Emissions trading with non-signatories in a climate agreement – An analysis of coalition stability

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Abstract

We investigate how different designs for a carbon offset mechanism like the Kyoto Protocol's Clean Development Mechanism (CDM) affect the success of self-enforcing climate treaties. In a game-theoretic numerical model of coalition formation it is shown that effects of emission trading with non-signatories are generally negative if strategic behaviour and free-rider incentives are explicitly considered. Even imposing selling targets on credit supplying countries cannot change this result. Only if the volume of credit trading is sufficiently large (due to a sufficiently high heterogeneity between members and non-members) and hence also the gains from trade, this may be different. This, however, requires that treaty members do not use the gains from credit trading to lower their emission caps but stick to modest abatement targets to keep leakage effects at a minimum. Similarly, when allowing for a limited amount of "hot air" to be traded, the gains from higher participation may outweigh the losses of the diluted abatement target.

Keywords: self-enforcing international environmental agreements, emission permit trade, offset mechanisms, clean development mechanism
JEL: C72 (Noncooperative Games), H41 (Public Goods), Q54 (Global Warming), Q58 (Government Policy)

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1. Introduction

The Kyoto Protocol introduced three flexible mechanisms for those countries that accepted emission ceilings (i.e. Annex-I countries). The emission trading system (ETS) and joint implementation (JI) allow to trade emission permits among Annex-I countries, whereas the Clean Development Mechanism (CDM) provides an opportunity for Annex-I countries to buy emission credits from non Annex-I countries (i.e. mainly developing countries which have not accepted an emission cap). The CDM includes an additionality clause which requires that any emission credit offered must correspond to a reduction of emission levels "below [what] would have occurred in the absence of the registered CDM project

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activity" (UNFCCC, 2002, p. 43). All three flexible mechanisms provide abatement cost-saving opportunities. This is in particular true for the CDM because the difference in marginal abatement costs between Annex-I and non Annex-I countries is likely to be large: Annex-I countries have to resort to increasingly costly abatement options to meet their emission caps. Conversely, non Annex-I countries do not have abatement commitments. Additionally, they typically face less steep abatement cost functions compared to Annex-I countries.[1] As compliance costs are a major obstacle to signing ambitious climate treaties, one should expect that all flexible mechanisms, and in particular the CDM, should have a positive effect on the incentive to sign a climate treaty. However, the question arises whether this conclusion is also true when departing from a first-best world and explicitly considering strategic effects. Given the current (so far futile) efforts to negotiate a Post-Kyoto agreement, it is therefore of great importance to understand how the design of an offset mechanism will affect participation and the success of future climate treaties.

In a game-theoretic model of coalition formation there are at least two reasons why a credit trading scheme between members and non-members may not have the intended positive effect on the success of a climate treaty. First, the option of emission credit trading will affect equilibrium emissions of members and non-members of a climate agreement. If lower abatement costs translate into more ambitious abatement targets of members, free-riding, i.e. less abatement by non-members may become more attractive. Second, it is critical that the gains from trade accrue on the side of coalition members – if it is primarily the CDM credit seller who benefits from trading, we cannot expect the agreement to become more attractive. The first issue may be addressed by restricting members' emission allowance choices such that the gains from trade are not used for the implementation of more ambitious abatement targets. The second issue could be addressed through the implementation of selling targets.[2] If Annex-I countries can only sell emission credits that correspond to emission reductions much below baseline emissions, a large share of the gains from trade is shifted to the coalition, making it more attractive to stay in a climate treaty. We investigate the different options in a systematic way.

Our paper draws on two strands of literature. The first strand analyzes the stability of self-enforcing international environmental agreements. This literature goes back to Barrett (1994), Carraro and Siniscalco (1993), and Hoel (1992). Since then various departures from the standard model have been analyzed which include for instance issue linkage (Barrett, 1997; Botteon and Carraro, 1998; Carraro and Siniscalco, 1997; Folmer et al., 1993; Lessmann and Edenhofer, 2010; Lessmann et al., 2009), a minimum participation clause (Carraro et al., 2009), multiple agreements (Asheim et al., 2006; Eyckmans and

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[1] See, for example, the marginal abatement cost curves from two integrated assessment models reported in Criqui et al. (1999).

[2] Selling targets (Kim and Baumert, 2002), similar to non-binding targets (Philibert, 2000) and no-lose targets (Meckling and Chung, 2009), specify an emission path relative to a baseline below which emission reductions can be sold as credits.

Finus, 2006; Finus and Rundshagen, 2003) and modest emission reductions (Barrett, 2002; Finus and Maus, 2008). The two papers closest to ours are Altamirano-Cabrera and Finus (2006) and Hoel and Schneider (1997). However, the first paper analyzes emission trading among coalition members, and not among coalition members and outsiders as we do. Moreover, the total equilibrium emissions are not endogenously affected by the permit trading scheme, but only the distribution of the gains from cooperation. The second paper considers the possibility that coalition members pay non-members for additional emission reductions, though Hoel and Schneider do not use the term CDM. However, as argued in Finus (2003, p. 116-118), this paper suffers from a couple of conceptual shortcomings which by construction lead to smaller coalitions through the CDM.

The second strand of literature analyzes the strategic incentive of a permit trading scheme in which emission allowances are chosen endogenously. Helm (2003) compares a Nash equilibrium without trading to a Nash equilibrium in which permit trading is anticipated in a stylized model. He shows that the effect of permit trading on global emission levels is ambiguous: countries with steep damage cost functions may abate more but countries with flatter damage cost functions may choose larger emission allowances if they anticipate permit trading and how their choice will affect the permit price and the pattern of trade. Moreover, it is shown that an agreement on permit trading that reduces emissions globally may be vetoed by individual countries because it makes them worse off. And, conversely, an agreement implying higher global emissions may be endorsed by all countries due to its welfare enhancing effect. A similar analysis is conducted in Carbone et al. (2009) with a calibrated CGE-model and a focus on treaty participation in the light of general equilibrium effects. However, in their paper, participation in an agreement means something different than in our context of coalition formation. In our context, members of a coalition internalize the externality among themselves (i.e. they cooperate among each other, though not with outsiders) whereas this is not the case in Carbone et al. (2009), where coalition members trade in emission permits but act non-cooperatively. Furthermore, Carbone et al. derive their results for subgame perfect Nash equilibria , i.e. players take the behavior of others as given. In contrast, we remain within the standard approach of internal and external stability, which (in a departure from Nash behavior) lets a player anticipate the change in other players strategies due to the player's membership decision.

In what follows, we informally introduce our model in Section 2 (details are provided in the appendix). Section 3 reports and discusses our results, and Section 4 concludes.

2. The model

2.1. Economic dynamics

We use an extended version of the numerical model MICA (Modeling International Climate Agreements) in our analysis, which builds on the multi-region optimal growth model with international trade presented in Lessmann et al. (2009). The most important extension concerns the in emission allowances. The details of the model are provided in the appendix.

The model is a Ramsey type optimal growth model with N world regions. Each region allocates income to either consumption or investment at every point in time. Welfare, which is the net present value of utility, is maximized by each region. We assume a standard utilitarian utility function, i.e. utility is increasing in per capita consumption with diminishing marginal utility and is discounted at the pure rate of time preference. Income stems from the production of a single good, assuming a neoclassical production function with capital and labor as factor inputs. Economic growth is driven by exogenous population growth as well as exogenously improving labor productivity.

Greenhouse gas emissions are modeled as a byproduct of economic activity. The global total of emissions drives greenhouse gas concentration, which in turn determines the temperature increase relative to pre-industrial levels. The damage function, adapted from Nordhaus and Boyer (2000), translates global warming into economic impact. Impacts can be reduced at the cost of investing in a generic mitigation option, which lowers the emission intensity of economic production.

An alternative way of abating emissions is to buy emission allowances from other regions. This is implemented by introducing endogenous allowance choices as a strategic variable for all regions. Hence, a region's emissions may exceed its allowances if this is compensated by imported emission allowances. Likewise, regions may export emission allowances by choosing emission levels below their current allowances. In accordance with the Kyoto Protocol, we introduce two restrictions on allowance trading between coalition members and outsiders: (1) Under the Kyoto Protocol, countries that provide CDM credits must be signatories of the protocol but without abatement commitment (i.e. they are non Annex-I countries) and conversely Annex-I countries may never offer CDM credits. Therefore, we distinguish between "regular" non-members and a representative CDM-supplier who can offer CDM credits to coalition members but who will never join the coalition.[3] (2) Following the Kyoto Protocol's additionality clause, we make it a default requirement that CDM credits represent true emission reductions (as opposed to so called "hot air").[4] We assume a perfectly competitive market of emission allowances. Trade in goods is the means to finance imports of allowances. Goods from different regions are perfect substitutes.

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[3] This allows us to determine the equilibrium in the first stage as the endogenous outcome of the membership game between $N-1$ players, deciding whether to become a member or non-member.

[4] In model runs without such an additionality constraint the CDM-supplier prefers to sell large amounts of "hot air." This turns out to have a strongly negative effect on coalition stability, as buying "hot air" drives up the costs of being a coalition member, making an effective climate policy very unlikely.

2.2. Calibration

In most parts of the analysis, we restrict our attention to symmetric players as it is common practice in many stylized models of coalition formation (e.g. Ulph, 2004; Barrett, 2006; Carraro et al., 2009), since it makes the analysis of coalition formation more transparent. Nevertheless, we calibrate the model such that aggregate values (e.g. global totals of emissions and economic output as well as greenhouse gas concentration and temperature increase) correspond to those of other climate-economy growth models, e.g. RICE-2010 (Nordhaus, 2010), REMIND-R (Leimbach et al., 2010), or WITCH (Bosetti et al., 2006). For instance, in the business as usual scenario, which corresponds to the non-cooperative equilibrium with no CDM trade, average economic growth over the next century is approximately 2.4 percent (cf. 2.2 percent in RICE-2010), and CO_2 emissions rise from close to 8GtC in 2005 to about 20GtC in 2105 (cf. 7.8GtC and 19.5GtC in RICE-2010), triggering a temperature rise by 2.0°C in 2105 with climate change damages amounting to 6.1 percent of economic output (cf. 2.8°C and 3.3 percent in RICE-2010). In contrast, under fully cooperative behavior (i.e. all climate change damages are internalized), global CO_2 emissions in 2105 are 13.8GtC; the associated increase in global mean temperature is 1.5°C with damages amounting to 4.1 percent of economic output that year (cf. 2.0°C and 2.3 percent in RICE-2010).[5]

2.3. The coalition formation game

The aim of this study is to investigate the impact of various CDM designs on the success of self-enforcing international environmental agreements. We follow the mainstream of the literature and model an agreement as a two-stage cartel formation game. In the first stage, players decide about their membership, i.e. whether to sign the agreement, and hence become a coalition member, or to remain a non-member, acting as a singleton. In the second stage, they decide on their economic strategies. That is, they decide upon consumption, trade in the consumption good, allocation of investment to production and mitigation (this implicitly determines their level of their emissions), and upon emission allowances. The choices of emissions and emission allowances also determine the export of excess allowances or the required import of allowances.

The entire game is solved by backwards induction with the understanding that strategies form a Nash equilibrium in each stage. In the first stage, this corresponds to the concept of internal and external stability (going back to d'Aspremont and Gabszewicz, 1986), implying that no signatory should have an incentive to leave the agreement and no non-signatory wants to join the agreement. In the second stage, this corresponds to a Nash equilibrium between the coalition (maximizing the joint payoff of the coalition) and the singletons (maximizing their individual payoffs), called partial Nash equilibrium (PANE,

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[5] Data from RICE-2010 is taken from figures in Nordhaus (2010) and its supporting material where possible, and from the available spreadsheet version of the model otherwise.

Chander and Tulkens, 1995) in the specific context of a single coalition, and in the more general context of a social coalitional equilibrium (Ichiishi, 1981).

2.4. Scenarios

In our analysis of different designs for offset mechanisms, we consider the following different policy scenarios:

NT. As a benchmark, we consider the "No Trade" scenario. This scenario serves to explore the incremental effects of allowing for CDM trade; all discussions of relative effects will be related to the NT case. In contrast, we will refer to model runs with no coalition (the "all singletons" coalition structure) as the non-cooperative equilibrium.

CDM/xa. This scenario introduces CDM trade *ex ante*, i.e. the CDM clause of the agreement is known *before* the membership decision is taken. Consequently, players' decisions in the emission game will be taken in anticipation of CDM trade. We interpret this case as joint negotiations of the abatement commitments and the CDM clause of the agreement.

CDM/xp. We will see in Section 3 that CDM/xa is counterproductive to the success of agreements, as the anticipation of low mitigation options through the CDM ultimately increases the incentive to free-ride. An alternative design of the negotiation process circumvents this effect by adding the CDM clause to the agreement *ex post* (CDM/xp), i.e. *after* abatement commitments have been negotiated. This amounts to negotiating abatement commitment and CDM clause separately. In effect, we ensure that the coalition's emission level does not drop below the NT baseline. This implies that we exclude non-members from the benefits of additional abatement due to CDM trade.

Selling targets. We generalize the Kyoto Protocol's concept of additionality by introducing *selling targets* for the CDM-supplier. A selling target specifies reductions relative to the NT baseline that need to be achieved before any emission credits can be sold under the CDM agreement. We refer to a selling target below the NT baseline as being *stringent*, a selling target above the baseline is said to introduce *hot air* into the allowance trading system. Our default requirement of additionality is the special case where the baseline is the selling target, in other words a selling target $sel = 0.0$, whereas a selling targets of $sel = 0.1$ requires a 10 percent reduction below the NT baseline.

3. Results and discussion

3.1. The "No Trade" baseline (NT)

We begin the discussion of our model results with the NT baseline. The stability functions in Figure 1 show the difference between the payoff received as a member of a coalition with n members, and the payoff received by a non-member after leaving and thus reducing the coalition size to $n-1$ members.

A coalition with n members is internally stable if the stability function is non-negative at n and externally stable if it is negative at $n + 1$. Thus, the stability function for NT indicates that only a coalition of 2 is stable.

[Figure 1 about here.]

3.2. Introducing CDM trade (CDM/xa)

Figure 1 also shows how coalition stability changes when CDM trade is part of the agreement decided upon in the membership stage game (denoted CDM/xa). Evidently, introducing CDM trade is counterproductive to raising participation since the stability function lies below the stability function of the NT baseline case.

The reason is that CDM trading makes cheaper abatement available to coalition members: the coalition chooses lower emission allowances than the CDM-supplier because the coalition internalizes damages among its members. Hence, without trade, marginal abatement costs are higher compared to those outside the coalition. With trade, the lower marginal abatement costs of the CDM-supplier are exploited until marginal abatement costs are equalized. This is evident from Figures 2 and 3: for CDM/xa, the emissions of the CDM-supplier and the allowances of coalition members are at the same level due to the symmetry assumption and equalization of marginal costs. Coalition members choose lower emission allowances than their baseline emissions NT and buy the necessary emission credits from the CDM-supplier. The CDM-supplier's equilibrium emission allowances correspond to the upper limit of baseline emissions NT due to the additionality clause. The difference to equilibrium emissions is sold to members.

Overall, the abatement cost reduction from CDM trade, which encourages the coalition to aim for more ambitious abatement targets, results in lower global emissions despite a small leakage effect in the form of an increase in equilibrium emissions by non-members (not shown). Thus, non-members benefit from lower damages and lower abatement costs. Though coalition members also benefit from lower damages, the availability of cheaper abatement options is used to buy more abatement and hence total abatement costs will not necessarily drop. Therefore, the gains from trading are larger for non-members than for members and hence it becomes more attractive to leave a coalition of a given size as displayed in Figure 1.

[Figure 2 about here.]

[Figure 3 about here.]

3.3. CDM trade with selling targets (CDM/xa/sel)

Figure 4 provides an alternative illustration why CDM trade does not lead to larger coalitions: The global gains from CDM trade compared to the NT baseline are unequally distributed among the different groups of players. For the default value of a zero selling target, which corresponds to the additionality assumption, all the welfare gains are appropriated by non-members and the CDM-supplier. In particular the CDM-supplier benefits from selling emission allowances to coalition members. This is shown in Figure 4 for a fixed coalition size of five members but it also holds for other coalition sizes.

[Figure 4 about here.]

[Figure 5 about here.]

Figure 4 also visualizes how the gains from CDM trade may be shifted from the CDM-supplier to coalition members using selling targets. Selling targets specify emission reductions for the CDM-supplier relative to their business-as-usual emissions projected for this particular coalition size (in our case this is the NT scenario) that they need to achieve before engaging in CDM trade. For instance, a selling target of 0.2 implies that the CDM-supplier has to reduce 20 percent compared to baseline emissions before selling emission credits.

More stringent selling targets shift welfare gains from the CDM trader towards coalition members. Essentially, by imposing selling targets the coalition receives an emission reduction up to the selling target for free and only pays for additional emission reductions beyond the target. These gains come at the expense of the CDM-supplier. In equilibrium, global levels of welfare and emissions remain constant when increasing selling targets as is evident from Figure 5.

In view of the fact that selling targets improve welfare of coalition members, a positive effect of selling targets on stability is very plausible. This is confirmed by Figure 6, which shows isolines of the stability function for non-negative values. All points within this area correspond to internally stable coalitions, and coalitions “on the frontier” of this set are also externally stable. However, things are slightly more complicated because credit trade must also be profitable for the supplier, i.e. the CDM-supplier, in order to be a feasible global equilibrium. This condition is also visualized in Figure 6 using isolines to indicate non-negative welfare gains for the CDM-supplier. Therefore, only points in the area of intersection of these two areas are feasible solutions. In fact, this implies that no coalition larger than 2 members is stable and profitable for the CDM-supplier at the same time, which is the level of cooperation we already found in the baseline scenario NT.

[Figure 6 about here.]

[Figure 7 about here.]

In summary, the first type of offset design in the form of adding a CDM to the coalition agreement had a negative impact on coalition stability: the benefits from CDM trade are realized on the side of the CDM-supplier rather than on the side of coalition members; more importantly, non-member payoffs are increased, which raises the incentive to free-ride. In theory, selling targets allow to shift the benefits from the CDM-supplier to the coalition, which has a stabilizing effect on the latter. However, whenever larger coalitions could be obtained, this is prevented by the violation the profitability constraint on the side of the CDM-supplier.

3.4. Introducing CDM trade ex post *(CDM/xp and CDM/xp/sel)*

From the previous section it became apparent that CDM credit trading encourages free-riding when coalition members anticipate CDM trade prior to (*ex ante*) their abatement decision, and hence abate in excess of the NT scenario. In the CDM/xp scenario, CDM trade is therefore introduced only after (*ex post*) the decision on abatement by coalition members has been made: we implement a constraint on coalition members' emission allowances such that they cannot revise their original abatement decision.

Analogous results to the CDM/xa calculations for the CDM/xp case are shown in the previous figures for coalition stability (Figure 1), emissions from coalition members (Figure 2) and the CDM-supplier (Figure 3). Figure 5 compares the CDM/xp to the CDM/xa scenario from the previous section in terms of global emissions and welfare. For the default additionality assumption (i.e. a zero selling target) welfare gains in the CDM/xa scenario exceed those of the new CDM/xp setting because the additional constraint in CDM/xp prevents further abatement by the coalition (cf. global emissions in the figure). Furthermore, we see that due to the additionality clause and the *ex post* setting, equilibrium allowances of members and CDM-supplier correspond to their NT baseline emissions (Figures 2 and 3), and their emissions are higher than under CDM/xa (Figures 2 and 3). Coalition stability is slightly improved under CDM/xp, but this is is not sufficient to achieve a coalition larger than 2 members (see Figure 1). Consequently, we now turn to explore whether selling targets could help to improve stability as they did in the CDM/xa scenario.

The effect of selling targets on global emissions and welfare is shown in Figure 5. Selling targets require additional abatement from the CDM-supplier, and abatement of the coalition is effectively fixed by the CDM/xp assumptions. Therefore, selling targets reduce global emissions. Since this moves global emissions closer to the social optimum, it has a positive impact on global welfare. Quite the contrary under CDM/xa, selling targets only redistributed welfare gains among players, leaving the global levels of welfare and emissions untouched.

The effect on coalition stability and on the profits of the CDM-supplier are shown in Figure 7. Again, like in the CDM/xa scenario illustrated in Figure 6, the area of feasible solutions is small, namely the overlapping area, where coalitions are stable and CDM trade is profitable for the supplier (despite the selling target). On the one hand, the area of profitability becomes smaller compared to the CDM/xa scenario. This is because coalition members choose higher emission allowances and hence buy less emission credits from the CDM-supplier. On the other hand, the area of stability does not increase with more stringent selling targets as before in CDM/xa scenario since members and non-members benefit from globally reduced emission levels more or less to the same extent (Figure 8). Only for negative selling targets (i.e. hot air) can this trend be reversed. While the world is actually worse off with negative selling targets for a given coalition size (Figure 5) and so are both members and non-members (Figure 8), the negative effect on non-members exceeds the one on members.

Both are negatively affected by the higher global emission level. However, for coalition members this is partially offset by the greater amount of CDM credits which are now available at a lower price, leading to a stabilization of a coalition of three members for a selling target of -0.1. Thus, there is a trade-off between global welfare and environmental effectiveness by allowing for hot air and larger coalition sizes. The effect is similar to the idea of "modest" emission reductions analyzed in Finus and Maus (2008). Hence, if hot air generates sufficiently larger stable coalitions, the overall effect may be positive. Figure 10, discussed in detail at the end of the next section, illustrates this effect further.

[Figure 8 about here.]

3.5. Increasing the volume of CDM trade

For the coalition the emission reductions achieved through CDM credits are relatively small compared to their overall reductions. For example, CDM credits make up 17 percent of abatement of a 5 player coalition (assuming symmetry and zero selling target) whereas the UK national allocation plan proposes a 2/3 contribution of CDM credits (DEFRA, 2006).[6] This is because in the symmetric setup with one CDM-supplier, the region selling CDM credits only accounts for one ninth of the world. In reality, non-Annex I countries account for about half of global emissions.[7] Thus, it is likely that we underestimate the volume of CDM credit trade due to this assumption.

One simple way of modeling a higher increased potential for CDM trade is to increase the volume of available permits on the market. We introduce this idea by reducing the marginal cost of abatement in the CDM-supplier region such that more low cost CDM credits can be supplied.[8] To keep everything else as much the same as possible (compared to symmetry), i.e. to be able to discuss the effects in a *ceteris paribus* manner, we simultaneously reduce marginal damages.[9] This way, we are able to obtain scenarios where emissions in the newly parameterized CDM-supplier regions are about the same as before as long as there is no CDM trade. In case of a 5 player coalition, these measures raise the contribution of CDM trade is raised from 17 percent to 67 percent.

Figure 9 shows that introducing heterogeneity for the CDM-supplier increases both, the area of coalition stability and the area of profitable CDM trade. The increased volume of traded credits implies larger welfare gains from trade. These gains partly accrue to the coalition with a positive effect on its stability, and partly to the CDM-supplier making credit trade more profitable.

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[6] The contribution of CDM credits to mitigation is computed as the ratio of imported credits to overall abatement, where the latter is the difference between emissions in the non-cooperative equilibrium and allowance choice in a given PANE.

[7] According to the World Resources Institute, 55.1 percent of global CO_2 was emitted by developed countries versus 44.9 percent by developing countries in 2005 (CAIT, 2009).

[8] In terms of the model equations given in the appendix, this is implemented by increasing the investment effectiveness parameter ξ in Equation A.9.

[9] Implemented by reducing parameter θ_1 of the damage function in Equation A.15.

In fact, even with stringent selling targets is the profitability of credit trade always guaranteed.[10]

As before in the symmetric case of the CDM/xp/sel scenarios (Figure 7), participation is higher for less stringent selling targets, and again, higher participation can be 'bought' at the cost of allowing some hot air in credit trade.

Figure 10 summarizes the effect of *ex post* credit trade on participation in the agreement and global welfare. Under CDM/xp we find a positive effect of CDM credit trade on coalition stability, measurable in form of an increase in participation by several members. Figure 10 also indicates the level of welfare associated with the stable coalition that are achieved due to trade in CDM credits on a scale from 0 percent (non-cooperative equilibrium) to 100 percent (full cooperation, social optimum).[11] This emphasizes a point we hinted at earlier: (i) introducing hot air can stabilize an agreement in the CDM/xp scenario (notice that participation is always greater or equal), and (ii) this comes at the expense of reduced environmental effectiveness and global welfare levels (notice the lower welfare levels where participation is the same), but (iii) the overall benefits outweigh the loss. Therefore, introducing some hot air may pay off.

[Figure 9 about here.]

[Figure 10 about here.]

Sensitivity

In order to test the robustness of the findings in Figure 10, we conducted model runs with different values for key model parameters. Recall that in the CDM/xp scenario coalition size rises with increasing heterogeneity from 2 players (for the symmetric set-up) to 4 players (with maximum heterogeneity), and from 3 to 5 for scenarios with hot air (CDM/xp/sel=-0.1).

Table 1 summarizes results from additional runs for the CDM/xp/sel=-0.1 scenario for exemplary *high* and *low values* of the parameter, reporting participation for the no trade (NT) scenario, and the cases of symmetry and maximum heterogeneity.[12] Values for participation that deviate from the default calculations are in bold face.

The results in Table 1 suggest a good degree of robustness of our results: deviations from the default are rare, and participation never deviates from the default by more than 1. Furthermore, even with these deviations, our conclusion that there is a positive effect on participation due to CDM trade (magnified by heterogeneity) holds for all parameter variations.

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[10] One might suspect that heterogeneity also amplifies the effects of CDM trade in the CDM/xa scenarios, in particular that coalition stability is strongly reduced. We have confirmed this intuition in additional calculations, which we do not discuss further to keep the exposition short.

[11] Without CDM, participation remains at 2 independent of the degree of heterogeneity.

[12] The NT scenario produces the same participation results regardless whether there is symmetry or some degree of heterogeneity because due to the *ceteris paribus* condition, heterogeneity does not affect the behavior of members and non-members (cf. Section 3.5).

[Table 1 about here.]

4. Conclusion

This paper explored how the success of a self-enforcing climate agreement is affected by emission trading between members and non-members. This captures the concept of the Clean Development Mechanism (CDM) under the current Kyoto Protocol. In a first-best world, the CDM will clearly have an unequivocally positive effect, as it lowers total abatement cost. However, in a world with strategic interaction and free-rider incentives, this is less evident. If the gains from CDM trade are higher for non-members than for members, participation in a climate treaty is actually discouraged. More specifically, in our game-theoretic model of coalition formation, two main driving forces could be identified which illustrate that conclusions are anything else than straightforward. On the one hand, the option of emission credit trading will affect equilibrium emissions of members and non-members of a climate agreement. If lower abatement cost translate into more ambitious abatement targets of the members of the agreement, free-riding and thus less abatement by non-members may become more attractive. On the other hand, if the bulk of the gains from CDM trading accrue to the CDM-supplier rather than to the coalition, there is little room to improve the agreement. Hence for the success of future climate treaties, it is of high importance to understand how various designs of CDM trading will affect the success of climate change policy.

We have shown that if emission credit trading is anticipated already during the negotiation of a climate treaty, and no restrictions are imposed, then a negative impact on participation and hence on the overall success of a climate agreement has to be expected. In equilibrium, the access to cheaper abatement via CDM trading means that members choose lower emission allowances; non-members benefit from the associated reduced temperature increase, and from raising their own emissions in response.

In these calculations, imposing an additionality clause allowing only emission reductions below baseline emissions to be sold as emission credits (similar to the additionality clause Kyoto Protocol), has proven very important. In fact, hot air undermines the environmental effectiveness but also the stability of the agreement. Better results with respect to participation could be obtained by introducing so called selling targets, which allow only emission reductions in excess of a certain threshold to be sold to members. This allows members to appropriate a larger share of the gains from trade. Unfortunately, it turned out that whenever this share becomes sufficiently large to allow for larger stable coalitions, it is no longer attractive for the CDM-supplier to engage in trading.

In view of this negative result, we investigated the implications of a CDM trading that is not anticipated at the stage of negotiating a climate treaty but negotiated separately, once coalition members have committed themselves to abatement targets. This implies less ambitious abatement targets of the members of the agreement and also smaller leakage effects caused by non-members. Although going in the right direction, in our model it turned out that without further modifications this will also not have a significant effect. Only if marginal abatement costs between members and those offering emission credits are assumed to be sufficiently large, such that the volume of CDM-credit trading and the gains from trade increase significantly, could we obtain more successful coalitions.

The role of hot air in this setting turned out to be ambivalent: while it reduces the environmental effectiveness of the agreement, which is reflected also in reduced global welfare levels, it may help to draw additional members into the coalition. This is because it is less costly to comply with the watered down agreement. However, such a larger coalition may actually outperform a smaller coalition without hot air.

Overall, it is fair to say that our results are quite pessimistic. They clearly suggest that if implemented naively (e.g. ignoring strategic aspects and the need for self-enforcing agreements) and without careful design, A CDM may do more harm than good. One should resist the temptation to use the cost savings derived from trade to aim for a more ambitious climate agreement. Moreover, the offset mechanism has to be designed such as to channel as much as possible of the gains towards treaty members, without discouraging the supply side of emission credits too much.

Evidently, our model shares many restrictions of most stylized models. We think the most interesting extension for future research concerns dynamic membership. That is, whereas in our model the membership is a one-shot decision, one could allow for the possibility that countries can revise their decision continuously like in Rubio and Ulph (2007). Such an extension would allow studying how the design of emission credit schemes affects participation in successive climate agreements.

References

Altamirano-Cabrera, J., Finus, M., 2006. Permit trading and stability of international climate agreements. Journal of Applied Economics 9, 19–47.

Asheim, G., Froyn, C., Hovi, J., Menz, F., 2006. Regional versus global cooperation for climate control. Journal of Environmental Economics and Management 51, 93–109.

Barrett, S., 1994. Self-enforcing international environmental agreements. Oxford Economic Papers 46, 878–894.

Barrett, S., 1997. The strategy of trade sanctions in international environmental agreements. Resource and Energy Economics 19, 345–361.

Barrett, S., 2002. Consensus treaties. Journal of Institutional and Theoretical Economics 158, 529–547.

Barrett, S., 2006. Climate Treaties and “Breakthrough” Technologies. The American Economic Review 96, 22–25.

Bosetti, V., Carraro, C., Galeotti, M., Massetti, E., Tavoni, M., 2006. WITCH: A World Induced Technical Change Hybrid model. The Energy Journal Special Issue Hybrid Modelling of Energy Environment Policies: Reconciling Bottom-up and Top-down, 13–38.

Botteon, M., Carraro, C., 1998. Game Theory and the Global Environmental. Edward Elgar Publishing, Cheltenham, UK. chapter Strategies for environmental negotiations: issue linkage with heterogeneous countries. pp. 180–200.

CAIT, 2009. Climate Analysis Indicators Tool (CAIT) version 6.0. Washington, DC: World Resources Institute. Available online: http://cait.wri.org.

Carbone, J., Helm, C., Rutherford, T., 2009. The case for international emission trade in the absence of cooperative climate policy. Journal of Environmental Economics and Management 58, 266–280.

Carraro, C., Marchiori, C., Oreffice, S., 2009. Endogenous minimum participation in international environmental treaties. Environmental and Resource Economics 42, 411–425.

Carraro, C., Siniscalco, D., 1993. Strategies for the international protection of the environment. Journal of Public Economics 52, 309–328.

Carraro, C., Siniscalco, D., 1997. International Environmental Agreements – Strategic Policy Issues. Edward Elgar Publishing. chapter R&D Cooperation and the Stability of International Environmental Agreements. pp. 71–95.

Chander, P., Tulkens, H., 1995. A core-theoretic solution for the design of cooperative agreements on transfrontier pollution. International Tax and Public Finance 2, 279–93.

Criqui, P., Mima, S., Viguier, L., 1999. Marginal abatement costs of CO_2 emission reductions, geographical flexibility and concrete ceilings: an assessment using the POLES model. Energy Policy 27, 585–601.

DEFRA, 2006. EU Emissions Trading Scheme, UK National Allocation Plan. Available at http://www.defra.gov.uk/environment/climatechange/trading/eu/phaseII-nap.pdf.

d'Aspremont, C., Gabszewicz, J.J., 1986. New Developments in the analysis of market structures. Macmillan, New York. chapter On the stability of collusion. pp. 243–64.

Eyckmans, J., Finus, M., 2006. Coalition formation in a global warming game: how the design of protocols affects the success of environmental treaty-making. Natural Resource Modeling 19, 323–358.

Finus, M., 2003. The International Yearbook Of Environmental And Resource Economics 2003 – A Survey of Current Issues. Edward Elgar Publishing. chapter Stability and design of international environmental agreements: the case of transboundary pollution. pp. 82–158.

Finus, M., Maus, S., 2008. Modesty may pay. Journal of Public Economic Theory 10, 801–826.

Finus, M., Rundshagen, B., 2003. The Endogenous Formation of Economic Coalitions. Edward Elgar. chapter Endogenous Coalition Formation in Global Pollution Control: A Partition Function Approach. pp. 199–243.

Folmer, H., Mouche, P., Ragland, S., 1993. Interconnected games and international environmental problems. Environmental and Resource Economics 3, 313–335.

Helm, C., 2003. International emissions trading with endogenous allowance choices. Journal of Public Economics 87, 2737–2747.

Hoel, M., 1992. International environment conventions: The case of uniform reductions of emissions. Environmental and Resource Economics 2, 141–159.

Hoel, M., Schneider, K., 1997. Incentives to participate in an international environmental agreement. Environmental and Resource Economics 9, 153–170.

Ichiishi, T., 1981. A social coalitional equilibrium existence lemma. Econometrica: Journal of the Econometric Society 49, 369–377.

Kim, Y.G., Baumert, K.A., 2002. Building on the Kyoto Protocol: Options for Protecting the Climate. World Resources Institute. chapter Reducing Uncertainty Through Dual-Intensity Targets. pp. 109–133.

Leimbach, M., Bauer, N., Baumstark, L., Edenhofer, O., 2010. Mitigation costs in a globalized world: climate policy analysis with REMIND-R. Environmental Modeling and Assessment 15, 155–173.

Lessmann, K., Edenhofer, O., 2010. Research cooperation and international standards in a model of coalition stability. Resource and Energy Economics , doi:10.1016/j.reseneeco.2010.01.001.

Lessmann, K., Marschinski, R., Edenhofer, O., 2009. The effects of tariffs on coalition formation in a dynamic global warming game. Economic Modelling 26, 641–649.

Meckling, J., Chung, G., 2009. Sectoral approaches for a post-2012 climate regime: a taxonomy. Climate Policy 9, 652–668.

Negishi, T., 1972. General Equilibrium Theory and International Trade. North-Holland Pub. Co.

Nordhaus, W., Boyer, J., 2000. Warming the world: economic models of global warming. The MIT Press.

Nordhaus, W.D., 2010. Economic aspects of global warming in a post-Copenhagen environment. Available online at http://nordhaus.econ.yale.edu.

Nordhaus, W.D., Yang, Z., 1996. A regional dynamic general-equilibrium model of alternative climate-change strategies. The American Economic Review 86, 741–765.

Petschel-Held, G., Schellnhuber, H.J., Bruckner, T., Tóth, F.L., Hasselmann, K., 1999. The tolerable windows approach: Theoretical and methodological foundations. Climatic Change 41, 303–331.

Philibert, C., 2000. How could emissions trading benefit developing countries. Energy Policy 28, 947–956.

Rubio, S., Ulph, A., 2007. An infinite-horizon model of dynamic membership of international environmental agreements. Journal of Environmental Economics and Management 54, 296–310.

Ulph, A., 2004. Stable international environmental agreements with a stock pollutant, uncertainty and learning. The Journal of Risk and Uncertainty 29, 53–73.

UNFCCC, 2002. Report to the Conference of the Parties on its seventh session, held at Marrakesh from 29 October to 10 November 2001 (Marrakesh Accords) – Part II: Action taken by the Conference of the Parties. Available online at: http://unfccc.int/resource/docs/cop7/13a02.pdf.

Appendix A. Model Equations

In this section, we present the details of our numerical model. The model builds on Lessmann et al. (2009) and Lessmann and Edenhofer (2010) and is extended to include endogenous choice and trade of emission allowances. Deviations from the original model will be made explicit.

Preferences

We model the world economy as a set of N regions (or players). Players decide in an intertemporal setting which share of income to consume today and which share to save and invest for future consumption. Intertemporal welfare W_i and instantaneous utility U derived from per capita consumption are given by:

$$W_i = \int_0^\infty l_{it}\, U(c_{it}/l_{it})\, e^{-\rho t}\, \mathrm{dt} \tag{A.1}$$

$$U(c_{it}/l_{it}) = \begin{cases} \dfrac{(c_{it}/l_{it})^{1-\eta}}{1-\eta} & \text{if } \eta \neq 1 \\ \log(c_{it}/l_{it}) & \text{if } \eta = 1 \end{cases} \tag{A.2}$$

where c_{it} and l_{it} denote consumption and labor in region i at time t, respectively. Parameter ρ is the pure rate of time preference, and parameter η denotes the elasticity of marginal utility.

Technology

The economic output y_{it} in each region is produced with a Cobb-Douglas production technology F with a capital income share of β. Climate change damages (to be defined below in Equation A.15) destroy a fraction $1 - \Omega_{it}$ of the production.

$$\begin{aligned} y_{it} &= \Omega_{it} F(k_{it}, l_{it}) && \text{(A.3)} \\ F(l_{it}, k_{it}) &= (\lambda_{it} l_{it})^{1-\beta} k_{it}^{\beta} && \text{(A.4)} \end{aligned}$$

Labor l_{it} is given exogenously, as is labor productivity λ_{it}, which grows at a fixed rate α. Capital k_{it} accumulates with investments i_{it} assuming zero depreciation.

$$\begin{aligned} \frac{d}{dt} k_{it} &= i_{it} && \text{(A.5)} \\ & && \text{(A.6)} \end{aligned}$$

Emissions and Emission Allowances

Greenhouse gas emissions e_{it} are a byproduct of economic activity y_{it}. We assume that the emission intensity falls exogenously due to technological progress at rate ν. Beyond this, emissions may be reduced by investments b_{it} into abatement a_{it}, bringing down the instantaneous emission intensity σ_{it}. Parameter ξ describes the effectiveness of these investments, and γ the effectiveness of the abatement option.

$$\begin{aligned} e_{it} &= \sigma_{it}\, e^{-\nu\, t}\, y_{it} && \text{(A.7)} \\ \sigma_{it} &= (1 + a_{it})^{-\gamma} && \text{(A.8)} \\ \frac{d}{dt} a_{it} &= \xi\, b_{it} && \text{(A.9)} \end{aligned}$$

Emissions cannot exceed allowances q_{it}, which in our model are chosen endogenously by individual regions. Emission allowances may be traded internationally (z_{it} denotes allowance exports by region i), but we exclude intertemporal banking and borrowing, i.e. total imported and exported allowances must be balanced in every period.

$$\begin{aligned} e_{it} &= q_{it} - z_{it} && \text{(A.10)} \\ \sum_j z_{jt} &= 0, \qquad t = 1, \ldots && \text{(A.11)} \end{aligned}$$

Climate Dynamics

Global warming is driven by total global emissions of CO_2 into the atmosphere, which are equal to cumulative total emission allowances q_{it}.[13] For details on the following simple climate equations, see Petschel-Held et al. (1999).

$$\begin{aligned} \frac{d}{dt}C_t &= \zeta \sum_j q_{jt} - \kappa(C_t - C_0) + \psi\, E_t && \text{(A.12)} \\ \frac{d}{dt}E_t &= \sum_j q_{jt} && \text{(A.13)} \end{aligned}$$

Equation A.12 translates global emissions into carbon concentration in the atmosphere C. Concentration C rises with global allowances (same as emissions), where ζ converts emissions into a change in concentration, and it decreases due to the carbon uptake of the oceans proportional (κ) to the increase above the pre-industrial level C_0. The final term limits the ocean carbon uptake (to the fraction $1 - \psi/\zeta\kappa$ in equilibrium).

$$\frac{d}{dt}T_t = \mu \log(C_t/C_0) - \phi(T_t - T_0) \qquad \text{(A.14)}$$

Equation A.14 transforms concentration levels into a global mean atmospheric temperature increase T. Here, parameter μ controls the strength of the temperature reaction to a change in concentration, whereas parameter ϕ is related to its timing. Together, they have an interpretation as the "climate sensitivity" ($\mu/\phi \cdot \log 2$), i.e. the equilibrium temperature increase for a doubling of the concentration. In view of the inertia of the climate system, we run the model for 250 years in steps of 10 years.

The climate change damage function is taken from Nordhaus and Yang (1996):

$$\Omega_{it} = 1/(1 + \theta_{1i}(T_t)^{\theta_{2i}}) \qquad \text{(A.15)}$$

Two sets of "book keeping" equations complete the model: the budget constraints for consumption and investments for each region at every point in time, as well as the intertemporal budget constraint ensuring that over the entire time horizon, the import value must equal the export value in each region.

$$\begin{aligned} y_{it} + m_{it} &= c_{it} + i_{it} + b_{it} + x_{it} && \text{(A.16)} \\ \int_0^\infty p_t\, m_{it}\, \mathrm{dt} &= \int_0^\infty p_t\, x_{it} + p_t^z\, z_{it} \mathrm{dt} && \text{(A.17)} \end{aligned}$$

Variables m_{it} and x_{it} are imports and exports of region i, respectively, and p_t and p_t^z are the prices of goods and allowances.

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[13] This is different from the previous model versions where global emissions rather than allowance choices entered in this equation. The numbers are the same, i.e. $\sum_j e_{jt} = \sum_j q_{jt}$, but when the choice of allowances is endogenous, it is important that their impact on climate change is taken into account.

Solving the model for the game's equilibrium

As detailed in the main text, we are considering a two stage game of, first, *membership* in an international environmental agreement (IEA), and second, an *emission game* where players choose their emission allowances.

The game is solved numerically by backward induction, i.e. first we compute PANE for all possible coalitions, then we test these coalitions for internal and external stability according to the following criteria:

$$W_i|_S \quad \geq \quad W_i|_{S\setminus\{i\}} \text{ for } i \in S \quad \text{(internal stability)} \tag{A.18}$$

$$W_j|_S \quad > \quad W_j|_{S\cup\{j\}} \text{ for } j \notin S \quad \text{(external stability)} \tag{A.19}$$

The computation of the PANE for the second stage is complicated by the fact that we are looking at an intertemporal optimization model featuring an environmental externality as well as international trade. To our knowledge, there are no out-of-the-box solvers available to solve such a model in primal form. Lessmann et al. (2009) suggest an iterative approach based on Negishi's approach (Negishi, 1972). For this study, we use a modified version of the iterative algorithm, which works as follows:

Negishi's approach searches for the social planner solution that corresponds to a competitive equilibrium by varying the weights δ_i in the joint welfare maximization:[14]

$$\max_{\{i_{jt}, b_{jt}, m_{jt}, x_{jt}, z_{jt} \;:\; j=1\ldots N\}} \quad \sum_{i=1}^{N} \delta_i \, W_i \tag{A.20}$$

$$\text{subject to Equations A.1-A.16} \tag{A.21}$$

Since this exploits the fundamental theorems of welfare economics, the approach cannot be applied for an economy with externalities. In principle, this problem is circumvented by making any external effect on other players exogenous to model (turning variables into parameters that are adjusted in an iteration).

Here, the externalities are climate change damages through aggregate global emissions. In Nash equilibrium, players will only anticipate the effect that their emissions have on their own economic output, not the effect onto other players' output. We can mimic this in a social planner solution by giving each player his own perception of the causal link between emissions and global warming. Instead of Equation A.12, which describes one trajectory of concentration C_t,

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[14] Note that the intertemporal budget constraint Equation A.17, which contains the (*a priori* unknown) market clearing prices is omitted from the model.

we introduce N equations for C_{it}:

$$\frac{d}{dt}C_{it} = \zeta\left(q_{it} + \sum_{j\neq i}\overline{q_{jt}}\right) - \kappa(C_t - C_0) + \psi\, E_t \qquad \forall_{i\notin S} \tag{A.22}$$

$$\frac{d}{dt}C_{it} = \zeta\left(\sum_{k\in S} q_{kt} + \sum_{j\notin S}\overline{q_{jt}}\right) - \kappa(C_t - C_0) + \psi\, E_t \qquad \forall_{i\in S} \tag{A.23}$$

Here, the allowance choices of other players enter as a fixed value (a parameter, indicated by the bar), set to the levels of the corresponding variables during the previous iteration (or some initial value). The sum of allowances in Equation A.13 needs to be adjusted analogously, and the temperature Equation A.14 will consequently have N instances for T_{it}, too. The temperature change T_{it}, anticipated by player i, will then enter in Equation A.15 instead of T_t.

The thusly modified model is then solved in a nested iteration: In the inner iteration we solve the model for a given vector $\overline{q} = (\overline{q_{it}})$ of allowance choices repeatedly, updating $\overline{q_{it}} = q_{it}$ at the end of each iteration, i.e. we perform a fixed point iteration of the mapping $q = G(q)$ where G is the best response of players to the exogenously given strategy $\overline{q_{it}}$ of the other players. If the inner iteration converges, it converges to a Nash equilibrium in allowance choices. However, the international markets for allowances and private goods may not be a competitive equilibrium. This is what the outer iteration achieves.

The outer iteration follows the standard Negishi approach: we adjust the welfare weights δ_i in the joint welfare function (Equation A.20) until the intertemporal budget constraint (Equation A.17) is satisfied. The resulting equilibrium is the desired PANE.

Numerical verification of the equilibrium

We verify the resulting 'candidate' PANE equilibrium strategies in emissions and trade numerically by comparing them to the results of the following maximization problems:

$$\begin{gathered}\forall_i \max_{\{i_{it}, b_{it}, m_{it}, x_{it}, z_{it}\}} W_i \\ \text{subject to Equations A.1-A.17 and prices } p_t, p_t^z\end{gathered} \tag{A.24}$$

Deviations of this model from our solution should be within the order of magnitude of numerical accuracy only, which is what we find (not shown). In particular, simultaneous clearance of all international markets confirms the competitive equilibrium in international trade.

[Table 2 about here.]

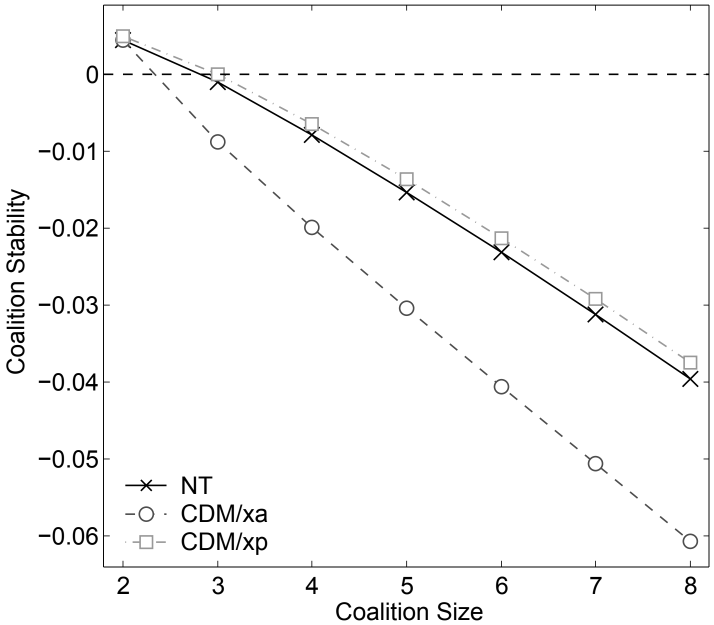

Figure 1: Stability functions with no CDM trade (NT), and with CDM clause negotiated *ex ante* (CDM/xa) and *ex post* (CDM/xp)

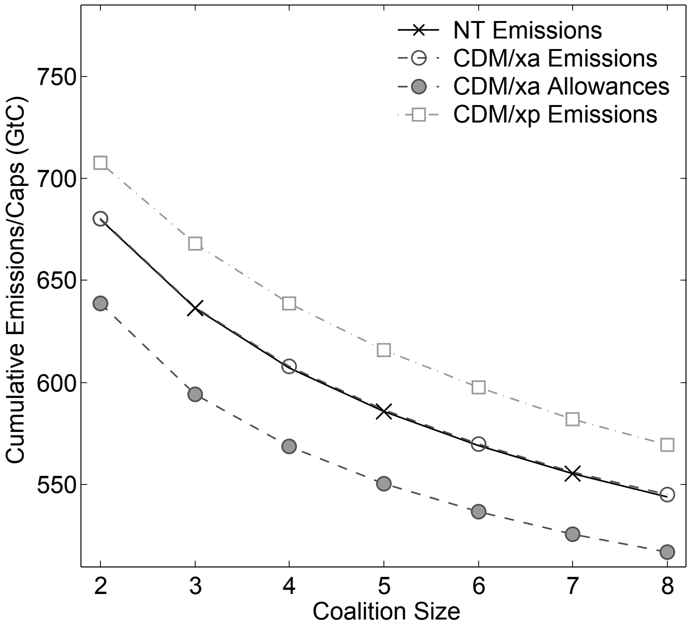

Figure 2: Emissions of an exemplary coalition member

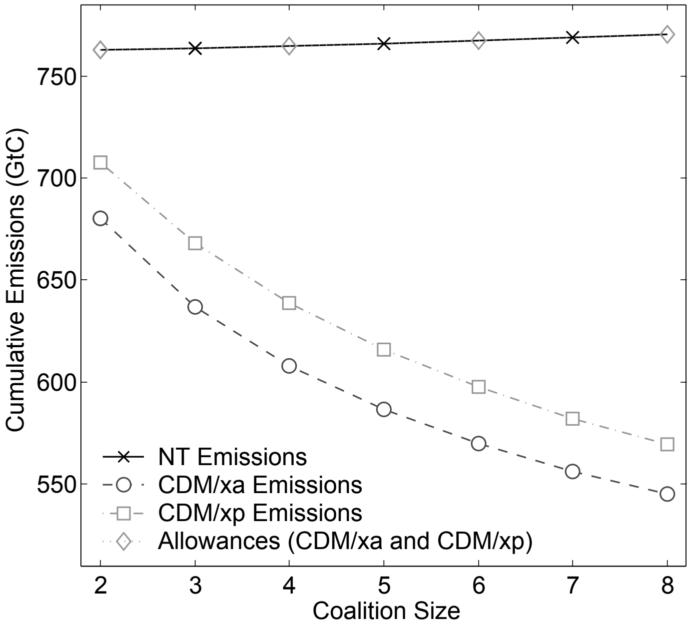

Figure 3: Emissions of the CDM-supplier

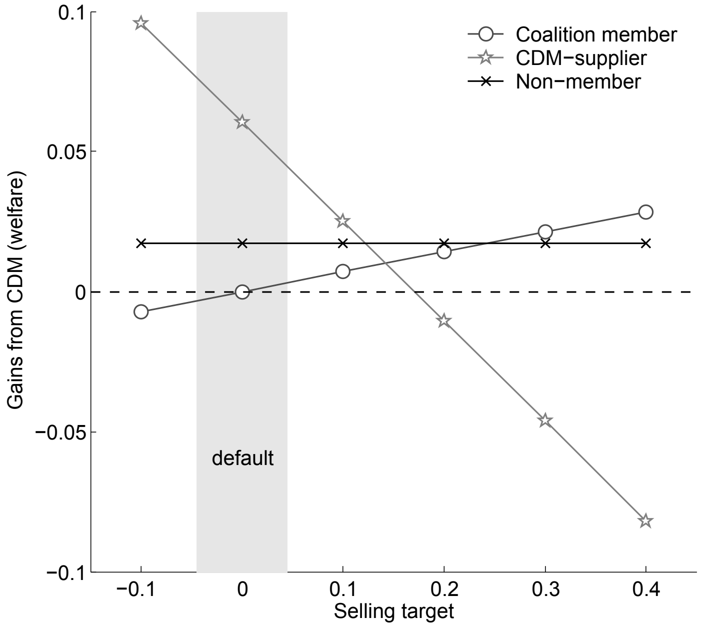

Figure 4: Welfare gains from CDM trade (CDM/xa/sel) for an exemplary coalition of 5 players

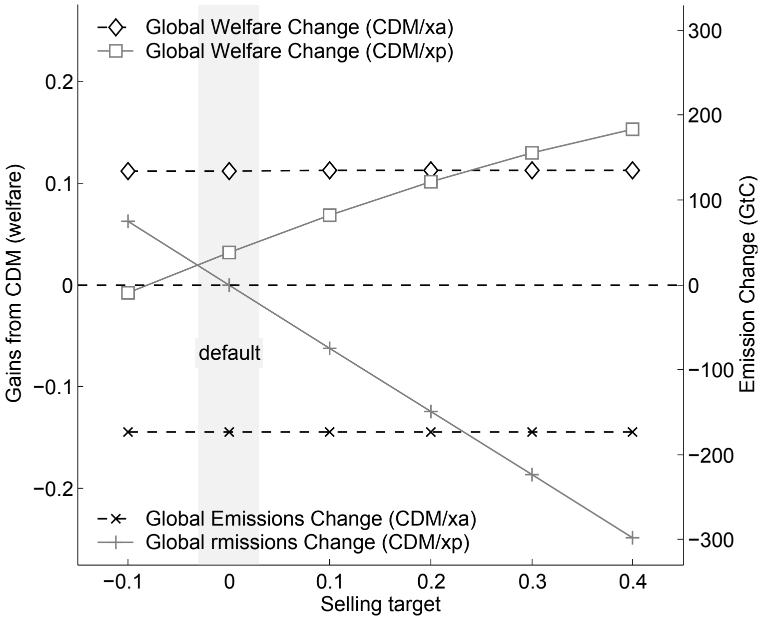

Figure 5: Global changes of emissions and welfare due to selling targets (CDM/xa/sel and CDM/xp/sel) for an exemplary coalition of 5 players

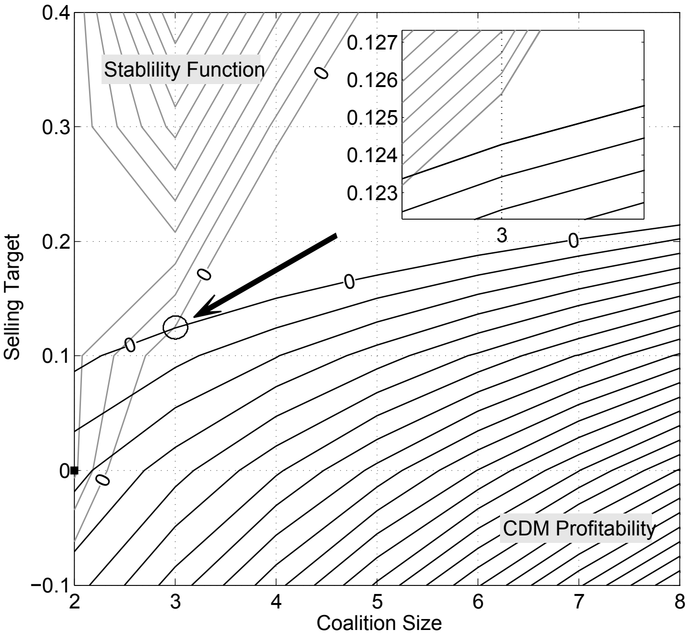

Figure 6: Coalition stability and CDM trade profitability (CDM/xa/sel), square solid bullets indicate feasible and stable coalitions

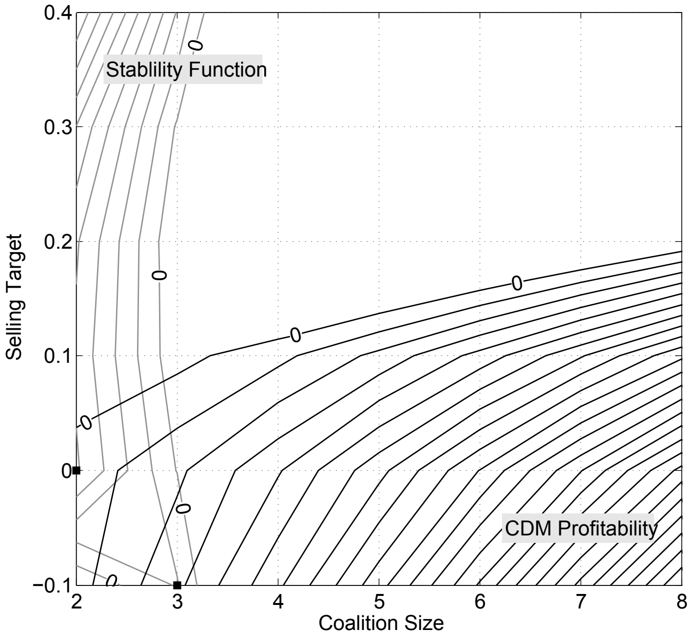

Figure 7: Coalition stability and CDM trade profitability (CDM/xp/sel), square solid bullets indicate feasible and stable coalitions

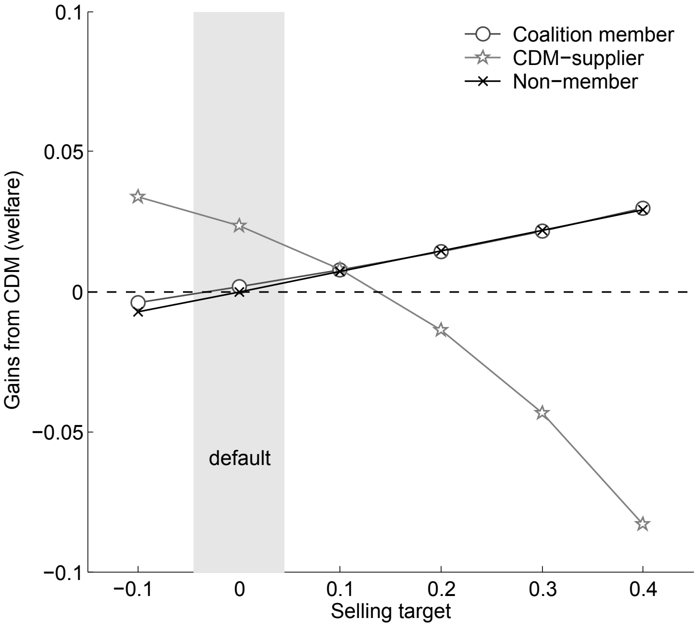

Figure 8: Welfare gains from CDM trade (CDM/xp/sel) for an exemplary coalition of 5 players

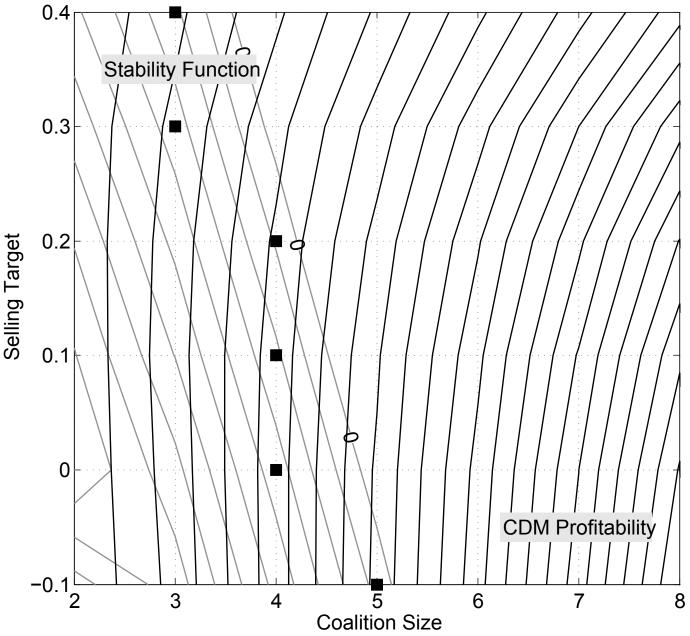

Figure 9: Coalition stability and CDM trade profitability in a heterogeneous world (CDM/xp/sel), square solid bullets indicate feasible and stable coalitions

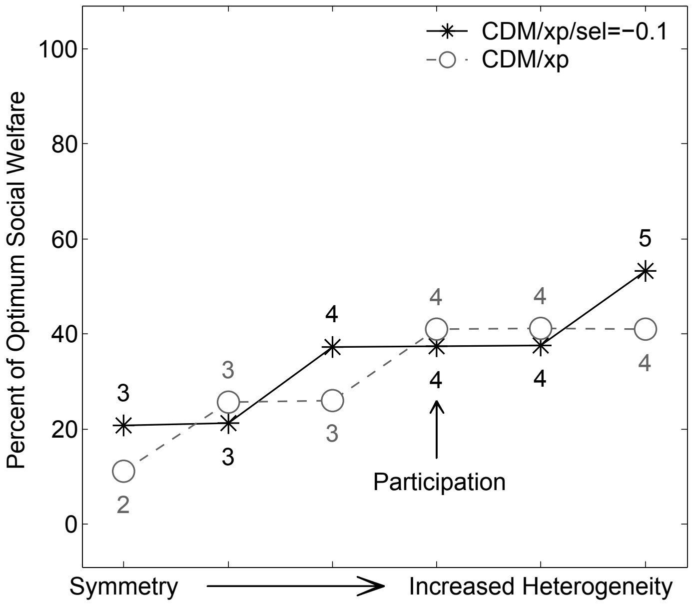

Figure 10: Participation induced by heterogeneity for the default CDM/xp scenario and for 10 percent hot air (CDM/xp/sel=-0.1)

Table 1: Participation for high/low values of selected parameters.

Parameter	high/low Values	Participation No Trade	Symmetry	Heterogeneity
ρ	0.001	2	3	5
ρ	0.02	2	3	5
α	0.01	2	3	5
α	0.05	**3**	3	5
ν	0.005	2	3	5
ν	0.02	2	3	5
ξ	2.5	2	3	**4**
ξ	10.0	2	3	5
γ	-0.1	2	3	5
γ	-0.3	2	3	**4**
θ_1	1.0	**3**	3	5
θ_1	2.0	2	3	**4**
θ_2	0.01	2	3	**4**
θ_2	0.04	2	3	5

Parameter	Symbol	Value
Rate of labor efficiency improvement	α	0.023
Income share capital	β	0.35
Abatement cost exponent	γ	0.2
Emission/concentration conversion factor	ζ	0.47
Elasticity of marginal utility	η	1
Damage function coefficient	θ_1	0.02
Damage function exponent	θ_2	1.5
Rate of ocean CO_2 uptake	κ	2.15e-2
Labor efficiency	λ	$e^{\alpha t}$
Radiative temperature driving factor	μ	8.7e-2
Exogenous rate of decarbonization	ν	0.01
Effectiveness of investments in a_{it}	ξ	5.0
Pure rate of time preference	ρ	0.01
Temperature damping factor	ϕ	1.7e-2
Atmospheric retention factor	ψ	1.51e-3
Initial labor productivity	a_0	1
Initial concentration	C_0	377
Initial cumulative emissions	E_0	501
Initial capital stock	k_0	70
Initial labor	l_0	6.6
Initial temperature change	T_0	0.41

Table 2: Parameters and initial values.