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

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

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Abstract

We investigate how different designs of carbon offset mechanisms 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 negative if strategic behaviour and free-rider incentives are explicitly considered. Even imposing selling targets on credit supplying countries do not change this result. Larger stable coalitions are achieved when the treaty is designed such that its signatories 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. Selling targets that introduce some "hot air" may exacerbate this effect on participation, albeit without a substantial effect on welfare.

1 Introduction

The Kyoto Protocol introduced three flexible mechanisms. The emission trading system (ETS) and joint implementation (JI) allow to trade emission entitlements among Annex-I countries, those countries which accepted emission ceilings. In contrast, 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 emission ceilings. The CDM includes an additionality clause which requires that emission credits offered by non-Annex I-countries must correspond to a reduction of emission levels "below [what] would have occurred in the absence of

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the registered CDM project activity" (UNFCCC, 2002, p. 43). All three flexible mechanisms provide opportunities to save abatement costs. 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. On the one hand, Annex-I countries have to resort to increasingly costly abatement options to meet their emission caps. On the other hand, non-Annex-I countries do not face such constraints on their emissions. Additionally, they typically face less steep abatement cost functions compared to Annex-I countries.[1] As compliance costs are a major obstacle for signing ambitious climate treaties, one is inclined to 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 the assumption of a first-best world, explicitly considering strategic effects and the need for self-enforcing treaties due to the lack of a supranational enforcement power. 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 offset mechanisms will affect participation and the success of future climate treaties.

In a strategic context, there are at least two reasons why a credit trading scheme between members and non-members of a climate treaty 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. If abatement cost savings translate into more ambitious abatement targets of members and this is matched by less abatement by non-members, free-riding may become more attractive. This is an equilibrium effect associated with carbon-leakage. Second, CDM-trading offers a win-win situation, but the gains from trade may unevenly distributed between members and non-members. If the gains for non-members are larger than for members, the incentive to free-ride may well increase.

The first issue may be addressed by restricting the members' choices of emission allowances such that the gains from trade are not used for the implementation of more ambitious abatement targets. The second issue could be fixed through the implementation of selling targets.[2] If non-Annex-I countries can only sell emission credits that correspond to emission reductions below baseline emissions, a share of the gains from trade can be shifted to the members, making it more attractive for members to stay in a climate treaty and/or for non-members to join a 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; Weikard et al., 2009), multiple agree-

[1]This is for instance illustrated by 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 and only below this emission path emission reductions can be sold as credits.

ments (Asheim et al., 2006; Eyckmans and 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 only among coalition members, and not among coalition members and outsiders as we do. Moreover, in their TU (transferable utility)-setting, equilibrium emissions are not affected by permit trading, but only the distribution of the gains from cooperation. The second paper considers the possibility that coalition members buy additional emission reductions from non-members, even though Hoel and Schneider do not use the term CDM. But, 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 under a permit trading scheme with endogenous choice of emission allowances, but stability of treaties is tested in a rather simplistic way. In a stylized model, Helm (2003) compares the Nash equilibrium without trading to the Nash equilibrium in which permit trading is anticipated . He shows that the effect of permit trading on global emissions is ambiguous: countries with steep damage cost functions may abate more but countries with flat damage cost functions may choose larger emission allowances. His results are driven by countries anticipating how their allowance choices influence the equilibrium permit price and hence their revenues from trade. Furthermore, he shows 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. However, the decision whether to participate in an agreement abstracts from strategic membership decisions and is only based on the concept of profitability, similar to the analysis conducted in Carbone et al. (2009) who base their analysis on a calibrated CGE-model. Moreover, in their paper, the design of an agreement is different from our game-theoretic model of coalition formation. In our paper, members of an agreement cooperate and internalize the externality among their members (though not with outsiders). In contrast, in Carbone et al. (2009) countries entering an agreement just benefit from the possibility of permit trading, but all countries decide non-cooperatively on their emission allowances before trade takes place.

In what follows, in Section 2, we first discuss the setup and develop an intuitive understanding of the main driving forces. Then we informally introduce our numerical model in Section 3 and provide the details in the Appendix. Section 4 reports and discusses our results, and Section 5 concludes.

2 Model: Setting, Policy Options and Driving Forces

2.1 The coalition formation game

The aim of this study is to investigate the impact of various designs of the CDM 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 with N players. In the first stage, players decide on membership, i.e. whether to sign the agreement and hence become a coalition member (which we sometimes also call signatory), or to remain a non-member (to which we refer sometimes also as non-signatory), acting as a singleton. In the second stage, players decide on their economic strategies. In our model this relates to the choice of emission allowances, with the decision on exporting (importing) of excess (shortfall) allowances following from the market equilibrium in the CDM-market. The game is solved by backwards induction. In each stage, equilibria form a Nash equilibrium.

In the second stage, we solve for a Nash equilibrium between the coalition and the remaining players, often termed *Partial Agreement Nash equilibrium* (PANE, Chander and Tulkens, 1995) in the specific context of a single coalition, a special case of the *social coalitional equilibrium* (Ichiishi, 1981). This implies that the coalition *de facto* act as a single player, coordinating strategies such as to internalizing the externalities among coalition members. Non-members simply maximize their welfare. In the first stage, we apply the concept of cartel stability following d'Aspremont and Gabszewicz (1986) . In equilibrium, players have no incentive to revise their membership strategy, given the strategies of other players. That is, a coalition is internally stable if no member has an incentive to leave and externally stable if no non-member wants to join the coalition. Note that for symmetric players, following Hoel (1992) and Finus and Maus (2008) stability can be compactly summarized by a stability function,

$$\Phi = W_{i \in S}(n) - W_{i \notin S}(n-1), \tag{1}$$

with a coalition of n symmetric members being internally stable if the stability function is non-negative at n and externally stable if it is negative at $n+1$ and where S denotes the coalition and W_i individual welfare of player i.

The details of the underlying economic model are further explained in Section 3 and all details are provided in the Appendix.

2.2 CDM policy designs

In our model, all regions can decrease their emissions by lowering their emission-intensity of production. In addition, coalition members have a second option for mitigating climate change: they can buy permits on the international CDM emissions trading market. This is implemented through the choice of emission allowances for all regions. A region's actual emissions may exceed its allowances if the shortfall is matched by imported emission permits. Likewise, regions may export emission permits, selling surplus emission allowances by choosing lower emissions. In the analysis of different designs of offset mechanisms, we consider the following scenarios.

NT As a benchmark, we consider the "No Trade" scenario without permit trade. This allows to explore the incremental effects of allowing for CDM-trade; all discussions of relative effects will be related to the NT-scenario. Note that we also sometimes refer to the non-cooperative equilibrium, which is different. The NT-scenario allows for the possibility of coalition formation whereas the non-cooperative equilibrium corresponds to the "all singletons coalition structure" (though also without trade because no coalition exists).

CDM/xa This scenario assumes that the possibility of CDM-trading is an integral part of the climate treaty, and that it is fully taken into account when the decisions on emission allowances are made. That is, the combined choices of CDM-trade and allowances maximize welfare. In this sense, the possibility of CDM-trading is an *ex ante* feature of the treaty.

CDM/xp This scenario assumes that CDM-trading is added to the climate treaty to reduce implementation costs as much as possible, i.e. to achieve cost-effectiveness in abatement while allowance choices remain at their NT-benchmark values. Thus, CDM-trading only improves the treaty *ex post*. That is, equilibrium abatement remains at the NT-benchmark level and trading "only" improves on cost-effectiveness. This design requires the ability of coalition members to commit themselves to constraints on allowance choices, similar to the commitment required in minimum participation clauses, burden sharing rules, or 'modest' abatement targets.[3]

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 scenario that need to be achieved before any emission credits can be sold. We refer to a selling target below the NT-baseline as being *stringent*, and a selling target above the baseline is said to produce *hot air*. Our default requirement of additionality corresponds to the special case of taking the NT-baseline as the selling target, i.e. a selling target $sel = 0.0$. In contrast, a selling target $sel = 0.1$ would require 10 percent additional emission reduction below the NT-baseline.

2.3 General effects of CDM-trading on stability of agreements

In this section, we briefly discuss some general effects of CDM-trading on the stability of coalitions. Recall that stability comprises internal and external stability. The effect of trade may positively effect the payoff of members and non-members and hence overall conclusions depend on the relative size of these effects. In the following, we split the overall effect into separate effects, even though in equilibrium all effects occur simultaneously in most scenarios. We distinguish three groups of players: a) members, b) non-members and c) a representative CDM-supplier. Members choose their emission allowances cooperatively and if their actual emissions exceed those, they can buy credits from the CDM-supplier. Members if they leave the agreement become non-members. Non-members choose their emission allowances non-cooperatively but cannot trade credits, as long as they do not join the agreement. Finally, the CDM-supplier chooses emission allowances and if the actual emissions falls short of allowances, he can sell credits to members. The CDM-supplier does not take a membership decision, though he will only engage in credit trading if this improves his welfare position compared to the NT-scenario.[4]

[3] See, for example Courtois and Haeringer (2012).

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

Taken together, only the CDM-supplier and members are directly affected by selling and buying of permits, but non-members are indirectly affected through a change of equilibrium emissions.

i. *Cost-effectiveness Effect*. Trade between coalition members and the CDM-supplier occurs whenever the marginal abatement costs of the CDM-supplier are lower than those of coalition members. Then, the coalition can substitute own costly abatement by cheaper CDM-permits. Provided coalitional abatement is solely replaced (but not increased) by cheaper CDM-permits, the cost-effectiveness effect exclusively benefits those involved in the transaction. If total abatement efforts remain constant, non-signatories are unaffected by trade. Overall, it becomes more attractive to stay in the coalition and/or to join the coalition.

ii. *Ambition Effect*. If signatories anticipate the options of permit-trading, the possibility of buying credits *de facto* shifts their marginal abatement cost curve downward. Consequently, in equilibrium, the coalition will increase its abatement efforts, choosing lower emission allowances. This will have a positive effect on signatories but the effect on non-signatories will be even greater since they will get the extra abatement at zero cost. Hence, the net effect on the size of stable coalitions is most likely negative.

iii. *Leakage Effect*. For downward sloping reaction-functions in abatement (because abatement levels are strategic substitutes), additional abatement by signatories will be partially offset by increased emissions of non-signatories, which is typically called carbon leakage. This undermines the position of signatories while saving costs of non-signatories. The leakage effect will clearly lead to smaller stable coalitions.

As the first effect has a positive, the third effect a negative and the second effect also most likely a negative effect on forming large stable coalitions, a quantitative analysis is necessary to draw overall conclusions. This will be conducted with a numerical model which is described subsequently.

3 Numerical model

3.1 Model 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 trade of emission permits. The details of the model are provided in the Appendix.

MICA is an optimal growth model of the Ramsey-type with N world regions. Each region allocates income to either consumption or investment at every point in time. Regions maximize welfare, which is the net present value of utility, either by themselves or, when part of the coalition, jointly with the other members. 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 activities. Total global emissions drive 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 negative economic impacts. 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 meeting emission targets is to buy emission allowances from other regions. In accordance with the Kyoto Protocol, we impose two restrictions on emission credit 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 cannot offer CDM credits. This is why 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. We assume that the CDM-supplier has little own motivation to reduce emissions. (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").[5] Additionality is defined in relation to the no trading scenario (NT scenario). We assume a perfectly competitive market of emission credits. Trade in goods is the means to finance imports of allowances. Goods from different regions are perfect substitutes.

3.2 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). This renders the analysis much simpler and in particular more transparent. Nevertheless, we calibrate the model such that aggregate values (e.g. total global emissions, 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). The model is run over 250 years in 10 year periods, but reported results relate to the first 100 years. 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 full cooperative behavior

[5]In model runs without such an additionality constraint the CDM-supplier prefers to sell large amounts of "hot air." Naturally, 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 even more unlikely.

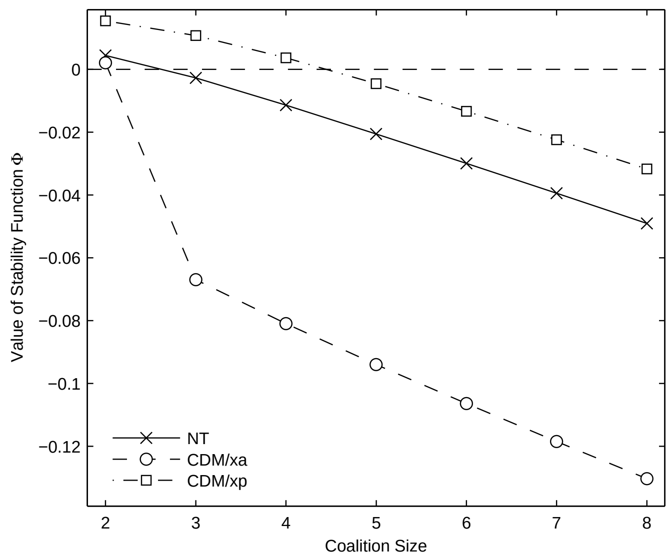

Figure 1: Stability functions with no CDM-trading (NT), and with the CDM-clause negotiated *ex ante* (CDM/xa) and *ex post* (CDM/xp)

(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 in that year (cf. 2.0°C and 2.3 percent in RICE-2010).[6]

4 Results

4.1 No Trade-baseline (NT)

We begin with our benchmark, the no trade scenario. The stability function Φ is shown in Figure 1, which we may recall is the difference between the welfare of a player as a member in a coalition with n members, and the welfare when he leaves the coalition, becoming a non-member, and hence the coalition size is $n-1$ (Equation 1). As mentioned in Section 2.1, a coalition with n symmetric members is stable if the stability function is non-negative at n and negative at $n+1$. Thus, the stability function of the NT-scenario indicates that only a coalition of 2 players is stable.

[6] Data from RICE-2010 has been taken from Nordhaus (2010) and its supporting material if possible, and from the available spreadsheet version of the model otherwise.

4.2 Ex-ante CDM-trading without selling targets (CDM/xa)

Figure 1 also shows how coalition stability changes when CDM-trading is part of the agreement and accounted for in allowance choices (denoted CDM/xa). Evidently, introducing CDM-trading is counterproductive for participation as the stability function lies below the stability function of the NT-baseline scenario (the effect is less pronounced at coalition size 2 because defecting from this coalition means that no cooperating countries can be exploited by non-cooperating countries).

The reason is that the *ambition effect* identified in Section 2.3 outweighs any benefits from the *cost-effectiveness* accruing to the coalition (the third effect, the *leakage effect*, turns out to be negligible). Figures 2 and 3 show the interaction of coalition member and CDM-supplier in detail. Without CDM-trade, the CDM-supplier emits substantially more than coalition members (NT). But in the CDM/xa scenario, the CDM-supplier reduces emissions down to the level of allowances chosen by coalition members: at this level, marginal abatement costs equal the permit price. The CDM credits are purchased by the coalition and the benefits are mainly used to aim for more ambitious abatement targets rather than to replace domestic abatement (cf. member allowance choice in Figure 2).

Overall, the abatement cost reduction from CDM-trade results in lower global emissions. Thus, non-members benefit from lower damages. Though coalition members also benefit from lower damages but due to the increased net abatement by the coalition, 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.

4.3 Ex-ante CDM-trade with selling targets (CDM/xa/sel)

Figure 4 provides an alternative illustration why CDM trade does not lead to larger coalitions. It shows the gains from CDM-trade, i.e. the increase in global welfare as measured by the models objective function, relative to welfare in the NT-baseline scenario. These gains are unequally distributed among the different groups of players. For the default value of a zero selling target, which corresponds to the additionality assumption, 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 two members, but it also holds for other coalition sizes. This figure also shows that the coalition members suffer a slight loss of welfare relative to the NT-scenario.

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 his 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-supplier to coalition members. Essentially, by imposing selling targets, the coalition receives an emis-

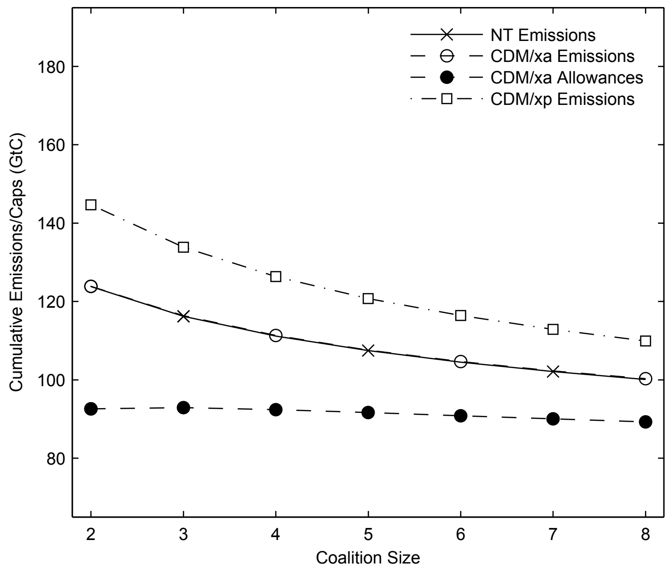

Figure 2: Emissions of a representative coalition member over a time horizon of 100 years.

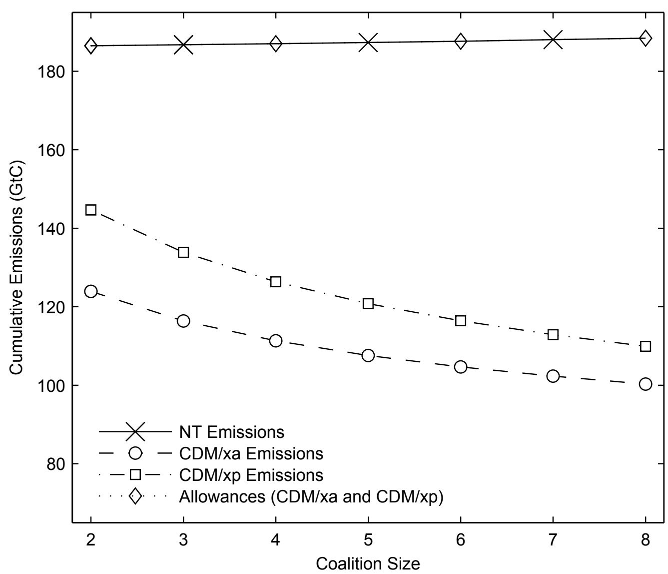

Figure 3: Emissions of the CDM-supplier over a time horizon of 100 years.

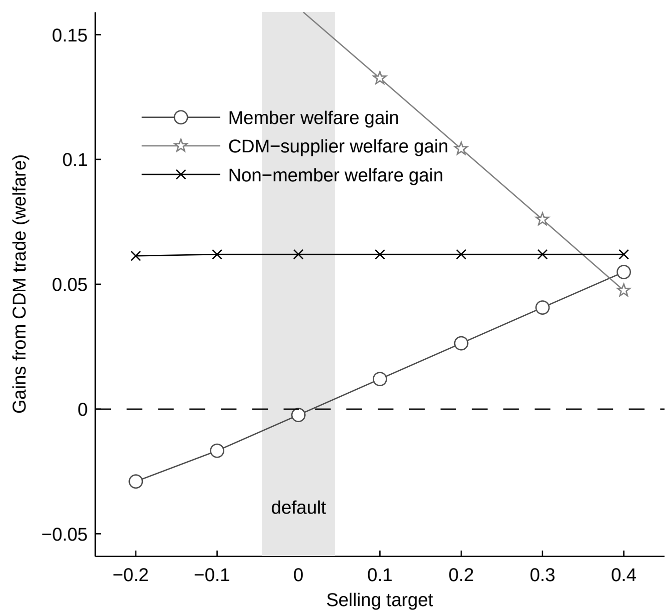

Figure 4: Welfare gains from CDM-trade (CDM/xa/sel) relative to the NT scenario for a representative coalition of two players.

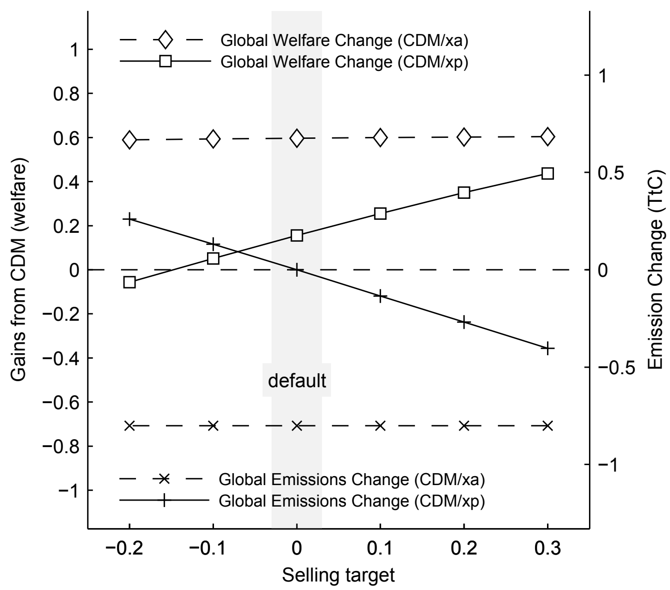

Figure 5: Changes of global emissions and global welfare when going from the NT scenario to the CDM scenarios for different selling targets. Numbers are for a representative coalition of four players, and welfare reflects the value of the models objective function.

sion 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 for all selling targets because the selling targets do not alter marginal abatement costs and marginal damages, which in turn determine the efficient allocation of abatement.[7] This is evident from Figure 5, which shows the change in global totals of emissions (in tons of carbon) and welfare (in terms of social welfare as defined by the model's objective function) brought about by CDM-trade: positive numbers indicate that CDM-trade raises emissions (or welfare).

In view of the fact that selling targets improve welfare of coalition members, a positive effect of selling targets on stability is very plausible. Indeed, the stability function for CDM/xa in Figure 1 would shift upwards with more stringent selling targets (not shown). Yet, no coalition larger than two members is stable. The largest stable coalition is therefore unchanged.

In summary, the first type of offset design in the form of adding a CDM to the coalition agreement has 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-members' welfare is increased, which raises the incentive to free-ride. Selling targets allow to counteract this effect. However, this is not sufficient to raise participation above the NT-benchmark.

4.4 Ex-Post CDM-trade without selling targets (CDM/xp)

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 an alternative design for the offset mechanism, CDM-trade is introduced solely to reduce compliance costs for a given level of allowance choices. Essentially, this places a constraint on coalition members' emission allowances such that they cannot exceed abatement under the NT-scenario.

Analogously to the CDM/xa-scenario, the CDM/xp-scenario is illustrated in Figure 1, Figure 2, Figure 3 and Figure 5. For the default additionality assumption (i.e. a zero selling target) global welfare gains in the CDM/xp scenario fall short of those in the CDM/xa, previously considered, because the additional constraint in CDM/xp prevents further abatement by the coalition (cf. global emissions in the same 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, and their emissions are higher than under CDM/xa (Figures 2 and 3). Coalition stability is improved under CDM/xp such that a coalition of four players becomes stable (Figure 1). We now turn to explore whether selling targets could help to improve stability further as they did in the CDM/xa scenario.

[7] Similar to the findings in Manne and Stephan (2005), a separability of equity and efficiency (i.e. the distribution of abatement burden and welfare) holds in MICA due to the feature of international trade in goods.

4.5 Ex-Post CDM-trade with selling targets (CDM/xp/sel)

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 assumption. 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 contrary from CDM/xa, selling targets only redistributed welfare gains among players, leaving the global levels of welfare and emissions untouched. Also in contrast to CDM/xa, where member gain approaches non-member gain, here it is advantage in welfare gain of the member that declines with more stringent selling targets, making a stable coalition less likely (Figures 4 and 6). For CDM/xp, both members and non-members alike benefit from globally reduced emission levels. Members also benefit from a bounty of cheap CDM credits but with more stringent selling targets, credits become scarcer and more expensive, thus diminishing this benefit. For negative selling targets (i.e. hot air) this trend is reversed. While the world may be worse off with negative selling targets (e.g. -0.2) for a given coalition size (Figure 5) and likewise for members and non-members (Figure 6), the negative effect on non-members exceeds that 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 five members for a selling target of -0.2. Thus, there is a trade-off between global welfare and environmental effectiveness by allowing for hot air which leads to larger coalitions. The effect is similar to the idea of "modest" emission reductions analyzed in Finus and Maus (2008).

Figure 7 summarizes the effect of credit trading on participation in the agreement and global welfare. Under CDM/xp we find a positive effect of CDM credit trading on coalition stability, i.e. an increase in participation. Figure 7 also indicates the level of welfare associated with stable coalitions that are achieved due to trading in CDM-credits on a scale from 0 percent (non-cooperative equilibrium) to 100 percent (full cooperation, social optimum). For CDM/xp, welfare increases with coalition size and selling targets. But since more stringent selling targets reduce participation, these two effects offset each other. In fact, two effects are estimated to have about the same strength such that the net effect of having a small coalition with stringent selling targets is about the same as forming a larger coalition by allowing "hot air" into the system.

The CDM/xa scenario is much simpler. The largest stable coalition has two members unless CDM-trade is not profitable for its members, or "hot air" undermines the stability. Where CDM-trade is not profitable, we have omitted the data point from Figure 7. As discussed previously, the global welfare achieved by 2 player coalition is independent of selling targets.

Both CDM/xa and CDM/xp improve upon the NT-baseline, and overall, both achieve similar levels of global welfare, irrespective of selling targets.

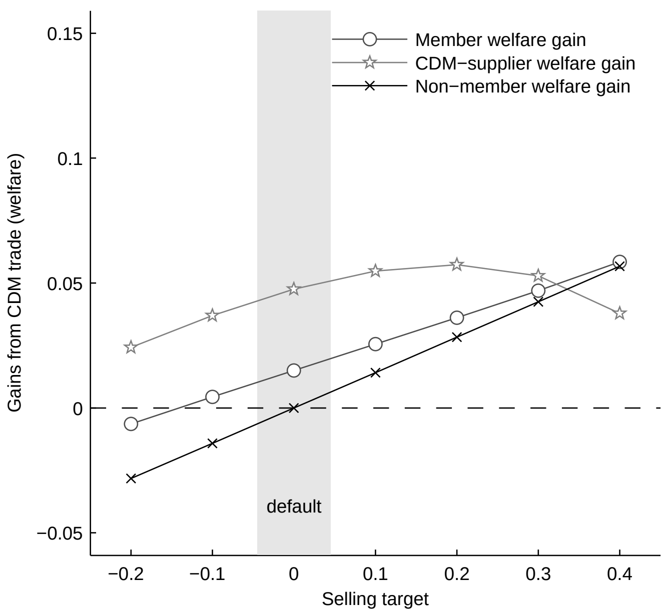

Figure 6: Welfare gains from CDM-trade (CDM/xp/sel) relative to the NT scenario assuming a representative stable coalition of four players.

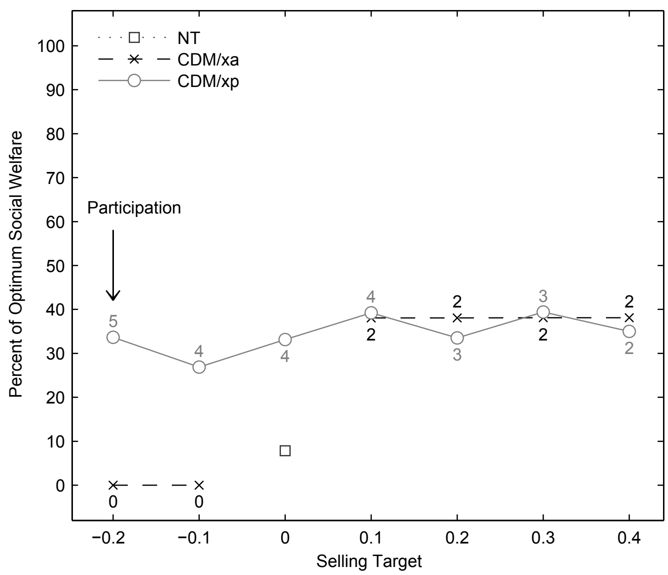

Figure 7: Participation and global welfare. The data point for CDM/xa at 0.0 (stable coalition of two) is omitted because participating in CDM/xa trade is not rational for members in this case.

5 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 the cost saving potential from trade translates into more ambitious abatement targets by the members of the agreement, free-riding through less abatement by non-members becomes 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 possibility to raise participation in a climate agreement. Hence for the success of future climate treaties, it is of utmost 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 negotiations of the allowance caps, 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 lower abatement costs due to higher emissions.

In this context, imposing an additionality clause, allowing only emission reductions below baseline emissions to be sold as emission credits (similar to the additionality clause of the Kyoto Protocol), has proven to be important. In fact, allowing for hot air undermines the environmental effectiveness but also the stability of agreements. Better results 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 allowed members to appropriate a larger share of the gains from trade. In our setting, it turned out that this was not enough to outweigh the increased incentive to free-ride.

In view of this negative result, we investigated the implications of constraining abatement choices to preclude increased ambition due to CDM-trade. This implies less ambitious abatement targets of the members of the agreement and thus a reduction of the incentive to free-ride.

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 larger coalitions were hardly able to outperform a smaller coalition without hot air in our simulations.

Overall, our results suggest that if CDM-trading is implemented naively (e.g. ignoring strategic aspects and the need for self-enforcing agreements) and without careful design, it may do more harm than good to cooperation. 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.

Finally, 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.

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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. In the following, we first describe the model equations, their calibration, and the numerical procedure to solve the model.

Preferences

The world economy is modelled as a set of $N = 9$ 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 function U, which is based on per capita consumption, are given by:

$$W_i = \int_0^\infty l_{it}\, U(c_{it}/l_{it})\, e^{-\rho t}\, \mathrm{dt} \tag{2}$$

$$U(c_{it}/l_{it}) = \begin{cases} \dfrac{(c_{it}/l_{it})^{1-\eta}}{1-\eta} & \text{if } \eta \neq 1 \\ \log(c_{it}/l_{it}) & \text{if } \eta = 1 \end{cases} \tag{3}$$

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 16) destroy a fraction $1 - \Omega_{it}$ of the production.

$$y_{it} = \Omega_{it} F(k_{it}, l_{it}) \tag{4}$$

$$F(l_{it}, k_{it}) = (\lambda_{it} l_{it})^{1-\beta} k_{it}^{\beta} \tag{5}$$

Labor l_{it} is given exogenously, as is labor productivity λ_{it}, which grows at a fixed rate α: $\lambda_{it} = \exp\{\alpha t\}$. Capital k_{it} accumulates with investments i_{it}, assuming zero depreciation.

$$\frac{d}{dt}k_{it} = i_{it} \tag{6}$$

$$\tag{7}$$

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.

$$e_{it} = \sigma_{it}\, e^{-\nu t}\, y_{it} \tag{8}$$

$$\sigma_{it} = (1 + a_{it})^{-\gamma} \tag{9}$$

$$\frac{d}{dt}a_{it} = \xi\, b_{it} \tag{10}$$

Emissions can 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.

$$e_{it} = q_{it} - z_{it} \tag{11}$$

$$\sum_j z_{jt} = 0, \qquad t = 1, \dots \tag{12}$$

Climate Dynamics

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

$$\frac{d}{dt}C_t = \zeta \sum_j q_{jt} - \kappa(C_t - C_0) + \psi E_t \tag{13}$$

$$\frac{d}{dt}E_t = \sum_j q_{jt} \tag{14}$$

Equation 13 translates global emissions into carbon concentration in the atmosphere C. Concentration C rises with global allowances (like emissions do), where

ζ converts emissions into changes in concentration, and it decreases with the carbon uptake of oceans proportional (with factor 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).

$$\frac{d}{dt}T_t \quad = \quad \mu \log(C_t/C_0) - \phi(T_t - T_0) \tag{15}$$

Equation 15 transforms concentration levels into a global mean atmospheric temperature increase T. Parameter μ controls the strength of the temperature reaction due to a change in concentration, whereas parameter ϕ is related to its timing. Together, they can be interpreted as "climate sensitivity" ($\mu/\phi \cdot \log 2$), i.e. the equilibrium temperature increase due to a doubling of 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 Ω_{it} is taken from Nordhaus and Yang (1996):

$$\Omega_{it} \quad = \quad 1/(1+\theta_{1i}(T_t)^{\theta_{2i}}) \tag{16}$$

Parameters θ_{1i} and θ_{2i} describe the vulnerability of region i.

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 constraints ensuring that, over the entire time horizon, the import value must equal the export value in each region.

$$y_{it} + m_{it} \quad = \quad c_{it} + i_{it} + b_{it} + x_{it} \tag{17}$$

$$\int_0^\infty p_t\, m_{it}\, \mathrm{dt} \quad = \quad \int_0^\infty p_t\, x_{it} + p_t^z\, z_{it} \mathrm{dt} \tag{18}$$

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.

Solving the model for the game's equilibrium

As detailed in the main text, we are considering a two stage game of coalition formation in which in the first stage, decisions about *membership* in an international environmental agreement (IEA), and in the second stage decision about *emission allowances* are taken by players.

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:

$$W_i\big|_S \quad \geq \quad W_i\big|_{S\setminus\{i\}} \text{ for } i \in S \quad \text{(internal stability)} \tag{19}$$

$$W_j\big|_S \quad > \quad W_j\big|_{S\cup\{j\}} \text{ for } j \notin S \quad \text{(external stability)} \tag{20}$$

The computation of the PANE in 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 at the same time. To the best of 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). In this paper, 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 under the assumption of joint welfare maximization:[8]

$$\max_{\{i_{jt},b_{jt},m_{jt},x_{jt},z_{jt}\,:\,j=1\ldots N\}} \sum_{i=1}^{N} \delta_i W_i \tag{21}$$

$$\text{subject to Equations 2-17} \tag{22}$$

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

In our context, externalities are climate change damages caused by aggregate global emissions. In the Nash equilibrium, players will only anticipate the effect that their emissions have on their own economic output, not, however, the effect this has on 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 13, which describes one trajectory of concentration C_t, we introduce N equations for C_{it}:

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

$$\frac{d}{dt}C_{it} = \zeta\left(\sum_{k\in S} q_{kt} + \sum_{j\notin S}\overline{q_{jt}}\right) - \kappa(C_t - C_0) + \psi E_t \qquad \forall_{i\in S} \tag{24}$$

where the allowance choices of other players enter as a fixed value (a parameter, indicated by the bar), and are set to the levels of the corresponding variables during the previous iteration (or some initial value). The sum of allowances in Equation 14 needs to be adjusted analogously, and the temperature Equation 15 will consequently have N instances of T_{it}, too. The temperature change T_{it}, anticipated by player i, will then enter in Equation 16 instead of T_t.

The so 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 markets for allowances and private goods may not be a competitive equilibrium. This is what the outer iteration achieves.

[8] Note that the intertemporal budget constraint Equation 18, which contains the (*a priori* unknown) market clearing prices, is omitted from the model.

The outer iteration follows the standard Negishi approach: we adjust the welfare weights δ_i in the joint welfare function (Equation 21) until the intertemporal budget constraints (Equation 18) are 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:

$$\begin{aligned} &\forall_i \max_{\{i_{it}, b_{it}, m_{it}, x_{it}, z_{it}\}} W_i \\ &\text{subject to Equations 2-18 and prices } p_t, p_t^z \end{aligned} \tag{25}$$

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

Internalization of Damages

In the model and its solution algorithm outlined above, climate change damages that occur within a region (or coalition of regions) are fully internalized. A priori, this also holds for the CDM-supplier. However, this particular player represents a number countries. Hence, full internalization of damages of this group would overestimate the abatement taken by this player. This point was already made in Nordhaus and Yang (1996, p. 743). Therefore, they divide the damages perceived by such a representative player by the number of countries represented by her. This is implemented in our model in the following way: the anticipated climate change damages Ω_{it} in Equation 16 are only a fraction $1/n_i$ of the original right-hand-side of the equation. In Equation 5, we add the remaining damages $\bar{\Omega}_{it}$ that were not anticipated, i.e. $(\Omega_{it} + \bar{\Omega}_{it})$ instead of just Ω_{it}. The parameter $\bar{\Omega}_{it}$ then needs to be updated in an iteration to $\bar{\Omega}_{it} = (n_i - 1)\,\Omega_{it}$. Through this procedure, full damages take effect even though only a fraction is anticipated.

For the calculations in this study, we set $n_i = 1$ for all players but the CDM-supplier, where we chose n_i large enough such that very little abatement action is taken in the business-as-usual scenario.

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 1: Parameters and initial values.