

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

Jared Carbone and Thomas F. Rutherford

University of Colorado

Carsten Helm

Humboldt University

Talk Prepared for the
Sixth Annual Conference on Global Economic Analysis
Den Haag, The Netherlands

June 12, 2003

Background

There are two branches of literature on the role of international permit markets in climate policy:

1. Empirical analyses of the costs of abatement measures and the role of international permit markets in minimizing abatement costs (Manne and Richels, Oliviera-Martins et al., Jacoby et al., etc.)
 - Explicit representation of the sectors of economic sectors which are the sources of the pollution (fossil fuel markets, energy-intensive goods).

- Recognition of the importance of international trade – regional policies induce changes in the prices of a number of internationally traded goods.
- Subglobal abatement policies affect energy prices, inducing increases in emissions abroad (carbon leakage).
- Abatement targets and permit markets are exogenous to the model.

2. Strategic analyses studying the determinants of effective international policy (Barrett, Carraro, Helm, Hoel, Chander & Tulkens)

- No international institution can enforce a globally efficient policy.
- There is scope for cooperation, but member states must benefit more from participation than defection.
- Most models are based on stylized, partial equilibrium, game-theoretic models with limited empirical foundation.

Helm (2003) formulated a model in which burden sharing within abatement coalitions is endogenous.

- Governments choose whether or not to be part of an international emissions permit trade coalition.
- When countries are members of a coalition, they choose emissions rights allocations non-cooperatively in a Nash-equilibrium game. This process serves as a decentralized burden-sharing mechanism.
- Permits are subsequently allocated to firms and traded in a competitive market.

Our operational version of Helm (2003) gives the theory a complete description of the economic costs of abatement in a GE framework.

Our model has sufficient empirical detail to permit us to characterize the qualitative properties of *optimal* coalition structures within this context. We enumerate all possible coalitions and evaluate equilibria based on welfare and emissions characteristics.

Calibrating the model to projected changes in regional economies over time (environmental Kuznets curve effects) allows us to look at the prospects for cooperation into the future.

Key Insights

Optimal coalition structures tend to be sub-global, even when the grand coalition is an equilibrium.

“*Good*” equilibria tend to pair large developing world countries (low abatement cost and low demand for environment) as permit sellers with Europe and/or Japan as the major permit buyers.

“*Good*” equilibria often do not possess *external stability*

Permit trade levels are typically heavy in these equilibria. China must sell lots of permits to make it worthwhile for them to be a member.

In contrast to Helm (2003), permit demands by developing countries are moderated in the general equilibrium framework, producing qualitatively different outcomes. Terms of trade play an important role.

In the general equilibrium framework, coalitions are more effective in abatement and welfare terms but a substantial burden is shifted to energy exporters.

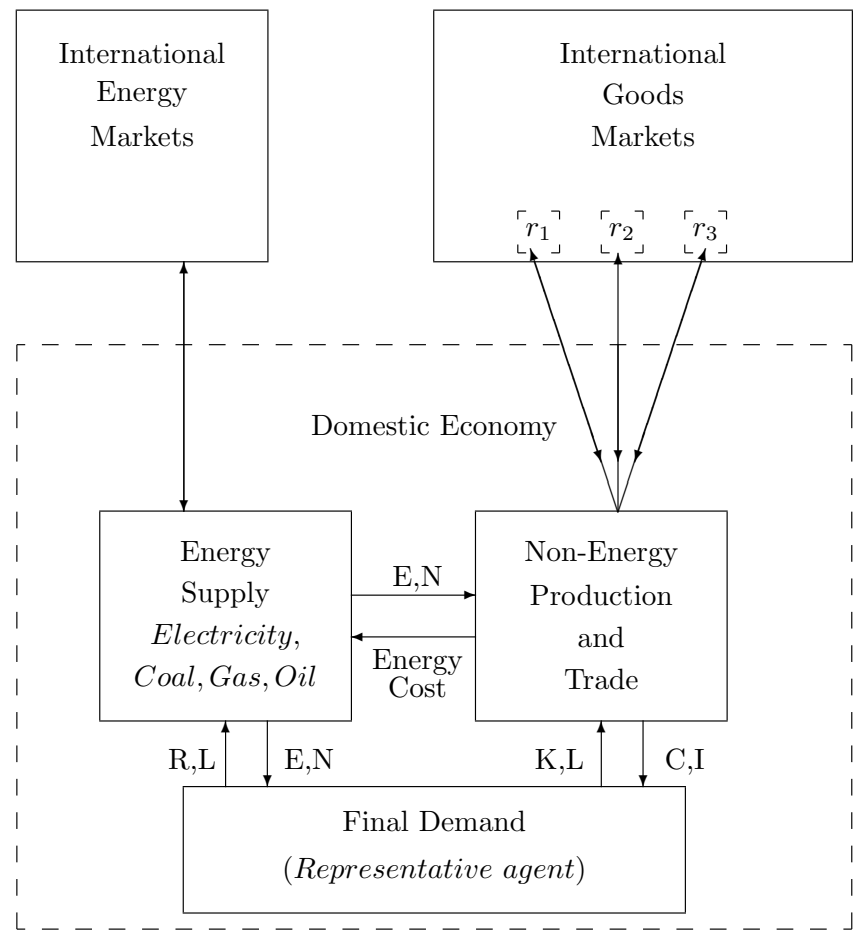
Burden-sharing through non-cooperative agreements is fairly successful. The best equilibrium outcomes produce $1/2$ of first-best abatement.

If we alternatively assume that cooperation characterizes intra-coalition bargaining (using the Shapley Value), equilibrium abatement increases to $2/3$ of first-best.

Prospects for cooperation do not change much over the next twenty years based on assumed changes in the profiles of regional economies.

Convergence in willingness to pay for greenhouse gas abatement makes permit markets *less attractive*.

Figure 1: Regional Flows of Goods and Factors



The Model

Economic equilibrium (for exogenously-specified emissions targets):

$$F(z; e) = 0$$

where:

$z = \begin{pmatrix} \pi \\ y \end{pmatrix}$ is the vector of equilibrium prices and quantities
 e is the vector of regional emissions

Global emissions:

$$e^G = \sum_{i=1}^n e_i$$

Regional welfare incorporates both economic well-being and environmental impact:

$$W_i = U_i(\pi, \Omega_i) - \nu_i e^G$$

Linearly homogeneous welfare:

$$W_i = \frac{\sum_k \Omega_{ik} \pi_k}{p_i^c(\pi)} - \nu_i e^G$$

Individual Nash equilibrium emissions:

$$U_i \left[\epsilon_i^M - \epsilon_i^p \right] = \nu_i e_i$$

where ϵ_i^M is the emissions-elasticity of region i income, i.e.

$$\epsilon_i^M = \left(\sum_k \Omega_{ik} \frac{\partial \pi_k}{\partial e_i} \right) \frac{e_i}{\sum_k \Omega_{ik} \pi_k}$$

and ϵ_i^p is the emissions-elasticity of the region i price level, i.e.

$$\epsilon_i^p = \frac{\partial p_i^c(\pi)}{\partial e_i} \frac{e_i}{p_i^c} = \sum_k \frac{\partial p_i^c}{\partial \pi_k} \frac{\partial \pi_k}{\partial e_i} \frac{e_i}{p_i^c}$$

Alternatively:

$$\sum_k (\Omega_{ik} - C_{ik}) \frac{\partial \pi_k}{\partial e_i} = \nu_i$$

When “Rest of World” region (row) is non-strategic, we adopt a *leakage-adjusted* first order condition:

$$\sum_k (\Omega_{ik} - C_{ik}) \frac{\partial \pi_k}{\partial e_i} = \nu_i \left(1 + \frac{\partial e_{row}(\pi)}{\partial e_i} \right) \quad i \neq \text{row}$$

Computational challenge: calculation of $\frac{\partial \pi_k}{\partial e_i}$. Equivalent to incorporating factor market impacts (the “Ford Effect”) in general equilibrium models with imperfectly competitive firms.

Equilibrium with an abatement coalition determines ω_i , the region i permit allocation

$$e_i = \omega_i \quad \forall i \notin \mathcal{C}$$

and

$$\sum_{i \in \mathcal{C}} e_i = \sum_{i \in \mathcal{C}} \omega_i$$

(There is a competitive market for permits among firms within the coalition.)

New equilibrium condition: $F(z; \omega) = 0$ in which

$$z = \begin{pmatrix} \pi \\ y \\ p \end{pmatrix}$$

where p is the equilibrium permit price within the coalition.

First order condition for a coalition member:

$$\sum_k (\Omega_{ik} - C_{ik}) \frac{\partial \pi_k}{\partial \omega_i} + (\omega_i - e_i) \frac{\partial p}{\partial \omega_i} + p = \nu_i \left(1 + \frac{\partial e_{row}(\pi)}{\partial e_i} \right)$$

Compare with the partial equilibrium formulation:

$$(\omega_i - e_i) \frac{\partial p}{\partial \omega_i} + p = \nu_i$$

In the partial equilibrium model, the marginal valuation of the environment (ν_i) alone determines whether a member state is a permit seller or a buyer. In the general equilibrium framework, a much wider range of impacts are possible.

Solution

Key challenge: computing sensitivity of prices to strategic instruments, e.g. $\frac{\partial \pi_k}{\partial e_i}$ and $\frac{\partial e_{row}(\pi)}{\partial e_i}$.

N.B. These partial derivatives are *functions* of the equilibrium values.

Implicit function theorem implies:

$$\left[\frac{\partial z}{\partial \omega} \right] = - \left[\frac{\partial F}{\partial z} \right]^{-1} \left[\frac{\partial F}{\partial \omega} \right],$$

but programming of such a system of equations is nontrivial.

Define $z(\omega)$ as the solution of the system of equations,

$$F(z; \omega) = 0$$

and let $z_k(\omega)$ represent the k th element of the solution vector.

The local dependence of endogenous variables on exogenous variables can alternatively be *numerically approximated* as:

$$\frac{\partial z_k}{\partial \omega_i} \approx \frac{z_k(\omega + \delta^i) - z_k(\omega)}{\delta}$$

in which δ^i is the i th perturbation vector:

$$\delta_j^i = \begin{cases} \delta & i = j \\ 0 & i \neq j \end{cases}$$

Here is the new idea:

Consider then the following $N \times n + n - 1$ equation system for a model with N economic equilibrium variables $n - 1$ strategic regions:

$$\begin{aligned} F(z; \omega) &= 0 \\ F(z^i; \omega + \delta^i) &= 0 \quad i \neq \text{row} \end{aligned}$$

This system of equations computes z and the adjacent perturbed solutions z^i *simultaneously*.

Difference approximations can then be used to characterize Nash optimal permit allocation:

$$\sum_k (\Omega_{ik} - C_{ik}) \frac{\pi_k^i - \pi_k}{\delta} + (\omega_i - e_i) \frac{p^i - p}{\delta} + p = \nu_i \left(1 - \frac{e_{row}^i - e_{row}}{\delta} \right) \quad i \in \mathcal{C}$$

and

$$\sum_k (\Omega_{ik} - C_{ik}) \frac{\pi_k^i - \pi_k}{\delta} = \nu_i \left(1 - \frac{e_{row}^i - e_{row}}{\delta} \right) \quad i \neq \text{row}, i \notin \mathcal{C}.$$

GDP Statistics

	<i>Total (Billion \$)*</i>			<i>\$ / Capita*</i>		
	2000	2020	% per yr	2000	2020	% per yr
usa	9219	16832	4.1	334	517	2.7
jpn	4270	6542	2.7	335	519	2.7
eur	9168	14786	3.1	234	381	3.1
chn	1095	4314	14.7	8	29	13.1
fsu	610	1501	7.3	21	54	7.9
row	6843	15746	6.5	18	31	3.6

* – All figures in 1998 \$.

Data sources:

- GTAP5 trade and production database provides, in addition to economic values, a consistent representation of energy markets in physical units
- The US DOE International Energy Outlook (2002) provides growth projections from for emissions by fuel and GDP are used to calibrate our simulation over a time horizon from 2000 to 2020.

Carbon Statistics

	<i>Total (Million Tons)</i>		<i>Tons Per Capita</i>		<i>100 Tons / \$ GDP*</i>		<i>1000 Tons /</i>
	2000	2020	2000	2020	2000	2020	2000
usa	1545	2087	5.6	6.4	1.6	1.2	9.0
jpn	310	368	2.4	2.9	0.7	0.6	2.7
eur	952	1199	2.4	3.0	1.0	0.8	4.2
chn	685	1715	0.5	1.1	6.3	4.0	11.6
fsu	623	869	2.1	3.1	10.2	5.8	42.3
row	2106	3674	0.5	0.7	3.1	2.3	11.7

* – All figures in 1998 \$.

Calibration of Willingness to Pay Parameters

Regional valuations of emissions, represented in the model through the willingness to pay parameters, ν_{it} , are *calibrated* to match an exogenously-specified Nash equilibrium abatement target in 2010:

$$\bar{\nu}_i = \sum_k (\Omega_{ik} - C_{ik}) \left. \frac{\partial \pi_k}{\partial e_i} \right|_{e_i = \bar{e}_i}$$

where $\bar{e}_i$ is based on region i abatement targets tended in the Kyoto round of climate negotiations. (Europe and Japan are assumed to abate by 20%, the United States 15%, 5% in China and -5% in the FSU.)

The evolution over time of willingness to pay is assumed to increase with per-capita GDP:

$$\nu_{it} = \bar{\nu} \Gamma_{it}^{\eta}$$

Equilibrium Allocations in 2010

	usa	jpn	eur	chn	fsu	Δe^G	EV%
usa-eur-chn	0.6	4.1	1.7	2.5	0.4	13.6	0.7
eur-chn-fsu*	0.3	3.6	1.8	1.0	5.1	12.9	0.6
eur-chn	0.3	3.2	1.8	0.9	0.2	12.1	0.4
usa-jpn-eur-chn-fsu*	0.3	2.5	1.5	1.4	6.1	11.9	0.7
jpn-chn	0.2	2.4	2.0	0.2	0.2	11.6	0.2
usa-eur-fsu	0.4	1.8	0.3	0.1	8.4	9.7	0.4
usa-eur	0.4	1.5	0.4	0.1	0.2	9.1	0.1
usa-jpn	0.2	0.4	0.7	0.1	0.1	8.3	0.1
eur-fsu	0.1	0.9	0.4	0.0	3.4	8.1	0.2
jpn-fsu	0.1	0.5	0.5	0.0	0.8	7.7	0.1
usa-chn	0.0	0.7	0.5	0.3	0.0	7.7	0.1
jpn-chn-fsu	0.0	0.1	0.1	0.0	0.6	6.6	0.1
Nash	0.0	0.0	0.0	0.0	0.0	6.5	0.0

* = externally stable coalitions

Δe^G = % emissions reduction from BaU

EV% = equivalent variation in money-metric utility relative to individual Nash equilibrium

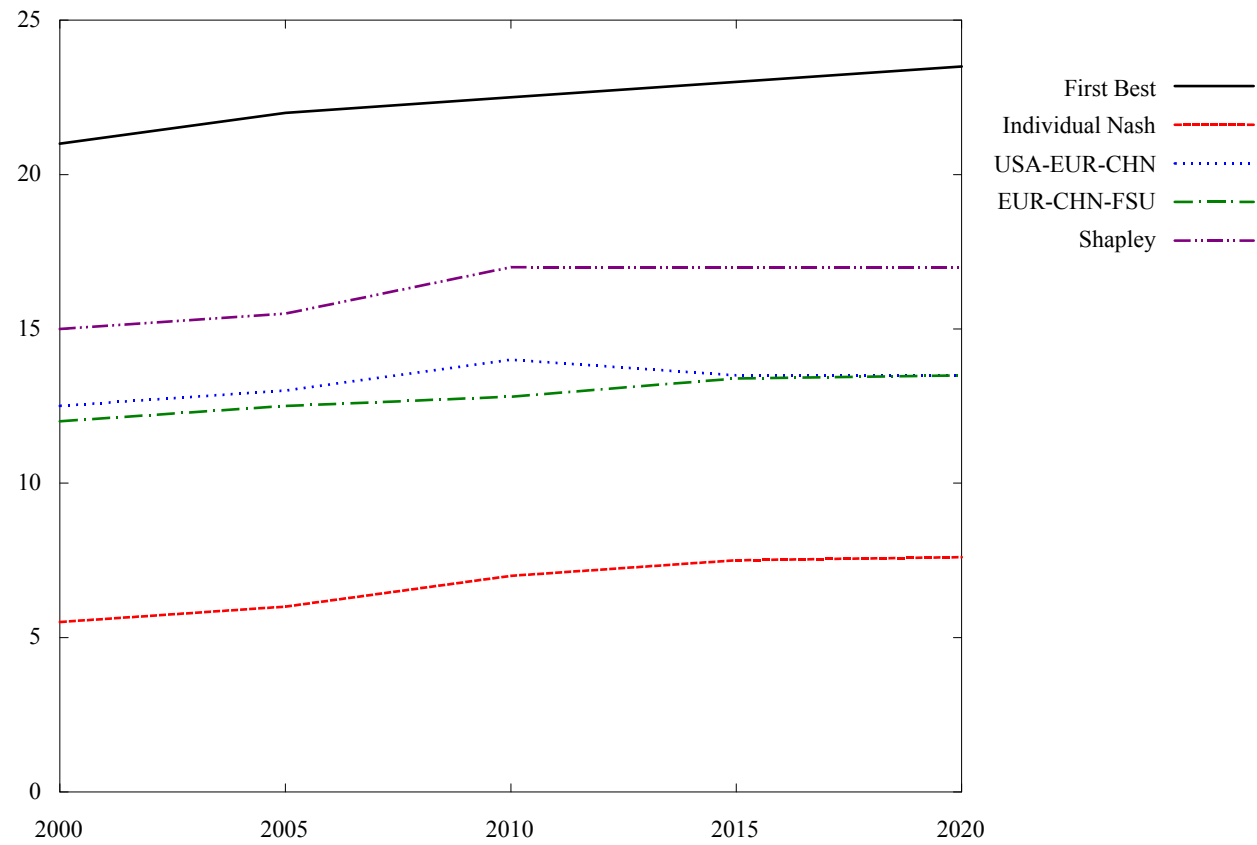
usa-eur-chn Coalition Profile in 2010

	e_i^N	e_i^C	ω_i	ev_i	p	ν_i
usa	84.3	74.3	92.2	0.6	117.9	59.6
eur	77.6	86.9	3.1	1.7	117.9	415.3
chn	88.1	41.9	89.7	2.5	117.9	7.1
jpn	79.5	80.0	-	4.1	195.2	247.1
fsu	103.4	103.0	-	0.4	1.7	6.4
row	106.8	108.7	-	-	-	-

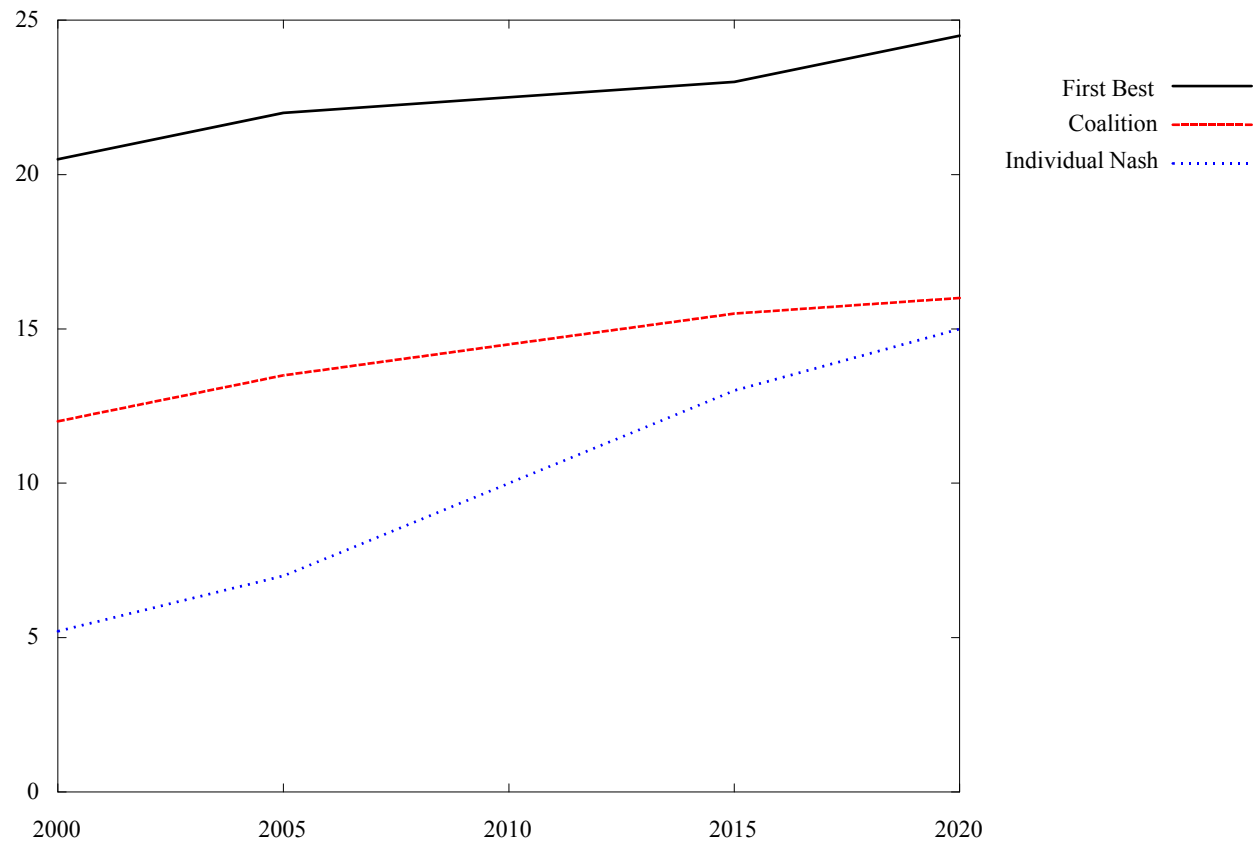
Key:

e_i^N	Individual Nash emissions as a % of BaU
e_i^C	usa-eur-chn equilibrium emissions as % of BaU
ω_i	Coalition allocations as % of BaU
ev_i	% change in EV from the individual Nash equilibrium
p	Permit price (\$ per ton)
ν_i	Marginal value of emission reductions (\$ per ton)

Figure 4: Selected Abatement Trajectories (% BaU emissions)



**Figure 5: Abatement Trajectories with
High Convergence (% BaU emissions)**



Conclusions

- International carbon abatement policy should be informed not only as to what is efficient, but also as to what is *feasible*.
- Self-enforcing agreements provide about one half of the first-best level of abatement when compared to BaU levels, but they offer considerable improvement over the individual Nash outcome.
- Suboptimal abatement is due more to the free-rider problem than to inefficient negotiations within the coalition.
- Terms of trade effects have important implications for the model's predictions of equilibrium outcomes.
- Good agreements are typically subglobal.
- Convergence in willingness to pay for emissions reductions by developing countries does not increase the likelihood of forming effective global coalitions.

- Better coalitions may be formed when certain countries are *excluded* from participation. There is a crucial role for international institutions such as the Framework Convention for Climate Change.