles of permit allocation.

The examples point to a general issue. There is a tension in much of the economic literature on climate change between utilitarian notions and an emphasis on 'efficiency' and Pareto-optimality. Efficient policies may produce a welfare loss, from a utilitarian perspective, if they hurt the poor. Conversely, welfare gains can be obtained if – starting from an efficient solution with inequality – the poor regions are allowed to increase their emissions E_B with a concomitant reduction in rich-region emissions E_A. The reason is obvious: this reallocation of emissions redistributes income towards the poor who have a high marginal utility, and if the initial allocation is efficient, the first-order welfare gain dominates the second-order efficiency loss. From a welfare perspective, an inefficient outcome can be better than many efficient solutions.

Inefficient reallocations of emissions may not be the best way to implement a welfare enhancing redistribution of income. A standard economic argument suggests that if redistribution is desired, it should be implemented without creating unnecessary distortions. There is something disingenuous, however, about an approach that (i) insists on mitigation efficiency, whatever the distributional consequences, (ii) argues that compensation must also be done efficiently, but (iii) fails to provide a mechanism to ensure that compensation will in fact be made and (iv) introduces revenue-neutral allocations which cannot be justified on efficiency grounds and which (almost certainly) are distributionally regressive.

The fact that compensation payments from the rich to the poor could potentially produce a Pareto improvement is largely irrelevant. As argued by Sen (2000),

> There is a real motivational tension in the use of the logic of compensation for reading social welfare. If compensations are actually paid, then of course we do not need the compensation criterion, since the actual outcome already includes the paid compensations and can be judged without reference to compensation tests.... On

---

[23] Another option, founded in the language of the UN Framework Convention on Climate Change, is to allocate rights across nations on the basis of the two principles of responsibility and capacity; see the 'greenhouse development rights' proposal by Baer, et al (2008) for an example translating these two principles into an operational plan.

> the other hand, if compensations are not paid, it is not at all clear in what sense it can be said that this is a social improvement.... The compensation tests are either redundant or unconvincing (p. 947).

5 Conclusion

It is sometimes suggested that the science behind global warming may be weak but that the economics of the integrated assessment models is well-established and sound. We are not in position to evaluate the science but well-established as it may be, the economics is questionable.

The descriptive representative-agent approach is not value free. It has an intrinsic regressive bias, and this bias also has implications for the calculations of 'optimal emissions'. The damages of climate change are expected to be relatively concentrated in poor regions while the benefits from continued greenhouse gas emissions accrue more strongly to richer regions. As a result, the maintenance of standards of living in the rich areas is overemphasized at the expense of environmental degradation. The policy that is best for the representative agent will impose relatively lower utility costs on rich regions of world than would be justified by evaluations that are sensitive to distributional considerations.

There are no objective, value-free answers to normative questions that involve distributional conflicts. Any attempt to derive an 'optimal' amount of emissions is contingent on some underlying – implicit or explicit – value judgment. The descriptive representative-agent approach tries to avoid judgments of this kind. But not wanting to take sides easily leads to a *de facto* siding with the rich. Regressive biases are introduced into the IAMs through the use of descriptive representative agents, the reduction of consumption bundles to a 'generalized consumption good', and the allocation of emission permits.

Appendix: Derivation of equation (24)

The pre-policy solution has $q_{2B} = \bar{q}$ and $q_{3B} = (1-\alpha)\bar{q}_3$. Thus, the policy problem in this case is to maximize $U^A = q_1^\beta q_{3A}^{1-\beta}$ subject to the constraints

$$q_1 + q_2 = 2\bar{q} \tag{A.1}$$

$$q_{3A} + q_{3B} = \bar{q}_3 \tag{A.2}$$

$$U^B = q_2^\beta q_{3B}^{1-\beta} = \bar{q}^\beta((1-\alpha)\bar{q}_3)^{1-\beta} \tag{A.3}$$

Substituting (51) and (52) in (53) the problem can be re-written as

$$\max q_1^\beta q_{3A}^{1-\beta} \tag{A.4}$$

$$s.t \tag{A.5}$$

$$(2\bar{q} - q_1)^\beta(\bar{q}_3 - q_{3A})^{1-\beta} = \bar{q}^\beta((1-\alpha)\bar{q}_3)^{1-\beta}$$

The Lagrange function becomes

$$L = q_1^{\beta} q_{3A}^{1-\beta} + \theta[(2\bar{q} - q_1)^{\beta}(\bar{q}_3 - q_{3A})^{1-\beta} - \bar{q}^{\beta}((1-\alpha)\bar{q}_3)^{1-\beta}] \tag{A.6}$$

and the first-order conditions with respect to q_1 and q_{3A} imply that

$$\frac{q_1}{q_{3A}} = \frac{2\bar{q} - q_1}{\bar{q}_3 - q_{3A}} (= \frac{q_2}{q_{3B}}) \tag{A.7}$$

This equality between consumption ratios for the two types of agents – which follows from the symmetry of their utility functions – implies that

$$\frac{q_2}{2\bar{q}} = \frac{q_{3B}}{\bar{q}_3} \tag{A.8}$$

Using γ to denote the common value of these ratios, the constraint (A.3) can be written

$$\gamma(2\bar{q})^{\beta}\bar{q}_3^{1-\beta} = \bar{q}^{\beta}((1-\alpha)\bar{q}_3)^{1-\beta} \tag{A.9}$$

Hence,

$$\gamma 2^{\beta} = (1-\alpha)^{1-\beta} \tag{A.10}$$

and

$$\frac{q_2}{q_1} = \frac{\gamma}{1-\gamma} = \frac{2^{-\beta}(1-\alpha)^{1-\beta}}{1 - 2^{-\beta}(1-\alpha)^{1-\beta}} = \frac{[2(1-\alpha)]^{1-\beta}}{2 - [2(1-\alpha)]^{1-\beta}} \tag{A.11}$$

References

[1] Ackerman, F. and Heinzerling, L., 2005. *Priceless: On Knowing the Price of Everything and the Value of Nothing*, The New Press, New York.

[2] Ackerman, F., Stanton, E., and Bueno, R., 2010. “CRED: A new model of climate and development”, Stockholm Environment Institute Working Paper WP-US-1003.

[3] Anthoff, D., Hepburn, C. and.Tol, R.S.J., 2009."Equity weighting and the marginal damage costs of climate change". *Ecological Economics*, 68, pp. 836-849.

[4] Anthoff, D. and.Tol, R.S.J., 2010."On international equity weights and national decision making on climate change".*Journal of Environmental Economics and Management*, 60, pp. 14-20.

[5] Azar, C. and Sterner, T., 1996. "Discounting and distributional considerations in the context of global warming".*Ecological Economics*, 19, 169-184.

[6] Baer, P., Athanasiu, T. and Kartha, S., 2008. “The greenhouse development rights framework”, G-24 policy brief No. 38.

[7] Baum, S., 2009. “Description, prescription and the choice of discount rates”, *Ecological Economics*, Volume 69(1), 197-205.

[8] Blanchard, O.J., 2008. “The state of macro”, NBER working paper 14259, http://www.nber.org/papers/w14259.

[9] Brenner, M., Riddle, M. and Boyce, J., 2007.“A Chinese sky trust? Distributional impacts of carbon charges and recycling in China”, *Energy Policy*, Volume 35(3), pp. 1771-1784.

[10] Chichilnisky, G., 1996.“An axiomatic approach to sustainable development”, *Social Choice and Welfare*, Volume 13, 231-257.

[11] Chichilnisky, G. and Heal, G., 1993. “Who should abate carbon emissions? An international viewpoint”, NBER Working paper 4425, http://www.nber.org/papers/w4425.

[12] Dasgupta, P., 2011. "The ethics of intergenerational distribution: reply and response to John E. Roemer". *Environmental and Resource Economics*, 50 (4), 475-493.

[13] Davis, L. and Skott, P., 2012. “Positional goods, climate change and the social returns to investment”, forthcoming in a volume edited by A. Rezai, T. Michl and L. Taylor, Routledge.

[14] Debreu, G., 1974. “Excess demand functions”, *Journal of Mathematical Economics*, Volume 1(1), 15-21.

[15] Hoel, M. and Sterner, T., 2007. “Discounting and relative prices”, *Climatic Change*, Volume 84, 265-280.

[16] Intergovernmental Panel on Climate Change, 1996. “Climate Change 1995: Economic and Social Dimensions of Climate Change”, contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change.

[17] Intergovernmental Panel on Climate Change, 2001. “Climate Change 2001: Impacts, Adaptation and Vulnerability: Summary for Policymakers”, approved by Intergovernmental Panel on Climate Change Working Group II in Geneva, 13-16 February.

[18] Kirman, A., 1992. “Who or what does the representative individual represent?” *The Journal of Economic Perspectives*, Volume 6(2), 117-136.

[19] Mantel, R., 1976. “Homothetic preferences and community excess demand functions”, *Journal of Economic Theory*, Volume 12(2), 197-201.

[20] Narain, S. and Riddle, M., 2007. “Greenhouse justice: an entitlement framework for managing the global atmospheric commons”, in *Reclaiming Nature: Environmental Justice and Ecological Restoration*, ed. J. Boyce, S. Narain, and E. Stanton. Anthem Press, London.

[21] Nordhaus, W.D., 1992. “An Optimal Transition Path for Controlling Greenhouse Gases”, *Science*, Volume 258, 1315-1319.

[22] Nordhaus, W.D., 1994.*Managing the Global Commons: The Economics of Climate Change*. Cambridge, MA: MIT Press.

[23] Nordhaus, W.D., 2008. *A Question of Balance: Weighing the Options on Global Warming*, Yale University Press, New Haven.

[24] Nordhaus, W.D. and Boyer, J., 2000.. *Warming the World: Economic Models of Global Warming,* MIT Press, Cambridge.

[25] Rezai, A., Foley, D. and Taylor, L., 2011.“Global Warming and Economic Externalities”, *Economic Theory* forthcoming (DOI 10.1007/s00199-010-0592-4)

[26] Roemer, J.E., 2011. "The ethics of distribution in a warming planet", *Environmental and Resource Economics*, 48(3), 363-390..

[27] Sen, A., 2000. “The discipline of cost-benefit analysis”, *The Journal of Legal Studies*, University of Chicago Press, Chicago.

[28] Sonnenschein, H., 1972. “Market excess demand functions”, Volume 40(3), 549-563.

[29] Stanton, E., 2010.“Negishi welfare weights in integrated assessment models: the mathematics of global inequality” *Climatic Change*,

[30] Stern, N., 2006. *The Economics of Climate Change: The Stern Review*. Cambridge University Press, Cambridge. Online at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_climate_change/sternreview_index.cfm.

[31] Stern, N., 2008. "The Economics of Climate Change". *American Economic Review: Papers & Proceedings*, 98:2, 1–37

[32] Tol, R., 1995. “The damage costs of climate change–toward more comprehensive calculations”, *Environmental and Resource Economics*, 5, 353-374.

[33] Tol, R., 2002. “Estimates of the damage costs of climate change - part II: dynamic estimates”. *Environmental and Resource Economics*, 21, 136-160.

[34] Weitzman, M.L., 2007."A Review of The Stern Review on the Economics of Climate Change". *Journal of Economic Literature,* Vol. XLV (September), 703–724.

[35] Weitzman, M.L., 2009. "On modeling and interpreting the economics of catastrophic climate change" *Review of Economics and Statistics*, 91(1), 1-19.

[36] Woodford, M, 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy.* Princeton University Press, Princeton.