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Summary

In this paper, we study the incentives for international cooperation if (some) countries prefer a more equitable distribution of per capita emission levels. For countries that differ with respect to their population size, we analyze the impact of such an equity preference first for a bilateral, and then for a multilateral environmental problem. We show that — contrary to the two-country-case — for the latter there is no uniform percentage reduction of emissions that makes all countries better off. Rather, equity oriented countries (for example developing countries) enter a coalition only if they don't have to reduce as much. We demonstrate that a high degree of cooperation in international environmental negotiations can be explained if most countries are interested in equity and are not too different with respect to their per capita levels. If, however, countries differ too much in population size and per capita emissions, generally no coalition will be stable without restrictions on entry into or exit out of a coalition. We show that in such a situation equity-orientation does not improve upon the prospects for cooperation.

Keywords: International environmental negotiations, equity preference, coalition formation, per capita emission level

JEL: C7, D63, H41, Q00

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1 Introduction

The solution of many environmental problems, such as global warming and the depletion of the ozone layer, requires international cooperation. In general, however, the impact of a single country on the global pollution level is small, and the incentives to free-ride are consequently large. In such a situation, economic theory predicts that only a small fraction of countries cooperate.

The standard approach to the study of coalition formation was formulated by Barrett (1992, 1994) and Carraro and Siniscalco (1993). They use a two-period structure and study cooperation within a non-cooperative framework: Countries must first decide whether or not to join a coalition. In a second step, both the coalition and the remaining countries choose their emission levels non-cooperatively. A coalition is stable if there is neither an incentive to join nor to leave the coalition. Simulations by Barrett (1992, 1994, 1997), Carraro and Siniscalco (1993), and Hoel (1992) have shown that – although there is cooperation – the coalition size is rather small. For specific quadratic utility functions, usually only two or three countries cooperate. The incentives to free-ride are rather strong. Even if one allows for transfers to allocate the efficiency gains from cooperation according to a special rule (Nash-Bargaining or Shapley-value), as shown by Barrett (1997) and Botteon and Carraro (1997), only a a few (three) countries cooperate. There is, however, the possibility of enlarging a coalition using an appropriate transfer scheme if countries are sufficiently asymmetric.[1] The transfers are paid by those countries that benefit most. As shown in the simulations by Botteon and Carraro, these are developing countries like India and China.[2] This clearly does not reflect observations in the negotiations on global environmental problems in which developing countries are neither net payers nor commit to any emissions cap.

Hence, there are two potential problems of the standard coalition models from a positive point of view. On the one hand, empirical evidence shows that there are international environmental agreements on subjects of (global) environmental concern. The Montreal Protocol on Substances that deplete the Ozone Layer (1987) and the (not yet ratified) Kyoto Protocol (1997) may serve as two examples. So, the question remains under which circumstances might one expect international environmental agreements that involve many countries to be stable. On the other hand, developing countries

[1] Botteon and Carraro (1997) show that even the grand coalition is stable if transfer payments are calculated using a two-stage Shapley-value procedure. Note that transfers are equivalent to an appropriate distribution of tradable emission permits.

[2] Botteon and Carraro measure damages in terms of mortality rates where the value of life is identical in all countries. Hence, countries with high population suffer the largest (marginal) damages.

are not net payers in these international agreements. Conversely, for example, within the Kyoto protocol, their emissions are not capped while – via the Clean Development Mechanism and monetary funds – they receive transfers.[3] Similarly, within the Montreal protocol, a multilateral fund for the implementation was established to compensate developing countries.[4] For these transfer payments and the implicit burden sharing, equity considerations are decisive – and sometimes overrule efficiency aspects.

Such equity arguments are frequently used in international negotiations with respect to an equalization of per capita emission levels.[5] They are stressed not only by delegates of developing countries, but also by environmental interest groups in developed countries. A government facing voters with such preferences must clearly take them into account. The weight that a government attaches to the equity argument will then depend on the impact these interest groups have on the national policy. As observed by Cazorla and Toman (2001, p. 238), "Equity might be one motivation for countries to pursue GHG emissions policies. However, equity principles will not override other elements of national self-interest."

While the impact of such equity considerations on financial burdens hase been studied in several models (eg. Tol (2000), Böhringer and Helm (2001)), the importance of fairness and equity considerations – or equity preferences – so far has played little role in the theoretical analysis of coalition formation. Exceptions are Jeppesen and Andersen (1998) and Hoel and Schneider (1997), who introduce a non-material payoff from membership or a disutility from breaking the agreement, respectively, and Bosello et al. (2001) who study the stability of coalitions for different equity rules that determine the burden-sharing between cooperating countries. Lange and Vogt (2002) have a different approach on fairness: They rely on a preference structure given by ERC-theory (Bolton and Ockenfels 2000) in which which the utility of a country is not solely based on the absolute payoff but also on the relative payoff compared to the overall payoff to all agents. Given a certain relative payoff share, the utility strictly increases in the own absolute payoff of the agent. Given a fixed absolute payoff, the agent is best off when receiving just the equal (fair) share. To both sides of this equal share, i.e. when receiving less or more than the fair amount, utility is lower, even if the absolute payoff

[3]For example, in a political declaration at COP6bis in Bonn, the EU, Canada, Iceland, Norway, New Zealand and Switzerland promised to fund developing nations and to provide an annual contribution of US$410 million by 2005.

[4]For further information, see http://www.unmfs.org/.

[5]This principle of equity is even fixed in Article 3 of the Convention on Climate Change as well as in the decision approved by the COP 6 in Bonn which states that measures shall be implemented "...with a view to reducing emissions in a manner conducive to narrowing per capita differences between developed and developing country Parties".

does not change. Lange and Vogt show that if all countries are sufficiently interested in equity (defined as getting close to the average payoff), even the grand coalition can be stable. The analysis, however, is restricted to symmetric countries.

In this paper, we extend the analysis by Lange and Vogt (2002) to the heterogeneous country case. We concentrate on equity preferences with respect to average per-capita emission levels.[6] Countries are assumed to differ with respect to their population size and, hence, with respect to their per capita emission level. Countries are either highly equity-oriented or purely payoff-driven. We distinguish the policy scenarios in which trade of emissions allowances within the coalition (i) is and (ii) is not agreed upon.

We first study the case of a bilateral environmental problem. Here, the consequences of equity-orientation for the non-cooperative Nash-equilibrium as well as for the possible negotiation outcomes are discussed. For countries which are highly interested in equity, an agreement must not decrease their emissions share. Given this, large equity-oriented countries (with less than average per capita levels) try to negotiate a proportionally smaller than average reduction in order to increase their emissions share, whereas payoff-oriented countries try to keep the non-cooperative proportional emissions distribution. For the bilateral case, it can be shown that there is always an agreement that makes both countries better off by changing their emissions by the same percentage.

This, however, is different in the multilateral setting. Here, we analyze a standard two-stage coalition formation model in which the coalition plays Cournot-Nash against the rest of the world. In such a setting, equity-driven countries generally would not agree to a proportional cut of emissions from the Nash-levels. Rather, they would only agree to do less.

If countries are not too asymmetric with respect to their population size and all are highly equity-driven, a high degree of cooperation can be explained. For the more realistic case in which some large countries – developing countries like India and China – have a low per capita level but are concerned with narrowing per capita differences, while others – as might be presumed for developed countries – are solely payoff oriented, we can show that the prospects of cooperation do not improve compared to standard preferences. Rather, if no restrictions on entering or leaving a coalition exist, equity-oriented countries enter any coalition and thereby drive out other countries. This might destroy the stability of all coalition structures. It is therefore necessary to implement some rules on entering the coalition. However, even if cooperating countries had to

[6] A country's utility is therefore determined solely by its own absolute payoff and its per capita emission level as compared to the average per capita level of the world.

agree to allow a new member to join, the cooperation rate does not change compared to standard preferences in which equity does not play any role. Only if countries can credibly commit not to leave a coalition after convincing new countries to enter, can the coalition be enlarged by including large equity-driven countries. For this possibility, the implementation of an emissions trading scheme turns out to be essential.

The paper is organized in the following way: After introducing the model, we discuss the non-cooperative choice of emission levels in section 2.1. Section 2.2 then deals with the bilateral 2-country-problem, whereas in section 2.3 multilateral negotiations are studied in a coalition formation model. After discussing some policy implications of the analysis, the final section – as always – concludes.

2 The model

The analysis in this paper relies on a preference structure in which players – along with their own absolute payoff – are motivated (non-monotonously) by the relative per capita emission assignment they initially receive. So, the setting is similar to the ERC-model by Bolton and Ockenfels (2000) and the approach taken by Lange and Vogt (2002) in which equity is based on the relative payoff of the agent.

Let the number of countries be denoted by N. Each country must choose its emission level $e_i \in [0, e_i^{\max}]$ $(i = 1, \ldots, N)$. The reduction of emissions from a status quo level $e_i^{\max}$ induces some costs $c(e_i)$ that are assumed to be increasing and convex in the abatement level, $-c'(\cdot) \geq 0$, $c''(\cdot) \geq 0$, $-c'(e_i^{\max}) = 0$. Environmental damages $D(E)$ depend on the sum of all countries' emissions $E = \sum_i e_i$. Damages are increasing and convex, $d'(\cdot) \geq 0$, $d''(\cdot) \geq 0$. The payoff to a country is therefore determined by

$$y_i = -c(e_i) - d(\sum_j e_j) + p \cdot (\bar{e}_i - e_i) \tag{1}$$

where p denotes the (equilibrium) price for emissions, $\overline{e_i}$ the assigned emission rights, and $p \cdot (\bar{e}_i - e_i)$ represents the net gains from selling permits in case countries agree on an emissions trading scheme.

The population size of country i is given by L_i. Furthermore, let the total population size be denoted by $L = \sum_j L_j$, and $L_{-i} = \sum_{j \neq i} L_j$. Analogously, $E_{-i} = \sum_{j \neq i} E_j$. Therefore, the relative (assigned) per capita emission level (as compared to the rest of the world) is given by

$$\sigma_i = \frac{\overline{e_i}/L_i}{\overline{E_{-i}}/L_{-i}} \; .$$

The utility of country i is then given by:

$$W_i = y_i + b_i r(\sigma_i)$$

where $b_i \geq 0$, denotes the equity parameter, and $r(\cdot)$ is differentiable, concave and has its maximum at $\sigma_i = 1$ ($r'(1) = 0$). We assume that all countries are identical with respect to their payoff function but differ with respect to their preference for equity (b_i) and their population size (L_i).

2.1 Reaction function – Nash-Equilibrium

Countries differ with respect to their preference for equity and are heterogeneous with respect to their population size. *A single player i* maximizes W_i and chooses its emission level $e_i = \bar{e}_i$ according to the first order condition:

$$-c'(e_i) + b_i r'(\sigma_i) \frac{1/L_i}{E_{-i}/L_{-i}} \geq d'(E) \tag{2}$$

with equality if $e_i < e_i^{\max}$. For comparing the results, let $e_i^*(E_{-i})$ denote the optimal non-cooperative emission level for country i if $b_i = 0$. If $b_i > 0$ and $r'(\sigma_i) > (<)0$, i.e. the per capita emission level falls short (or exceeds) the average level ($e_i^* < (>)L_i E_{-i}/L_{-i}$), marginal abatement costs are smaller (larger) than marginal damage.

Thus, for single players, an increased weight on the equity preference (increasing b_i) implies a convergence towards the average per capita level of the rest of the world. The reaction function $e_i(E_{-i})$ rotates around $(e_i^* L_{-i}/L_i, e_i^*)$, where $-c'(e_i^*) = d'(e_i^* L/L_i)$ and converges for $b_i \to \infty$ to the increasing line with slope L_i/L_{-i} capped at $e_i^{\max}$.

Throughout the paper, we will illustrate the main features of equity-preferences with the following specification of utility function:

$$c(e_i) = \frac{1}{2}\alpha(\beta - e_i)^2 \qquad\qquad d(E) = \gamma E \tag{3}$$

The reaction function is illustrated in figure 1. Note that for $b_i = 0$ we have orthogonal reaction functions ($e_i^*(E_{-i}) = \beta - (\gamma/\alpha)$ whereas for $b_i > 0$ the reaction function is upward-sloping.

This means, on the one hand, that countries with more than average emissions voluntarily reduce their emissions even beyond the level which equates marginal damages and abatement costs. On the other hand, if a country with large population and hence small per capita emission level is interested in equity, it might choose its maximal emission level and thereby behave as if it were not experiencing environmental damages at all.

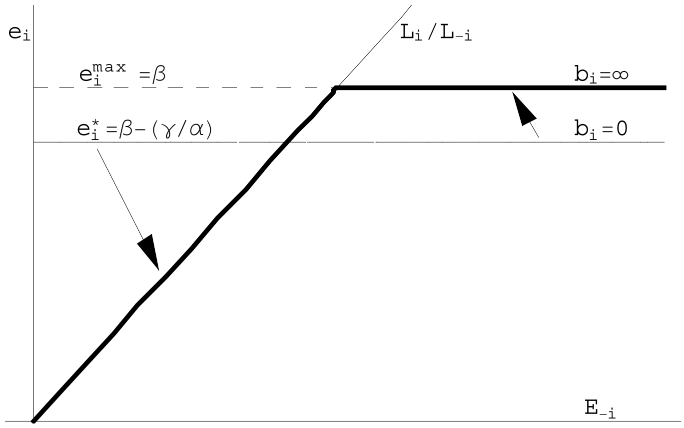

Figure 1: *The change of the reaction function $e_i(E_{-i})$ of a single player from $b_i = 0$ to $b_i \to \infty$.*

To demonstrate the effects of equity-orientation, we concentrate in the following on the case in which one of two types of countries is infinitely interested in equity (type 2, $b_2 = \infty$) while the other is not (type 1, $b_1 = 0$). That is, the former country primarily desires an equalized per-capita distribution of emission (permits), but, given a certain emissions share, maximizes its payoff.

2.2 Bilateral environmental problems

In this section we consider the simplest version of an international environmental problem in which only two countries are involved. We consider two different institutional settings: (NTR) no trade of emissions between the countries, and (TR) (competitive) international emissions trading among firms. This means that payoff to country i is given by (1) with $\bar{e}_i = e_i$ for (NTR) and $p(E) = -c'(e_i)$ for (TR), respectively.

Under our assumption that $b_1 = 0$ and $b_2 = \infty$, the non-cooperative Nash-equilibrium is given by

$$-c'(e_1^N) = d'(E)$$

and

$$e_2^N = \min[e_1^N \frac{L_2}{L_1}, e_2^{\max}]$$

For the specific utility function (3), this leads to

$$e_1^N = \beta - \frac{\gamma}{\alpha} \qquad\qquad e_2^N = \min[(\beta - \frac{\gamma}{\alpha})\frac{L_2}{L_1}, \beta]$$

Note that in the case in which the small country is interested in equity ($L_2 < L_1$), an interior Nash-equilibrium is guaranteed, i.e. $e_2^N/e_1^N = L_2/L_1$.

Any agreement consists of decisions on two variables: First, the proportion of the allocation of emissions (permits), $z_i := \bar{e}_i/E$, secondly on the aggregate emission level $E = \bar{e}_1 + \bar{e}_2$.

Given z_i, a country would like to implement

$$-c'(E^{*i}z_i)z_i - d'(E^{*i}) = 0$$

in case (NTR).

If, however, one allows for the possibility of trade, for any initial distribution of the aggregate emission level E, the resulting emission levels are given by $e_1 = e_2 = E/2$.[7] Thus, the desired aggregate emission level for the TR-case is given by

$$-c'(E^{*i}/2)z_i - d'(E^{*i}) + c''(E/2)(1/2)(1/2 - z_i)E^{*i} = 0$$

It is obvious that if the equity-oriented country 2 can equalize per capita emissions in the Nash-equilibrium, i.e. $\bar{e}_2^N = \bar{e}_1^N \frac{L_2}{L_1}$, this proportion must be kept in the agreement. Hence, in this case, countries can only choose the absolute emission level, E. In order to be feasible, the choice must not decrease the payoffs to either country.

However, if $\bar{e}_2^N < \bar{e}_1^N \frac{L_2}{L_1}$, country 2 will desire to increase its emissions share z_i to the "fair" level, whereas country 1 will want to stay with $z_i = e_i^N/E^N$. Thus, if country 2 has maximal bargaining power, it optimizes its emissions share while taking into account that the payoff to country 1 does not decrease. If, however, country 1 has bargaining power, it maximizes its payoff given $z_i = e_i^N/E^N$. It does not have has to consider the payoff of country 2 since it could – by a small increase of z_2 – secure the participation of country 2. The solutions for the respective assumptions of the distributions of bargaining power are denoted by $(z_i^{\text{opt}}, E_i^{\text{opt}})$.

We arrive at the following proposition:

Proposition 1 *For the bilateral case, if the large country is equity-oriented, it is always possible to agree on a proportional cut of emissions which leaves all countries better off. Very large equity-oriented countries want to increase their emissions share, whereas small countries and payoff-oriented countries try to implement an agreement with equal emissions reductions in proportion to the Nash-levels.*

The proof is given in the appendix. It shows that – for having the emissions shares fixed at the non-cooperative level – the payoff to both countries increases with a reduction of emissions from the Nash-level.

[7] Here it is assumed that both countries distribute their initial endowment of emission permits to small domestic firms which themselves act as price-takers on the allowance market.

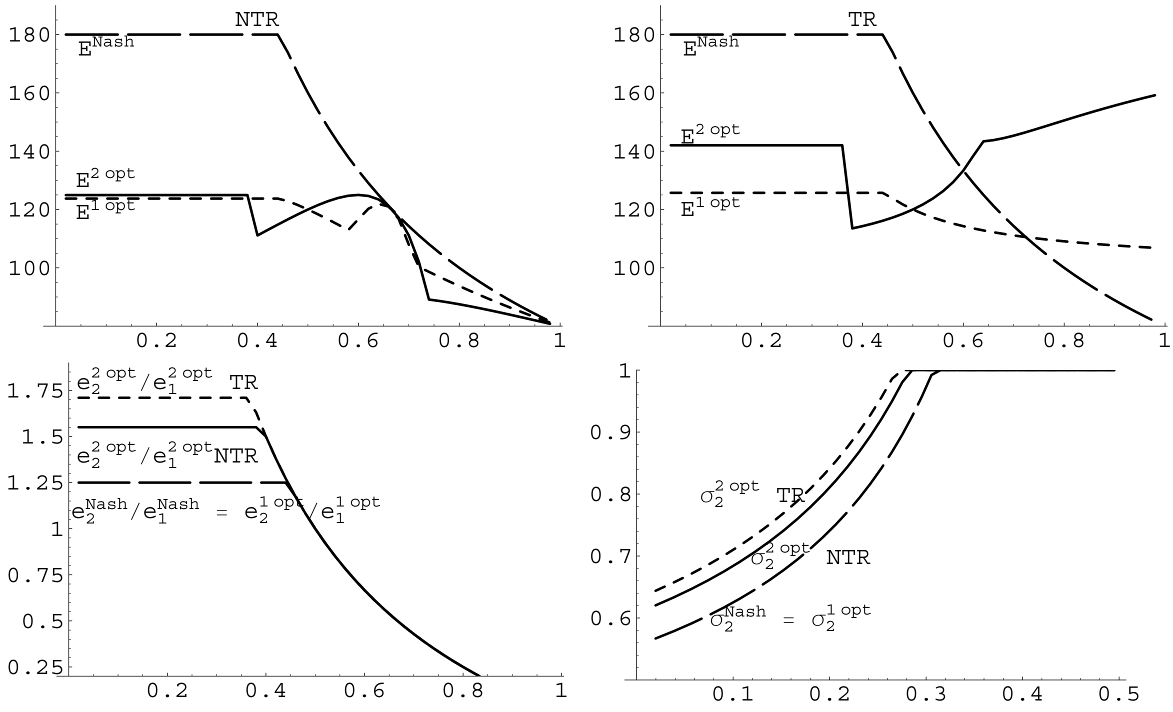

Figure 2: *Aggregate emission levels E and emissions share e_2/e_1, and σ_2 as function of L_1/L for the Nash-equilibrium and for maximal bargaining power of country $i = 1, 2$.*

In figure 2 we illustrate the two extreme cases in which either country 1 or 2 has maximal bargaining power, i.e. maximizes its utility such that the other country is not worse off than in the Nash-equilibrium. Simulations are based on utility functions (3) with $\alpha = 1$, $\beta = 100$, $\gamma = 20$. Besides the Nash-levels, the figure also shows the aggregate emission levels $E^{\mathrm{i\ opt}}$, and relative per capita emissions $\sigma_i^{\mathrm{i}\ ,+\mathrm{opt}}$, as well as the relative emission levels $(\bar{e}_2/\bar{e}_1)$ desired by the two countries for the trade and no trade case as a function of L_1/L.

For the choice of z_i, country 1 always wants to keep the original distribution. Country 2, for large L_2/L_1, wants to close the gap in per capita levels. Hence, the relative emissions of country 2 are larger if it has bargaining power. Since it has to concede to country 1 the Nash-payoff, the emissions share in the TR-case may increase even more than in the NTR-case since country 2 can use the additional efficiency gains from emissions trading. The different z_i clearly also leads to varying aggregate emission levels which the countries propose.

For the NTR-scenario, the aggregate emission levels desired by both countries are below the Nash-level. Clearly, here, for a given z_i, the countries would benefit only from a further reduction of emissions. In the TR-case, however, if the equity-interested country 2 is very small, the agreement would lead to an increase of emissions, whereas if country 2 is large, emissions would be decreased. The reason is that in the Nash-equilibrium, country 2 chooses a very small (large) emission level in order to equalize the per capita level. Due to the mechanism of emissions trading, the equalization of per-capita endowments and choice of aggregate emissions can now be uncoupled, leading to an increase (decrease) of total emissions.

Comparing the emission levels desired by the two countries, we obtain the following results for the specific utility function given by (3): If the equity-oriented country 2 is small, it receives less allowances than it needs in equilibrium on the permit market. Hence, it wants to implement a higher emission level than country 1, because this reduces its costs of buying permits. If country 2 is large, the aggregate emission level which is optimal for country 2 is again larger than the one desired by 1. Here, however, the intuition is different: Country 2 wants to increase its share of emission permits. In order to make country 1 – which is now a buyer of permits – not worse off, it has to agree to a higher emission level and, thus, to a lower price of permits.

Summarizing the results for the bilateral case, although desired agreements differ substantially because of differing equity-orientation and per capita emission levels, there remains the possibility of agreement on proportional emission reductions.

2.3 Multilateral environmental problems

We now study the case in which more than two countries contribute to some environmental problem by emitting a certain pollutant.

We study a two-stage game of international negotiations as introduced by Barrett (1994), Carraro and Siniscalco (1993), and Hoel (1992). In the first stage, countries decide whether or not to join a coalition S. Here, each country takes the decisions of the other countries as given. Each country i also anticipates, however, that the emission levels, which are chosen in the second stage, and national welfare $W_i(S)$ depend on the coalition S, i.e. on whether it does or does not enter the coalition. In stage 2, countries inside and outside the coalition simultaneously select their abatement levels. The coalition plays Nash against the non-signatory-countries, which simultaneously maximize their individual utility. A coalition is stable if $W_i(S) \geq W_i(S \backslash i)$ for $i \in S$ and $W_i(S) \geq W_i(S + i)$ for $i \notin S$.

We again assume that countries differ only with respect to their population level and their equity-orientation. Note that for our specification of utility functions (3), the coalition size in equilibrium is 2 or 3 if all countries have standard preferences, i.e. are only payoff-driven. For such standard preferences, even if emissions trading is possible, one cannot improve upon this result since countries are assumed to be payoff-symmetric.

In the following we look at stable coalitions when some countries are (infinitely) equity-oriented, i.e. choose their non-cooperative emission level $e_i = \min[E \leq L_i/L, e_i^{\max}]$. Unlike the bilateral case, a proportional cut of emissions is generally not feasible if more countries are involved. To prove this, assume a reduction of emissions by the coalition S to x_S per cent. In order not to make a country i, which is infinitely interested in equal per capita levels, $e_i/E \leq L_i/L$, worse off, the negotiated emission level $x_i e_i$ of this country must satisfy

$$\frac{x_i e_i}{x_S E_S + E_{-S}} \geq \frac{e_i}{E_S + E_{-S}}$$

and hence

$$x_i \geq \frac{x_S E_S + E_{-S}}{E_S + E_{-S}} > x_S$$

We immediately obtain the following proposition:

Proposition 2 *For the multilateral case, no agreement by a coalition S that includes some equity-oriented insiders and some payoff-oriented outsiders can be based on a proportional reduction of emission levels, i.e. $e_i/e_i^N = E_S/E_S^N$ for all $i \in S$. Equity oriented countries within a coalition abate proportionally less than payoff-oriented insiders.*

Equity-oriented countries outside a coalition, however, might increase the incentive of a payoff-driven country to join a coalition. The reason is that after joining a coalition, the coalition takes into account the external effects on the entering country and, hence, reduces the emission levels. Equity-oriented outsiders now would honor this reduction by reducing their emissions as well. Hence, the environmental damages are further reduced and the entering country's utility is increased even further.

We immediately obtain the following general result:

Proposition 3 *Equity-oriented countries outside the coalition increase the incentives of a coalition to reduce emissions. The incentives of payoff-oriented countries to enter the coalition increase.*

For the specific example given by (3), a third country has zero incentives to enter a coalition if all countries have standard preferences, $b_i = 0$. If now equity-oriented outsiders with upward-sloping reaction functions exist, the third country has a strictly positive incentive to enter. Thus, the coalition size generally is larger. If, however, there are strong asymmetries in the population size, and equity-oriented countries are much larger, these countries choose their maximal emission level $e_i^{\max}$ as we have seen in section 2.1. In this case, the additional benefit of entering countries vanishes again. Hence, the result by Lange and Vogt (2002) which states that even the grand coalition can be stable if all countries are symmetric and interested in equity, only extends to the case of countries that do not greatly differ with respect to their population size.

More realistic, however, is the case in which only some countries are (highly) interested in equity while others are not. Let us again assume that there are two types of countries: Type 1 is payoff-driven only, type 2 is infinitely interested in equity. Here we concentrate on the case in which the equity-oriented countries are rather large and thus have relatively small per capita emission levels. These assumptions reflect the empirical fact that particularly large developing countries like India or China regularly bring forward equity concerns and demand, and – at least in the long run – a distribution of emission permits according to the equal per capita rule.

Let the total number of type i countries be denoted by n_i. A coalition is then described as a pair (k_1, k_2). The emission levels of cooperating (non-cooperating) countries depend on (k_1, k_2) and are denoted by e_i^s, e_i^n, the payoff by y_i^s, y_i^n and the relative per capita emission level by $\sigma_i^s = (\bar{e}_i^s/L_i)/(\bar{E}/L)$, σ_i^n $(i = 1, 2)$.

The emission levels of outsiders are again given by

$$-c'(e_1^n) = d'(\cdot)$$

and

$$e_2^n = \min[E\frac{L_2}{L}, e_2^{\max}]$$

We further assume that the population size of type 2-countries secures that for all coalitions (k_1, k_2), $e_2^n = e_2^{\max}$. A stable coalition therefore must satisfy

$$y_1^s(k_1, k_2) \ \geq y_1^n(k_1 - 1, k_2) \tag{4}$$

for $k_1 > 0$, $k_2 \geq 0$, and

$$\sigma_2^s(k_1, k_2) \geq \sigma_2^n(k_1, k_2 - 1) \tag{5}$$

for $k_1 \geq 0$, $k_2 > 0$.

We look at the case in which type 1-countries have all the bargaining power. Then, in the NTR-case, the coalition chooses the emission levels e_i^s by maximizing

$$\begin{aligned} y_1 &= -c(e_1) - d(k_1 e_1 + k_2 e_2 + E_{-S}) \\ \text{s.t. } & \frac{e_2/L_2}{(k_1 e_1 + k_2 e_2 + E_{-S})/L} = \sigma_n(k_1, k_2 - 1) \end{aligned}$$

leading to

$$
\begin{aligned}
e_2 &= \frac{(k_1 e_1 + E_{-S})L_2/L\sigma_n(k_1, k_2-1)}{1 - k_2 L_2/L\sigma_2^n(k_1, k_2-1)} \\
-c'(e_1) &= d'(E)\frac{k_1}{1 - k_2 L_2/L\sigma_2^n(k_1, k_2-1)}
\end{aligned}
$$

In the TR-case, however, the coalition chooses the assigned emission levels $\bar{e}_i^s$, which then lead to real reductions e_i which are given by $p = -c'(e_1) = -c'(e_2)$, and, hence, $e_1 = e_2 = (k_1\bar{e}_1 + k_2\bar{e}_2)/(k_1 + k_2)$. Thus, the coalition maximizes

$$
\begin{aligned}
&-c(e_1) - d(k_1\bar{e}_1 + k_2\bar{e}_2 + E_{-S}) + (-c'(e_1))(\bar{e}_1 - e_1) \\
&\text{s.t. } \frac{\bar{e}_2/L_2}{(k_1\bar{e}_1 + k_2\bar{e}_2 + E_{-S})/L} = \sigma_2^n(k_1, k_2-1) \\
&e_1 = \frac{k_1\bar{e}_1 + k_2\bar{e}_2}{k_1 + k_2}
\end{aligned}
$$

which yields the following first order condition:

$$
\begin{aligned}
\bar{e}_2 &= \frac{(k_1\bar{e}_1 + E_{-S})(L_2/L)\sigma_n(k_1, k_2-1)}{1 - k_2 L_2/L\sigma_2^n(k_1, k_2-1)} \\
-c'(e_1) &= d'(E)\frac{\partial E}{\partial \bar{e}_1} - c''(e_1)\frac{\partial e_1}{\partial \bar{e}_1}(e_1 - \bar{e}_1)
\end{aligned}
$$

Note that for $k_2 = 0$ we are back to the standard preference case of symmetric countries in which no trade takes place. For $k_1, k_2 > 0$, however, although the countries are payoff-symmetric, efficiency gains through emissions trading can be realized since type 2 countries are assigned with a larger amount of allowances. In the case of $k_1 = 0$ the cooperation of type 2 countries has no effect at all, since they are assumed to maximize their emissions share by choosing $e_i^{\max}$.

In order to explore the properties of the equilibria of the coalition formation game, we rely on numerical simulations. Again, we use the payoff function given by (3). We assume that

$$
\alpha = 1, \qquad \beta = 100, \qquad \gamma = 5, \qquad L_2 = 4L_1, \qquad n_1 = n_2 = 5
$$

The simulation results, payoffs to both types, as well as emission levels are stated in table 1 for the no trade case NTR and in table 2 for the TR case.

Let us first discuss the results when no trade of emissions is possible (NTR). Note again that type 1 countries use their bargaining power to give type 2 countries only the minimal emissions share to induce them to enter the coalition ($\sigma_2^s(k_1, k_2) = \sigma_2^n(k_1, k_2 -$

		k_2=0	k_2=1	k_2=2	k_2=3	k_2=4	k_2=5
y_1^s	k_1=0						
	k_1=1	-4887.50	-4887.34	-4887.49	-4888.27	-4890.37	-4895.39
	k_1=2	-4875.00	-4874.33	-4874.94	-4878.17	-4887.00	-4908.87
	k_1=3	-4837.50	-4835.92	-4837.32	-4845.03	-4866.97	-4925.06
	k_1=4	-4775.00	-4771.99	-4774.51	-4789.46	-4834.81	-4966.37
	k_1=5	-4687.50	-4682.30	-4686.25	-4712.34	-4797.52	-4911.38
y_1^n	k_1=0	-4887.50	-4887.50	-4887.50	-4887.50	-4887.50	-4887.50
	k_1=1	-4887.50	-4884.32	-4880.20	-4874.66	-4866.80	-4854.75
	k_1=2	-4837.50	-4824.60	-4807.77	-4784.79	-4751.34	-4697.36
	k_1=3	-4737.50	-4707.72	-4668.19	-4612.66	-4527.34	-4372.68
	k_1=4	-4587.50	-4532.40	-4457.23	-4346.31	-4157.64	-3709.17
	k_1=5						
y_2^s	k_1=0		-4875.00	-4875.00	-4875.00	-4875.00	-4875.00
	k_1=1		-4871.82	-4867.70	-4862.16	-4854.31	-4842.28
	k_1=2		-4812.14	-4795.33	-4772.41	-4739.08	-4685.51
	k_1=3		-4695.42	-4656.05	-4600.87	-4516.56	-4366.05
	k_1=4		-4520.62	-4446.11	-4336.93	-4154.62	-3755.20
	k_1=5		-4286.11	-4159.02	-3959.35	-3573.55	-3408.66
y_2^n	k_1=0	-4875.00	-4875.00	-4875.00	-4875.00	-4875.00	
	k_1=1	-4875.00	-4871.82	-4867.70	-4862.16	-4854.30	
	k_1=2	-4825.00	-4812.10	-4795.27	-4772.29	-4738.84	
	k_1=3	-4725.00	-4695.22	-4655.69	-4600.16	-4514.84	
	k_1=4	-4575.00	-4519.90	-4444.73	-4333.81	-4145.14	
	k_1=5	-4375.00	-4283.95	-4154.45	-3946.87	-3513.18	
e_1^s	k_1=0						
	k_1=1	95.00	94.43	93.71	92.77	91.51	89.69
	k_1=2	90.00	88.84	87.38	85.45	82.79	78.83
	k_1=3	85.00	83.22	80.94	77.87	73.46	66.39
	k_1=4	80.00	77.55	74.32	69.81	62.86	49.61
	k_1=5	75.00	71.77	67.39	60.87	49.32	13.31
	k_1=05	95.00	95.00	95.00	95.00	95.00	95.00
e_1^n	k_1=1	95.00	95.00	95.00	95.00	95.00	95.00
	k_1=2	95.00	95.00	95.00	95.00	95.00	95.00
	k_1=3	95.00	95.00	95.00	95.00	95.00	95.00
	k_1=4	95.00	95.00	95.00	95.00	95.00	95.00
	k_1=5						
	k_1=0		100.00	100.00	100.00	100.00	100.00
e_2^s	k_1=1		99.93	99.92	99.89	99.84	99.75
	k_1=2		99.73	99.65	99.52	99.30	98.86
	k_1=3		99.37	99.16	98.81	98.15	96.57
	k_1=4		98.80	98.34	97.50	95.65	89.18
	k_1=5		97.92	96.98	95.00	89.01	32.85
	k_1=0	100.00	100.00	100.00	100.00	100.00	
e_2^n	k_1=1	100.00	100.00	100.00	100.00	100.00	
	k_1=2	100.00	100.00	100.00	100.00	100.00	
	k_1=3	100.00	100.00	100.00	100.00	100.00	
	k_1=4	100.00	100.00	100.00	100.00	100.00	
	k_1=5	100.00	100.00	100.00	100.00	100.00	

Table 1: *Payoff and emissions for the no-trade-case NTR.*

		k_2=0	k_2=1	k_2=2	k_2=3	k_2=4	k_2=5
y_1^s	k_1=0						
	k_1=1	-4887.50	-4882.62	-4875.83	-4869.27	-4863.26	-4858.45
	k_1=2	-4875.00	-4867.28	-4855.00	-4843.06	-4832.76	-4826.29
	k_1=3	-4837.50	-4827.56	-4811.24	-4795.61	-4783.95	-4781.99
	k_1=4	-4775.00	-4762.86	-4743.77	-4726.72	-4718.75	-4734.90
	k_1=5	-4687.50	-4672.77	-4651.97	-4636.70	-4641.81	-4692.78
y_1^n	k_1=0	-4887.50	-4887.50	-4887.50	-4887.50	-4887.50	-4887.50
	k_1=1	-4887.50	-4875.87	-4858.76	-4838.79	-4815.25	-4787.07
	k_1=2	-4837.50	-4813.50	-4776.74	-4732.01	-4677.56	-4609.56
	k_1=3	-4737.50	-4696.51	-4635.46	-4558.43	-4460.38	-4328.06
	k_1=4	-4587.50	-4522.58	-4429.09	-4306.41	-4138.23	-3866.06
	k_1=5						
y_2^s	k_1=0		-4875.00	-4875.00	-4875.00	-4875.00	-4875.00
	k_1=1		-4857.53	-4841.10	-4821.01	-4797.08	-4768.28
	k_1=2		-4770.94	-4738.09	-4693.45	-4637.52	-4566.82
	k_1=3		-4607.11	-4554.45	-4477.67	-4375.91	-4236.95
	k_1=4		-4363.55	-4281.94	-4158.63	-3983.50	-3707.43
	k_1=5		-4040.17	-3913.68	-3717.52	-3408.53	-2807.22
y_2^n	k_1=0	-4875.00	-4875.00	-4875.00	-4875.00	-4875.00	
	k_1=1	-4875.00	-4863.37	-4846.26	-4826.29	-4802.75	
	k_1=2	-4825.00	-4801.00	-4764.24	-4719.51	-4665.06	
	k_1=3	-4725.00	-4684.01	-4622.96	-4545.93	-4447.88	
	k_1=4	-4575.00	-4510.08	-4416.59	-4293.91	-4125.73	
	k_1=5	-4375.00	-4276.65	-4137.15	-3942.61	-3630.78	
$\bar{e}_1^s$	k_1=0						
	k_1=1	95.00	92.91	89.96	86.49	82.50	77.85
	k_1=2	90.00	87.85	84.69	80.86	76.31	70.85
	k_1=3	85.00	82.56	79.07	74.73	69.40	62.66
	k_1=4	80.00	77.11	73.12	68.03	61.45	52.17
	k_1=5	75.00	71.52	66.79	60.53	51.56	31.14
$\bar{e}_1^n$	k_1=0	95.00	95.00	95.00	95.00	95.00	95.00
	k_1=1	95.00	95.00	95.00	95.00	95.00	95.00
	k_1=2	95.00	95.00	95.00	95.00	95.00	95.00
	k_1=3	95.00	95.00	95.00	95.00	95.00	95.00
	k_1=4	95.00	95.00	95.00	95.00	95.00	95.00
	k_1=5						
$\bar{e}_2^s$	k_1=0		100.00	100.00	100.00	100.00	100.00
	k_1=1		99.76	99.65	99.59	99.51	99.41
	k_1=2		99.50	99.23	99.06	98.85	98.54
	k_1=3		99.13	98.70	98.33	97.84	97.03
	k_1=4		98.58	97.93	97.22	96.08	93.40
	k_1=5		97.75	96.74	95.30	92.09	68.86
$\bar{e}_2^n$	k_1=0	100.00	100.00	100.00	100.00	100.00	
	k_1=1	100.00	100.00	100.00	100.00	100.00	
	k_1=2	100.00	100.00	100.00	100.00	100.00	
	k_1=3	100.00	100.00	100.00	100.00	100.00	
	k_1=4	100.00	100.00	100.00	100.00	100.00	
	k_1=5	100.00	100.00	100.00	100.00	100.00	

Table 2: *Payoff and emissions if emission allowances are tradable (TR).*

1)). Looking at the results, however, one observes that $y_2^s(k_1, k_2) > y_2^n(k_1, k_2 - 1)$ and, thus, the type 2 countries have an incentive to enter any coalition. By doing this, they drive out type 1 countries. Type 1 countries only enter a coalition if this increases their own payoff, i.e. $y_1^s(k_1, k_2) \geq y_1^n(k_1, k_2 - 1)$. If $k_2 = 0$, as with standard preferences, 2 or 3 countries enter, for $k_2 = 1$ and $k_2 = 2$, 2 countries would enter. For $k_2 > 2$, no single type 1 country would stay in the coalition. Thus, just looking at the incentives to enter or leave a coalition, no coalition that comprises type 1 countries is stable. Consequently, with free entry and exit, the prospects of cooperation even are reduced compared to standard preferences: There is no emission reduction at all!

However, a situation in which type 1 countries have the bargaining power and would grant newly entering type 2 countries (and thereby all countries of type 2 which are already a member of the coalition) a benefit if this endangers the stability of the coalition is not very realistic. If we exclude such behavior, and assume that type 2 countries are only allowed to enter if they do not drive out type 1's, only the coalitions $(3, 0)$, $(2, 2)$ are stable. Here, $(3, 0)$ Pareto-dominates $(2, 2)$. Hence, although some countries are equity-oriented, the prospects of cooperation are identical with what we know from standard preferences. More optimistic results are only possible if the 3 cooperating type 1 countries could write a contract not to leave the coalition. Then they would allow one type 2 country to enter. Thus, the coalition could only be slightly enlarged.

For the TR-case, i.e. if trade of emission allowances is possible, the results change only slightly: Without restrictions on entering the coalition, again all type 2 countries enter, since – besides being granted the same emissions share $\sigma_2 = \sigma_2^N$ – they realize gains from selling emission allowances on the permit market. Differently from NTR, one type 1 country cooperates, i.e. $k_1 = 1$, $k_2 = 5$ is stable. The reason is that it is more beneficial to cooperate with type 2 countries in order to realize the efficiency gains from the equalization of marginal abatement costs. If, again, type 1 countries do not allow the entry of type 2 countries if this implies the loss of a type 1 country, with trade $(3, 0)$, $(2, 2)$, and $(1, 5)$ are stable. Pareto-dominant is again $(3, 0)$.

If these three countries can stabilize the coalition by a contract, they could allow all type 2 countries to enter the coalition. The payoff of type 1 countries is increasing in k_2 for the trade-case since they can successively realize gains from emissions trading.

The stable coalitions for the simulations are summarized in Table 3.

Result 4 *With free entry into and exit out of the coalition, equity-oriented countries enter any coalition and drive out payoff-oriented countries. This can destroy the pos-*

	Stable coalitions NTR	Stable coalitions TR
Free entry and exit	-	$(1,5)$
Entry controlled by type 1	$(3,0) \succeq (2,2)$	$(3,0) \succeq (2,2) \succeq (1,5)$
Enlarge $(3,0)$	$(3,1)$	$(3,5)$

Table 3: *Stable coalitions under different assumptions on entry and exit of countries.*

Coalition	$(3,0)$	NTR $(3,1)$	TR $(3,1)$	TR $(3,2)$	TR $(3,3)$	TR $(3,4)$	TR $(3,5)$
Aggregate emissions E	945.0	962.4	936.8	924.6	909.2	889.6	863.1
Status Quo $E_S(0,0)$	285.0	385.0	385.0	485.0	585.0	685.0	785.0
E_S	255.0	349.0	346.8	434.6	519.2	599.6	673.1
$\overline{e}_{1s}$	85.0	83.2	82.6	79.1	74.7	69.4	62.7
$\overline{e}_{2s}$		99.4	99.1	98.7	98.3	97.8	97.0
Reduction S (%)	10.5	9.3	9.9	10.4	11.3	12.5	14.3
Reduction Type 1 (%)	10.5	12.4	13.1	16.8	21.3	26.9	34.0
Reduction Type 2 (%)		0.6	0.9	1.3	1.7	2.2	3.0

Table 4: *Emissions and emission reduction in coalition with controlled entry and exit.*

sibility of improving upon the Nash-equilibrium. If payoff-driven countries can restrict the entry of type 2 countries, equity-orientation generally does not improve upon the standard result: The optimal stable coalition structure is $(3,0)$ *with and without trade. If type 1 countries can control entry and exit, they can enlarge the coalition* $(3,0)$*. Using efficiency gains from trade, they can include more (or even all) equity-oriented countries than in the NTR-scenario.*

Thus, in a setting where equity-oriented countries cannot realize their desired emissions share and therefore refuse to abate if they are outside the coalition, the prospects of cooperation are not much better than with standard preferences. They can only be enhanced if, first, some payoff-driven countries contract to cooperate and then allow equity-driven countries to enter the coalition. However, as shown in proposition 3, the proportional reduction of emissions must be differentiated between the two types of countries. Table 4 shows the proportional emissions reductions in the equilibrium structures that could be sustained by controlling entry and exit. In order to bring type 2 countries in to the coalition, the three type 1 countries have to undertake the largest part of emissions reduction. For example, in order to make the first entering equity-oriented country not worse off, type 1 countries must increase their reduction from 10.5% to 12.4% in NTR and to 13.1% in TR-case, whereas the type 2 country only abates 0.6% or 0.9%, respectively. For any further country, the gap between assigned emission reduction of type 1 and 2 countries increases even more.

Result 5 *In order to enlarge the coalition of three payoff-oriented countries by equity-driven countries, the former must undertake the main part of the additional emission reduction.*

Region	Baseline Emissions (Mt C)*		Nominal Reduction (% wrt. 1990)**		Emissions Goal (MtC) (2010)		Population (Millions)		Emissions Per Capita (tC), (2010)	
	1990	2010	OLD	NEW	OLD	NEW	1990	2010	OLD	NEW
Annex B (US out)	2545	2524	5.0	0.5	2398	2511	863	870	2.76	2.89
USA	1352	1835	7.0	3.2	1707	1776	255	300	5.69	5.92
Annex B (US in)	3897	4359	5.0	0.5	4141	4332	1118	1170	3.54	3.71
China	617	1127	-	-	1127	1127	1155	1366	0.83	0.83
India	153	349	-	-	349	349	845	1164	0.30	0.30
World (US out)	5827	7910			7783	7897	5255	6817	1.14	1.16
World (US in)	5827	7910			7692	7888	5255	6817	1.13	1.16

Table 5: *Emissions and emission reduction under Kyoto and revised Kyoto-targets as agreed in Marrakesh with and without U.S compliance. * Based on IEO(2002), ** estimates by European Commission (Nemry 2001).*

2.4 Some policy implications

Although it is always difficult to use such a stylized model to draw conclusions for real international negotiations such as those on the reduction of greenhouse gases, we think that these results might explain some of the outcomes of the Kyoto-process.

As mentioned in the introduction, Botteon and Carraro (1998) find in their analysis that India/China is a member of any coalition since it benefits most from reducing greenhouse gas emissions. The climate negotiations, however, have not succeeded in include these developing countries with substantial emissions reductions. Our results might offer an explanation: As these countries frequently point out the necessity of equalizing per capita emissions, it might be reasonable to assume that they are highly concerned with such equity-criterion and, thus, would not agree to any proposal that reduces their relative share of emissions. Without the participation of these developing countries, aggregate emissions are determined by the outcome of the Kyoto-process. Table 5 shows the original Kyoto-targets (OLD) and the revised targets after Bonn/Marrakesh (NEW) under and without U.S. compliance (US out, US in). Taking into account the expected emissions of China or India in 2010, one can calculate the relative per capita emissions of the two country, i.e. σ_i, i = CHN, IND. In order to convince India or China to join the agreement, these levels must not be undercut.

Figure 3 shows the possible maximal reductions (in per cent with respect to 2010) by China / India as a function of the reduction by Annex B countries which leave China / India better off. As can be seen, any cut of emissions by India or China must be accompanied by a much larger reduction by the rest of the world which goes beyond the Kyoto targets.

Due to the decision of the U.S. not to ratify the Kyoto-protocol, this gap of emissions

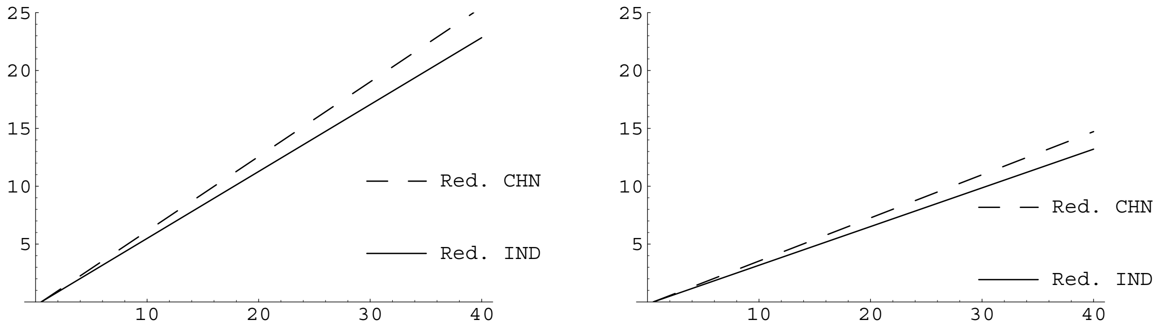

Figure 3: *Emissions reductions by China and India as a function of reductions by Annex B (left picture: US in, right picture: US out). (with respect to 2010 in %)*

reductions gets even wider. If – for example – Annex B (with U.S.) were to reduce by 10%, China would maximally abate 6.1% and India would reduce its emissions no more than by 5.5%. In order to get the same reduction from China / India without the participation of the U.S., the remaining Annex B countries would have to decrease their emissions by 16.9%. Hence, if China and India are equity-oriented as might be concluded from numerous statements in the climate negotiation process, the model suggests that after the U.S. have abandoned the Kyoto protocol, it is much harder to convince these countries to undertake substantial emission reductions.

3 Conclusions

In this paper we analyzed a cooperation between countries when some are interested in equity in terms of average per capita emission levels. Countries differ with respect to their population size and, hence, per capita emission levels. This paper demonstrates how equity orientation of countries changes both the non-cooperative Nash-equilibrium as well as the possible agreements. Small equity-oriented countries with higher than average per capita levels can be expected to voluntarily decrease their emission level beyond the level which equalizes marginal domestic damages and abatement costs. Large equity-oriented countries with small per capita levels, however, would not even internalize their own environmental damages.

We found that preferences for equity of some countries can improve the prospects of cooperation if countries are not too asymmetric with respect to their per-capita levels. The reason is that the reaction function of equity-driven single countries is upward-sloping. Thus, such countries reward the emission reductions by a coalition and thereby give additional incentives to cooperate. If, however, countries differ substantially with respect to their population level and large countries are interested in equity, generally no coalition will be stable without restrictions on joining a coalition. This leads to an increased necessity for building rules which regulate entering or exiting the coalition. If only entries are subject to approval by already cooperating countries, the prospects of cooperation are not less pessimistic than with standard preferences without equity-concerns: Only three countries cooperate in our simulations. There is, however, the possibility of enlarging this coalition by allowing (some) large equity oriented countries to enter.

These equity-oriented countries with low per capita emission levels (such as developing countries in the Kyoto-process) would accede to such an agreement only if it will not reduce their relative emissions share. Thus, these equity-oriented countries would only commit to a small percentage of emission reduction if the already cooperating countries undertake much higher additional abatement. For the possibility of enlarging the coalition, emissions trading is essential: On the one hand, further efficiency gains can be realized; on the other hand, emissions trading allows the uncoupling of the "fair" assignment of allowances and the real domestic emission reductions.

Note that we assumed that countries differ only with respect to their population size. In reality, clearly, they are heterogeneous with respect to abatement costs and environmental damages as well. The consequences of equity orientation for such a setting remains subject of further research.

4 Appendix

Proof of proposition 1:
Note first that if country 2 is large, we have for $z_2^{\text{Nash}} \geq z_1^{\text{Nash}}$ and the Nash-equilibrium is given by

$$-c'(E^N z_1^N) = d'(E^N)$$

Differentiating the payoff to country i in the NTR-case with respect to E and evaluating the expressions at E_E^N gives:

$$\frac{\partial y_i}{\partial E} = -c'(E^N z_i^N) z_i^N - d'(E^N) \leq -c'(E^N z_i^N) - d'(E^N)$$

For $i = 1$, the right hand side equals 0, for $i = 2$, we immediately get from $z_2^N \geq z_1^N$: $-c'(E^N z_2^N) - d'(E^N) \leq -c'(E^N z_i^N) - d'(E^N) = 0$. Therefore, the payoff to both countries can be increased by a proportional reduction of emissions.

Let us now look at the TR-case in which trade is possible. Here, payoff is given by

$$y_i = -c(E/2) - d(E) - (-c'(E/2))(E/2 - Ez_i^N)$$

Hence, differentiation of the respective payoffs gives

$$\frac{\partial y_i}{\partial E} = -c'(E^N/2)z_i^N - d'(E^N) + c''(E^N/2)(1/2)(E/2 - Ez_i^N)$$

For country 2, we obtain:

$$\frac{\partial y_i}{\partial E} \leq -c'(E^N/2) - d'(E^N) \leq -c'(z_1 E^N) - d'(E^N) = 0$$

Hence, at least country 2 wants to reduce aggregate emissions from its Nash-level. Country 1 is better off from the possibility of trading emission allowances. Hence, both countries can be better off with a proportional reduction of emissions (allowances).

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