Coalitions for Climate Cooperation
Venice, 15–16 June 2009

The Effects of Trade Sanctions in International Environmental Agreements

Kai Lessmann
Robert Marschinski,
Ottmar Edenhofer

Potsdam Institute for Climate Impact Research

The two-fold Aim of this Talk

- Algorithmic:
  - Implementation of trade, and trade sanctions in *optimal growth* modeling framework non-trivial
  - Competitive equilibrium in a model with multiple distortions
- Application:
  - Discussion on Post-Kyoto agreements ongoing
  - Linking climate coalitions to trade sanctions proposed, e.g. Barrett 1997, Aldy et al. 2001, Stiglitz 2007
  - How can we implement trade sanctions, and what are potential effects on climate treaties?
- Outline of the talk:
  - Model of coalition formation
  - The Competitive Equilibrium (*externalities!)*
  - Results: effects of sanctions on coalition formation

International Environmental Agreements as a Cartel Stability game

- Coalition formation: two stage game
  - Stage 1: Membership game
    - Players either sign the IEA or do not
  - Stage 2: Emission game
    - Players decide on investments + trade → emission trajectories

International Environmental Agreements as a Cartel Stability game

- Coalition formation: two stage game
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  - Stage 2: Emission game
    - Players decide on investments + trade → emission trajectories
- Stage 2: Nash Equilibrium
  - "Partial Agreement Nash Equilibrium" (Chander/Tulkens)
  - Members to the IEA act jointly ("as one player")
- Stage 1: Cartel Stability (d'Aspremont/Gabszewicz)
  - "internally stable" := no member has incentive to leave
  - "externally stable" := no non-member has incentive to join

Economy equations

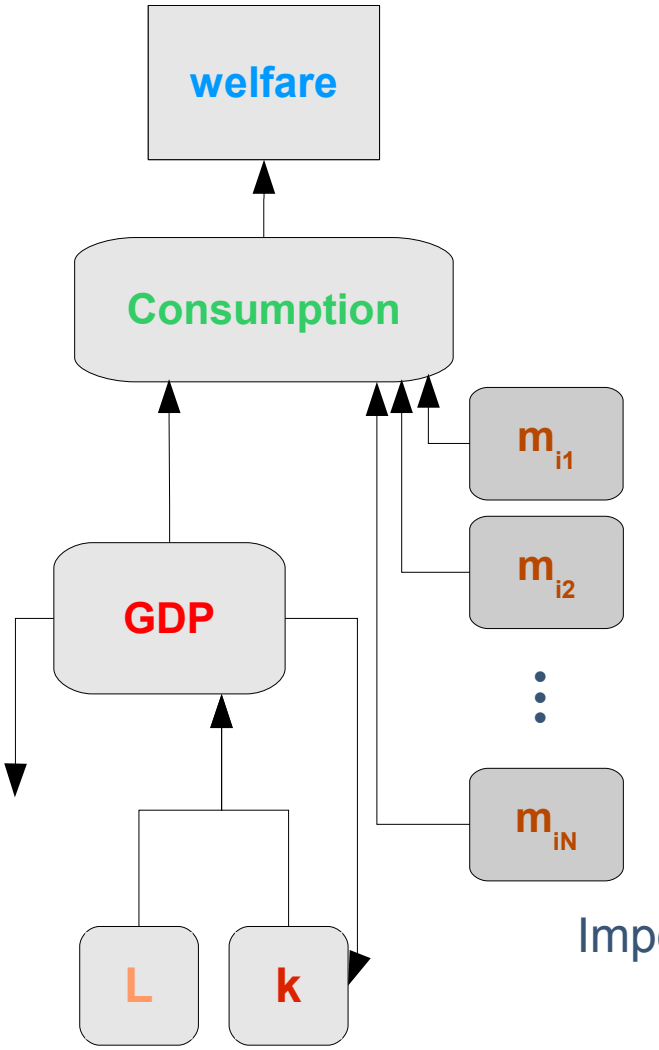
- Players maximize welfare

$$\max_{\{in_{it},\, im_{it},\, m_{ijt},\, x_{ijt}\}} \text{welfare}_i$$

$$\text{welfare}_i = \int_0^\infty e^{-\rho\, t}\; l_{it}\, U(c_{it}/l_{it})\; \mathrm{dt}$$

- Consumption is an Armington aggregate

$$c_{it} = \left[s^{dom} (c_{it}^{dom})^{\rho^A} + \sum_{j \neq i} s_j^{for}\, (c_{ijt}^{for})^{\rho^A} \right]^{(1/\rho^A)}$$



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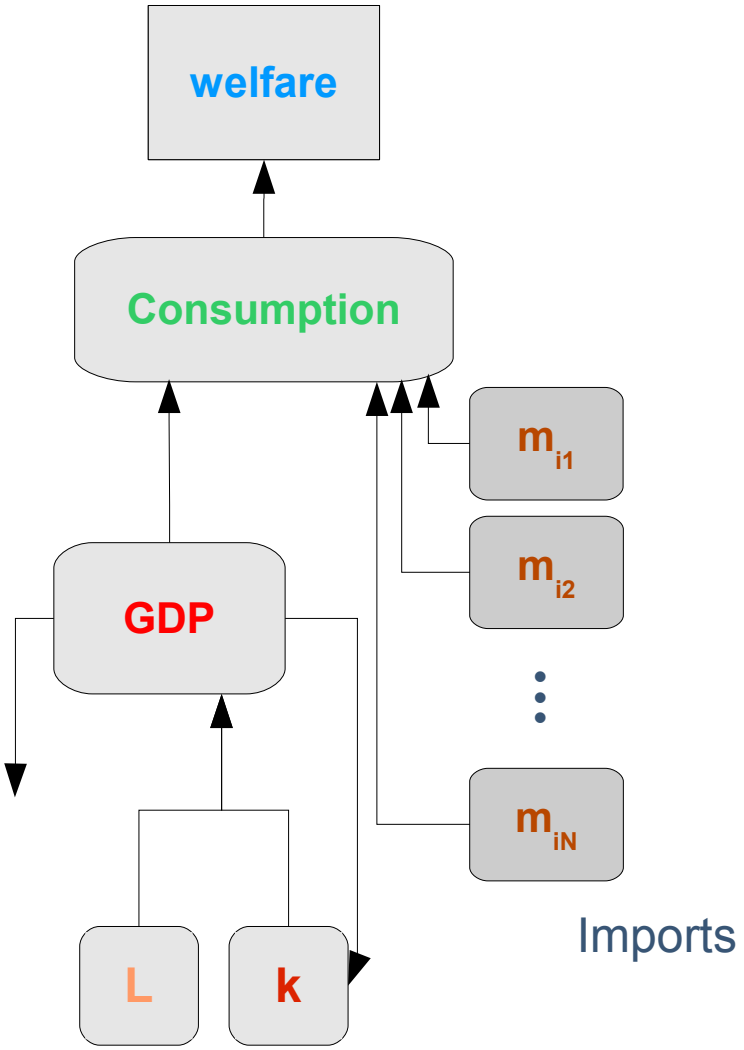
- ...of domestically produced

$$c_{it}^{dom} = GDP_{it} - in_{it} - im_{it} - x_{it}$$

$$y_{it} = (k_{it})^{\beta}\, (a_{it}\, l_{it})^{(1-\beta)}$$

- ...and imported goods

$$c_{ijt}^{for} = m_{ijt}$$



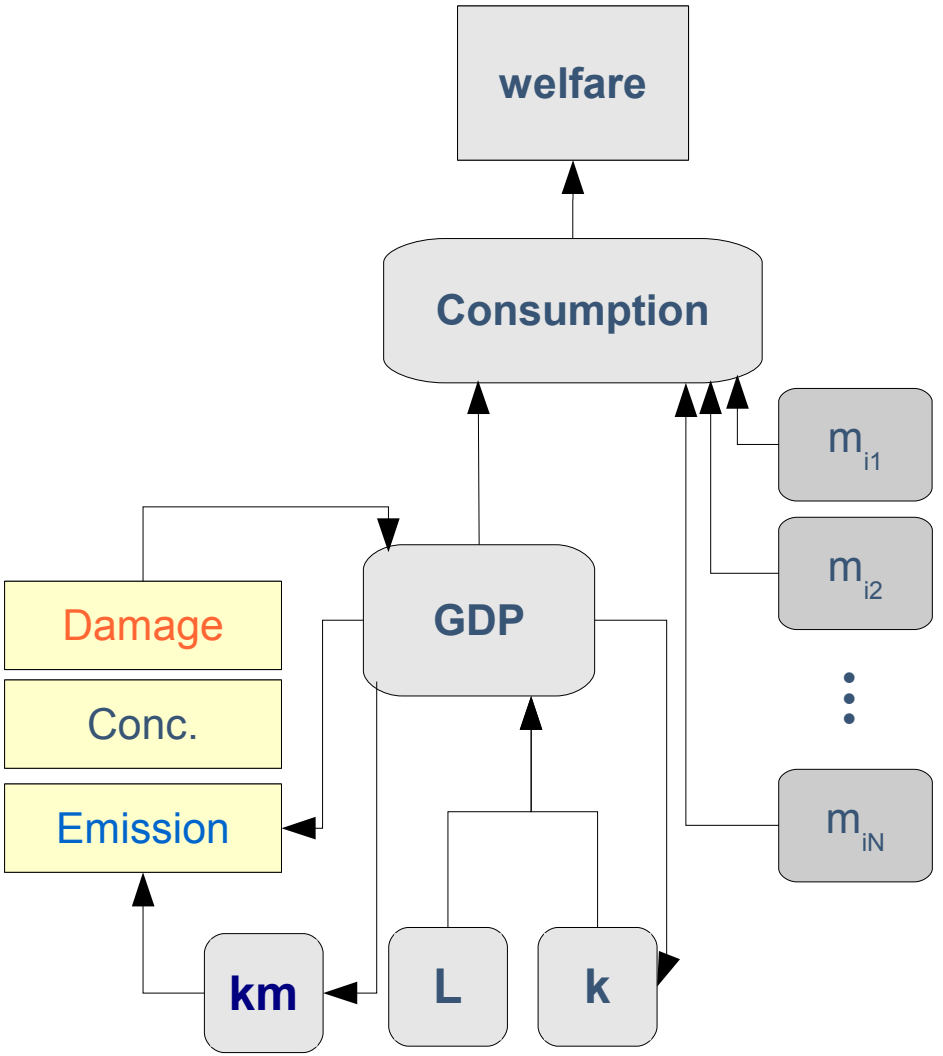
Emission externality: Damages

- Emissions and abatement

$$e_{it} = \sigma_{it}\, y_{it}$$

$$\sigma_{it} = (1 + km_{it})^{-\psi}$$

$$\frac{d}{dt} km_{it} = \xi\ im_{it}$$



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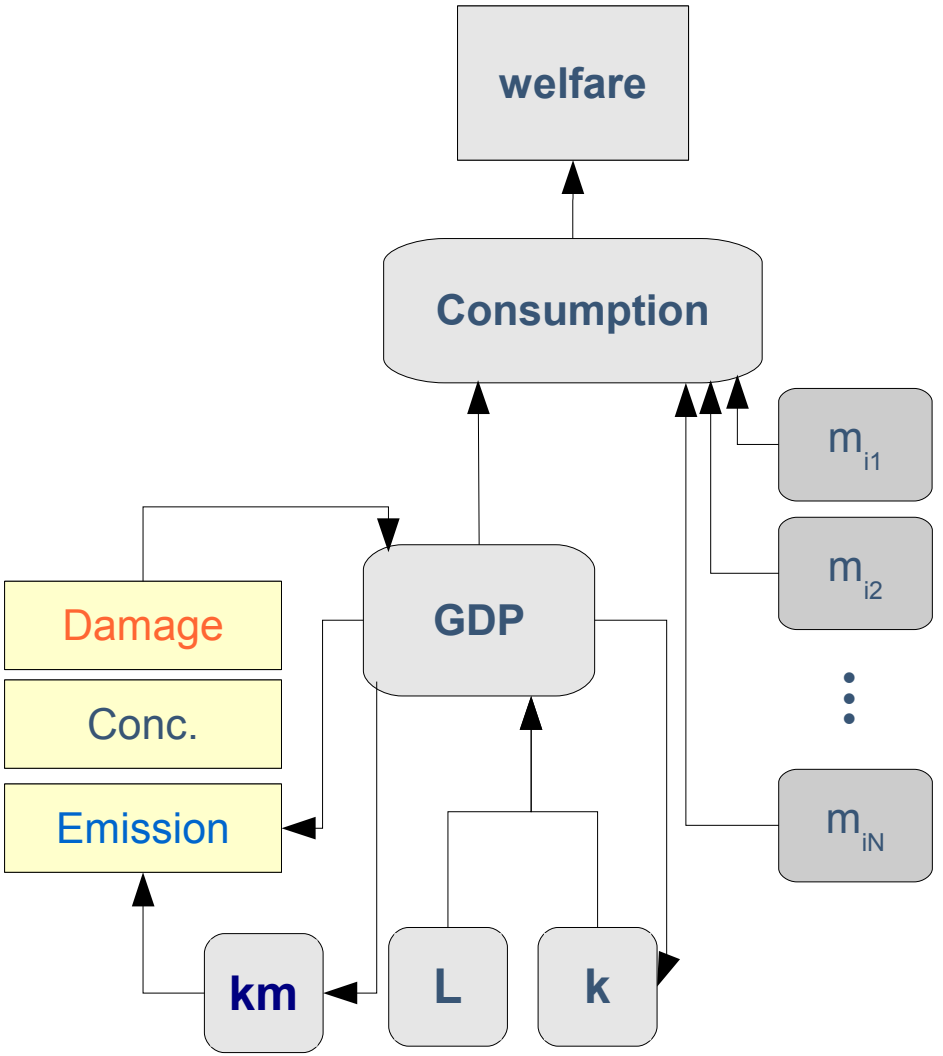
- Translation of emissions to
  - concentration to
  - temperature to
  - damages

$$\Omega_{it} = 1/(1 + dam1_i(temp_t)^{dam2_i})$$

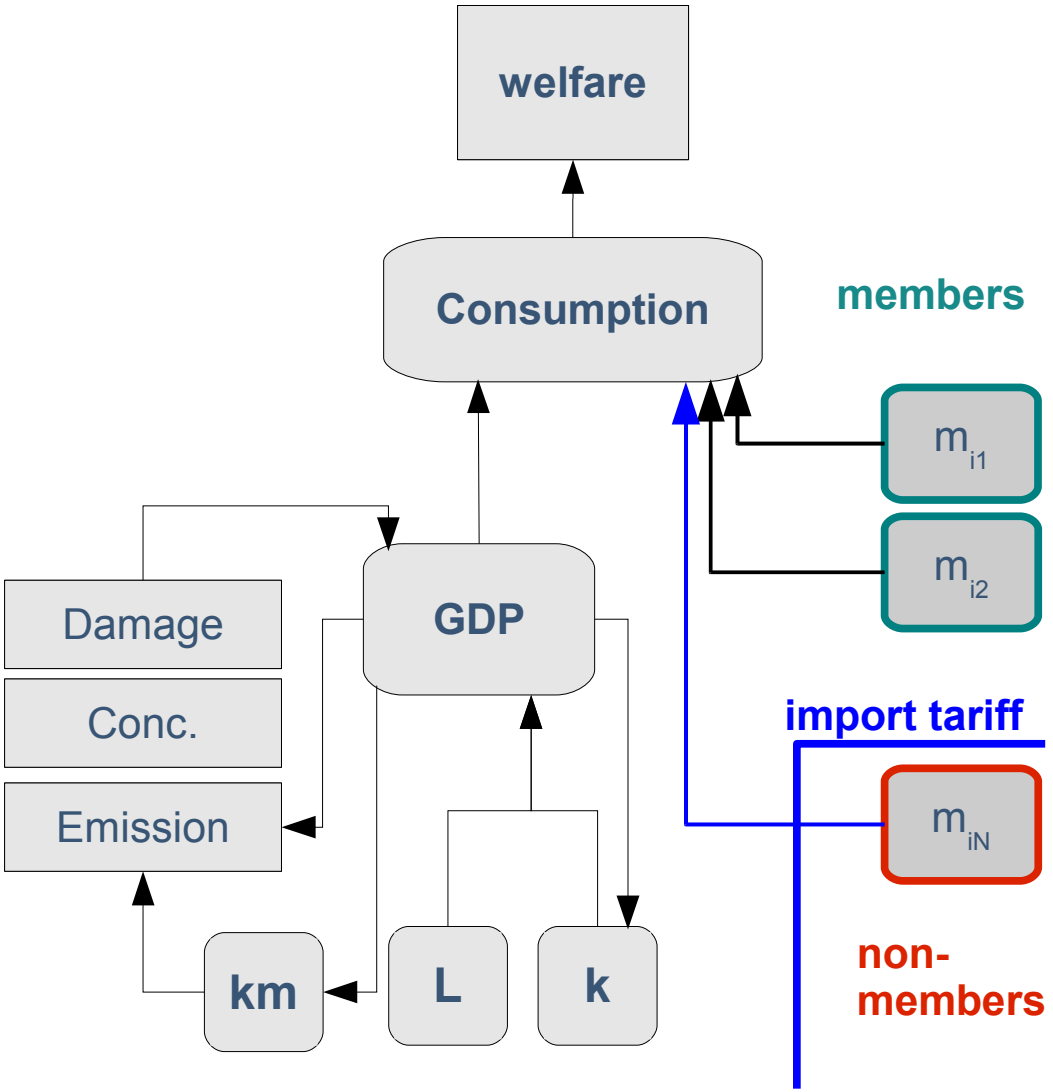
$$y_{it} = \Omega_{it}\, GDP(k_{it}, l_{it})$$



Trade externality: Import Tariffs

- Coalition S imposes import tariff

$$c_{ijt}^{for} = (1 - \tau_{ij})\, m_{ijt} \quad \text{for } i \in S,\ j \notin S$$



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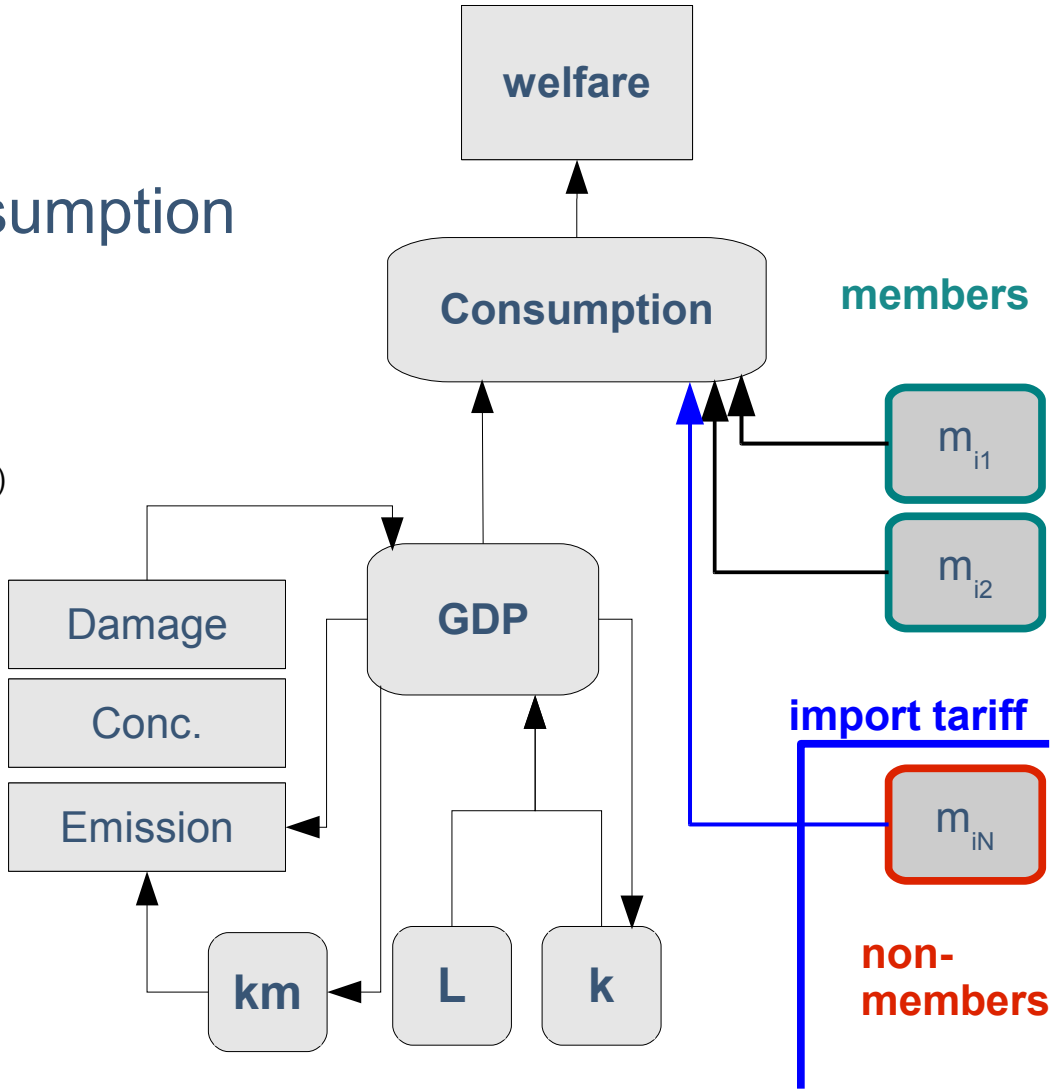
$$c_{ijt}^{for} = (1 - \tau_{ij})\, m_{ijt} \quad \text{for } i \in S,\ j \notin S$$

- Tariff revenue is recycled in consumption

$$tr_{ijt} = \tau_{ij}\, m_{ijt}$$

$$c_{it} = \left[s^{dom} (c_i^{dom} t)^{\rho^A} + \sum_{j \neq i} s_j^{for} \left(c_{ijt}^{for} + tr_{ijt}\right)^{\rho^A} \right]^{(1/\rho^A)}$$



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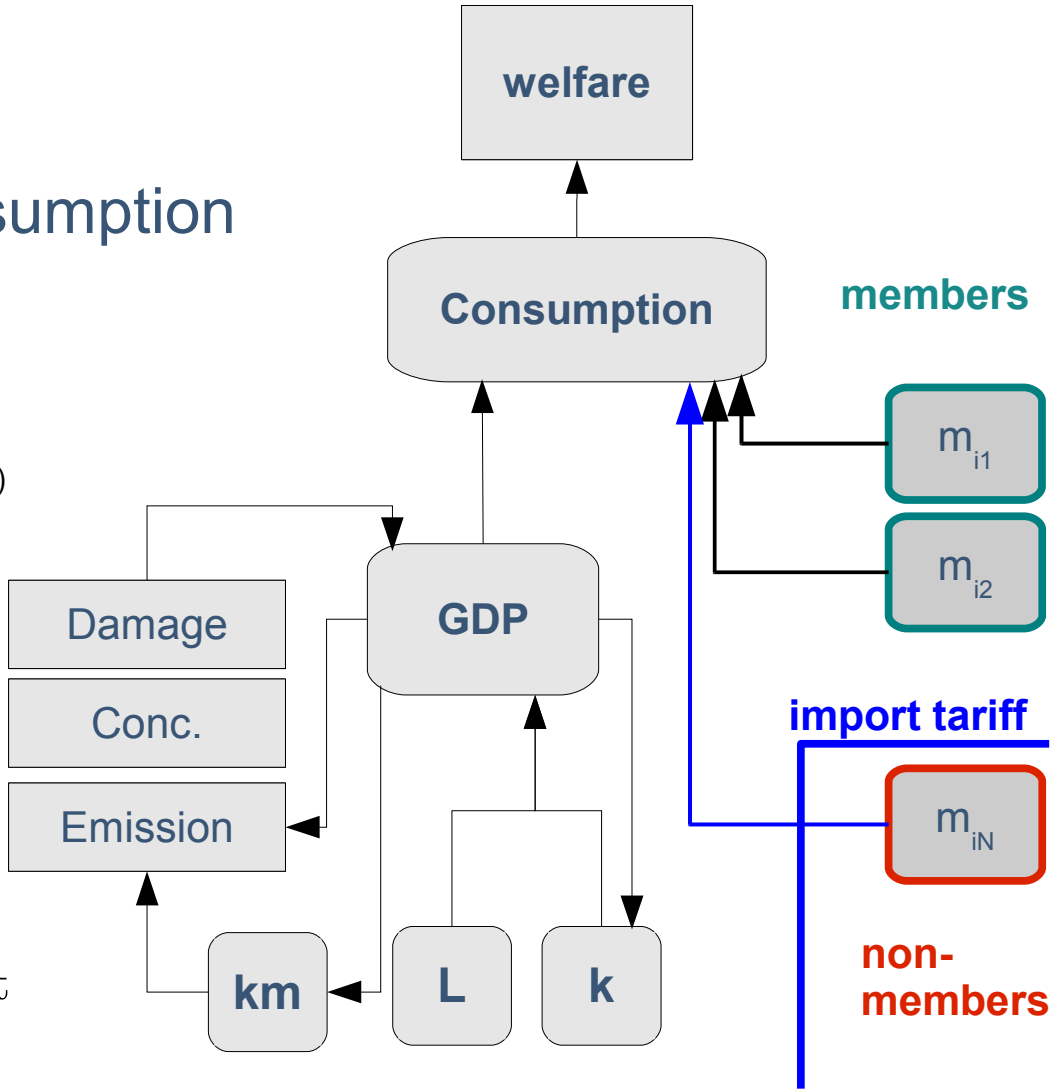
- Intertemporal budget balanced
  - import value = export value

$$\int_0^\infty \sum_{j \neq i} p_{ijt}^m\, m_{ijt}\ \mathrm{dt} = \int_0^\infty \sum_{j \neq i} p_{ijt}^x\, x_{ijt}\ \mathrm{dt}$$



Assumption that guided our choice of parameter values

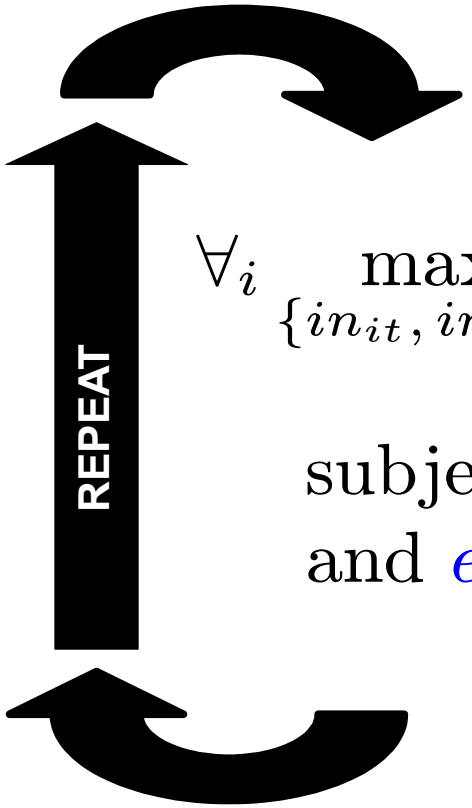
- In business-as-usual:
  - Economic growth at ~2.5 percent per year
  - Savings rate
    - at ~23 percent
    - approximately constant savings rate during first century
  - Trade: export ratio ~30 percent
  - Temperature increase 3°C by 2100, 7.5°C by 2200 in BAU
  - Climate change damages 6 percent in 2100, 17 percent in 2200
- Abatement costs:
  - full cooperation reduces temperature to 2.4°C in 2100

Trade Sanctions and the WTO

- Perez (2005) *U of Penn Journal of International Economic Law:*
  - *"Second Shrimp Ruling:"*
    US trade embargo on shrimp (caught without Turtle-Excluder Devices) considered legal
  - *Extension to "pure global goods, such as [...] the atmosphere [...] seems to follow naturally [...] and does not seem to raise difficult questions"*
- Stiglitz (2006) *Economists Voice:*
  - *Unfair advantage:*
    Not paying the costs of climate change is a subsidy
  - *Other countries should ban or tax goods from such countries*
  - *"Energy tariffs" would simply restore the balance*

Nash Equilibrium

- Search for Nash equilibrium using *Fictitious Play*



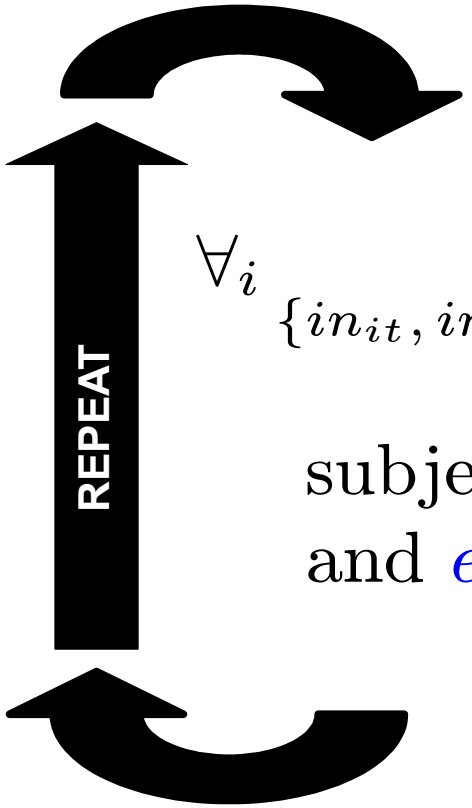
$$\forall_i \max_{\{in_{it},\, im_{it}\}} \text{payoff}_i$$

subject to economy and climate equations
and $e_{kt} = \overline{e_{kt}}$ for $k \neq i$

- That is, perform a *fixed point iteration*

Nash Equilibrium

- Search for Nash equilibrium using *Fictitious Play*



$$\forall_i \quad \max_{\{in_{it},\, im_{it},\, m_{ijt},\, x_{ijt}\}} \text{payoff}_i$$

m_{ijt} : imports from j
x_{ijt} : export to j

subject to economy and climate equations
and $e_{kt} = \overline{e_{kt}}$ for $k \neq i$

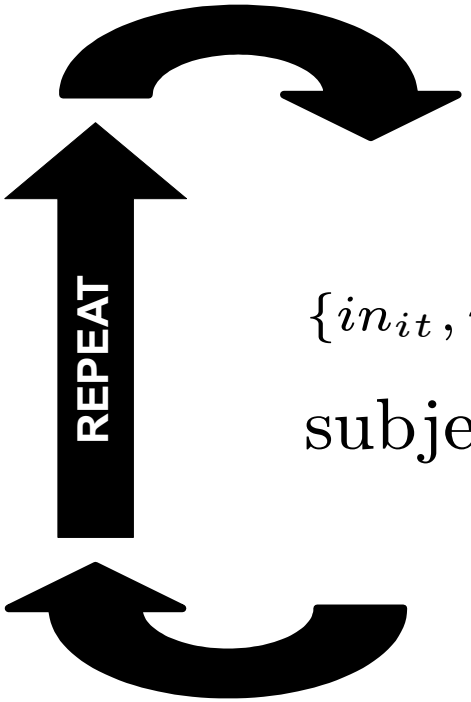
Problem: m_{ijt}, x_{ijt}: market price levels unknown
and determining price levels proved difficult

Competitive Equilibrium

- Determine competitive equilibrium using *Negishi's Approach*
- Idea: exploit fundamental welfare theorem
  - competitive equilibrium is Pareto efficient
  - so consider all Pareto efficient solutions
  - and select the one where markets clear
- *Problem:* presence of externalities / distortions
  - climate change damages
  - spillovers
  - tariffs

Competitive Equilibrium

- Determine competitive equilibrium using *Negishi's Approach*



$$\max_{\{in_{it},\, im_{it},\, m_{ijt},\, x_{ijt}\}} \sum_i \delta_i \,\text{payoff}_i$$

$$\text{subject to economy and climate equations}$$

- Find $\boldsymbol{\delta_i}$ such that the intertemporal budget constraint holds:

$$\int_0^\infty \sum_{j \neq i} p^m_{ijt}\, m_{ijt}\ \mathrm{dt} = \int_0^\infty \sum_{j \neq i} p^x_{ijt}\, x_{ijt}\ \mathrm{dt}$$

Competitive Equilibrium

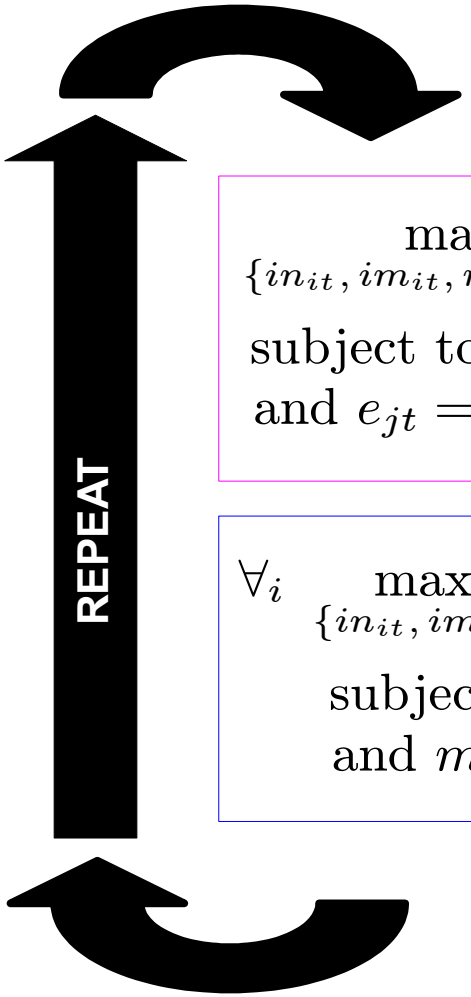
- Determine competitive equilibrium using *Negishi's Approach*
- Idea: exploit fundamental welfare theorem

- *Problem:* presence of externalities / distortions
  - climate change damages, tariffs

- Kehoe, Levine, and Romer (1992), *Economic Theory*
  "On characterizing equilibria of economies with externalities and taxes as solutions to optimization problems"
  - Idea: solve modified social planning problems
  - "Frequently, however, finding the optimization problem that a particular equilibrium solves is difficult."

Competitive Equilibrium

- Alternately ***fix*** emissions (in Negishi's Approach) and trade (in Fictitious Play)



$$\max_{\{in_{it},\, im_{it},\, m_{ijt},\, x_{ijt}\}} \sum_i \delta_i \,\text{payoff}_i$$

subject to economy and climate equations
and $e_{jt} = \overline{e_{jt}}$

$$\Rightarrow m_{ijt},\ x_{ijt}$$

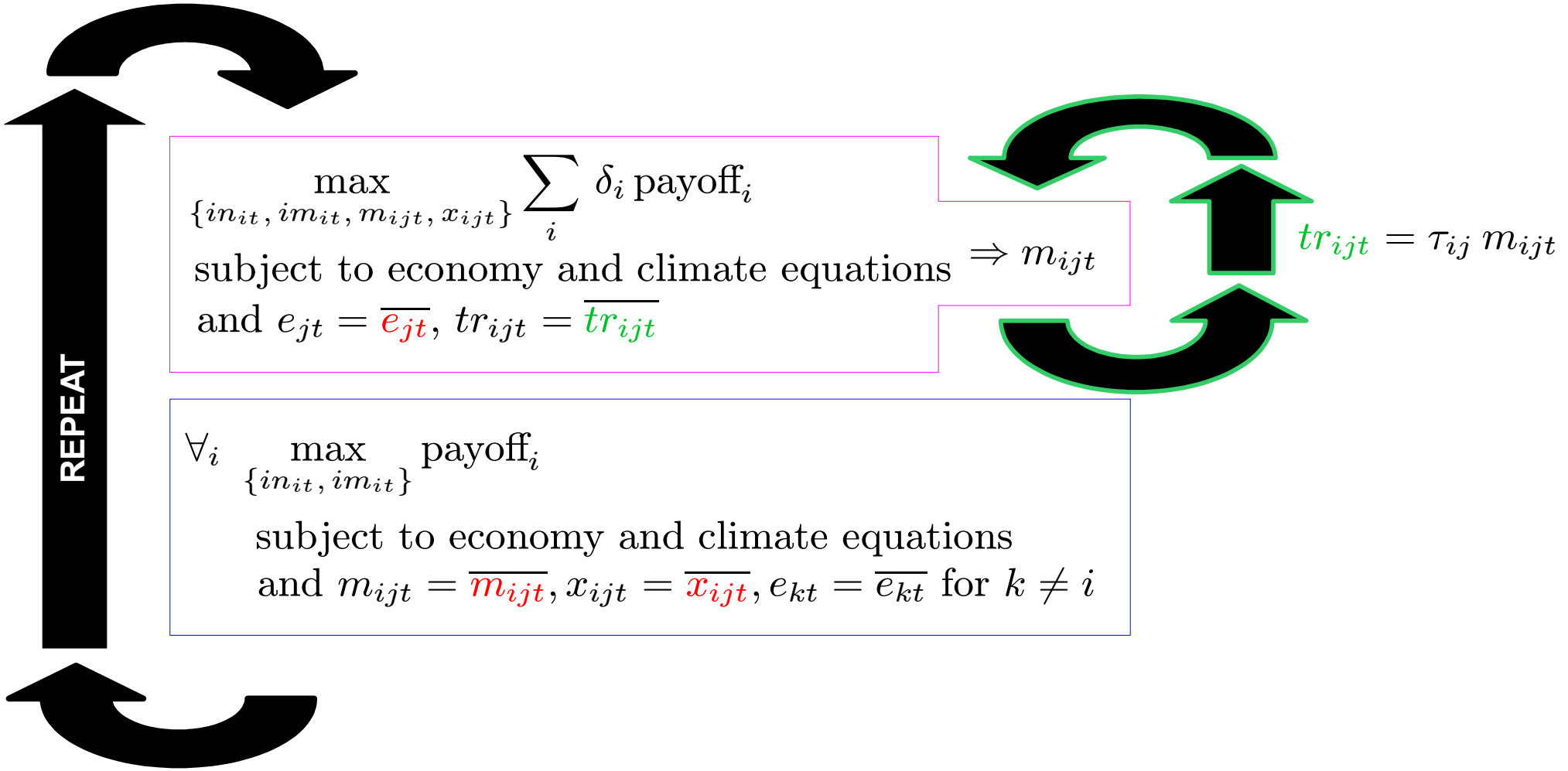
$$\forall_i \quad \max_{\{in_{it},\, im_{it}\}} \text{payoff}_i$$

subject to economy and climate equations
and $m_{ijt} = \overline{m_{ijt}}, x_{ijt} = \overline{x_{ijt}}, e_{kt} = \overline{e_{kt}}$ for $k \neq i$

$$\Rightarrow e_{it}$$

Competitive Equilibrium

- Treat tariff revenue recycling as a parameter, and update it outside the model



Numerically testing the Competitive Equilibrium

- Use *market prices* from equilibrium
- Solve

$$\forall_i \max_{\{in_{it}, im_{it}, m_{ijt}, x_{ijt}\}} \text{payoff}_i$$

subject to economy and climate equations
and the intertemporal budget constraint

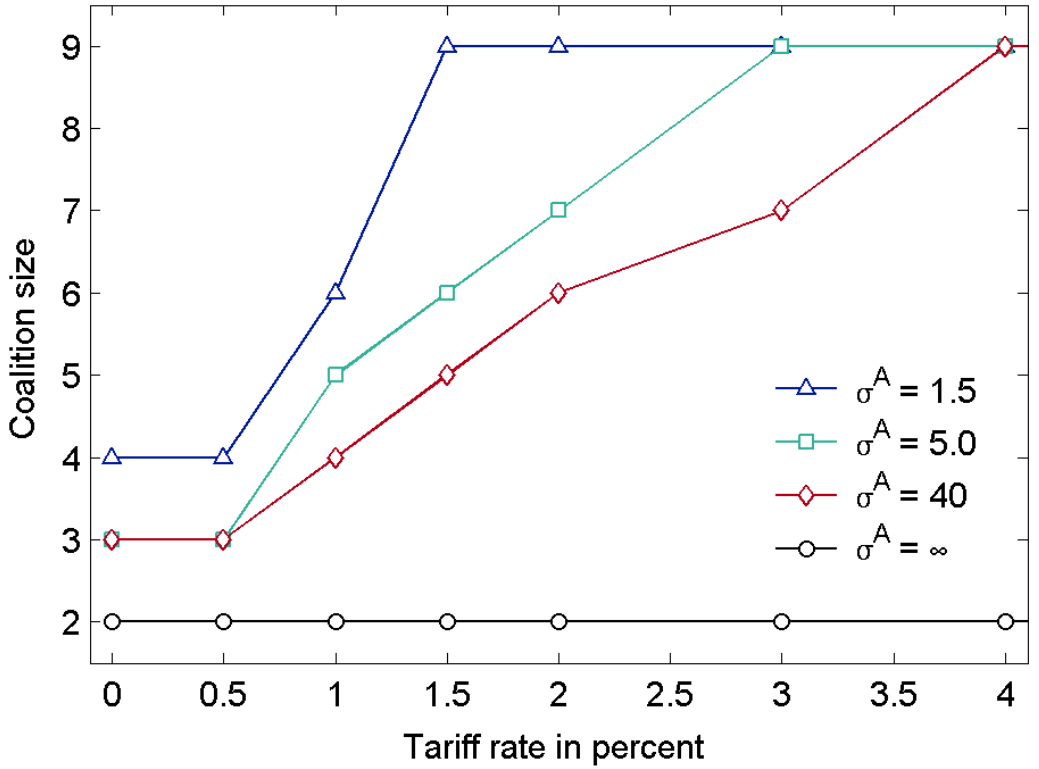
$$\int_0^\infty \sum_{j \neq i} p^m_{ijt}\, m_{ijt}\ \mathrm{dt} = \int_0^\infty \sum_{j \neq i} p^x_{ijt}\, x_{ijt}\ \mathrm{dt}$$

and $e_{kt} = \overline{e_{kt}}$ for $k \neq i$

- Compare to «competitive equilibrium»

Results

Effect on Participation

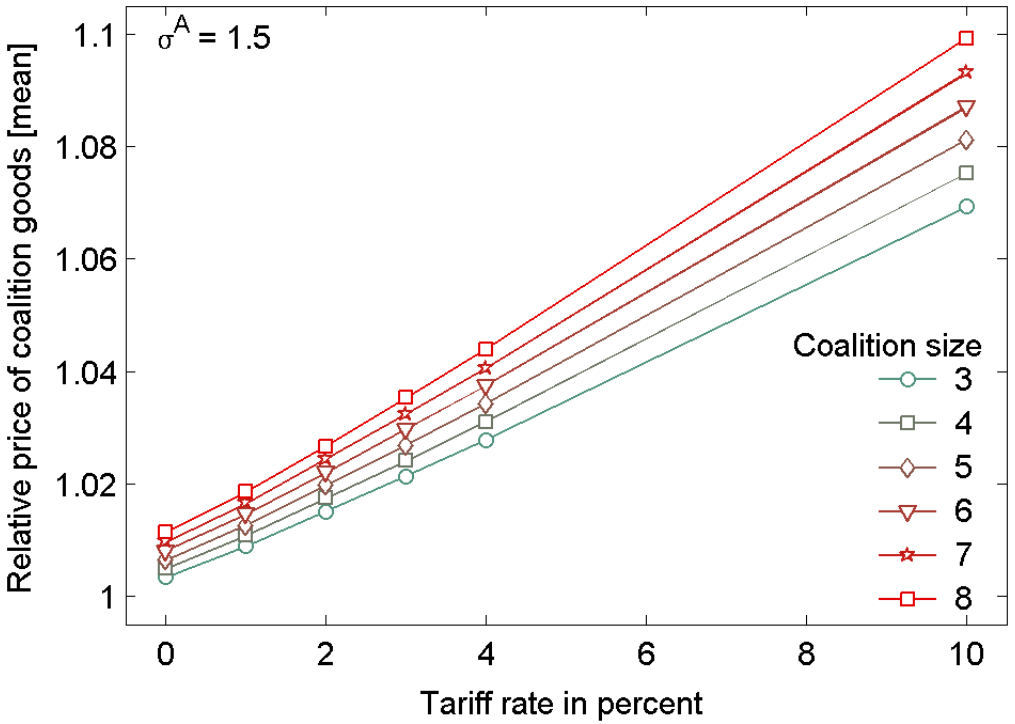


- Participation = Size of largest stable coalition
  - rises with the tariff rate τ
  - shrinks with elasticity of substitution σ^A

$$\sigma^A = \frac{1}{1-\rho^A}$$

Why does it work? The price effect of tariffs

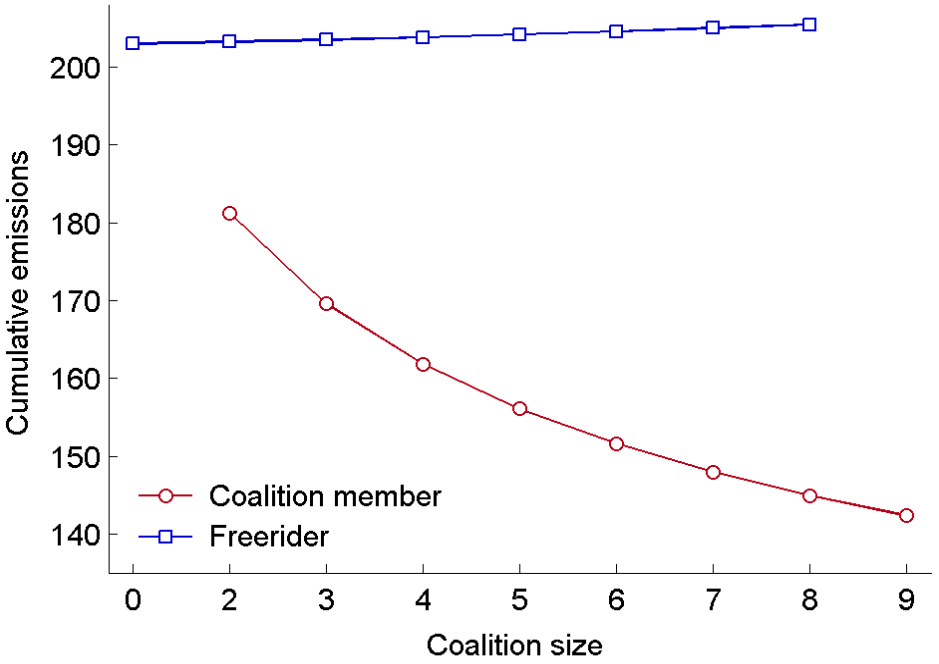
- Effects of tariffs are due to the assumption of monopolistic supply:
  - Players are price takers
  - Coalition good becomes rel. more expensive
  - Tariffs allow to realize market power



- Note: Coalition good scarcer due to reduced production

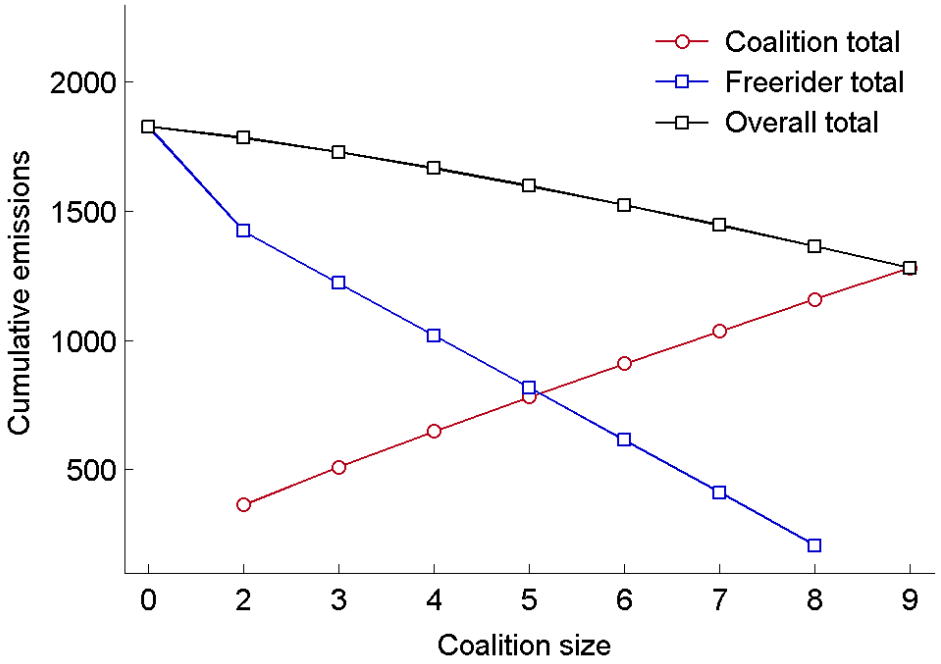
What about Leakage?

emissions of a single player



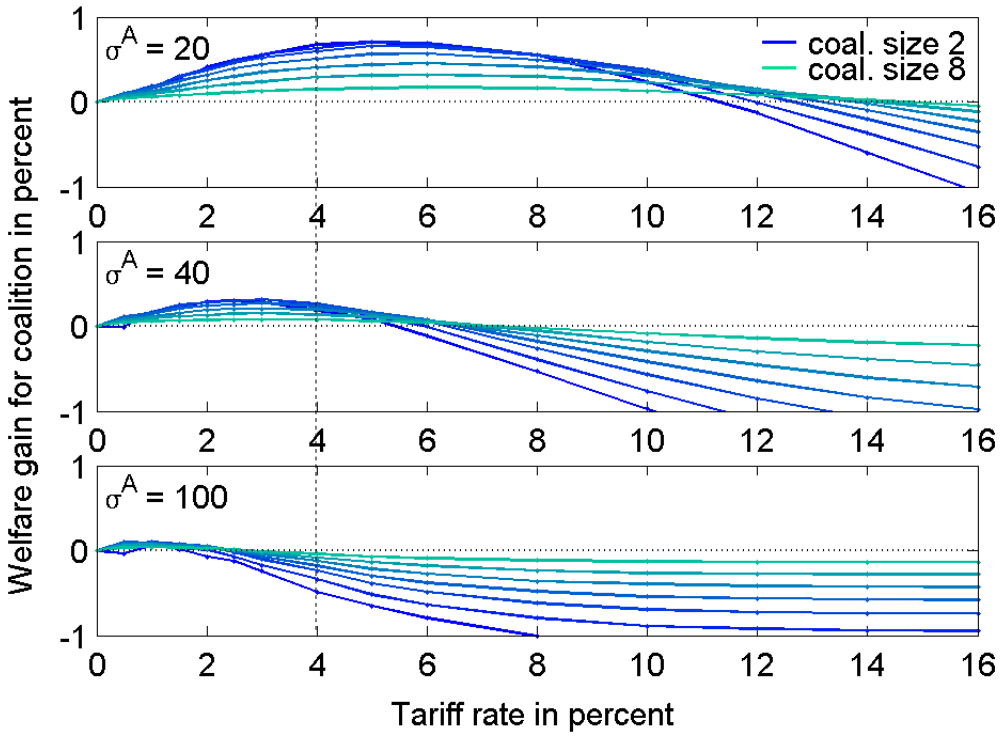
- Non-members show free-riding behavior

total emissions



- Overall emissions decrease unambiguously

Are tariffs credible?



Welfare gain = difference of welfare with tariffs and welfare without tariffs for a given coalition

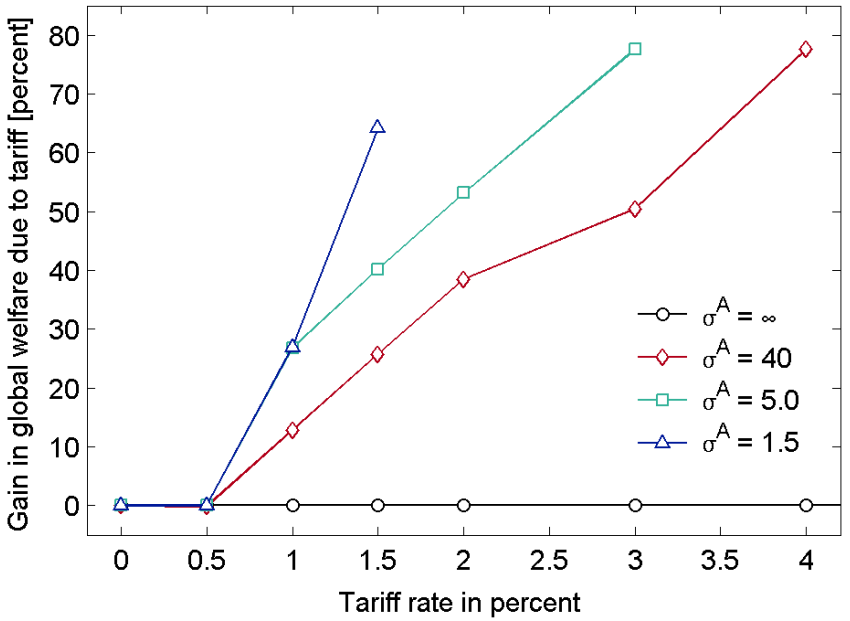
- Threatening tariffs is credible if beneficial for coalition
- a tariff allows exploiting market power, hence is credible if
  - substitutability σ is *low*
  - tariffs τ are not *too high*
- smaller coalition means more non-members means more players that *pay* tariffs

Will tariffs reduce global welfare?

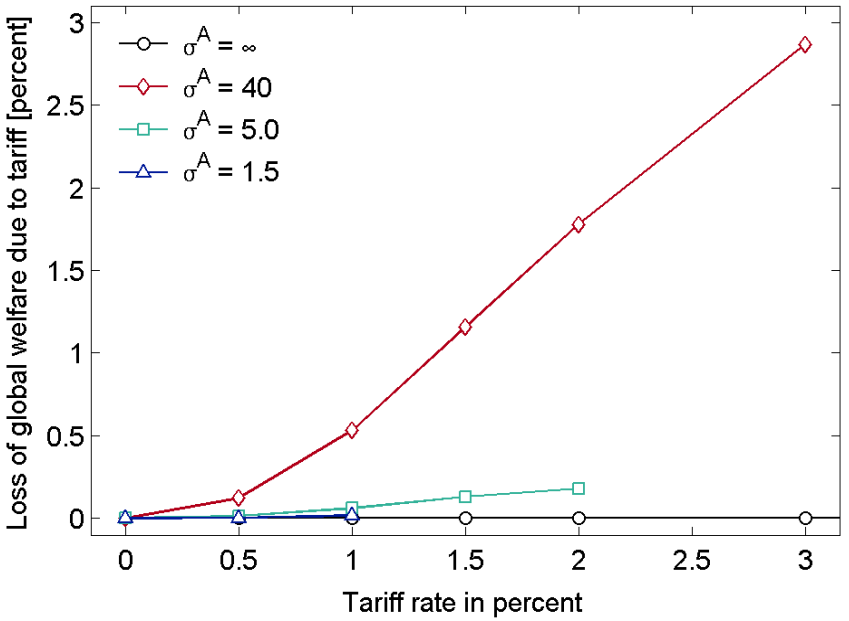
- Tariffs raise participation
- Participation closes gap between Nash and Pareto

- Tariffs obstruct trade
  - Reduce volume/efficiency
- Welfare loss compared to same equilibrium without tariffs

Welfare gains of *stable* coalitions with and without tariffs



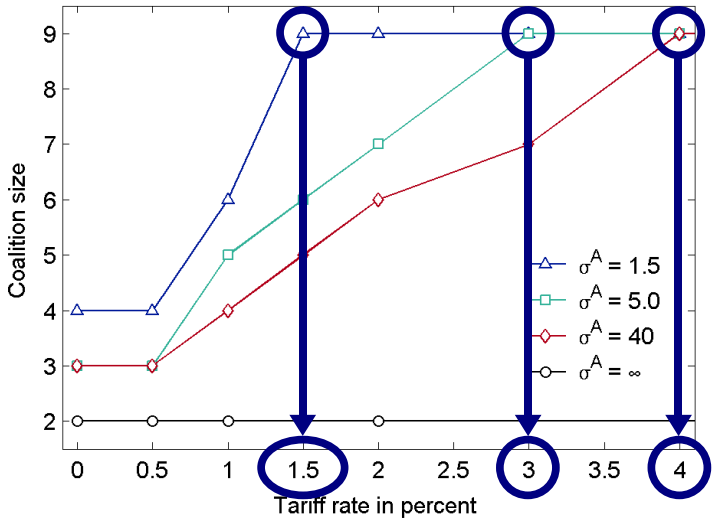
Welfare losses of a given coalition with and without tariffs



Sensitivity of main results

- Focus on main result:
  - Tariffs raise participation
  - Full cooperation is sustained
  - Necessary tariff rates are a few percent

- Indicator: *Tariff rate at which full cooperation is sustained*



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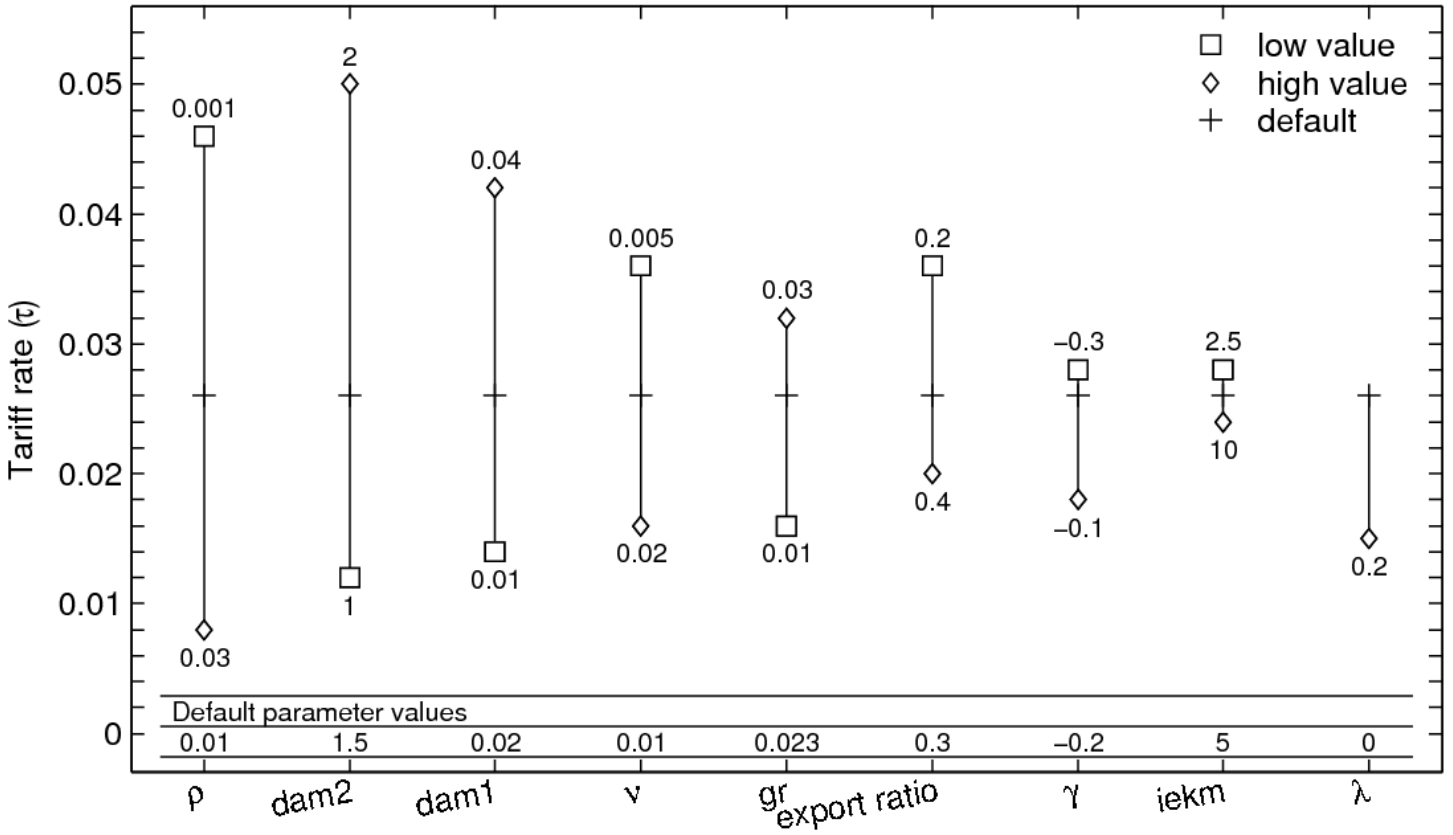


time preference

damage function coefficients

rate of autonomous emission intensity reductions

exogenous productivity growth rate

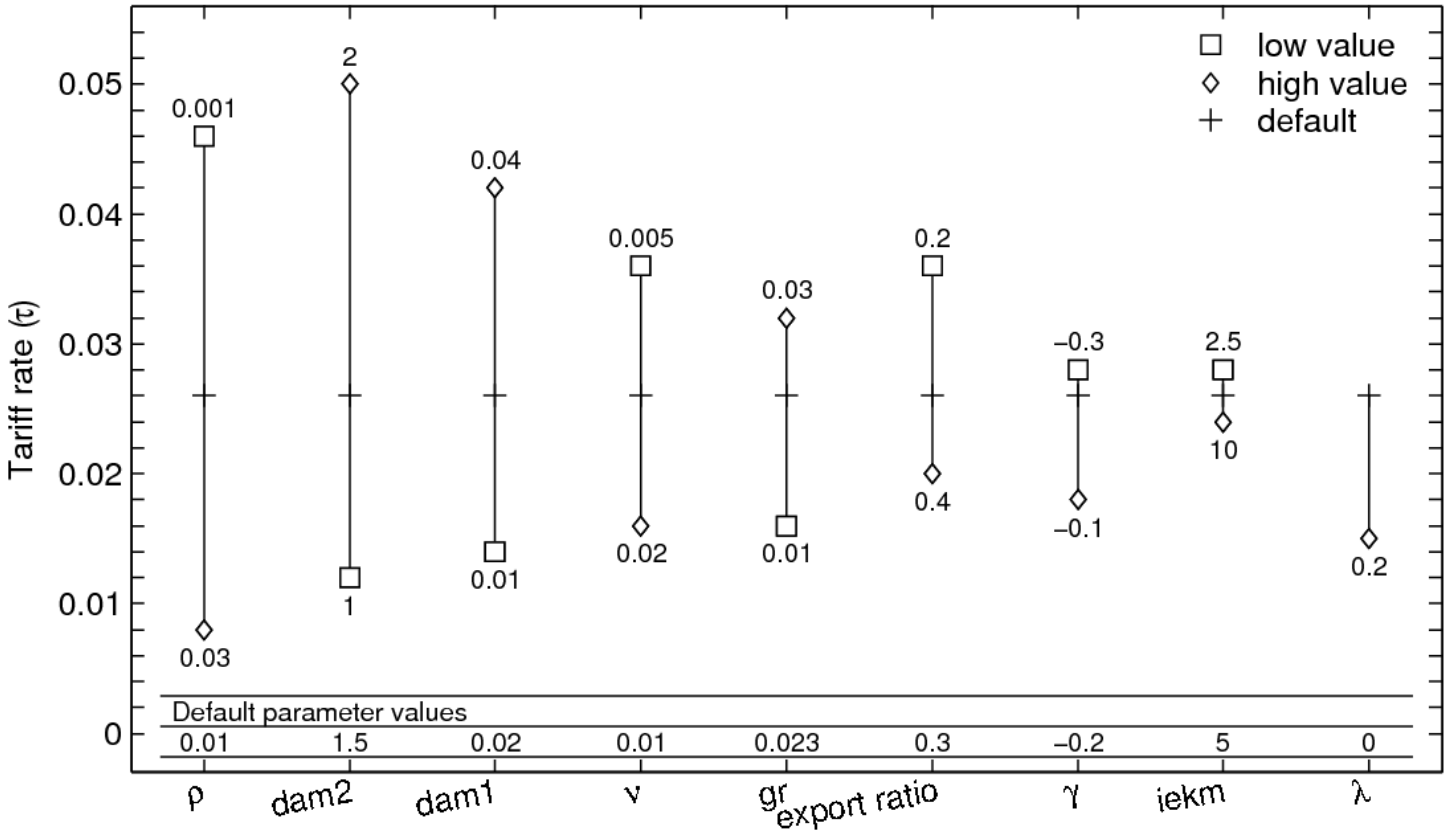
export ratio

abatement cost exponent

effectiveness of abatement

endogenous technological change

Sensitivity of main results



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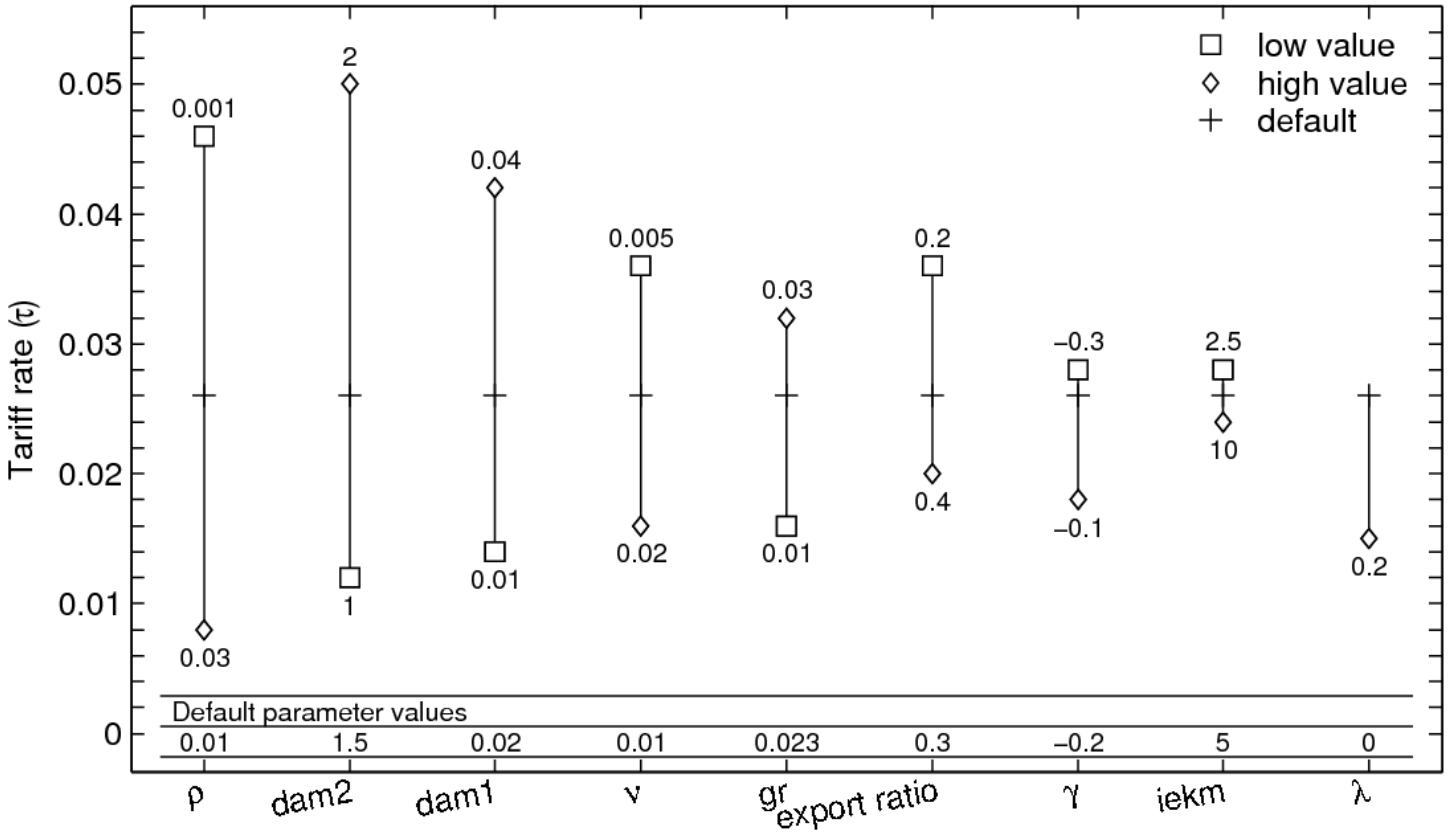

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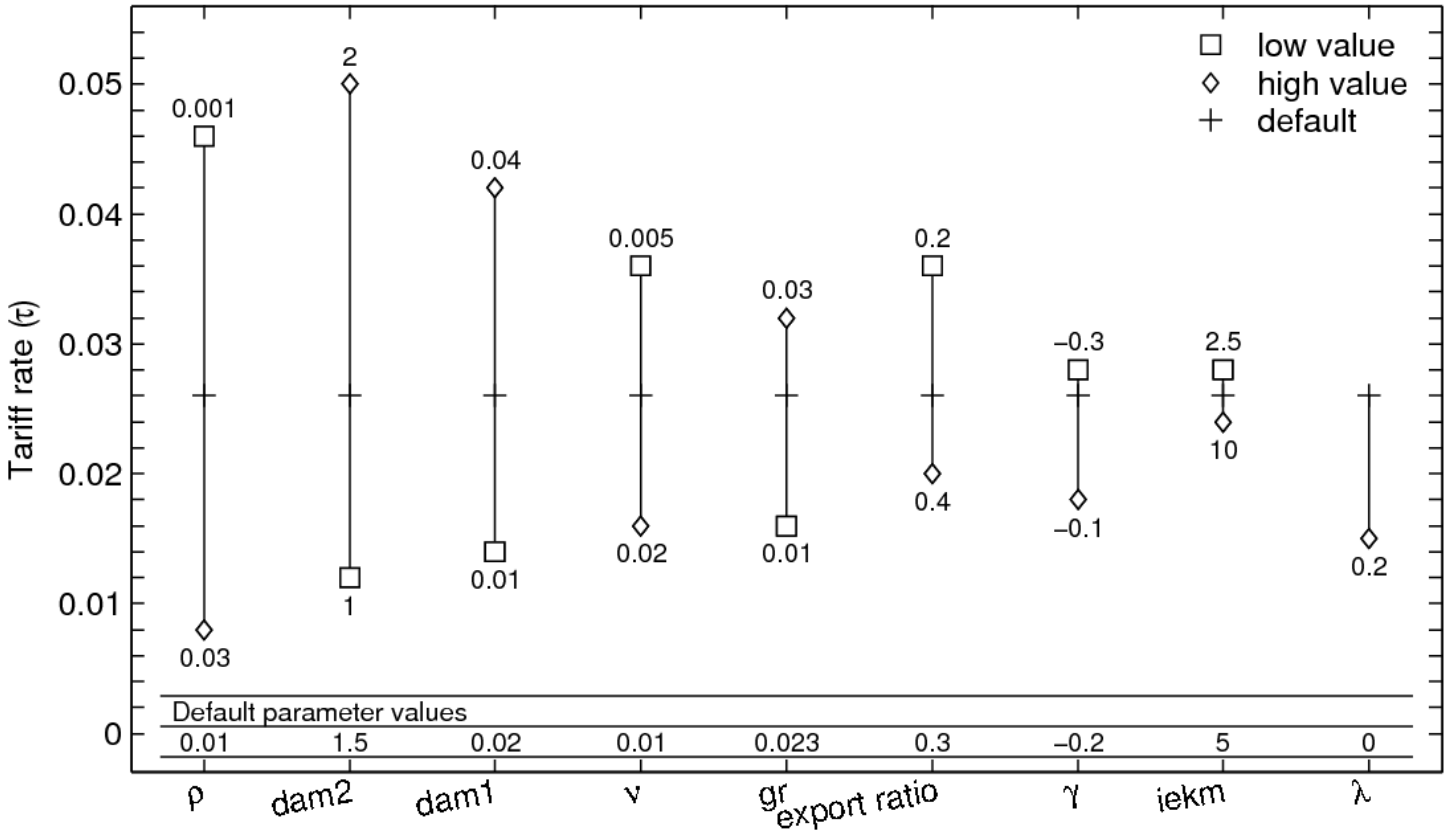

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$$\frac{d}{dt} = gr\,(iea \cdot ia_{it})^{\lambda}\,(a_{it})^{\varphi}$$

λ: stepping on toes

φ: standing on shoulders

endogenous technological change

Sensitivity of main results

- Impact of heterogeneity?
  - Heterogeneity in wealth → initial capital stock k_0
  - Heterogeneity in mitigation costs and vulnerability → introduce regions with
    - high damages + high mitigation costs
    - low damages + low mitigation costs *(these should be unlikely to cooperate)*

Sensitivity of main results

- Impact of heterogeneity?

		Region									Tariff
Parameter	Scenario	1	2	3	4	5	6	7	8	9	τ
dam2		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	
iekm	*default*	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	0.028
k0		34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	
k0	*1*	3.4	11.1	18.7	26.4	34	41.7	49.3	57.0	64.6	0.026
dam2	*2*	1.75	1.69	1.63	1.56	1.5	1.44	1.36	1.31	1.25	0.034
iekm		4.0	4.25	4.5	4.75	5	5.25	5.5	5.75	6	
dam2	*3*	2	1.88	1.75	1.63	1.5	1.38	1.25	1.13	1.0	0.042
iekm		3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	

Summary

- Model of coalition stability with externalities
  - Emissions damages
  - Trade sanctions
- Solved by combining Ficticious Play and Negishi's Approach in an iteration

- Tariffs
  - Raise participation
  - Credibility depends on σ
  - Welfare effect of coalitions outweighs losses from restricting free trade
- Main drivers of results
  - Armington assumption
  - Elasticity of substitution between Armington goods

Further Research

- Depart from symmetric players
  - heterogeneous players
  - calibrated to real world regions
- «Softer» trade restrictions
  - Border tax adjustments
  - Implicit trade restrictions through technology standards

Thanks!

Alternative: Modified Negishi

- Use *Negishi's Approach*, substitute externalities by parameters

parameters

$$\max_{\{in_{it},\, im_{it},\, m_{ijt},\, x_{ijt}\}} \sum_i \delta_i \,\text{payoff}_i(in_{it}, im_{it}, m_{ijt}, x_{ijt}, \overline{e_{jt}}, \overline{tr_{it}}, \ldots)$$

$$\text{subject to} \quad \text{economy and} \quad \text{climate equations} \qquad \Rightarrow \; m_{ijt},\, e_{it} \;\forall_{i,j}$$

$$\text{Update} \quad \overline{tr_{ijt}} = \tau_{ij}\, m_{ijt}, \;\; \overline{e_{jt}} = e_{jt}$$

- Determine prices by running the model with fixed trade flows