A Mechanism for the Fair Division of Climate Change Protection Burdens

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1 Introduction

Nowhere has the importance of fairness concerns for international environmental politics become more apparent than in the negotiations of a regime on the protection of the climate system. On the occasion of the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, the UN Framework Convention on Climate Change (UNFCCC) was adopted and ratified up until October 1998 by 176 states. The principle objective of the Convention is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Article 2).

Despite its lack of specific prescriptions how to achieve this objective, the Climate Convention provides some general principles on which climate change protection strategies should be based. In particular, Article 3 states that "Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities" (para 1). Furthermore, "policies and measures to deal with climate

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change should be cost-effective so as to ensure global benefits at the lowest possible cost" (para 3).

Economists have a fairly precise understanding of 'cost-effectiveness,' even though one should note carefully that this need not be shared by all signatories of the Climate Convention. On the other hand, the meaning of 'equity' is much more controversial, both inside and outside the economic profession.

Indeed, arguments based on equity considerations are generally treated with great suspicion. Two popular reservations, which are also common among economists, go as follows: "Equity is merely a word that hypocritical people use to cloak self-interest"; and "it is so hopelessly subjective that it cannot be analyzed scientifically" (Young 1994, xi). In many respects, negotiations about climate change seem to confirm those reservations because nearly every actor – ranging from low lying island states to oil exporters – has defended its policy proposal as the truly equitable one.

In the Kyoto Protocol, the so-called Annex I countries (the group of industrialized countries including the economies in transition) finally agreed to reduce their 1990 emissions of greenhouse gases by an average of 5.2 per cent until the period 2008-2012.[1] However, there exists a widespread consensus that much higher emission reductions will be required in the long run, and questions of burden sharing will receive increased attention on this way ahead. As Rose (1998, 1) has pointed out: "The hesitancy to make a major commitment to control greenhouse gases has often been ascribed to the lack of sufficient scientific information to support the global warming hypothesis. But future action may be less about solid evidence and more about stakeholders and perceptions of fairness."

Disputes about the participation of developing countries, referred to as non-Annex I countries in the context of climate change, do indeed hamper negotiations already now. For example, the Byrd-Hagel Resolution, passed 95 to 0 in the U.S. Senate in 1997, states that "the United States should not be a signatory to any protocol that excludes developing countries from legally binding commitments."[2] Although the USA have signed the Kyoto Protocol during the fourth Conference of the Parties (COP4) to the Climate Convention in Buenos Aires (November 1998), ratification will require approval by the U.S. Senate, which seems rather unlikely at the moment. But without ratification by the USA, coming into force of the Protocol moves into the distant future because it requires not only ratification by 55 Parties to the Convention, but also that those account for 55 per cent of Annex I

[1] There are some exceptions to the base year 1990 for economies in transition, in particular for Hungary (average of 1985–87), Poland and Slovakia (1988) and Romania (1989).

[2] The Byrd-Hagel Resolution, U.S. Senate, June 12^{th}1997, 105^{th} Congress, 1^{st} Session, Senate Resolution 98.

countries' emissions.

Developing countries on their part have argued that they carry only minor historical responsibility for the increase in global CO_2 concentrations. Therefore, industrialized countries should go ahead with climate protection measures. However, at least in the medium to long run the stabilization of greenhouse gas concentrations at a safe level will require quite substantial reductions also of emissions in developing countries.

How then should emission reduction burdens be allocated? In the following, I shall address this question from a normative point of view and try to put some substance on the notion of an equitable climate change policy – or, more generally, on the fair division of common property resources.[3]

Most studies on fair burden sharing in the climate change regime can be subsumed under two approaches (for a survey see Rose, Stevens, Edmonds, and Wise 1998). The first focuses on a 'fair initial allocation' of property rights to greenhouse gas emissions. These authors usually assume that property rights will then be traded internationally to achieve Pareto efficiency (for example Edmonds, Wise, and Barns 1995). Sometimes, mixed criteria have been proposed and it is also common to weigh them such that indicators expressing the status quo are emphasized initially, while those being perceived as more fair become increasingly important in the course of time. A much discussed example for this is a proposal by Cline (1992, 353) who uses GDP, historical emissions and population as criteria such that the latter receive more weight in the long run (see also Simonis 1996). Thereby, equity considerations are mixed with those of political feasibility.

The second class of studies focuses on a 'fair outcome' of climate protection strategies. A common criterion for this is the equalization of net cost per GDP (see Bohm and Larsen 1994). Another example is the requirement that developing countries should not be harmed by mitigation efforts (see Edmonds, Wise, and Barns 1995; Bohm 1997).

The approach adopted in the following, which is based on fair division theory, does not really fit into either of these two categories. Even though entitlements to the common property resource have to be defined in the first place, the main focus is on the fair division of the gains from their exchange, which arise from differences in marginal abatement cost across countries. A priori it is not obvious why the allocation of those gains should be governed by the market, as most of the writers on climate change seem to assume. In particular, it will be shown that the application of fairness

[3]There are, of course, other important equity issues raised by climate change, among them international equity in coping with the impacts of climate change, equity and social considerations within countries, equity in international processes, and equity among generations (IPCC 1996, 85; Tóth 1999).

criteria on the allocation of the gains from emissions trading can have as important implications for burden sharing in the climate change regime as the specification of the entitlements themselves.

Based on four general fair division criteria – individual rationality, envy-freeness, resource monotonicity, and population monotonicity – I will develop an allocation rule for emission reductions and associated costs. Through the restriction of the analysis to a limited class of utility function profiles and by allowing compensatory payments, I will avoid most of the inconsistency results generally found in the literature (for a survey see Moulin 1990). Although the empirical focus is on climate change, the proposed allocation rule is applicable to a much larger range of environmental problems. By framing them as problems of fair division of common property resources, a highly relevant field of application arises for the theory of fair division, which has until now largely been confined to theoretical contributions with very few applications to real world problems.

The paper is structured as follows. In Sections 2 and 3, I briefly discuss some prerequisites for the application of the theory of fair division, show its relevance for environmental problems and introduce the notation. In Section 4, the criterion of individual rationality and the stand alone utility are shown to constitute lower and upper bounds for fair division. This leads to the formulation of the WESA mechanism for the fair division of common property resources (Section 5). Next, I will analyze the consistency of the WESA mechanism with the criterion of envy-freeness (Section 6). The paper concludes with a quantitative application of the WESA mechanism to burden sharing in the emerging climate change regime (Section 7).

2 Fair Division Theory and Environmental Problems

Not only the formulation of fairness criteria is a normative decision, but also the choice of the perspective or starting position for their application involves some fundamental ethical judgments (see Wickström 1992), which are not captured by the criteria themselves and therefore deserve some discussion.

First, I shall treat the fair division of emission reductions of greenhouse gases and associated abatement costs as a *local* justice problem. I thereby assume that it can be analyzed in isolation from aspects of *social* justice like the global welfare distribution.[4] In contrast to this, some authors have explicitly argued that climate change protection strategies should be designed

[4] On the distinction between local and social justice see Young (1994).

such that they favor developing countries (for example Simonis 1996). I do not deny the legitimacy of such claims, and a welfarist approach would indeed offer some support for them. Nevertheless, in the present paper it is strictly distinguished whether the justification for monetary transfers rests on the injustice of the current global welfare distribution or on the characteristics of climate change. It should be noted, however, that ignoring superordinate aspects of social justice becomes questionable if the proposed solution for a local fair division problem significantly accentuates existing injustices.

Second, in concentrating exclusively on justice in efforts to limit polluting emissions, I abstract from other important ethical aspects, in particular from the negative impacts of environmental problems and associated risks. In some cases, emission reduction targets might actually be chosen such that no environmental damages occur. For example, the critical loads concept agreed to in the European regime to combat transboundary acidification seeks to reduce emissions to a level below which significant harmful effects on specified sensitive elements of the environment do not occur. However, in many cases there will be significant damages. My intention is not to deny the importance of justice in coping with those impacts, but I assume that this and other issues can be treated separately from the fair division of emission reductions and associated costs.

Third, I require that the allocation is fair in every period. This excludes situations where the unfair treatment of agents in one period is compensated by preferential treatment in other periods, although the issue of historical emission rights will be addressed briefly in the concluding remarks to this paper. Nevertheless, intertemporal equity trading might be reasonable if the transition from an unfair to a fair allocation involves a sharp increase in the efforts of some agents.

Finally, the application of fair division criteria requires the preceding specification of entitlements to a common property resource, for example to a particular service of the environment like the absorptive capacity for greenhouse gases. In inheritance problems, which are sometimes used to illustrate the theory of fair division, entitlements may indeed be exogenously given through the will of the deceased. However, for many other problems this is not the case and the specification of entitlements involves fundamental ethical judgments. Most of the results derived in this paper do not depend on the distribution of entitlements, but to put flesh on them in a particular fair division problem like climate change they have to be defined, of course.

In this respect, equal per capita entitlements, which correspond to the justice principle of 'equality of resources,' have received particular attention. This is especially so in the case of climate change, where the environment's absorptive capacity for greenhouse gases is often regarded as a global common, as it were 'manna fallen from heaven.' Accordingly, equal per capita entitlements is the proposal mentioned most often in the literature (see Bertram 1992; Kverndokk 1995). In fact, convergence towards equal per capita emission rights in the course of time was explicitly mentioned in an early draft of the Climate Convention, but later this provision was replaced by the weaker formulations of Article 3 para 1 as quoted on page 1 above (Beckerman and Pasek 1995, 408).

Some idea of equality has been the starting point of most theories of justice and historically it has guided the imagination and action of many people. As Tocqueville (1860) has put it: "The passion of mankind for equality is burning, unsatiable, eternal, invincible." And the Universal Declaration of Human Rights, adopted in 1948, states in its first article: "All human beings are born free and equal in dignity and rights." However, already Aristotle has restricted the force of equality in his 'formal principle of justice,' according to which "equals should be treated equally and unequals unequally, in proportion to relevant similarities and differences." Nevertheless, even here equal treatment is the starting point and unequal treatment requires the presence of relevant similarities and differences.

A first question that arises from the formal principle of justice is 'equality of what?' Indeed, the dispute whether to equalize resources or welfare, that is opportunities or outcomes, has a long tradition in social choice theory (Dworkin 1981a; Dworkin 1981b; Sen 1987; Roemer 1986). In this section, I will elaborate on the 'equality of resources' approach. However, it should be noted that an equal allocation of greenhouse gas entitlements is quite a different thing than the equal allocation of *all* resources as demanded by the advocates of resourcism. This means that the principle of equal resources is applied to a single commodity, while other resources are divided quite unequal, leading possibly to second best problems (Lipsey and Lancaster 1956).

The other question initiated by Aristotle's principle of justice concerns the presence of relevant similarities and differences, which would limit the appeal of an egalitarian allocation of emission entitlements. Obviously, quite substantial differences exist with respect to climate change. Most widely cited are the much lower income level in developing countries and the much higher emission level in industrialized countries, which would lead to considerable North-South transfers in the case of tradable equal per capita permits (see Grubb, Sebenius, Magalhaes, and Subak 1992). However, for a local fair division perspective those differences are not relevant because they relate to social welfare considerations, which are purposely excluded from the analysis in this paper.

Thus, within the local fair division framework I find it very hard to argue against an equal per capita allocation of entitlements. Some leeway for discussion remains, for example whether entitlements should relate to greenhouse gas emissions or rather to net emissions, which take countries' different endowment with biotic sinks (like forests) into account. Also the question whether to take account of historical emissions remains. But these are relatively minor issues compared to the choice of equal per capita entitlements as the ruling principle.

3 The Model and Notation

While it is sometimes helpful to have climate change as an empirical example in the back of one's head, the following setting is considerably more general. Many environmental problems arise from an overuse of ecosystems' natural absorptive capacity for a particular pollutant or class of pollutants. This capacity is assumed to be given exogenously by nationally or internationally agreed targets, independently of whether they are the result of a negotiation process, cost-benefit analysis, threshold effects in the environment or something else. Often, property rights are not defined and the absorptive capacity can be regarded as a continuously divisible common resource which has to be divided fairly among a group of agents.

If an agent does not use his full share of the absorptive capacity for pollutants in the 'business as usual' path without abatement measures, the marginal utility of a further increase of his share is zero so that there is satiation beyond a certain level of consumption of the common property resource. If all agents are satiated, the environmental problem does not exist.

Another issue is the feasibility of monetary compensations, which are excluded in most of the literature on fair division problems (for an exception see Moulin 1992). However, compensations become an increasingly common element of policies to tackle environmental problems. For example, in the international ozone regime developing countries are being compensated for their incremental costs of reducing the emissions of ozone depleting substances (see Biermann 1997).

Similarly, Article 17 of the Kyoto Protocol introduced for the first time a system of emissions trading at the international level. To take account of those political developments, I assume that compensatory payments are feasible via a single good (money), in which utility is linear. This representation of preferences by a quasilinear utility function can be justified by the assumption that the absorptive capacity is given exogenously, and each agent's demand for a share of it depends only on its relative price – that is whether, at the margin, compensatory payments are cheaper than the emission reductions required else – but not on the available income.

Finally, if more than one pollutant is responsible for the same environmental problem, it is assumed that these pollutants can be expressed in a common unit, which can also be used to define the environment's absorptive capacity for these pollutants. For example, it is common to express carbon dioxide, methane, CFCs and some other gases which have an effect on climate change in CO_2 equivalents, or respectively, their global warming potential. This leads to the following specification of the fair division problem.

In each period t, an infinitely divisible common property resource $\omega \in R^1_+$ has to be allocated among a set $N = \{1, ..., n\}$ agents, indexed by i.[5] Monetary compensation received (positive sign) or paid (negative sign) by agent i is denoted $m_i \in R^1$. Each agent i is characterized by a nonnegative entitlement ω_i to the common resource, where $\sum_{i \in N} \omega_i = \omega$, and by a continuous, monotone increasing and concave utility function defined on his consumption set in $R^1_+ \times R^1$, which consists of his share of the common property resource e_i and monetary compensations m_i. In particular, utility is strongly monotone increasing in monetary compensations, but as argued previously there exists a level e^s_i beyond which an agent i is satiated in the consumption of the common property resource, that is for all $i \in N : e_i \geq e^s_i \Rightarrow e_i \sim e^s_i$, assuming free disposal. Furthermore, preferences are additive separable between e_i and m_i and linear with respect to m_i. Accordingly, agent i's final utility in a period t is $u_i = u_i(e_i) + m_i$, and the set of all possible utility function profiles is denoted $U = \{u_1, u_2, \ldots, u_n\}$. Without loss of generality, I normalize $u_i(0) = 0$.

An allocation problem is a triple $(n, U, (\omega_i)_{i \in N})$, and an allocation criterion $F(n, U, (\omega_i)_{i \in N})$ is a correspondence that assigns each agent one or more vectors (e_i, m_i) such that $\sum_{i \in N} e_i \leq \omega$ and $\sum_{i \in N} m_i = 0$.

In applications to environmental problems, a particular share e_i of the common property resource, or its absorptive capacity respectively, entitles an agent i to emit pollutants in the size of this share. Accordingly, an agent's utility from e_i – his willingness to pay for e_i – are the additional abatement costs he would have to undergo without these pollution rights:

$$u_i(e_i) = \int_0^{e_i} -c'_i(e_i)\, de_i = c_i(0) - c_i(e_i), \tag{1}$$

where $c_i(e_i)$ is a decreasing convex function that gives agent i's minimum costs of reducing its emissions to e_i.

[5] As the possibility of intertemporal equity transfers has been excluded by requiring the allocation to be fair in every period, time indices t can be suppressed for ease of notation.

4 Upper and Lower Bounds for the Fair Division of Common Property Resources

Fair division theory takes entitlements to the common property resource as given and searches for an allocation mechanism which is compatible with different axiomatic fairness criteria. Hence, the approach does not explicitly look for the 'most equitable solution,' but successively excludes from the set of all feasible solutions the obviously inequitable ones. The solution set satisfying the individual fair division criteria is often large, but their intersection can be quite small. Indeed, a common problem is that no solution satisfying all desirable criteria simultaneously exists (Moulin 1990).

Turning to those criteria, an allocation is said to be Pareto efficient, if no individual can be made better off without making another individual worse off. Sometimes this has been termed the criterion of unanimity. This already shows that Pareto efficiency is not more than a smallest common denominator, the only normative argument on which there exists widespread agreement, at least within the economic profession.

If lump-sum transfers are feasible, Pareto efficiency is equivalent to the maximization of aggregated utility.

Definition 1 *With transferable utility an allocation* $((e_i)_{i\in N}, (m_i)_{i\in N})$ *is Pareto efficient if there exists no* $((e'_i)_{i\in N}, (m'_i)_{i\in N})$ *such that*

$$\sum_{i\in N} (u_i(e'_i) + m'_i) > \sum_{i\in N} (u_i(e_i) + m_i) \, . \qquad (2)$$

Accordingly, emission reductions have to be allocated such that corresponding marginal abatement cost are equalized in all countries. This is a far reaching result because it determines the allocation of emission reductions. However, it does not say who should bear the costs of them. After the cake has been maximized, it now has to be shared – as equitable as possible.

The first axiom of fair division is individual rationality. This principle has been introduced by Steinhaus (1948) and expresses the idea that each agent should be guaranteed at least the utility from consuming his fair share, that is his entitlement to a common property resource. If there are overall gains from a reallocation of the initial shares, this implies that everyone should be weakly better off after the reallocation has taken place. Thus, individual rationality puts a lower bound on each agent's utility.

Definition 2 *With transferable utility an allocation criterion* F *is individual rational if*

$$\text{for all}\, \omega \in R^1_+, \text{all}\, i \in N : u_i(e_i) + m_i \geq u_i(\omega_i). \qquad (3)$$

The next two axioms of resource monotonicity (Roemer 1986; Moulin and Thomson 1988) and population monotonicity (Thomson 1983; Chichilnisky and Thomson 1987) are of more recent origin, but they have received considerable attention, especially as a critique of the Walrasian mechanism to solve fair division problems. Both axioms set limits how agents' individual utilities should respond to changes of the allocation problem with respect to the size of the common property resource and to the number of claimants.

Resource monotonicity requires that if the common resource to be divided grows, each agent should be at least as well off as from the fair division of the smaller resource.

Definition 3 *With transferable utility an allocation criterion F is resource monotonic if*

$$\text{for all } \omega, \omega' \in R^1_+, \text{all } i \in N : \omega' \geq \omega \Rightarrow u_i(e'_i) + m'_i \geq u_i(e_i) + m_i. \qquad (4)$$

For climate change and other environmental problems, this criterion may indeed have high practical relevance. Our best assessment of the environment's absorptive capacity is only preliminary and likely to change as scientific knowledge improves. Furthermore, reduction targets will often be approached stepwise. In both cases, the size of the common resource to be divided changes and due to the commonality of ownership this should affect the welfare of all agents in the same direction.

The criterion of population monotonicity states that if the number of agents entitled to the common resource increases, no agent should be better off than before.

Definition 4 *With transferable utility an allocation criterion F is population monotonic if*

$$\text{for all } \omega \in R^1_+, \text{all } i \in N : N \subset N' \Rightarrow u_i(e'_i) + m'_i \leq u_i(e_i) + m_i. \qquad (5)$$

Similar to resource monotonicity, the criterion of population monotonicity is based on the ethical argument that common ownership implies a minimum degree of solidarity, namely that everyone should contribute to satisfy the legitimate claims of newcomers.

The monotonicity axioms can be used to deduce the stand alone utility $u_i(\omega)$, that is an agent's utility from the consumption of the whole common resource, as an upper bound on the utility an agent i may receive from fair division. This stand alone criterion is more commonly used for cost sharing problems, but it has been applied by Moulin (1992) to the fair division of unproduced commodities. Obviously, the bite of the stand alone criterion for the latter type of problems depends on the assumption that monetary compensations are feasible, because otherwise no agent could do better than using the whole resource.

Lemma 1 *For any allocation mechanism for the fair division of one good and monetary compensations which is either population monotonic or resource monotonic or both, there is no* $i \in N : u_i(e_i) + m_i \geq u_i(\omega)$*, where* $u_i(\omega)$ *is called agent* i*'s stand alone utility.*

Proof. If there is only one agent, he receives his stand alone utility by definition. Population monotonicity requires that the utility of this agent does not increase as the population increases, because the same common resource has to be divided among more agents. This implies that he may not receive more than his stand alone utility. Similarly, assume that in contradiction to Lemma 1 there would be an agent who receives more than his stand alone utility. By resource monotonicity, this agent's utility must not decrease as the common resource increases. With satiation in e_i, this step can be repeated until all agents are indifferent towards a further increase in the consumption of e_i and, therefore, receive exactly their stand alone utility, a contradiction.[6] □

Accordingly, the criteria of resource and population monotonicity require that no agent should be better off when the environment's absorptive capacity for polluting emissions is a scarce resource compared to the case where the environmental problem does not exist. Moulin (1992, 1333) justifies the stand alone test by arguing that "fair division conveys the idea of no subsidization: the presence of other agents who are willing to pay higher monetary transfers than me for consuming the resources should not turn to my advantage." This argument seems particularly justified if the willingness to pay higher monetary transfers is related to efforts to reduce a problem which affects all agents – like climate change. In this context, one could state the stand alone test bluntly as: 'no-one should benefit from the emission abatement burdens of others,' reflecting the solidarity ideal behind the monotonicity axioms.

Combining the criterion of individual rationality as a lower bound, the stand alone utility as an upper bound and Pareto efficiency determines a unique allocation for the group of agents whose entitlements ω_i are higher than their satiation level e_i^s.

[6] Obviously, the converse of Lemma 1 is not true: If no agent is better off than with his stand alone utility, this does neither imply population nor resource monotonicity. This follows immediately from the fact that the stand alone criterion only sets an upper bound to each agent's utility, but says nothing about allocations below this upper bound.

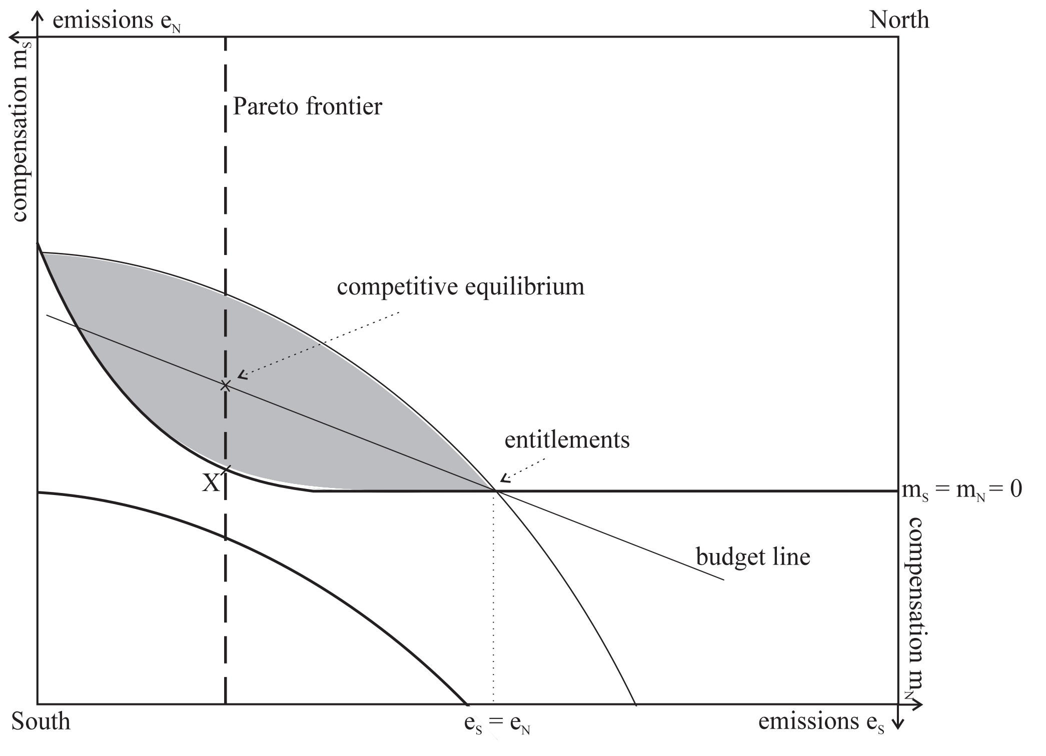

Figure 1: An Edgeworth box representation of fair division

Proposition 1 *Let $D = \{i \in N : \omega_i \geq e_i^s\}$. An allocation satisfying individual rationality and population and/or resource monotonicity for agents $i \in D$ gives them exactly their stand alone utility.*

Proof. By definition of set D, we have $u_i(\omega_i) = u_i(\omega)$ for all $i \in D$ and therefore individual rationality establishes the stand alone value as a lower utility bound. Similarly, by Lemma 1 population and/or resource monotonicity establish the stand alone value as an upper utility bound. □

Figure 1 depicts this in an Edgeworth box. Emissions and compensations for the agent $i \in D$, called 'South,' are measured in the usual way with the southwest corner as the origin. In contrast, emissions and compensations for the other agent, called 'North,' are measured using the northeast corner as the origin. The two curves in the middle of the figure give the agents' indifference curves at the initial equal allocation of emission entitlements ($e_S = e_N$). At this point, there are no transfers of compensatory payments ($m_S = m_N = 0$), and South' indifference curve is flat because it is satiated given its entitlements.

The Pareto efficient solutions are given by the points where the indifference curves of the two agents have the same slope, and due to the assumption of quasilinear utility functions this is a straight vertical line. The shaded area characterizes the set of solutions that are individual rational for both agents. Finally, the two bold curves give the stand alone utilities, which must not be exceeded. Therefore, the only solution satisfying simultaneously the criteria of Pareto efficiency, individual rationality and the stand alone test is point X. Compared to the competitive equilibrium from equal entitlements, South receives less transfer payments.

In applications to environmental problems, the set D may comprise a substantial number of agents. For example, if developing countries were included in a future protocol on the reduction of greenhouse gases, for many of them equal per capita entitlements would be higher than their emissions in the reference path without abatement, unless very strict overall reduction targets were chosen. This is the situation depicted in Figure 1. Nevertheless, for $n \geq 2$ it remains to define a general allocation rule for agents that do not belong to set D.

5 The Walrasian Mechanism with the Stand Alone Upper Bound

Often, the Walrasian mechanism, that is an assignment of property rights in proportion to each agent's entitlements and a subsequent allocation via competitive markets, has been advocated for fair division problems (see Young 1994). Indeed, many writers on climate change have restricted the discussion of fairness concerns to the initial distribution of emission permits, which are then traded on competitive markets. Even though the fairness properties of the Walrasian mechanism have not been discussed in those contributions, it has a number of attractive features. In particular, with quasilinear preferences the Walrasian mechanism has not only a unique efficient solution, but it is also individual rational and satisfies the criterion of envy-freeness, which will be discussed in Section 6.

However, the Walrasian mechanism has been criticized because on the general domain of continuous and monotone utility functions it is neither resource nor population monotonic (see Moulin 1990). This is the case even if one restricts attention to the domain of two-good allocation problems with quasilinear preferences.

Proposition 2 *In economies with quasilinear preferences, the Walrasian mechanism operated from equal division produces a unique and stable Pareto efficient equilibrium which is individual rational and envy-free. However, it* *may violate population and resource monotonicity and the stand alone criterion.*

Proof. For uniqueness, stability and Pareto efficiency see Mas-Colell, Whinston, and Green (1995). Individual rationality and envy-freeness are proven in Foley (1967). Violation of population and resource monotonicity and the stand alone criterion follows straightforwardly from Proposition 1 because members of set D could trade entitlements above their satiation level for a positive price if the common resource is scarce (see also Figure 1). □

Other well-known fair division mechanisms like egalitarian equivalence suffer from similar deficiencies (Moulin 1990). In this paper, I therefore introduce an alternative fair division mechanism, which takes the Walrasian mechanism as the starting point but supplements it by the stand alone utility as an upper bound.

Definition 5 *Let the WESA mechanism (WESA = Walrasian Mechanism with the Stand Alone upper bound) be defined as follows: For all $\omega \in R^1_+$, if compensatory payments m_i are feasible, every $i \in N$ should receive the bundle $(e^*_i, m_i(e^*_i))$ from the fair division of a common property resource ω, where e^*_i, p^* denote quantities and prices in the Walrasian equilibrium and the allocation rule for monetary compensations is given as*

$$m_i(e^*_i) = \min\left\{u_i(\omega) - u_i(e^*_i), (\omega_i - e^*_i)p^* + \frac{\sum_{i \in A}((\omega_i - e^*_i)p^* - (u_i(\omega) - u_i(e^*_i)))}{|N \setminus A|}\right\} \quad (6)$$

where $A = \{i \in N : m_i(e^*_i) = u_i(\omega) - u_i(e^*_i)\}$.[7]

Accordingly, the WESA mechanism divides the common resource efficiently, and with respect to compensations it distinguishes between two types of agents:

- members of set A receive compensations such that they are exactly as well off as with their stand alone utility, and
- members of set $N \setminus A$ receive (or pay) compensations as in the Walrasian equilibrium ($(\omega_i - e^*_i)p^*$) plus an equal per capita share of the difference between the compensations that members of set A would receive in the Walrasian equilibrium and the compensation they actually receive to reach their stand alone utility level.

[7] $|N \setminus A|$ denotes the cardinality of the set $N \setminus A$.

The choice of an equal per capita reallocation of compensations above the stand alone utility can be justified by arguing that the funds to be reallocated arise from a free service of members of A, from which equal agents should benefit equally. In the next section, I will show that this equal per capita reallocation of excess-compensations can also be derived from the criterion of envy-freeness.

It is straightforward to show that the WESA mechanism satisfies individual rationality and the stand alone test for all agents: The stand alone criterion has been integrated as an upper bound in the formulation of the WESA mechanism. Similarly, individual rationality follows immediately from the fact that all $i \in N$ get either their stand alone utility or are weakly better off than in the Walrasian equilibrium. In the following section, I shall introduce the last fair division criterion of envy-freeness and explore its relation to the WESA mechanism.

6 The No-Envy Criterion

An allocation from equal entitlements to a common resource is called envy-free if no agent prefers another's allocation to his own.[8] This describes the ideal that equally entitled agents should have equal liberty to choose from the same budget set. An early version of envy-freeness has been introduced by Tinbergen (1946), but its development is usually credited to Foley (1967) (see also Varian 1974 and Baumol 1986). The popularity of this criterion among economists has often been regarded as very high and Arnsperger (1994, 155) even states that "envy-freeness has become the first and foremost 'distributive companion' to the aggregative requirement of Pareto efficiency in the literature on normative economics."

Definition 6 *In an exchange economy with k goods, an allocation criterion F is envy-free from equal entitlements if*

$$\text{for all } \omega \in R_+^k, \text{all pairs of } i, j \in N : u_i(\mathbf{e}_i) \geq u_i(\mathbf{e}_j), \tag{7}$$

where $\mathbf{e}_i$ is a vector of k goods.

The no-envy criterion has rarely been formulated for the specific case of exchange economies in which agents are characterized by quasilinear utility

[8]The appropriateness of the name 'envy-freeness' is disputed and some authors prefer to call it the principle of equity. However, the term 'equity' is more commonly used in a broader sense, especially in the non-economic literature. See Kolm (1996) for a recent discussion of the terminology and the philosophical justification of this principle.

functions. This is not surprising because the general formulation for envy-freeness from equal entitlements is independent of whether utility is linear in one good. Nevertheless, if one wants to make the linearity of utility in money explicit, this could be easily done as follows: Let there be a bundle (ω, m) consisting of one good and money to be divided fairly. Envy-freeness from equal entitlements (to ω *and* m) requires that no agent prefers another's share of the common resource and money to his own, that is $u_i(e_i) + m_i \geq u_i(e_j) + m_j$ for all pairs of $i, j \in N$ (see Moulin 1995).

However, it would be wrong to simply apply this formulation to fair division problems for which monetary compensations are feasible. To see why, take the set D of agents whose entitlements are higher than their emissions without abatement measures. If D contains at least two different agents who receive exactly their stand alone utility – as has been shown to be the only solution satisfying individual rationality, resource monotonicity and population monotonicity – then they would envy each other according to the formulation of envy-freeness in the previous paragraph.

This can be seen from Figure 2, which depicts abatement costs $c_i(e_i)$ for two agents $i \in D$ as a function of emissions. By definition, abatement costs are zero for members of set D at the point where emissions equal their entitlement ω_i. Efficiency requires that marginal abatement cost are equalized, giving the agents e_1 and e_2 respectively. Furthermore, following the solution in Proposition 1, all $i \in D$ are fully compensated for their abatement costs, hence $m_i = c_i(e_i)$. Therefore, in the situation depicted agent 1 receives less of every good and would envy agent 2 according to the above formulation of the no-envy criterion.[9]

However, intuitively this result is not very appealing. If, as suggested above, members of set D are exactly compensated for their abatement costs, Figure 2 can be interpreted such that the ordinate gives the units of the numeraire good and the cost curves are the indifference curves that secure both agents the utility level of consuming their entitlements. Viewed from this perspective, the fact that some agents receive more of every good is a necessary requirement for equal treatment, in the sense that all $i \in D$ can secure their stand alone utility levels of the reference situation.

More precisely, in the present fair division problem m_i is not simply a second good in which utility is linear and that otherwise has to be divided fairly together with the common resource ω. It rather serves as compensation to assure that the efficient allocation of the other goods can be separated from

[9] An allocation where one agent receives more of everything than another agent is sometimes called *transparently unequal* (Young 1994). Obviously, any transparently unequal allocation from equal entitlements produces envy.

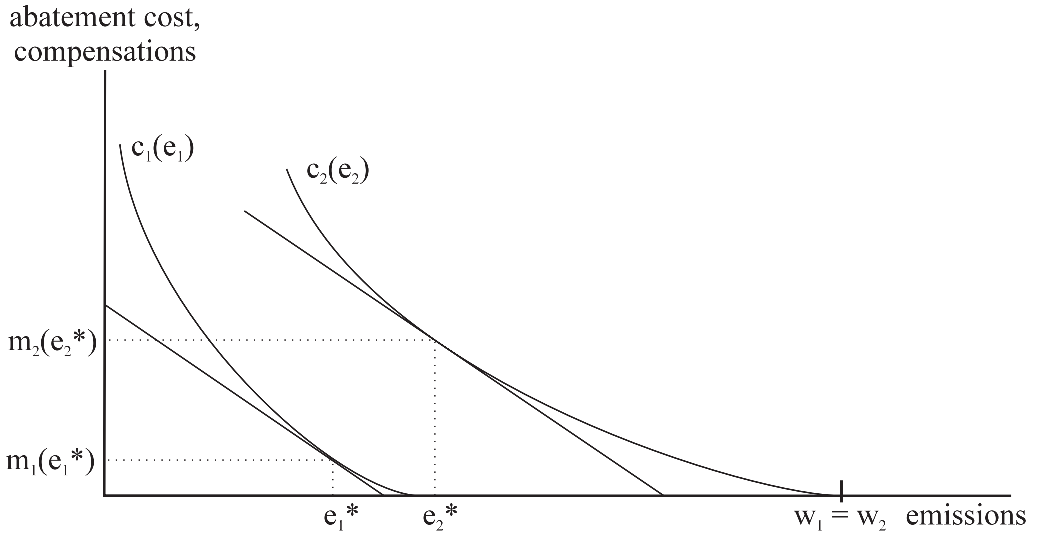

Figure 2: Abatement costs and compensations for low emission countries

fairness issues. Accordingly, the purpose of transfers m_i is to compensate agents for utility changes relative to some reference point such that the allocation of $(e_i^*, m_i(e_i^*))$ is not only efficient but also fair for all agents. Therefore, in general agents do *not* have equal entitlements to monetary compensations, and the no-envy criterion has to be adjusted accordingly.

Definition 7 *Let agents $i \in N$ have equal entitlements to a common resource and monetary compensations m_i are feasible. An allocation criterion F is envy-free with respect to a compensation rule if no agent prefers the bundle consisting of another agent's share of the common resource and the compensation he would receive or pay if he had the share of this other agent to his own bundle, that is if*

$$\text{for all } \omega \in R^1_+, \text{all pairs of } i, j \in N : u_i(e_i) + m_i(e_i) \geq u_i(e_j) + m_i(e_j), \quad (8)$$

where $m_i(e_i)$ is an allocation rule which determines the monetary compensations an agent i would receive with a share e_i of the common resource.

Thus, the criterion of envy-freeness with monetary compensations has two components: the allocation of the common resource – in which agents are assumed to have equal entitlements – and the allocation of monetary compensations, which is prescribed by a particular rule $m_i(e_i)$.

Accordingly, compliance with the no-envy criterion depends on the allocation rule $m_i(e_i)$ for monetary compensations. For example, let there be two fair division problems (one good and money) and a pair of agents $i, j \in N$.

Agent i receives the same final allocation (e_i, m_i) for both problems and so does agent j. If this final allocation is based on different rules for the allocation of monetary compensations, then it is possible that i envies j in one of the problems but not in the other. Thereby, the no-envy criterion narrows the set of just allocation rules for monetary compensations, as will be shown below.

Based on this formulation of envy-freeness with monetary compensations, we come to the central result of this paper:

Proposition 3 *The WESA mechanism for the fair division of one good (with equal entitlements) and monetary compensations (in which utility is linear) produces a unique and stable Pareto efficient equilibrium which is individual rational, envy-free with compensations, and satisfies the stand alone criterion.*

Proof. Pareto efficiency, stability, uniqueness, individual rationality, and the stand alone criterion have already been proved above so that it remains to analyze envy-freeness. As this entails pairwise comparisons and the WESA mechanism distinguishes between two types of agents, this has to be done for pairs of $i, j \in A$, pairs of $i, j \in N \setminus A$, and pairs of $i \in A, j \in N \setminus A$.

Envy-freeness of the WESA mechanism for pairs of $i, j \in A$

According to Definition 7, the WESA mechanism is envy-free for pairs of $i, j \in A$, that is agents for which $m_i(e_i^*) = u_i(\omega) - u_i(e_i^*)$, if for all $\omega \in R_+^1$:

$$u_i(e_i^*) + u_i(\omega) - u_i(e_i^*) \geq u_i(e_j^*) + u_i(\omega) - u_i(e_j^*), \tag{9}$$

what is obviously true. In contrast to the case analyzed above with equal entitlements to money (Figure 2), what matters for i's evaluation is not the compensation j receives but rather the compensation i would receive if it had j's share e_j^* of the common resource ω.

Envy-freeness of the WESA mechanism for pairs of $i, j \in N \setminus A$

For pairs of $i, j \in N \setminus A$, that is pairs of agents who are worse off than with their stand alone utility, the no-envy criterion requires that for all $\omega \in R_+^1$:

$$u_i(e_i^*) + (\omega_i - e_i^*)p^* + \kappa_i \geq u_i(e_j^*) + (\omega_i - e_j^*)p^* + \kappa_j, \text{where} \tag{10}$$

$$\kappa_i = \frac{\sum_{i \in A}((\omega_i - e_i^*)p^* - (u_i(\omega) - u_i(e_i^*)))}{|N \setminus A|}. \tag{11}$$

Taking into account that κ_i is the same for all $i \in N \setminus A$, this inequality can be simplified to $u_i(e_i^*) - u_i(e_j^*) \geq (e_i^* - e_j^*)p^*$. If $e_i^* > e_j^*$, efficiency implies that each unit of e which agent i receives more than j has a marginal utility above the market price for i. Similarly, if $e_i^* < e_j^*$, each unit of e which agent i receives less than j has a marginal utility below the market price for i, what proves the inequality.

Note that if κ_i is not constant for all $i \in N \setminus A$, envy-freeness may be violated. In particular, the difference $u_i(e_i^*) - u_i(e_j^*) \geq (e_i^* - e_j^*)p^*$ may be arbitrarily small so that (10) would not hold if $\kappa_i < \kappa_j$. Thereby, the envy-freeness criterion restricts the way how to reallocate excess compensations, as suggested on page 15.

Envy-freeness of the WESA mechanism for pairs of $i \in A$ and $j \in N \setminus A$

For pairs of $i \in A$, $j \in N \setminus A$, envy-freeness with compensations requires that for all $\omega \in R_+^1$:

$$\begin{aligned} u_i(\omega) &\geq u_i(e_j^*) + \min\left\{u_i(\omega) - u_i(e_j^*), (\omega_i - e_j^*)p^* + \kappa_j\right\}, \\ u_j(e_j^*) + (\omega_j - e_j^*)p^* + \kappa_j &\geq u_j(e_i^*) + \min\left\{u_j(\omega) - u_j(e_i^*), (\omega_j - e_i^*)p^* + \kappa_i\right\}. \end{aligned}$$

The left-hand side of the first part of the no-envy criterion denotes agent i's stand alone utility, which is the upper bound of the WESA mechanism and can therefore never be exceeded. Similarly, if

$$\min\left\{u_j(\omega) - u_j(e_i^*), (\omega_j - e_i^*)p^* + \kappa_i\right\} = (\omega_j - e_i^*)p^* + \kappa_i,$$

the second part of the no-envy criterion becomes

$$u_j(e_j^*) + (\omega_j - e_j^*)p^* + \kappa_j \geq u_j(e_i^*) + (\omega_j - e_i^*)p^* + \kappa_i.$$

This is exactly the same formulation of envy-freeness as inequality (10) (only the indices i and j have been exchanged), which has already been shown to be true. Finally, because $u_j(e_j^*) + (\omega_j - e_j^*)p^* + \kappa_j < u_j(\omega)$ by definition of set $N \setminus A$, it follows together with the previous statement that the possibility

$$\min\left\{u_j(\omega) - u_j(e_i^*), (\omega_j - e_i^*)p^* + \kappa_j\right\} = u_j(\omega) - u_j(e_i^*)$$

can be excluded, what concludes the proof. □

7 The WESA mechanism and Burden Sharing in the Climate Change Regime

In this section, a quantitative application of the WESA mechanism to the climate change regime will be presented. The results have been derived with the RICE model (Regional Integrated model of Climate and the Economy) (Nordhaus and Yang 1996; Nordhaus 1992), which is a regional, dynamic, general-equilibrium model of the economy with particular focus on climate change related activities.

The global level of greenhouse gas emissions and their allocation are based on the assumption of full cooperation, that is emission reduction policies are undertaken efficiently across countries and time so as to maximize global welfare. The WESA mechanism then determines corresponding monetary transfers, depending on the a priori allocation of entitlements to emissions. For the results presented here, equal per capita entitlements have been assumed.[10]

Figure 3 depicts control costs – that is abatement costs plus monetary compensations received or paid – in the WESA allocation for six regions: United States (USA), Japan (JPN), European Union (EEC), China (CHN), former Soviet Union (FSU) and the rest of the world (ROW). For comparison, Figure 4 depicts control costs in the Walrasian allocation, using otherwise the same assumptions regarding entitlements and emission allocations.

The main difference among the two allocation mechanisms can be seen immediately. In the Walrasian allocation, the region ROW (essentially the developing countries) and initially also China could yield substantial net gains from emission reductions, because monetary compensations exceed their abatement costs. In contrast, the WESA mechanism cuts off the area of negative control costs and reallocates those 'excess compensations' among the other countries. Accordingly, for regions with positive control costs, these are lower in the WESA allocation than in the Walrasian allocation.

Furthermore, in the RICE model optimal aggregated emissions as well as population size vary over time. Figure 3 shows that during the whole time span control costs change for all agents in the same direction. Accordingly, the WESA allocation not only satisfies the stand alone criterion but also the stronger criteria of resource and population monotonicity.

It should be noted that overall emission reductions in the cooperative RICE path are relatively modest and allow that global emissions increase to roughly four times their current level during the next century. With stricter reductions, it might well be that the Walrasian and the WESA allocation of control costs were identical, at least for the later periods.

Abstracting from any problems related to enforcement or incomplete information about states abatement cost functions, one way to implement the

[10]In principle, compensatory payments affect countries' growth paths and accordingly their abatement cost functions. These general equilibrium effects have not been taken into account. This can be partly justified by the illustrative character of this empirical section, and partly by the fact that compensatory payments are small relative to GDP levels.

WESA would be to allow permit trade on the basis of equal per capita entitlements, and to carry out additional compensatory payments for cases where countries violate the stand alone criterion ex post. Alternatively, one could use the inverse approach of searching for the initial allocation of tradable entitlements that would lead to the level of control costs in the WESA allocation.

Following the latter procedure, Figure 5 depicts the difference between the entitlements to implement the WESA allocation by tradable permits and equal per capita entitlements. As expected, OECD countries and the former Soviet Union would receive more than their equal per capita entitlements in the WESA allocation. Of particular interest is the fact that the difference between equal per capita and WESA-entitlements does not only decrease over time, but the values for the individual countries converge towards each other. Thus, the WESA mechanism seems to provide an axiomatic foundation for a characteristic which has often been advocated as crucial for fair burden sharing – namely that tradable entitlements should initially be related to current emission levels and gradually converge towards an equal per capita allocation (see Cline 1992).

8 Concluding Remarks

The question of what constitutes a fair burden sharing of climate protection measures is a highly controversial one. In this paper, the criteria of individual rationality, envy-freeness with monetary compensations, resource monotonicity and population monotonicity were applied to derive a mechanism for the fair division of common property resources.

The justification of the WESA mechanism rests on normative grounds. Obviously, this contrasts with the lack of a central authority to implement the WESA mechanism. Therefore, its attractiveness would gain if it had also some descriptive power.

In this respect, it is interesting that the requirement of imposing 'no harm' on developing countries, which corresponds to the full compensation for abatement costs in the WESA allocation, has been repeatedly mentioned as a central ingredient of any 'acceptable' treaty (Edmonds, Wise, and Barns 1995; Bohm 1997). This principle can in fact be found in some international agreements which have been praised for their fairness. Most prominently, this is so for the international agreement to combat stratospheric ozone depletion (Montreal Protocol), where low emission countries have been fully compensated for their incremental abatement costs by high emission countries (see Biermann 1997). The WESA mechanism has also close correspondence to the concept of joint implementation (JI) and the so-called clean development mechanism (CDM) established with the 1997 Kyoto Protocol.

Let me conclude the paper with some remarks on the issue of historical emission rights.[11] For pollution stock problems like climate change, optimal emission levels in the current and future periods are partly determined by past emissions. If these have been higher than the natural decay rate in the past, more abatement is required now. One position is to argue that bygones are bygones and, accordingly, the distribution of past emissions should not influence the distribution of current and future emissions.

On the other hand, the principle of *ethical presentism* states that "past practices are irrelevant to distribution in the present, except to the extent that they left morally relevant and causally efficacious traces in the present" (Elster 1991, 14). For climate change this would imply that there should be no punishment for high past emissions. However, the extent to which different countries have contributed to the current CO_2 concentration level, thereby leaving "causally efficacious traces in the present" – namely higher mitigation burdens –, should be reflected in the allocation of entitlements.

As entitlements enter the WESA mechanism only as an exogenous argument, its normative appeal is unaffected by this dispute, even though the resulting WESA allocation may change, of course. However, because countries are never more than fully compensated for their abatement costs, granting developing countries additional entitlements for historical reasons would have no effect for the ROW group in Figure 3. Also the allocation for China would only be affected after 2060. In particular, the time after which China would have to pay a share of the control costs would be shifted to the future.[12] Hence, if the negotiating partners would accept the fair division principles behind the WESA mechanism, agreement on the allocation of emissions and control costs in the near to medium-term future might be possible even if the dispute about the role of historic emissions remains unresolved.

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[11] For a discussion of this topic see Smith (1991); Ghosh (1993) as well as Beckerman and Pasek (1995).

[12] The use of historical emission rights would, of course, affect control costs in Annex I countries during the whole period. However, given the similarity of their historical emissions this issue is of considerably smaller empirical and in particular political relevance.

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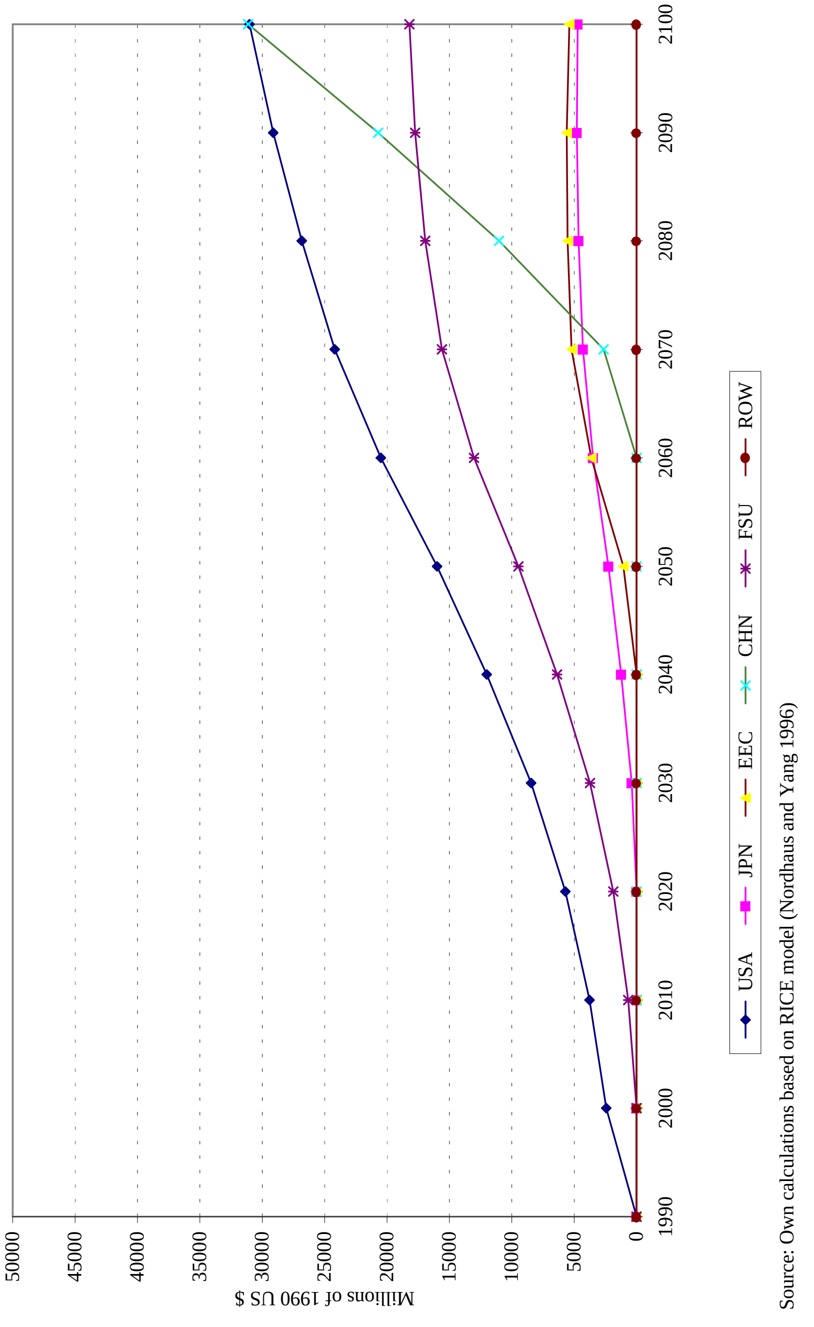


Figure 3: Climate change control costs in the WESA allocation

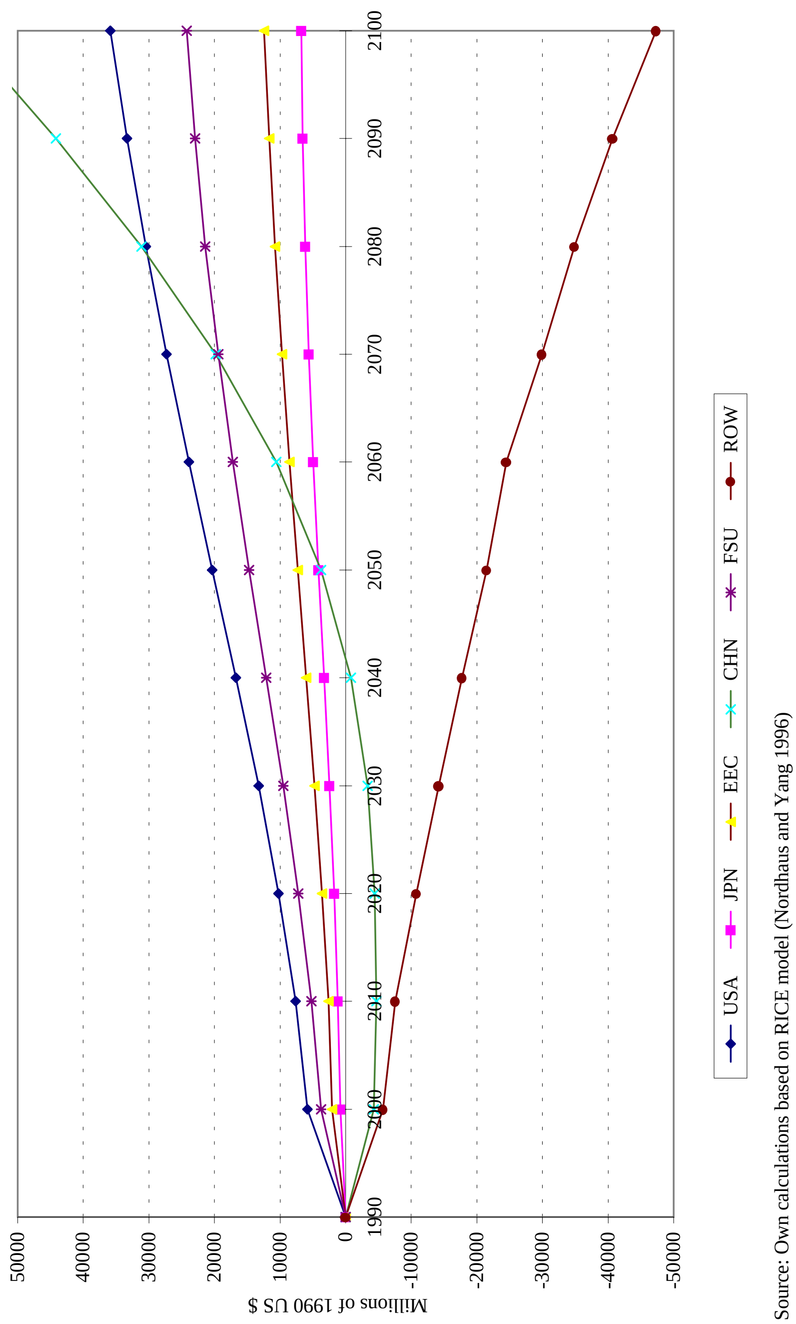
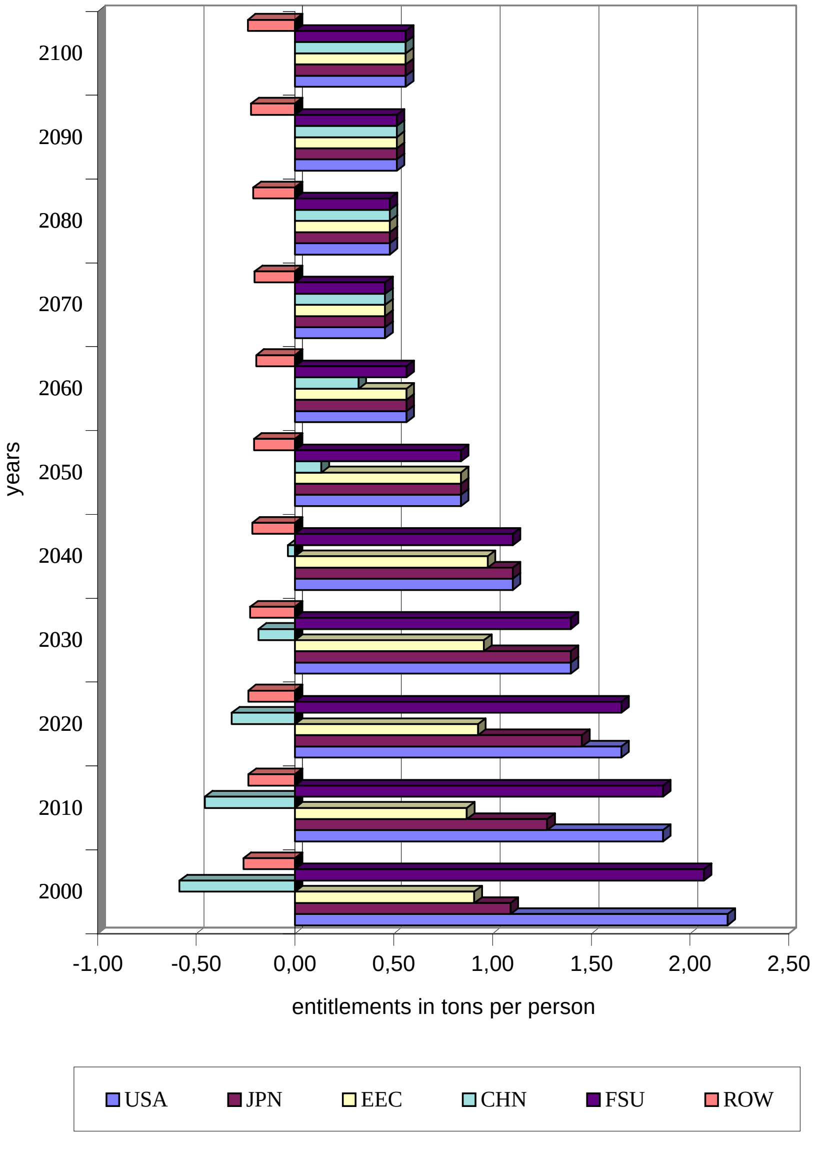


Figure 4: Climate change control costs in the Walrasian allocation



Source: Own calculations based on RICE-model (Nordhaus and Yang 1996)

Figure 5: Implementation of the WESA allocation