Carbon Abatement, Coalition Formation, and International Trade in Greenhouse Gas Emissions *

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Abstract

The success of any international climate change agreement depends on the strategic incentives of countries to participate. We use a calibrated non-cooperative game to consider how the terms on which countries are allowed to trade in emissions permits affect equilibrium cost and emissions predictions. Wealthy, high abatement demand countries will participate only in agreements which promise significant reductions in global emissions, the while developing countries entering such agreements must be allowed to sell sufficient emissions rights to make an their participation worthwhile. We find that stringent caps on the level of emissions rights that any individual country may allocate itself, combined with relatively weak restrictions on the volume of trade in which countries may engage are an effective way of aligning regional incentives. This result runs contrary to received wisdom from the non-strategic literature on emissions trading.

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1 Introduction

Over the past decade, society has become increasingly aware of the possibility of human-induced climate change, and a series of international greenhouse gas policy meetings of increasing frequency and intensity are a testament to this trend. The stated objective of these laboriously planned sessions is to develop a plan (such as the Kyoto Protocol) for a coordinated reduction in the use of fossil fuels, the major source of anthropogenic greenhouse gases. But what are the prospects for such an agreement to succeed? Abatement is likely to be costly, climate science is still very uncertain, and cooperative action against global warming has all the makings of a classic free-rider problem – the closer a coalition comes to achieving the efficient level of greenhouse gas emissions, the stronger are the incentives for individual countries to defect from the agreement. As a defector, a country can enjoy all of the benefits of the remaining coalition members reduced emissions levels, while relaxing its own costly abatement measures.

These strategic aspects of international climate politics are usually modelled as games in which countries choose their national levels of *emissions*. This is somewhat at odds with the current negotiations on climate change, where the instrument of choice has been *tradable emissions permits*. Although the two are closely related, the individual countries' strategic considerations when choosing permits may differ substantially from those when choosing emissions (see Helm [2002]).

In this paper, we therefore model international climate abatement such that countries may agree on a tradable permit system and, accordingly, the initial permit allocation becomes the choice variable. Because no country can be forced to participate in such a system, we also analyze the incentives to form trading coalitions. Thereby, we take up the current policy focus which has turned towards the possibility of coaxing the developing world to join the Kyoto agreement by means of a system of tradable permits. The essence of the idea is that the developing world, which is likely to have relatively low abatement costs and demand for abatement, might be willing to sell their emissions to countries for whom abatement is expensive, but also care a lot about climate change. The hope is that abatement targets could be met at significantly reduced costs to participating nations.

There is by now a considerable literature on the strategic aspects of coalition formation and climate change (see Missfeldt [1999] and Finus and Rundshagen [2002] for comprehensive surveys). In their seminal contributions, Barrett [1994] and Carraro and Siniscalco Carraro and Siniscalco [1993] use simple, non-cooperative games in which countries make decisions about whether or not to join an abatement agreement, and how to set their national levels of emissions. A country's preferences with respect to its own emissions choices are defined by simple, partial equilibrium supply and demand functions for abatement activity.

Being a participating member of the agreement in these games means setting the emissions level prescribed by a group objective function that minimizes group costs or maximizes group welfare. Non-members adopt individual best-reply strategies. The stability of a cooperating coalition is checked with a concept from the analysis of cartels in an oligopoly [d'Aspremont et al. 1983]. Roughly speaking, a coalition is stable when none of its members has an incentive to defect, and non-members have no incentive to join the coalition.

In these early works, all countries are assumed symmetric in their abatement cost and climate damage schedules. A convenience of this assumption is that there is no obvious need to redistribute the surplus of an agreement through transfer payments across participating countries. The simple and persistent result that comes out of these models is that meaningful cooperation (ie. sustaining an outcome significantly different from the status quo) between symmetric players is difficult to achieve. Either it is unlikely that a coalition of many countries will form, or, if large coalitions form, they will achieve only little compared to the Nash equilibrium (see also Murdoch and Sandler [1997]).

Barrett [1997] and Botteon and Carraro [1997] extend the above cited work by considering asymmetric country profiles. They use sharing rules from cooperative game theory to divide the surplus between the different coalition members. The assumption that countries will adopt such a sharing rule is somewhat ad hoc, however.

A persistent feature of all these models is that the choice variable is emissions. Furthermore, there is no role for permit trading because coalitions of cooperating countries are assumed to allocate their emissions efficiently. The present paper builds upon less optimistic assumptions about countries' ability to agree on efficient cooperation. In particular, we assume that countries always adopt non-cooperative best-reply strategies.

However, there is a role for an international body (or international negotiations) which can present a proposal for a tradable permit system. Countries decide whether they become a member of this trading coalition. If they do so, they non-cooperatively choose their initial allocation of permits. If not, they choose their emissions as a best response to the strategies of coalition internal and external members. In equilibrium, none of the countries must have an incentive to either leave or join the trading coalition.

Accordingly, the capabilities of the international body are rather limited. In particular, it cannot prescribe the initial allocation of permits, which is non-contractible (otherwise, one could simply write a contract codifying the efficient permit allocation). However, the international body has some power in that it can formulate the rules of the permit system – such as caps on the maximum amount of permits a country may allocate to itself or trade.

We use calibrated analysis to solve the model and to consider how the terms on which countries are allowed to trade in emissions permits effect equilibrium cost and emissions predictions. Wealthy, high abatement demand countries will participate only in agreements which promise significant reductions in global emissions, while the developing world must be allowed to sell sufficient emissions rights to make an agreement worth while. We find that caps on the level of emissions rights that any individual country may allocate itself are an effective way of aligning regional incentives. Furthermore, we find that relatively weak restrictions on the volume of trade that countries may engage in maybe welfare improving. This result runs contrary to received wisdom from the non-strategic literature on emissions trading.

2 The Model

We consider a simple partial equilibrium model with multilateral externalities. There is a set of countries, $N = \{1, \ldots, n\}$ with generic elements i, that generate pollutive emissions $e_i \in \mathbb{R}_+$. Emission abatement costs, $c_i(e_i)$, depend on domestic emissions, with $c_i'(e_i) < 0, c_i''(e_i) > 0$. Countries' willingness to pay for abatement, $v_i(e)$, depends on overall emissions, $e \equiv \sum_{i\in N} e_i$, with $v_i'(e) > 0, v_i''(e) \geq 0$.

International negotiations are represented by an international body, which can be thought of as the Principal, that can come forward with a proposal for a tradable permit system. In particular, this proposal specifies the members of the trading coalition, their initial permit allocation, as well as emissions for coalition external agents. None of these elements are contractible so that the power of the international body is rather limited. However, it can present certain basic rules as "take-it-or-leave-it" offers that all members of the trading coalition have to obey to. We will focus our attention on two such rules which appear to be the most interesting from a policy point of view: caps on the initial permit allocation and caps on the amount of permits that may be traded.

Given the non-contractability of the treaty elements, the allocation of permits and emissions must be incentive compatible, and participation of the designated members in a trading coalition must yield a higher payoff than non-participation. We first discuss the incentive compatibility constraints of the countries.

As in Helm [2002], Members of the trading coalition choose their initial allocation of permits, denoted ω_i, so as to maximize their payoff in a trading coalition, subject to the restrictions specified by the international body. In doing so, they anticipate the subsequent trading of the initial permit allocation on a competitive market. By the principle of backward induction, we start analyzing the interaction on this permit market. There, countries choose emissions, and thereby their permit sales, so as to minimize their abatement cost:

$$\forall\, i \in M:\ \min_{e_i}\ c_i(e_i) - p^*(\omega_i - e_i) \qquad \text{s.t.} \quad \alpha e_i \leq \omega_i, \tag{1}$$

where p^* is the equilibrium permit price, M is the set of agreement members, and $\alpha \in [0,1]$ is the percentage of a country's emissions that must covered by domestically held permits.[1] Assuming that the permit market is competitive, the solution to (1) together with the condition for market clearing, $\sum_{i\in M} e_i = \sum_{i\in M} \omega_i$, implicitly determine after-trade equilibrium emissions, $e_i^*(\omega)$, and the permit price, $p^*(\omega)$, as functions of the given level of overall allowances, $\omega \equiv \sum_{i\in M} \omega_i$.

Turning to the choice of permits in the previous stage of the game, members of the trading coalition follow the objective of minimizing domestic costs, thereby taking into account the effects that their choice will have on the permit market:

$$\forall\, i \in M:\ \min_{\omega_i}\ c_i(e_i^*(\omega)) + v_i(e) - p^*(\omega)(\omega_i - e_i^*(\omega)) \qquad \text{s.t.} \quad \omega_i \leq \overline{\omega}_i, \tag{2}$$

where $\overline{\omega}_i$ constitutes the cap on the initial permit allocation as specified by the international body. In contrast to the above cited literature on coalition formation (e.g., [Barrett 1994] and [Carraro and Siniscalco 1993]), this means that also members of the coalition behave non-cooperatively, apart from their honoring of permit rights.

By contrast, the countries who are not a member of the trading coalition choose their emissions so as to minimize domestic costs:

$$\forall\, i \in N \setminus M:\ \min_{e_i}\ c_i(e_i) + v_i(e). \tag{3}$$

The first order condition to this problem yields the familiar notion that a country will equate its private marginal cost and benefits associated with abatement, and take all

[1] We assume that there cannot be more than one trading coalition.

other countries' emissions levels as fixed. Furthermore, if abatement costs are strictly convex and willingnes to pay for abatement is convex, the first order conditions of (2) and (3) define a unique Nash equilibrium over ω_i and e_i.[2]

Turning to the participation constraints, countries base their decisions about being a member of a trading coalition on the payoffs that come out of conditions (2) and (3). In particular, the participation constraints are satisfied when (i) none of the coalition members has an incentive to leave the coalition (internal stability), and (ii) none of the coalition external agents has an incentive to join a coalition (external stability). Obviously, there may be multiple equilibria. We assume that the Principal will propose the one that minimizes overall emissions.

3 Data

3.1 Business as Usual (BaU) Levels

Calibrating our model requires assumptions about the time paths of GDP, population, and emissions intensity. To make our lives simple, we do not endogenize any of these factors. Emissions intensity estimates are take from Kverndokk [1994], a widely-cited study on the topic of calibrated greenhouse gas abatement simulations.

The estimates of per capita income growth are base on the RICE model. They are characterized by partial (but still relatively weak) convergence in per capita income across the model regions. USA, JPN, EUR, and FSU start off with growth around $2 - 2.5\%$ annual growth, while CHN and ROW regions are growing at $4 - 4.5\%$. Growth of all regions' economies is assumed to slow considerably (basically by half in percentage terms) by the year 2050.[3]

3.2 Willingness To Pay

Estimates of how a country's willingness to pay for action against climate change might evolve over time are nonexistent. Our solution is to assume that marginal WTP is constant in the global emissions stock within a model time period, but an increasing function of this stock over time. This specification is meant to reflect the fact that people are unlikely to have any significant curvature in their WTP schedules for changes in the global carbon stock as small as are likely to result from a single period's activity. As the emissions accumulate over time, however, we might expect people to update their feelings about emissions based on observable changes in their environment – like increased intensity in extreme weather events, or more accurate reports from scientists on the potential effects of increased emissions.

Because agents in our model are not forward-looking, they do not take into account their future, higher values for climate improvements. The WTP update schedule, however,

[2]Of course, this is subject to the provisio that the second order conditions hold. On the general domain of convex abatement and WTP functions, this need not be the case for (2) (see Helm [2002]). However, the second order conditions are satisfied for the functional specification which we use later for the numerical simulations.

[3]Our results, however, are not particularly sensitive to these assumptions. Far more important is the distribution of abatement costs and WTP schedules across regions.

is calibrated such that increasing the global carbon stock more than double would be prohibitively expensive, all else given. In other words, if the world reached the point of doubling the atmospheric concentration of GHGs, the climate effects would be intolerable enough that even the non-cooperative equilibrium would result in no further increases in the stock. This inter-temporal response of WTP is an exponential function of current CO_2 concentrations.

All countries are assumed to have the same intertemporal relationship between concentrations and marginal WTP, but we also attempt to model regional differences, which are captured in intercept dummy parameters. In other words, a country's marginal WTP schedule may be shifted higher or lower due to differences in their preferences or geography that are exogenous to our model. We calibrated these differences by choosing the intercept parameters such that 1990 marginal WTP yields the BaU level of emissions for 1990 when all countries are setting emissions in the manner of a Nash equilibrium, and countries are not allowed to trade permits.

This calibration method has its limitations. For example, our method implies that Japan cares about the climate approximately *twice* as much as the next highest region in our model. This undoubtedly reflects the fact that we are including the costs from other markets that are related to emissions in our measure of WTP for global climate improvements. Differences in energy prices and demand for local environmental improvements are among the likely candidates.

3.3 Abatement Costs

Abatement costs are defined on percentage reductions from BaU emissions, $E_{t,i}$, demanded by region i at time t:

$$C_i(e_i) = Y_{t,i}\phi_i \left[1 - \left(\frac{e_i}{E_{t,i}}\right)^{\sigma}\right],\ \phi_i < 0, \sigma = -1.$$

This implies that abatement costs are strictly convex and decreasing in e_i, and infinitely large for a full reduction to 0 emissions. $Y_{t,i}$ is the exogenous level of per capita income. The calibration for the abatement cost functions is derived from Nordhaus and Yang [1996]. We calibrate ϕ_i in our model to match the marginal cost of a uniform 30% reduction in emissions across all regions from RICE. Figure 1 plots the regions cost functions for 1990.

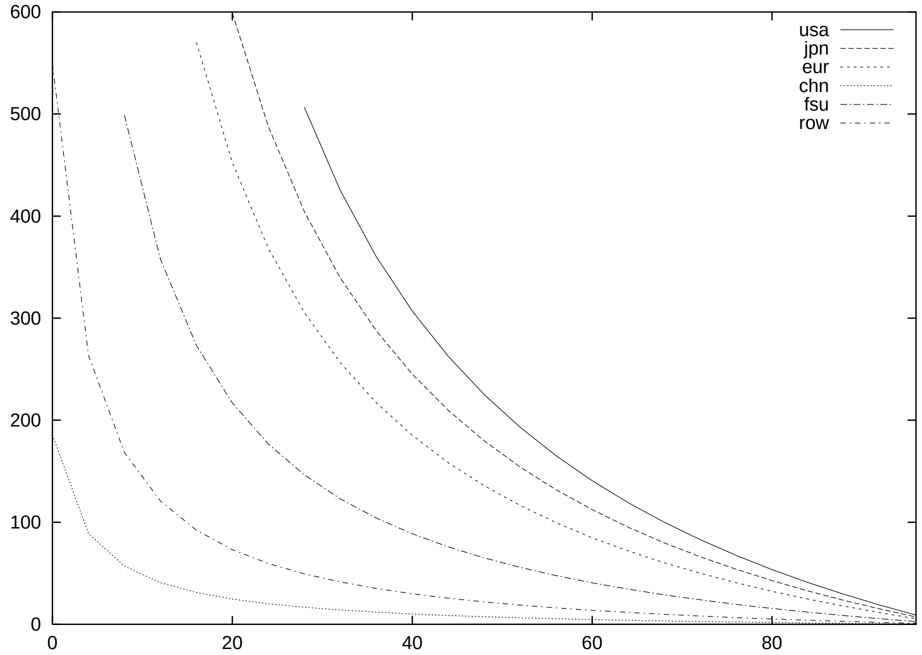
As time advances all countries in our model have larger needs for emissions according to our calibration. The result is that the same level reduction in emissions gets more expensive over time.

4 Results

When a member of a trading coalition chooses its initial allocation of allowances, it faces a trade-off similar to that of a quantity setting oligopolist. The more allowances it selects, the lower the price that it receive per emission right. However, given our parameter specification, a model of truly unrestricted choices in emissions and rights levels yields no equilibrium cooperation.[4] Our focus, therefore, is on opportunities to improve on this

[4]This result is robust to a number of different assumptions about the functional form of abatement costs.

Figure 1: Per Capita Abatement Costs For % of BaU Emissions, 1990



outcome by changing the rules of trade in two directions.

First and foremost, cooperation is foiled in the unrestricted model by the propensity of the South to choose very high levels of emissions rights. Without exception, our model predicts that they will choose rights far in excess of their non-cooperative emissions levels. This has the effect of making agreements unprofitable for members who value global emissions reductions, and suggests that placing caps on regional emissions rights choices might improve matters. Political and moral realities also motivate such a restriction; it is unlikely that China would be allowed to allocate itself more rights than the emissions levels it would choose in the absence of a trade agreement.

Capping the emissions rights levels controls the cumulative level of emissions that a coalition produces. A second important consideration in our analysis is the intensity of trade across regions, and the issue of subsidiarity. A current debate in policy-making sessions surrounds the idea of a provision limiting the fraction of abatement demand that any member country can satisfy by purhasing permits through trade. Proponents of such restrictions cite distributional concerns, and the risk associated with placing a large degree of abatement responsibility in the hands of a few developing countries. Economic studies on the subsidiarity question unanimously predict negative impacts from imposing such restrictions. These studies are all based on gains-to-trade arguments – competitive markets lead to efficient outcomes. Restricting trade can only move the market away from efficiency in this context. When we take the strategic aspects of the problem into account, we find that such restrictions may either help or hurt the global welfare. The answer depends on how tightly the limits bind.

The main exercise of the paper is to consider how the model results respond to changes along our two instrument dimensions. To build some intuition, however, we first examine the time profile of equilibria in detail for a single model run, and then go on to consider sensitivity to the two restrictions. In all simulation results the model has six region/agents, and is run over the time horizon 2000-2050, in ten-year intervals. The country aggregation scheme corresponds to the one used in Nordhaus and Yang [1996]; China, Japan, and the United States all remain sovereign, but the rest of the world are aggregated into three model regions: Western Europe, the Former Soviet Union States, and a "Rest of World" remainder region.[5]

4.1 The Equilibrium Profile

The fact that all non-singleton coalitions are thwarted by the incentive for permit sellers to increase their permit allocations suggests a potential remedy; by imposing a more stringent upper limit on the amount of permits any one country is allowed to secure for itself, we might eliminate the allocation expansion problem, and sustain larger coalitions.

This turns to out to be an effective strategy in the context of our model. When a cap is placed on permits which constrains each region to choose no more rights in that period than would cover their predicted emissions levels if trade was unavailable, then the model can sustain an equilibrium profile in which each region joins the coalition for some periods of the model. Table 1 presents the equilibrium profile in terms of emissions rights choice over time. Rights levels are presented as percentage differences from the non-cooperative emissions levels in the relevant time period.

Table 1: Equilibrium Rights Over Time: cap=100% of NC

	US	Japan	Europe	China	Former USSR	Rest of World
2020	N/A	-99.7	-99.9	0.0	-99.9	0.0
2030	N/A	-99.7	-99.9	0.0	-99.9	0.0
2040	-99.9	-99.7	-99.9	0.0	N/A	0.0
2050	-99.9	-99.7	-99.9	0.0	N/A	0.0

As expected, the developing world regions (China and Rest of World) choose the maximum allowable emissions rights, while all other participating regions choose almost none. Obviously, the two regions with all of the rights are also responsible for all of the equilibrium abatement. USA, Japan, and Europe all take advantage of the cheap permits to increase their emissions levels beyond their non-cooperative levels.

The "N/A" entries in the table signify that the corresponding region is not a participant in the trade agreement, and chooses to emit at the non-cooperative level. United States seems to replace the Former Soviet States in the coalition in 2040, suggesting that a coalition with both regions participating is not stable. Having both countries in the agreement puts upward pressure on the permits price. This added cost of abatement tips the profitability scales negative for these regions when both join the agreement.

Notice that no entries appear in table 1 for the first two time periods of our model. Under this set of assumptions, environmental concern is not large enough to enduce co-

[5]Roughly speaking, the aggregation rule tries to group countries with similar abatement cost profiles.

operation early in the time horizon. Only after twenty years of adding emissions to the global stock at the non-cooperative rate and updating their willingness-to-pay schedules do countries get together.

The distribution of costs in equilibrium is also interesting. Table 2 presents these results – also as percentage differences from non-cooperative costs. The table demonstrates that the gains are weighted towards the permit-selling regions, and the ROW region in particular. ROW sees over 100% reductions in its costs in some periods. This suggests that the permit trade has a naturally redistributive effect. In our model, poor countries are the ones who have both low abatement costs and demand for abatement. These are the countries which are natural permit sellers in equilibrium and, it seems, the recipients of most of trade's surplus.

Table 2: Equilibrium Costs Over Time: cap=100% of NC

	US	Japan	Europe	China	Former USSR	Rest of World
2020	-23.2	-24.4	-22.2	-45.9	-12.3	-125.1
2030	-21.4	-22.6	-21.0	-41.5	-12.5	-95.8
2040	-19.4	-20.9	-18.9	-51.6	-19.9	-113.0
2050	-18.3	-19.0	-17.5	-44.7	-18.1	-83.1

Now consider the effect of these coalitions on the time trajectory of global emissions concentrations. Figure 2 displays both the equilibrium trajectory of concentrations (as a % difference from the non-cooperative), as well as the concentrations implied by a first-best calculation.[6] The figure shows that a more restrictive rights cap improves upon the non-cooperative outcome that prevailed in our original model by 1% by 2050. This acheivement seems less impressive when compared to the first-best program, which would have us reduce concentrations by almost 6% in the same time frame.

The equilibrium also falls quite short of the first-best in terms of the cumulative cost reductions implied by equilibrium trade. At best, equilibrium costs are 25% below the non-cooperative levels. The first-best, on the other hand, would reduce global costs 65-70% in each period. The potential cost savings are growing over time, because emissions concentrations, and countries' willingness to pay to avoid further emissions, are also growing.

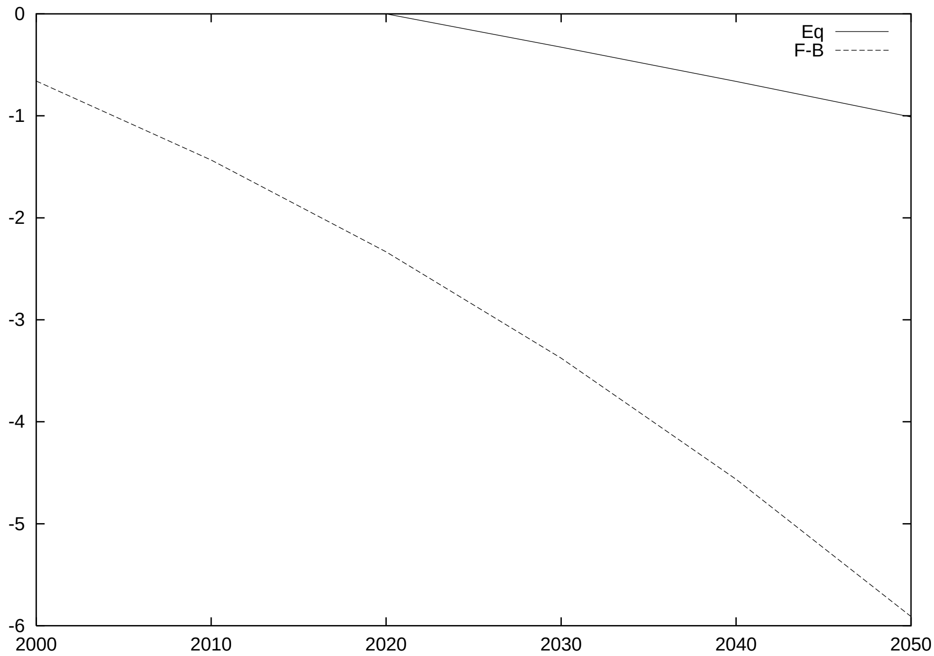
4.2 Lower Caps

What happens when we move the rights cap below non-cooperative emissions levels? Figure 3 shows reductions in emissions concentrations, again, but with the different series representing equilibrium outcomes under progressively lower caps.

The figure demonstrates the trade-off between forcing participants to commit to meaningful regional abatement, and enticing enough countries into the agreement. Lowering

[6]The first-best program simply minimizes the unweighted sum of regional costs for the current time period. It is, therefore, not forward-looking, just as the equilibrium choices are. By its design, it is also first-best only to the extent that the appropriate transfers could be made costlessly to ensure that all regions would be better off.

Figure 2: Emissions Concentrations, Equilibrium vs. First-Best: 2000-2050



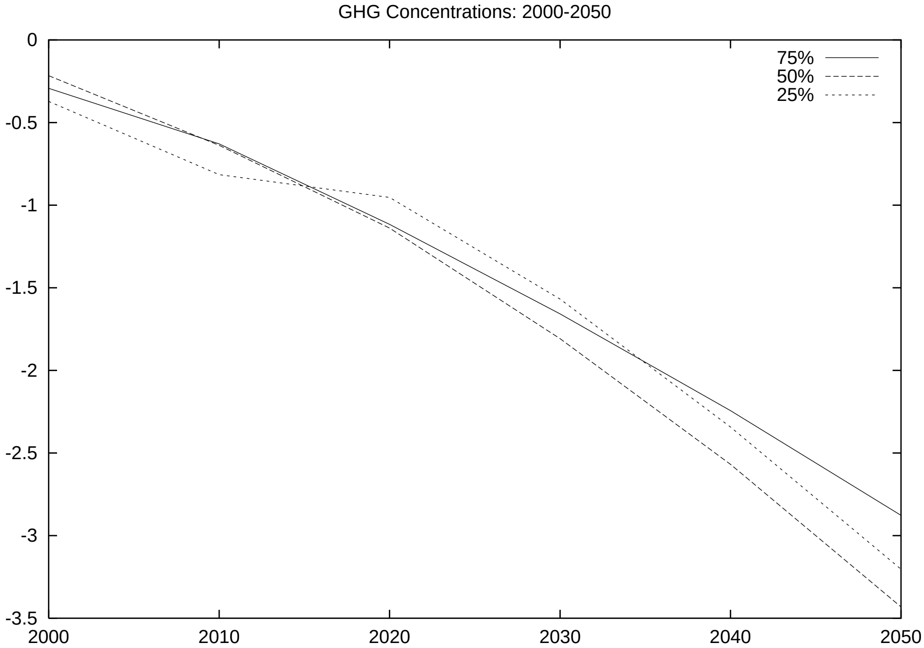
the limit increases emissions reductions up to a point. After this point, the effect of lower participation overwhelm the effect of the lower caps, and emissions begin to climb again. For the series shown here, placing a cap at 75% or 50% of the non-cooperative emissions levels yields a significant improvement over 100% (see the "Eq" series from Figure 2). However, pushing the limit too far down, e.g. to 25%, the benefits decrease.

While it is not true that relative positions of the *period* cost reductions are the same across the horizon, we can say that cumulative costs have the same rankings as the emissions reductions. In other words, the costs roughly track with the equilibrium abatement achievements. Furthermore, *all* regions, both trade participants and not, are better off when the rights cap is lowered within that range which lowers total costs.

4.3 Subsidiarity

Regional caps on rights are effective in controlling the aggregate level of emissions that a coalition produces, but they have no influence on the intensity of trade between different agreement members. We simulate concerns about this issue by introducing restrictions on the quantity of permits one country may purchase from another. The intuition produced by the non-strategic literature on the effects of such restrictions is simple; restricting trade can only serve to drive a wedge between equilibrium and the efficient outcome with free trade. When we endogenize a country's choice to participate in a permit market, the story changes. Figure 4 shows the equilibrium concentrations trajectories again, with each series representing a different assumption about the fraction of permit demand that a country may satisfy through trade. The labels on the series correspond to the percentage of a

Figure 3: Emissions Concentrations by Rights Cap Level: 2000-2050



country's emissions that must covered by domestically held permits, so a smaller number implies a larger degree of freedom in how countries trade.

The abatement acheivements are highest for a 20% subsidiarity restriction. The 10% and 30% series yield similar results, differing by less than a tenth of a percent in 2050. But giving countries full freedom to trade clearly has negative consequences – cutting reductions by from 3.7% under the 20% restriction, to 3.4%. The change comes from the restriction's effect on the permit price. When trade is unrestricted, Japan has a strong incentive to buy large quantities of permits and increase their emissions above NC levels. The incentive is strong enough that Japan drives the permit price up to the point where the coalition looses the participation of either USA or Europe in a number of time periods. The subsidiarity restriction lessens Japan's incentive to increase its emissions levels; this has both climate and permit price benefits for these other Northern countries. Making the restriction too tight is also damaging, as the 40% series shows. The volume of trade becomes low enough under this assumption that the permit-sellers, ROW and China, start to opt out of the agreement.

Figure 5 attests to the costs acheivements for the same exercise. The results parallel the abatement acheivement in the sense that greater emissions reductions lead to greater cumulative cost reductions. Timing is important, however. As the restriction moves from 10-30%, the benefits of cooperation shift forward in the time horizon. This is a consequence of the timing of Europe's entry into the coalition. Over this range of trade restrictions, the lower the restriction is, the longer it takes for Europe to enter, because it is waiting for the permit price to come down to profitable level.

Figure 4: Emissions Concentrations by Tradable Permits Fraction: 2000-2050

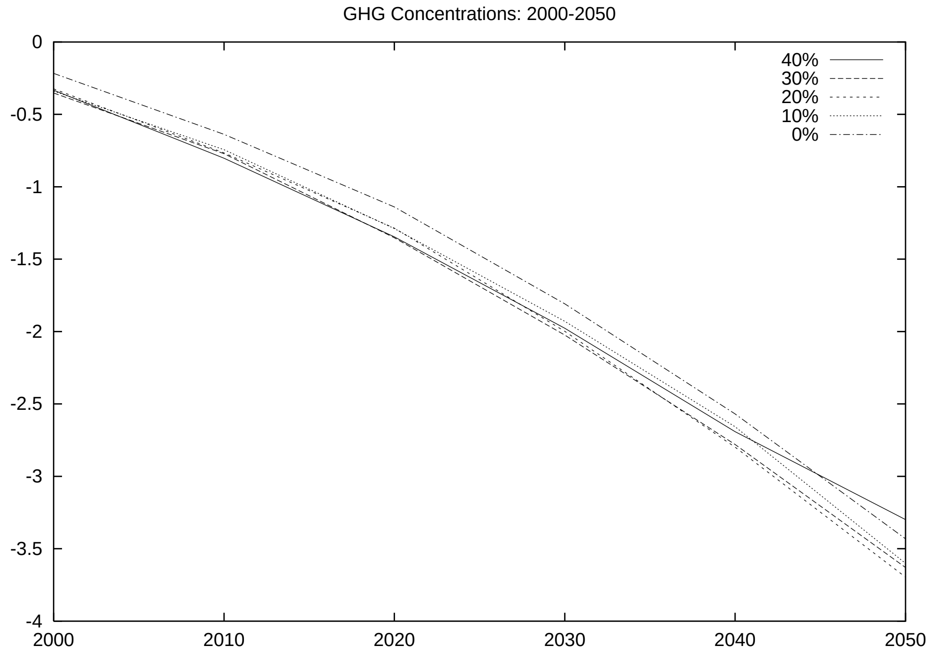
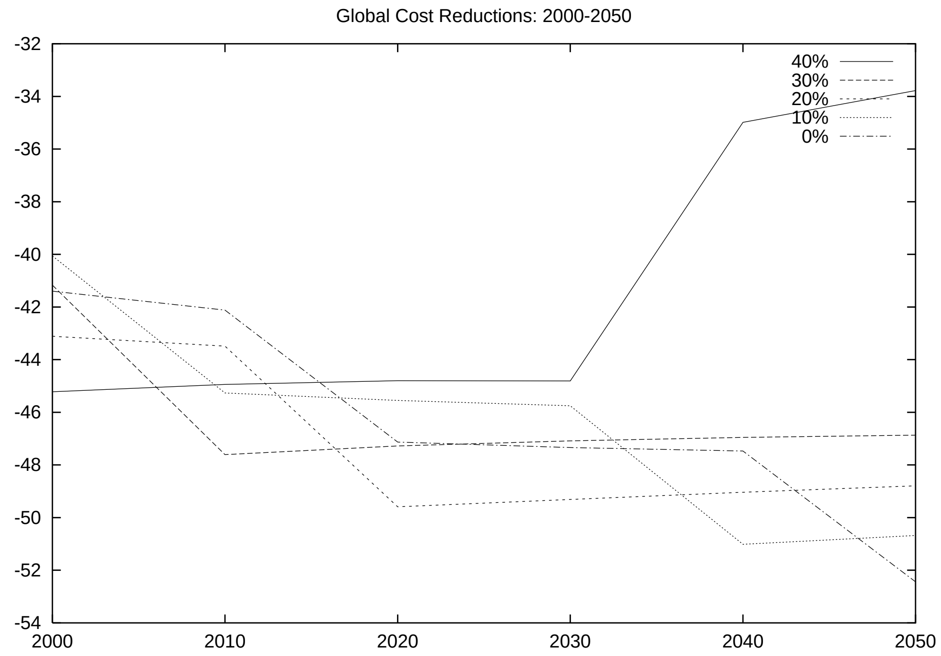


Figure 5: Global Costs by Tradable Permits Fraction: 2000-2050



5 Conclusions

The international scope of global warming introduces special complications to an otherwise classic free-rider problem. Tradeable permits have had some success in restoring efficiency to similarly disfunctional markets in the domestic arena, so it is natural to think that they might be applicable at the international level as well. Our model suggests that if countries are able to choose emissions and rights levels with a large degree of freedom, the unsurprising result is that there is no equilibrium cooperation. By choosing a game form in which emissions rights are explicit and chosen by each player non-cooperatively, we are able to analyze the effects of imposing more structure on the agreements, mimicking the role of a coordinating international institution. This exercise proves fruitful.

When we impose caps on the level of emissions rights any one country can choose, our simulations suggest that there would be wide international support, with potentially significant cost and emissions reductions. Intuitively, the level of abatement an equilibrium coalition can acheive under such restrictions depends on the level at which the cap is placed. The optimal cap level, in terms of both costs and emissions, may be well below the non-cooperative levels of emissions (50% in our simulations). Placing too stringent a cap, however, induces a rate of dropout from the equilibrium coalition that overwhelms the emissions reduction acheived by the remaining members. Under the best of conditions, the equilibrium yields about half of the emissions reductions that a first-best program would imply.

We also find a economic motivation for limiting the fraction of total permits that an individual country can purchase abroad. Again, too tight a restriction makes the agreement unprofitable for permit-sellers, like China. Without such a limit, however, the intensity of trade initiated by a permit buyer can drive the price up too high for other potential permit buyers, and force their exit from the agreement. As far as we know, this justification for trade restrictions has gone unacknowledged until now.

Finally, it is worth noting that the restrictions we model are universally preferred to a world with no trade. While this is by no means a robust test of the feasibility of imposing such restrictions, it certainly leaves the door open for further exploration at the policy level.

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