

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

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Basic Ideas

Success of any international climate change agreement depends on the strategic incentives of countries to participate.

A non-cooperative game in which abatement coalition membership, permit allocations and emissions are selected endogenously can be used to characterize the current and future climate negotiation process.

The terms on which countries are allowed to trade in emissions permits affect equilibrium cost and emissions.

Wealthy countries with relatively high marginal valuation of abatement only participate in agreements which promise significant reductions in global emissions.

Developing countries entering such agreements must be allowed to sell sufficient emission rights to make an their participation worthwhile.

Stringent caps on permit allocations together with relatively weak restrictions on the volume of permit trade lead to higher levels of abatement in equilibrium.

Some aspects of this policy advice run contrary to received wisdom from the non-strategic literature on emissions trading.

The Model

- N countries characterized by abatement cost functions $c_i(e_i)$ and marginal willingness to pay for abatement (v_i)
- The dynamic evolution model is represented as a sequence of static Nash equilibria.
- In each time period, countries interact strategically and thereby choose an abatement coalition, M . When there are multiple equilibria, the abatement coalition selected is that which leads to the lowest level of global emissions.

- Marginal willingness to pay for abatement by country i is assumed to be constant *within a given period*, but it may change over time (environmental Kuznets curve)
- Marginal willingness to pay for abatement may increase with global concentration.

Notation

$i \in N = \{1, \dots, n\}$	the set of countries,
$e_i \in \mathbb{R}_+$	greenhouse gas emissions,
$c_i(e_i)$	emission abatement cost ($c'_i(e_i) < 0, c''_i(e_i) > 0$),
$e \equiv \sum e_i$	global emissions,
v_i	country i 's marginal willingness to pay for abatement,
$M \subseteq N$	the set of agreement members,
$\omega_i, \quad i \in M$	initial allocation of permits for coalition member states,
$p^*(e)$	the equilibrium permit price,
$\alpha \in [0, 1]$	the fraction of a country's emissions that must be covered by domestically held per- mits (<i>a policy parameter</i>)

Coalition Members Emissions Choice (stage 2):

$$\forall i \in M : \min_{e_i} c_i(e_i) - p^*(\omega_i - e_i) - v_i e_i$$

$$\text{s.t. } \alpha e_i \leq \omega_i,$$

Market clearing condition for permits:

$$\sum_{i \in M} e_i = \sum_{i \in M} \omega_i$$

Non-Member State Emissions Choice Problem (stage 2)

$$\forall i \in N \setminus M : \min_{e_i} c_i(e_i) - v_i e_i.$$

Member State's Permit Choice Problem (stage 1)

$$\forall i \in M : \min_{\omega_i} c_i(e_i^*(\omega)) - p^*(\omega)(\omega_i - e_i^*(\omega)) - v_i e_i$$

$$\text{s.t.} \quad \omega_i \leq \bar{\omega}_i,$$

where:

- p^* is the equilibrium permit price
- $e_i^*(\omega)$ are the after-trade equilibrium emissions, as a function of the given level of overall allowances, $\omega \equiv \sum_{i \in M} \omega_i$.
- $p^*(\omega)$ the equilibrium permit price, as a function of the given level of overall allowances.

Rationality

Nash equilibrium: a country equates its private marginal cost and benefits associated with abatement, and taking all other countries' emissions levels as fixed.

A member of a trading coalition acts as an oligopolist in choosing its initial allocation of allowances. The more allowances a region chooses, the lower the price that it receives per emission right.

Subject to convexity of cost functions and a constraint qualification, the first order conditions of these choice problems define a unique Nash equilibrium over ω_i and e_i

Membership decisions depend on relative rewards of being in or out of the coalition.

Equilibrium

An equilibrium coalition satisfies two constraints:

1. none of the coalition members has an incentive to leave the coalition (*internal stability*), and
2. none of the coalition external agents has an incentive to join a coalition (*external stability*).

Multiplicity

Obviously, there may be multiple equilibria.

We assume that an international coordinating body will always choose an equilibrium that minimizes global emissions.

Regions and Countries in the Model

USA	United States
JPN	Japan
EUR	Europe
CHN	China
FSU	Former Soviet Union
ROW	Rest of World

Easily Available Data

Calibration of the model requires assumptions about the time paths of GDP, population, and emissions intensity; all of which are exogenous and unaffected by the model's equilibrium outcome.

Emissions intensity estimates are taken from Kverndokk (1994).

Population and per capita income growth are based on the RICE model (Nordhaus and Yang, 1996), exhibiting partial 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 rates slow considerably by the year 2050.

Base Year Data

	GDP	Emissions	Population
USA	5465	13.7	0.25
JPN	2932	2.9	0.12
EUR	6828	8.7	0.37
CHN	370	8.1	1.10
FSU	855	10.7	0.29
ROW	4629	34.3	3.10

GDP	Economic output (billions \$1990)
Emissions	Base year emissions (10^8 tons of CO ₂)
Population	Billions of people

Average Annual Emission Growth Rates (%)

	USA	JPN	EUR	CHN	FSU	ROW
1990	1.10	0.80	0.80	3.70	1.90	2.50
2000	0.80	0.70	0.70	3.50	1.30	2.40
2010	0.80	0.70	0.70	3.50	1.30	2.40
2020	0.60	0.60	0.60	3.20	1.00	2.00
2030	0.60	0.60	0.60	3.20	1.00	2.00
2040	0.60	0.60	0.60	3.20	1.00	2.00
2050	0.50	0.50	0.50	2.50	0.50	1.50
2060	0.50	0.50	0.50	2.50	0.50	1.50
2070	0.50	0.50	0.50	2.50	0.50	1.50
2080	0	0	0	2.00	0	1.00
2090	0	0	0	2.00	0	1.00
2100	0	0	0	2.00	0	1.00

Source: Kverndokk(1994)

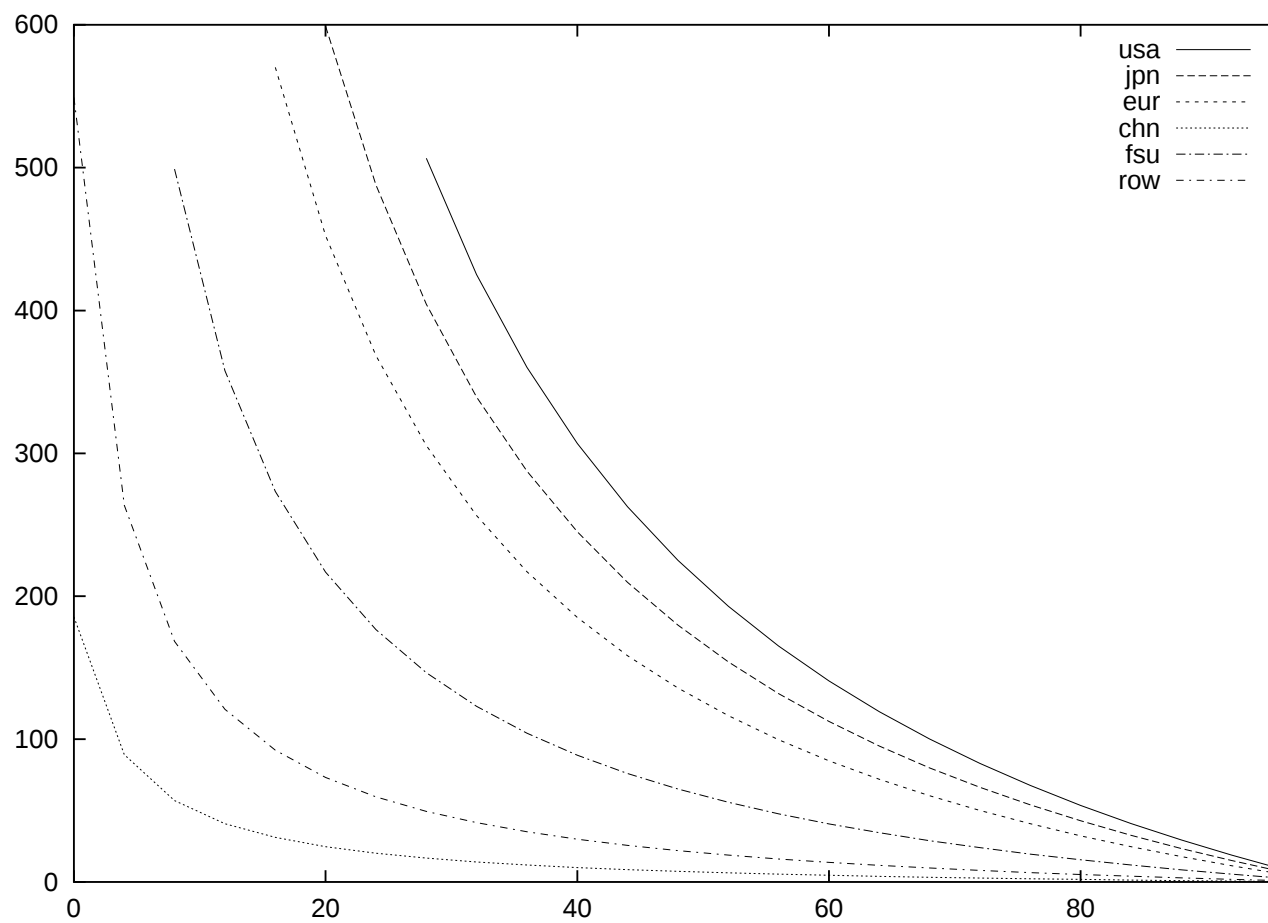
Abatement Costs

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

$$C_{it}(e_i) = \phi_i \left[\left(\frac{E_{it}}{e_i} \right)^\sigma - 1 \right] Y_{it}$$

The calibration for the abatement cost functions is based on Nordhous 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 with $\sigma = 1$.

Per Capita Abatement Costs, 1990



Willingness to Pay

Estimates of how a individual willingness to pay for action against climate change are not readily available.

Marginal WTP is assumed constant within a model time period, but WTP is an increasing function of this stock over time: we assume insufficient curvature in WTP schedules that changes in the global carbon stock within a single period have no effect.

Agents in our model are not forward-looking.

WTP are updated over time, consistent with the assumption that if the atmospheric concentration of GHGs were to double, the non-cooperative equilibrium result in no subsequent increase

in the atmospheric stock. This inter-temporal response of WTP is an exponential function of CO_2 concentrations.

Regional differences in marginal WTP are calibrated such that a Nash equilibrium for the model yields historical levels of emissions in 1990.

In the calibrated dataset Japan's marginal valuation is *twice* as great as the next highest region in our model.

Results

The model with unrestricted choices in emissions and rights levels yields the grim prediction of no equilibrium cooperation.

Cooperation is foiled in the unrestricted model by the propensity of the South to choose very high levels of emissions rights.

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.

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.

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.

Equilibrium Rights Over Time: cap=100% of NC

	USA	JPN	EUR	CHN	FSU	ROW
2000	N/A	N/A	N/A	N/A	N/A	N/A
2010	N/A	N/A	N/A	N/A	N/A	N/A
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

Notes on Equilibrium with cap=100%:

China and Rest of World choose the maximum allowable emissions rights.

All other participating regions choose almost

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.

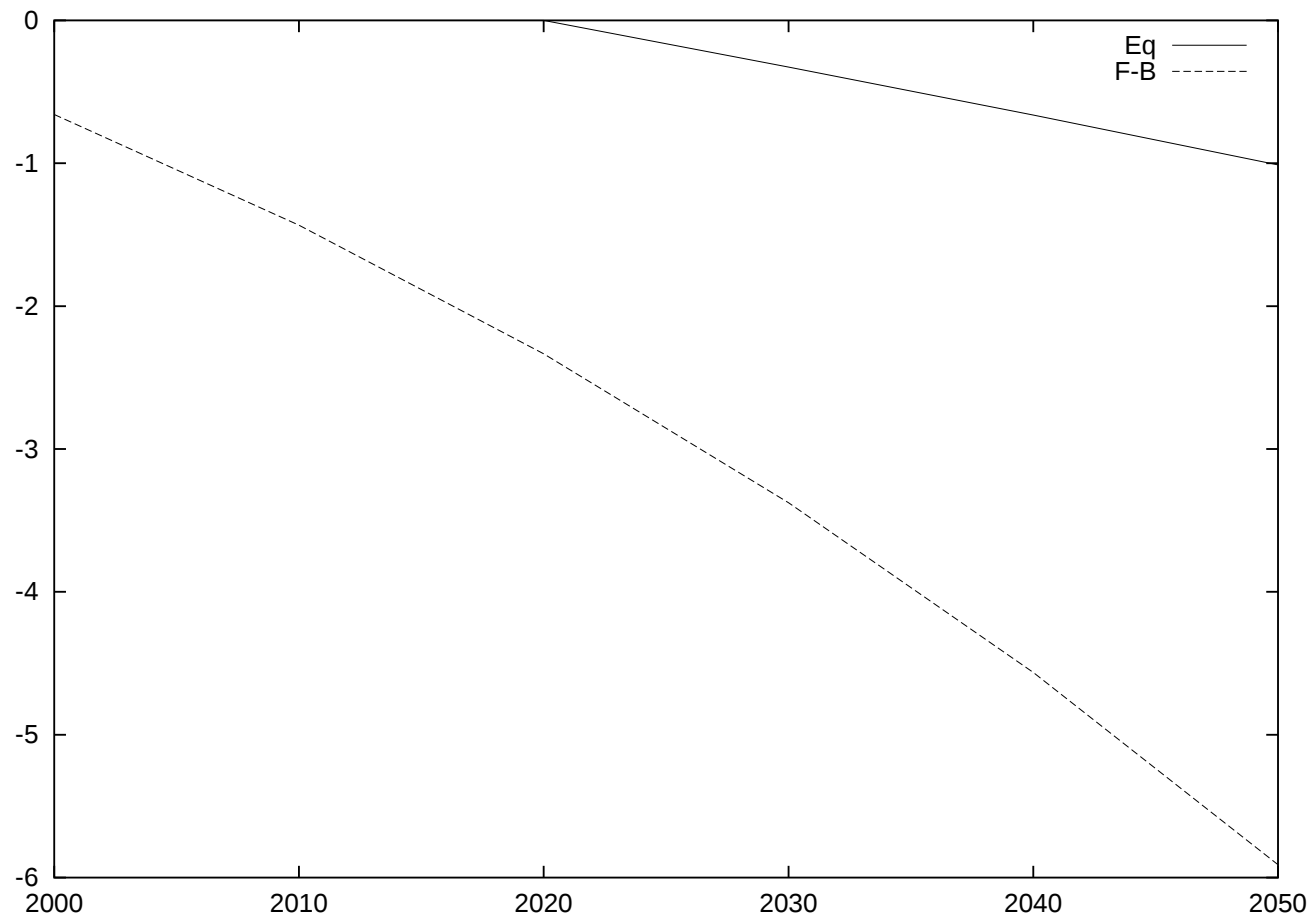
Under this set of assumptions, environmental concern is not large enough to induce cooperation early in the time horizon. Only after twenty years of adding emissions to the global stock at the non-cooperative rate and updating their willingness-to-pay schedules do countries get together.

Equilibrium Net Costs Over Time: cap=100% of NC

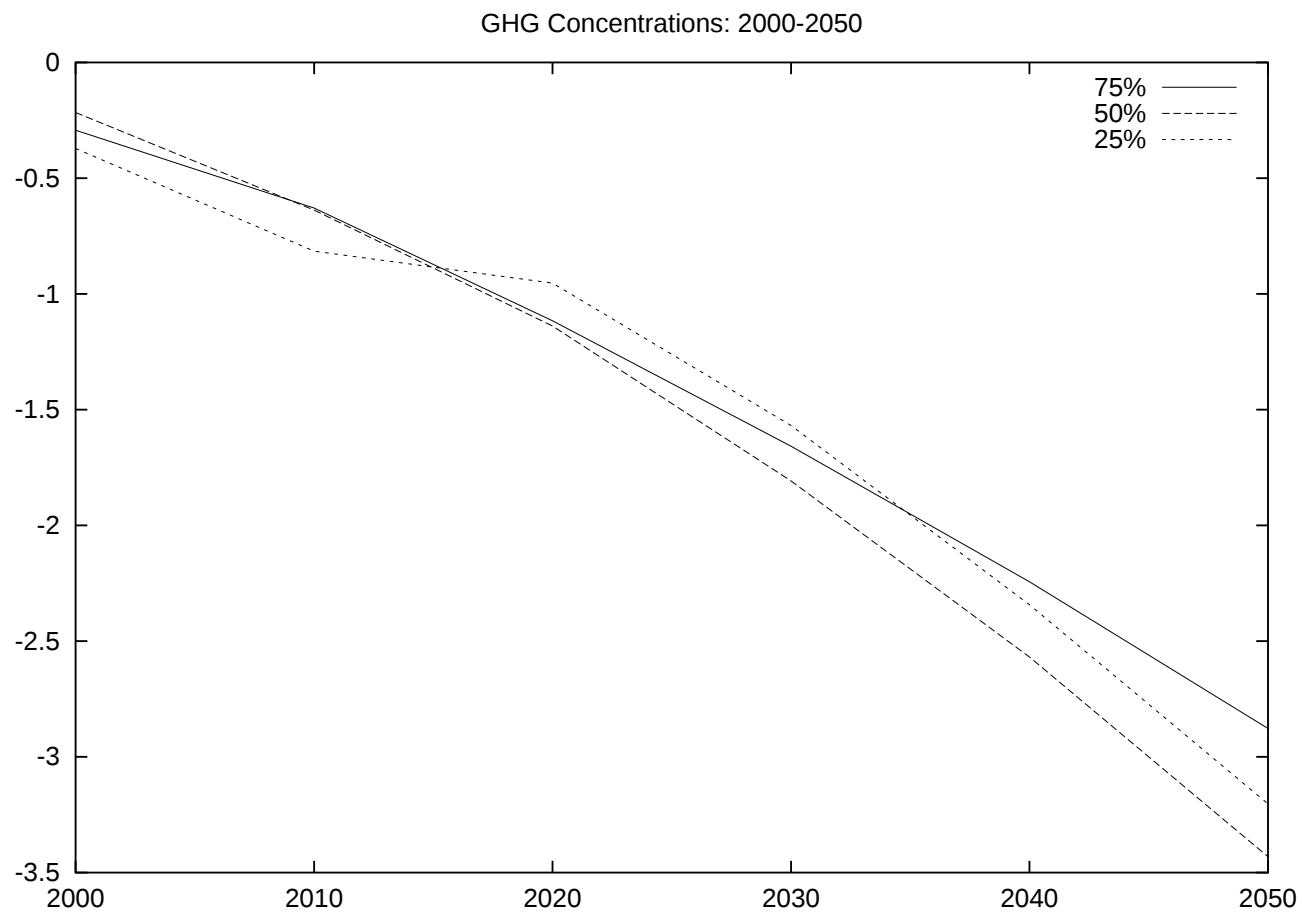
	USA	JPN	EUR	CHN	FSU	ROW
2000	N/A	N/A	N/A	N/A	N/A	N/A
2010	N/A	N/A	N/A	N/A	N/A	N/A
2020	-23.2	-24.4	-22.2	-45.9	-12.3	-125.1
2030	-21.4	-22.6	-21.0	-41.5	-12.5	-95.8
2040	-19.4	-20.9	-18.9	-51.6	-19.9	-113.0
2050	-18.3	-19.0	-17.5	-44.7	-18.1	-83.1

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. Permit trade has a naturally redistributive effect. poor countries have both low abatement costs and low demand for abatement. These countries are permit sellers in equilibrium and the recipients of most of trade's surplus.

Equilibrium Concentrations vs. First-Best



Emissions Concentrations for Different Caps



There is a trade-off between forcing participants to commit to meaningful regional abatement, and enticing enough countries into the agreement.

Lowering the limit on permit allocations increases emissions reductions up to a point.

After that point is reached, the effect of lower participation overwhelm the effect of the lower caps, and emissions begin to climb again.

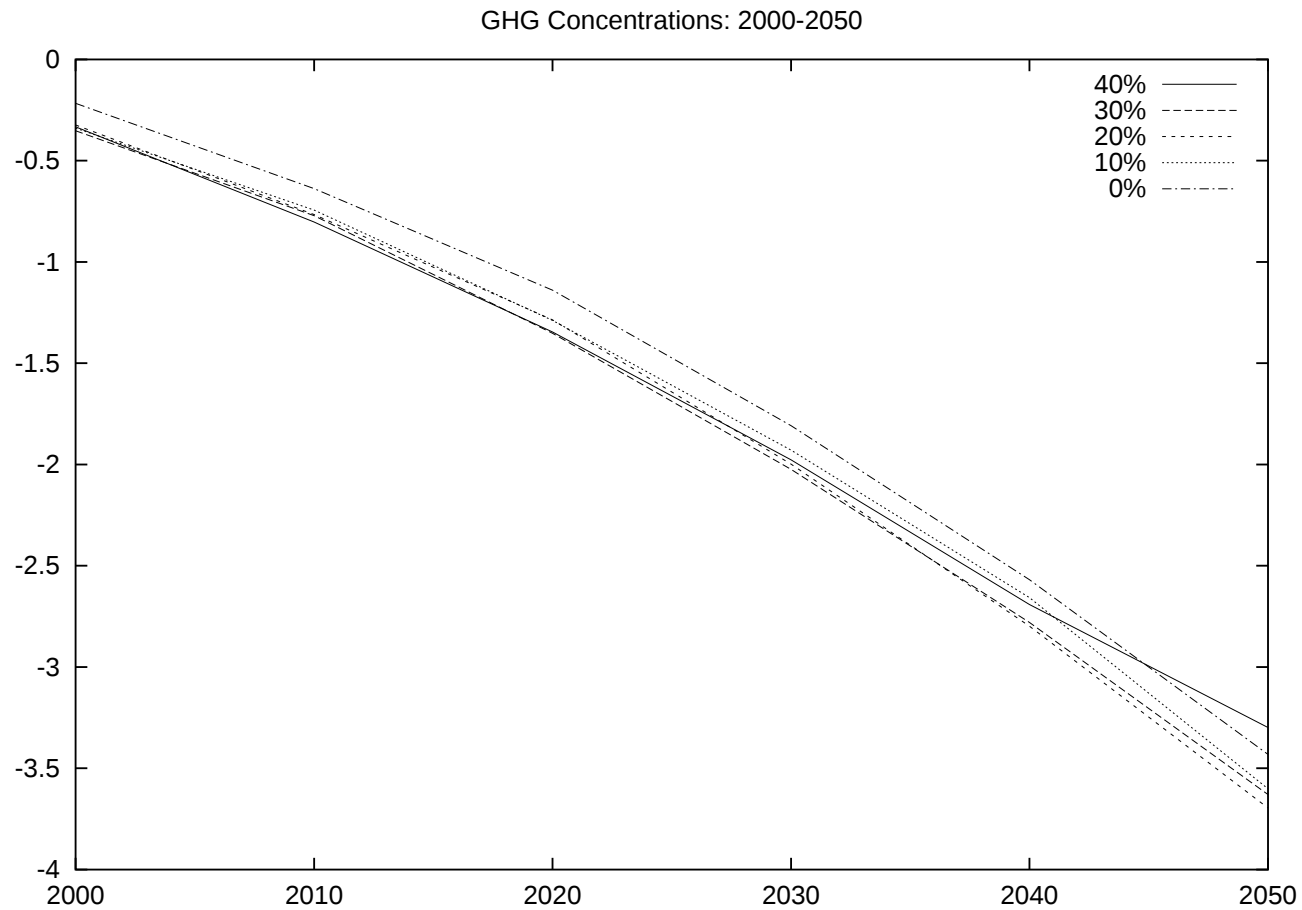
For the present model, a cap at 75% or 50% of the non-cooperative emissions levels yields a significant improvement over 100%. A cap of 25% decreases benefits.

Caps on permit allocations rights are an effective way to control coalition emissions, 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.

In a non-strategic model, a restriction on trade unequivocally lowers global welfare. Here, the results are different.

Subsidiarity Restrictions and Global Emissions



Global emissions are minimized with a 20% subsidiarity restriction.

Restrictions on trade affect the permit price.

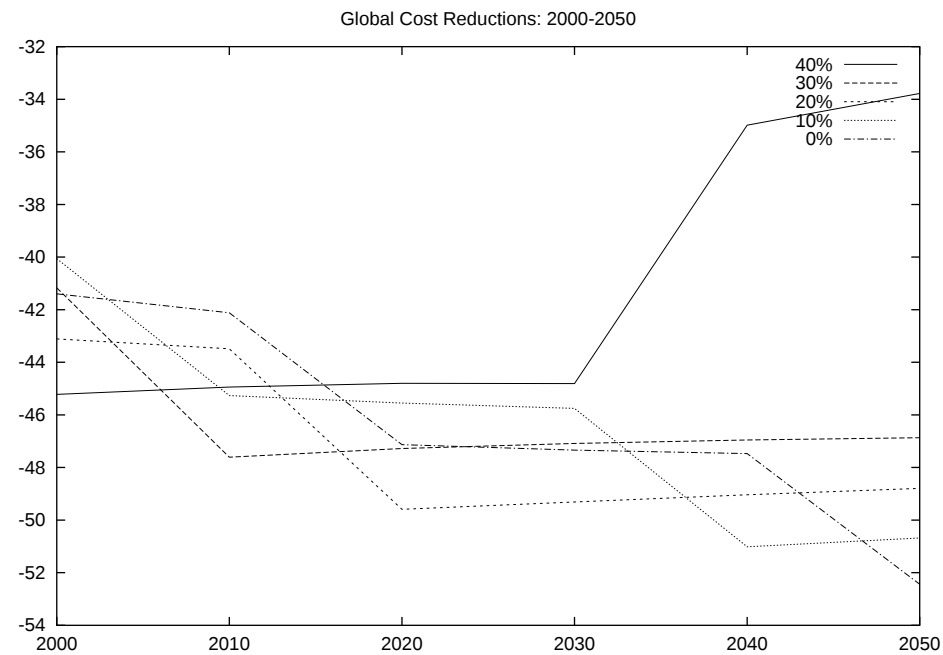
When trade is unrestricted, Japan has a strong incentive to buy large quantities of permits and increase their emissions above NC levels.

The incentive is strong enough that Japan drives the permit price up to the point where the coalition loses 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.

Subsidiarity and Global Costs



Conclusions

The international scope of global warming introduces special complications to an otherwise classic free-rider problem.

Tradable 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.

Further research seems warranted.