Disputation of the Thesis

Endogenous Technological Change in Strategies for Mitigating Climate Change

by Kai Lessmann
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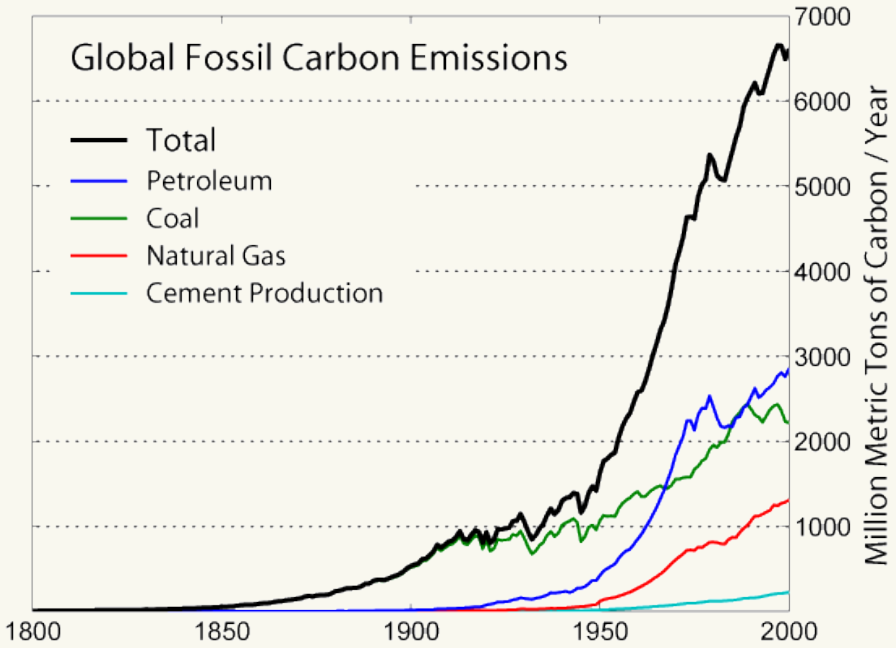
Technische Universität Berlin (TU)

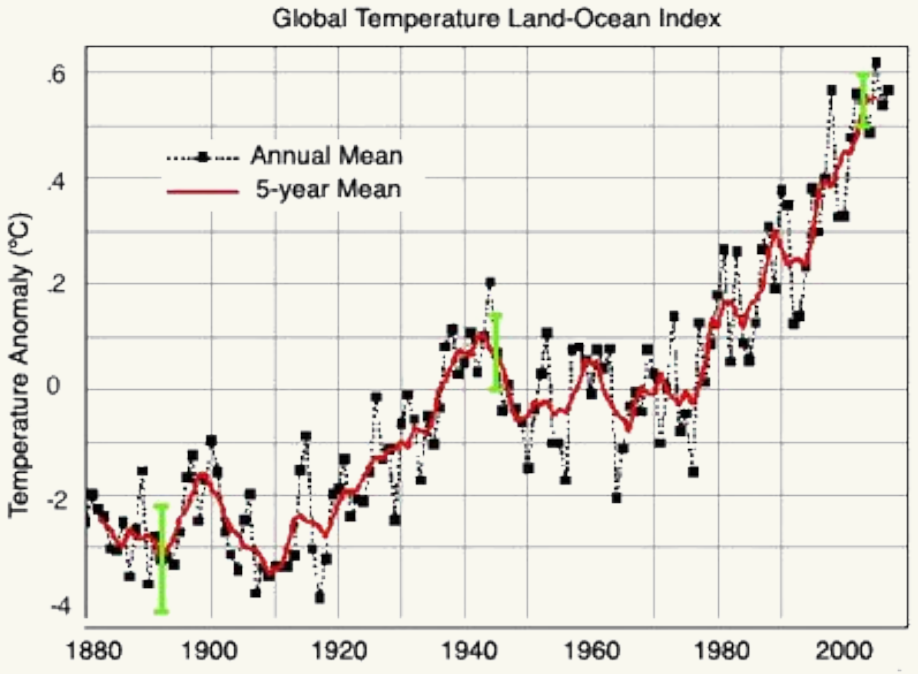
Thesis supervised by Ottmar Edenhofer
reviewed by Carlo Carraro

September 9th, 2009

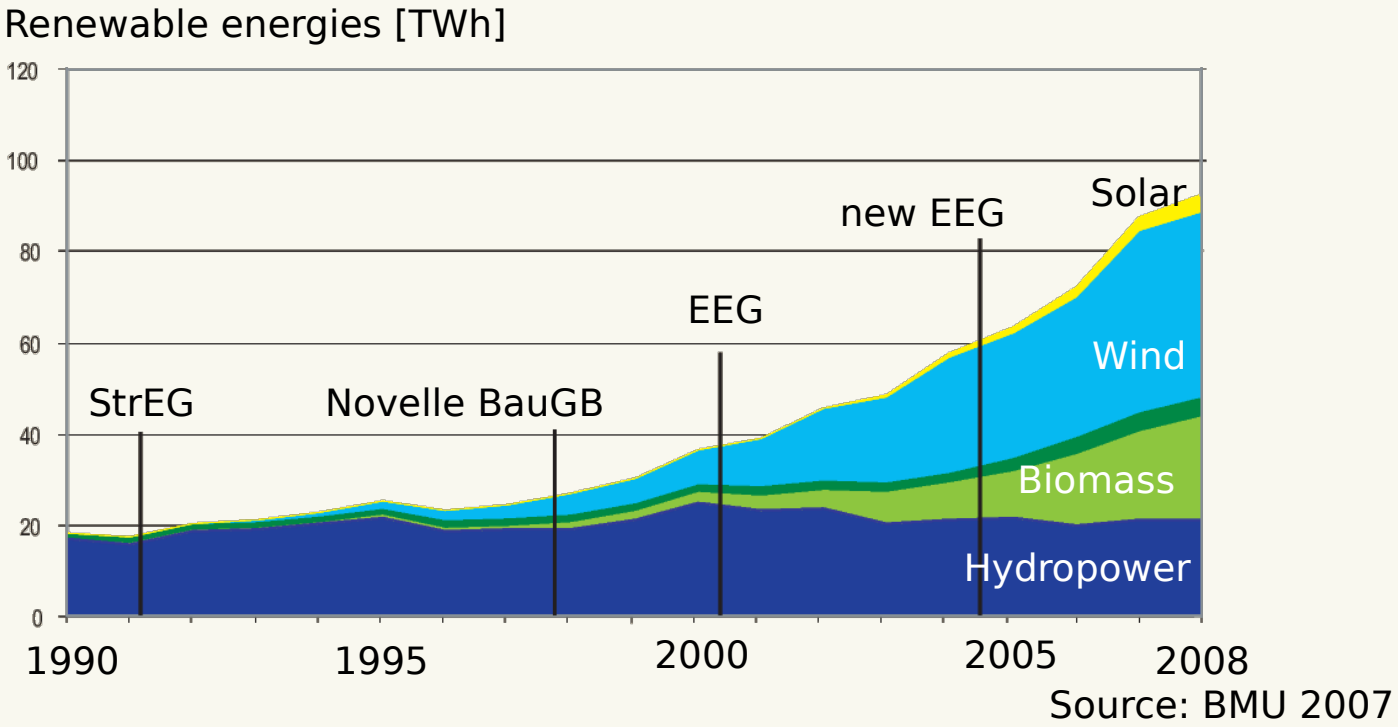
Technology and Global Warming

- "Emissions from fossil fuels cause global warming"





Endogenous Technological Change



Source: BMU 2007

- Policies may "induce" Technological Change
- Only when technological change is a model outcome
  → "Endogenous Technological Change"

- In short: $ETC + policy \rightarrow ITC$

Research Questions

1. What is the role of ETC for climate change mitigation?
   - Is it important for costs of mitigation?
   - How does it affect mitigation strategies?
   - What does this mean for climate-economy models?
2. How to implement global policies to trigger such ETC?
   - Can linking with other issues help climate agreements?

$$\underset{①}{ETC} + \underset{②}{policy} \rightarrow ITC$$

Outline

- Introduction and Motivation

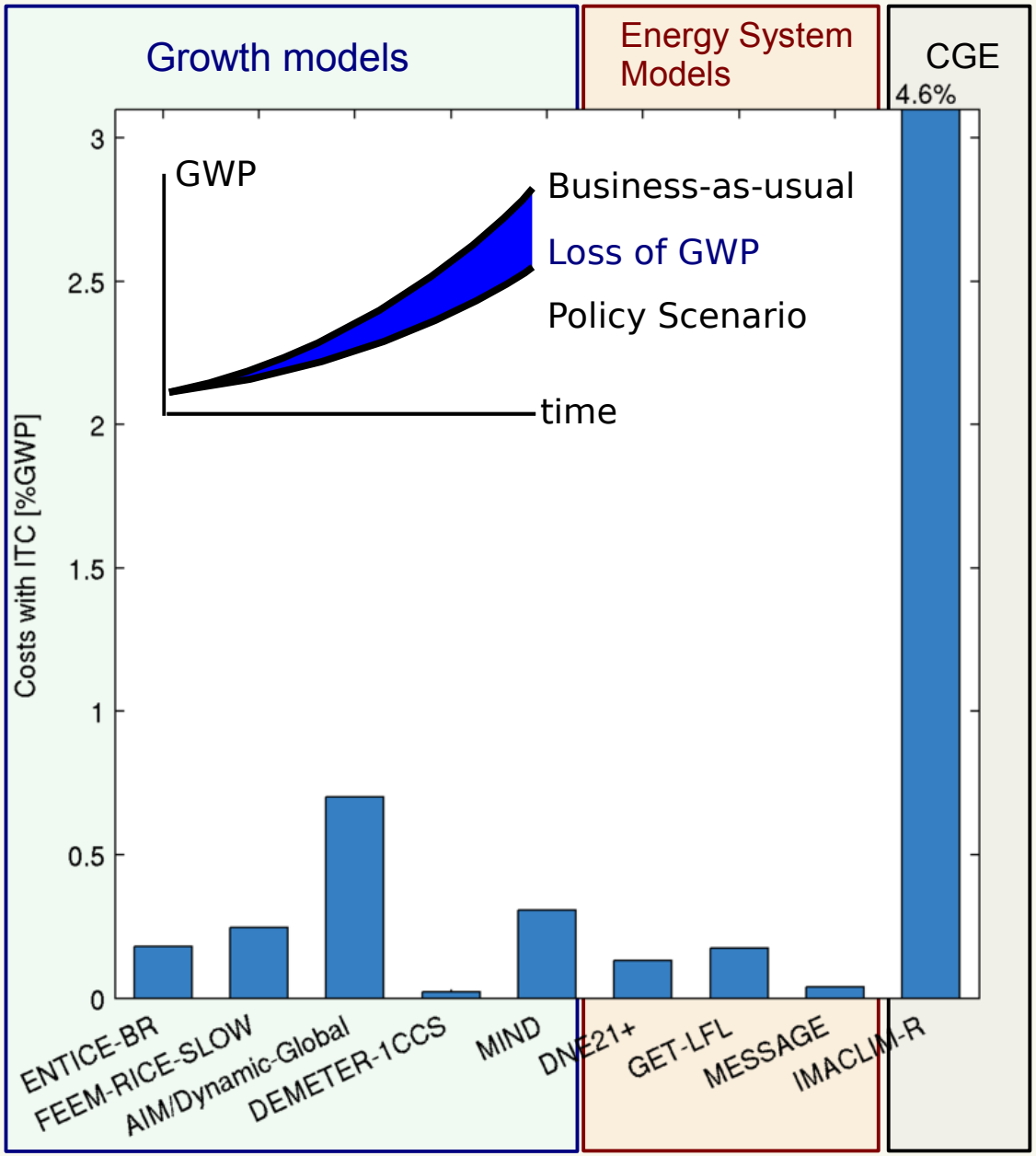
1. Modeling *ETC*
   - Impact of ETC in climate-economy models
     - Mitigation Costs
     - Mitigation Strategies
2. Achieving a cooperative climate *policy*
   - Introduction of Model of International Climate Agreements
   - Applications: linking with trade sanctions, research cooperation

- Summary and Conclusion

The **I**nnovation **M**odeling **C**omparison **P**roject

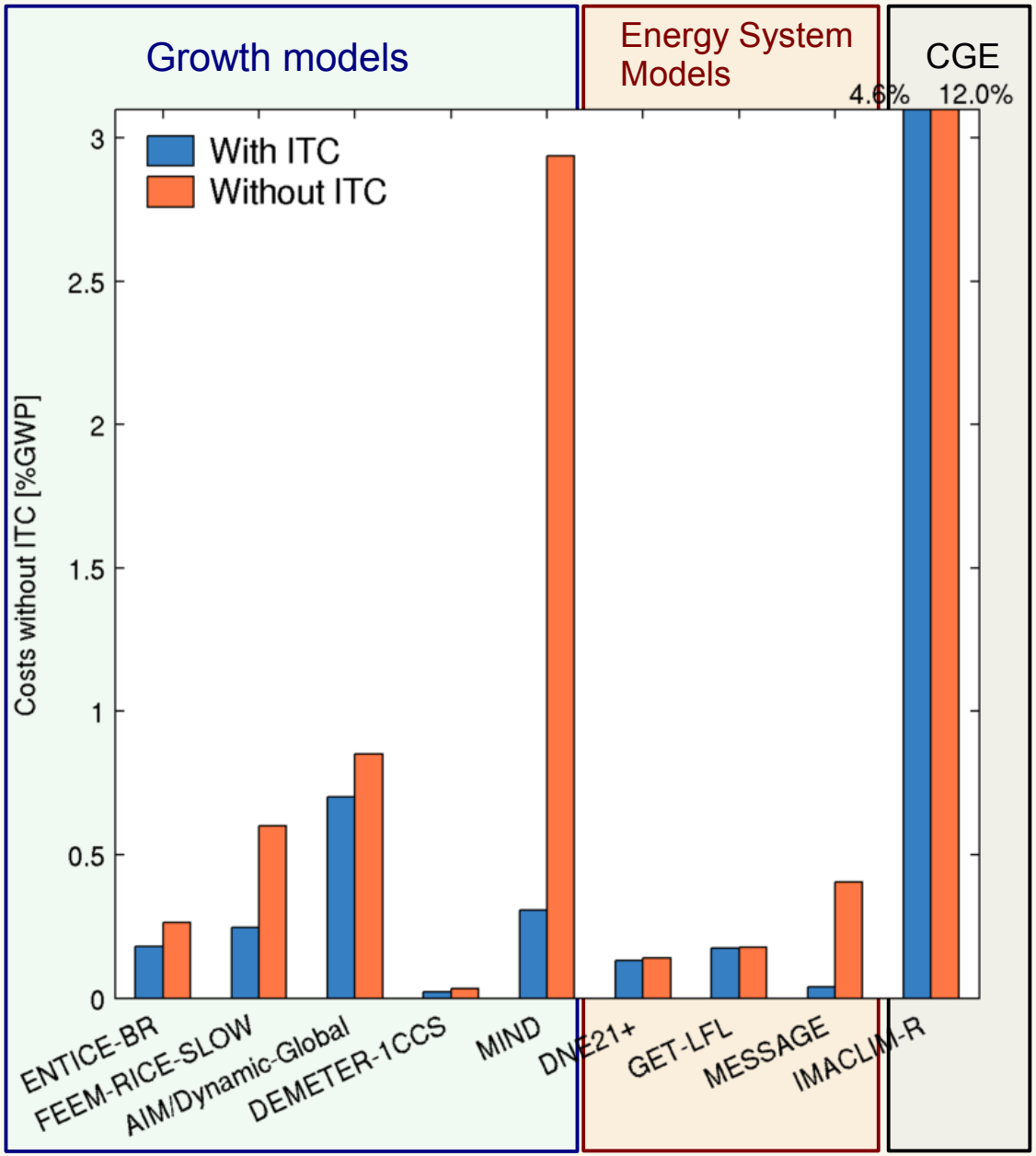
- No consent on ETC implementation
  - variety of approaches
  - "striking discrepancies in their basic conclusions" (Grubb et al. 2002)
- Compare ten climate-economy models
  - identify robust conclusions from ETC models
  - learn from the differences
- My contributions:
  - Definition of comparable Scenarios
  - Participation using PIK's MIND model
  - Collection of all model data and processing
  - Analysis and interpretation of results

Mitigation Costs



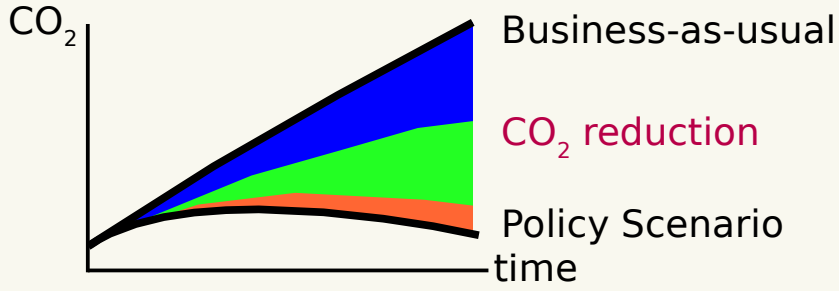
- Costs = Loss of GWP (percent)
- Low costs

Mitigation Costs without ETC



- Costs = Loss of GWP (percent)
- Low costs
- Disabling ETC
  - costs increase
  - magnitude differs

Mitigation Options



Emissions = *Carbon Intensity of primary energy* x *Energy Intensity of production* x *Income per capita* x *Population*

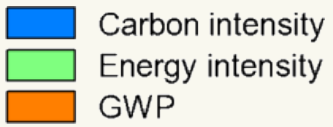
$$CO_2 = \frac{CO_2}{PE} \times \frac{PE}{GWP} \times \frac{GWP}{POP} \times POP$$

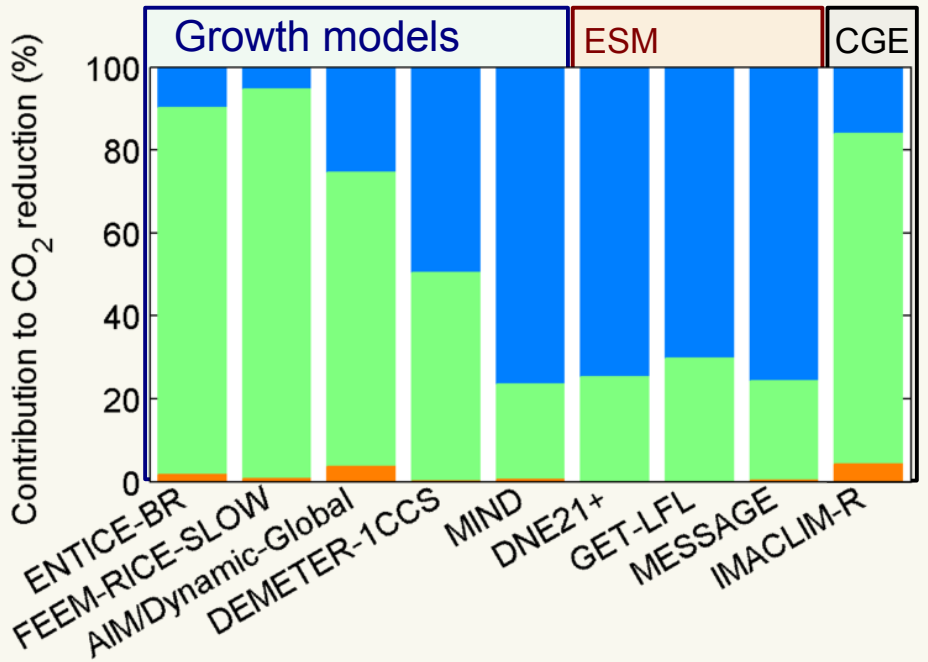
Kaya 1993

Substituting fossils with · renewables · nuclear · fossils + CCS	Improving energy efficiency Substituting energy with capital	Reduction of production, consumption

Mitigation Strategies

- Emission reduction decomposed into
  - carbon intensity
  - energy intensity
  - income effect





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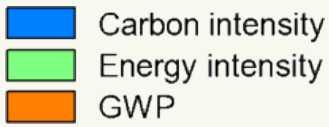
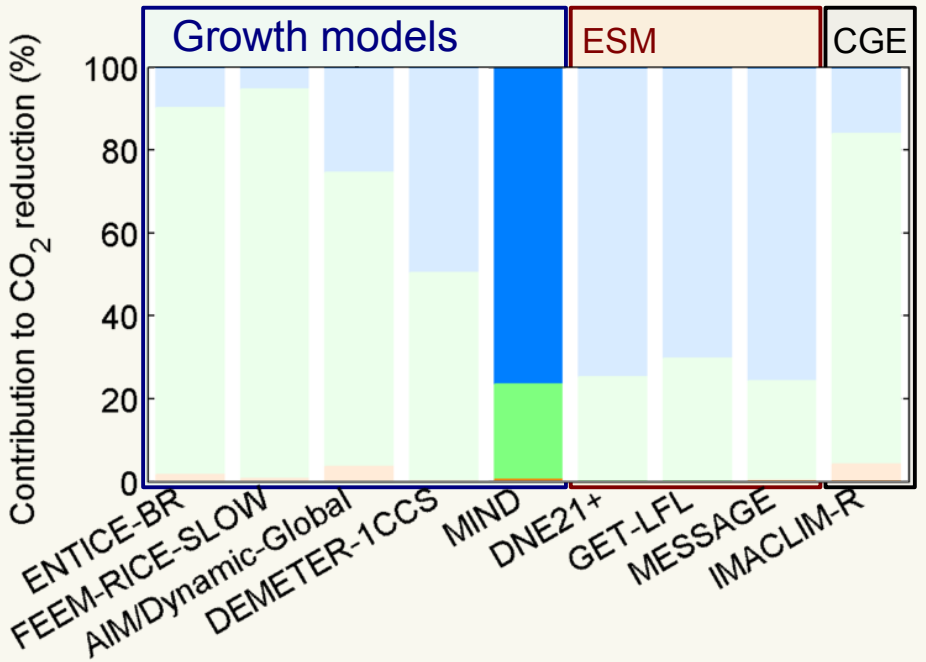
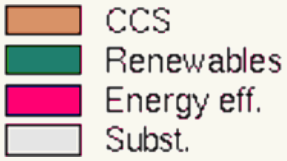
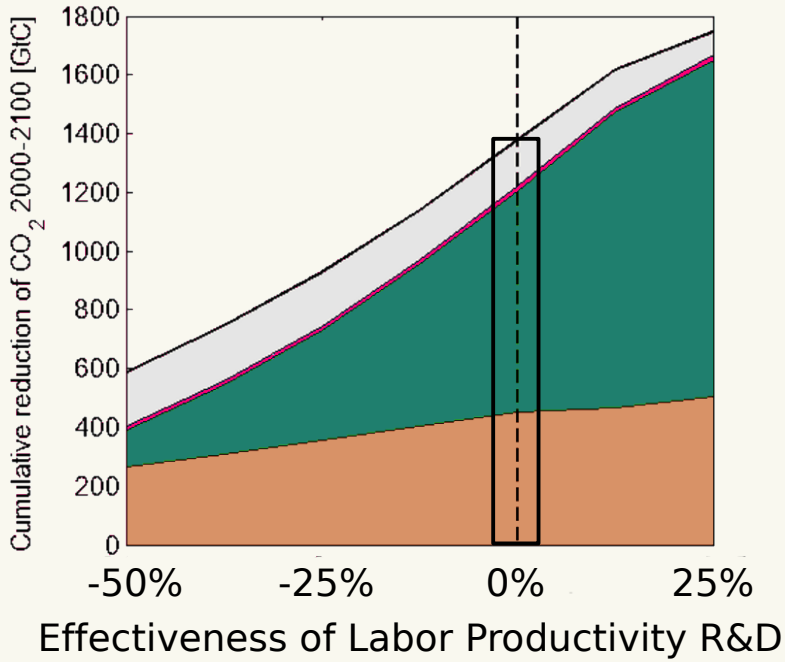




- Contribution of mitigation options in MIND:





- Macro-economic ETC
  - affects costs
  - affects strategy

Conclusions Modeling ETC

- Mitigation Costs: impact of ETC is...
  - potentially strong reduction of cost estimates
  - magnitude differs greatly
- Mitigation Strategies
  - Low cost strategy:
    CO_2 intensity reduction, carbon-free energy sources
- Modeling:
  - Combine macro-economy and energy sector (hybrid model)
  - ETC in macro-economy and energy sector
- Special Issue of *The Energy Journal*
  - Synthesis Report (Edenhofer, Lessmann et al. 2006a)
  - Model paper (Edenhofer, Lessmann et al. 2006b)

2. Cooperative Climate Policy

$$ETC \overset{①}{+} policy \overset{②}{\rightarrow} ITC$$

International Environmental Agreements

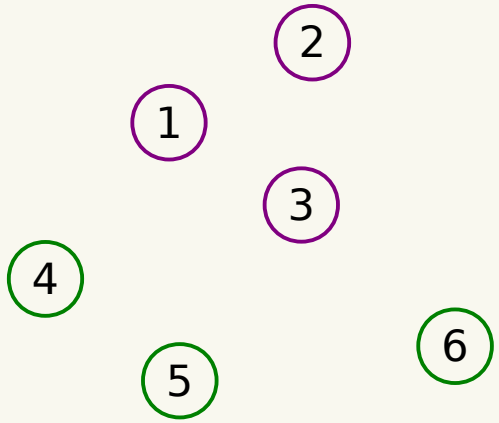
- Global climate targets imply fully cooperative climate policy
- Reality: no global authority but international environmental agreements
- Effective agreements tend to be small (Barrett 1994)
- Can linking climate agreements to
  - research cooperation
  - trade sanctions

  raise participation?

Bali 2007

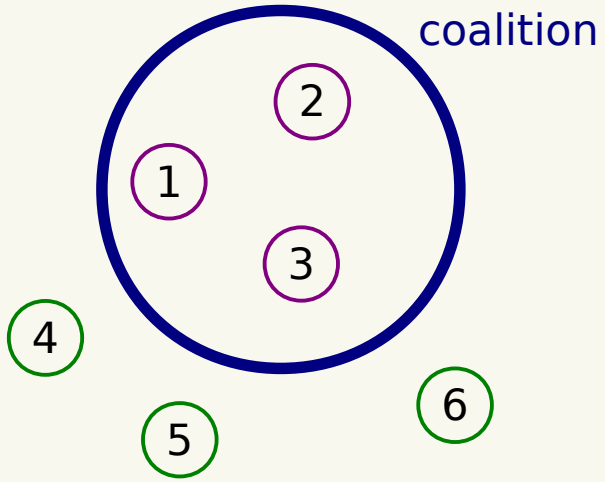
International Environmental Agreements

- Climate protection in a multi-actor world:
  - no cooperation (Nash Equilibrium)
  - full cooperation (Social Optimum)



International Environmental Agreements

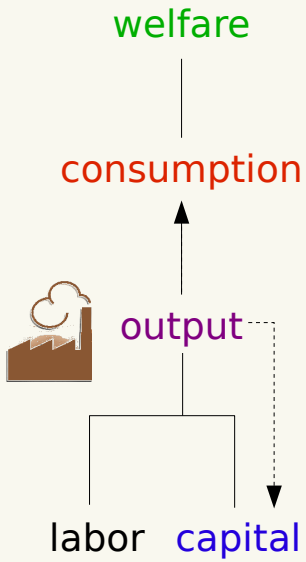
- Climate protection in a multi-actor world:
  - no cooperation (Nash Equilibrium)
  - full cooperation (Social Optimum)
- Partial Cooperation: Coalitions
  - Equilibrium: PANE (Chander/Tulkens 1995)
  - Members cooperate, act as one player
  - Non-member act non-cooperatively
- Stable Coalitions (Carraro/Siniscalco 1993)
  - no incentive to leave (*internally stable*)
  - no incentive to join (*externally stable*)
- MICA: explore incentives to improve participation



Structure of MICA

Model of International Climate Agreements

$$
\begin{aligned}
W &= \int_0^{\infty} L\, u(c/L)\, exp\{-\rho t\}\, dt \\
c &= F(aL, k) - i \\
\frac{d}{dt}k &= i - \delta k
\end{aligned}
$$



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Model of International Climate Agreements

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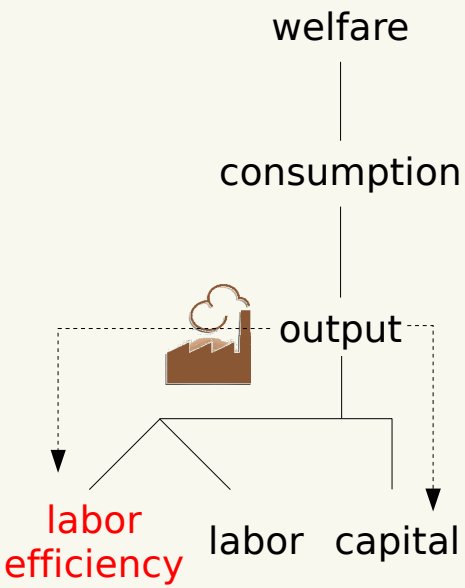
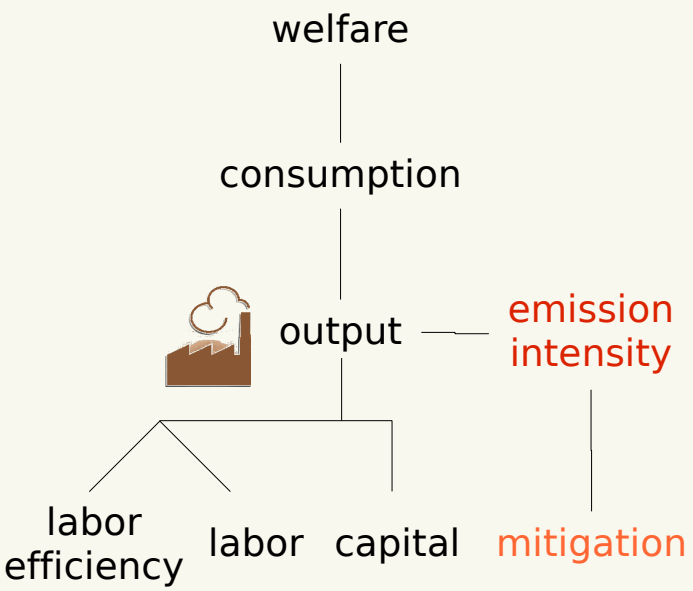
\begin{aligned}
W &= \int_0^\infty L\, u(c/L)\, exp\{-\rho t\}\, dt \\
c &= F(aL, k) - i - i^a \\
\frac{d}{dt}k &= i - \delta k \\
\frac{d}{dt}a &= f(i^a)
\end{aligned}
$$



Structure of MICA

Model of International Climate Agreements

$$
\begin{aligned}
W &= \int_0^\infty L\, u(c/L)\, exp\{-\rho t\}\, dt \\
c &= F(aL, k) - i - i^a - i^m \\
\frac{d}{dt}k &= i - \delta k \\
\frac{d}{dt}a &= f(i^a)
\end{aligned}
$$



$$
\begin{aligned}
e &= \sigma(km) \cdot F(L, k) \\
\frac{d}{dt}km &= f(i^m)
\end{aligned}
$$

Structure of MICA
Model of International Climate Agreements

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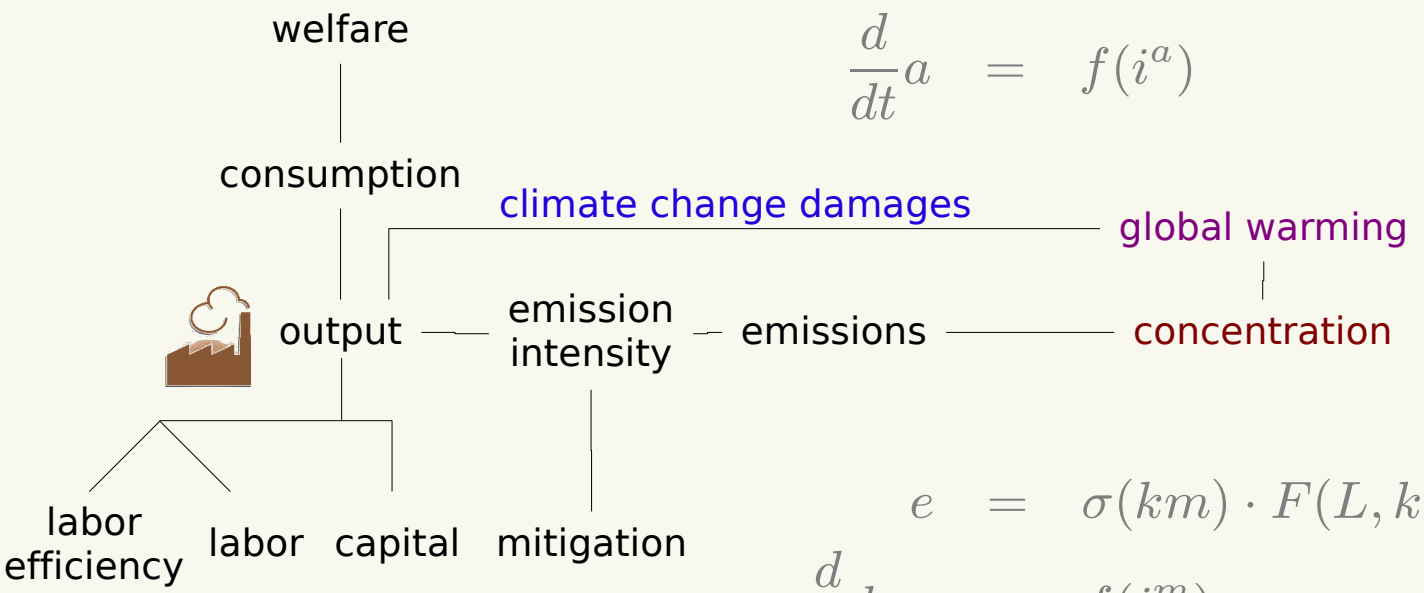

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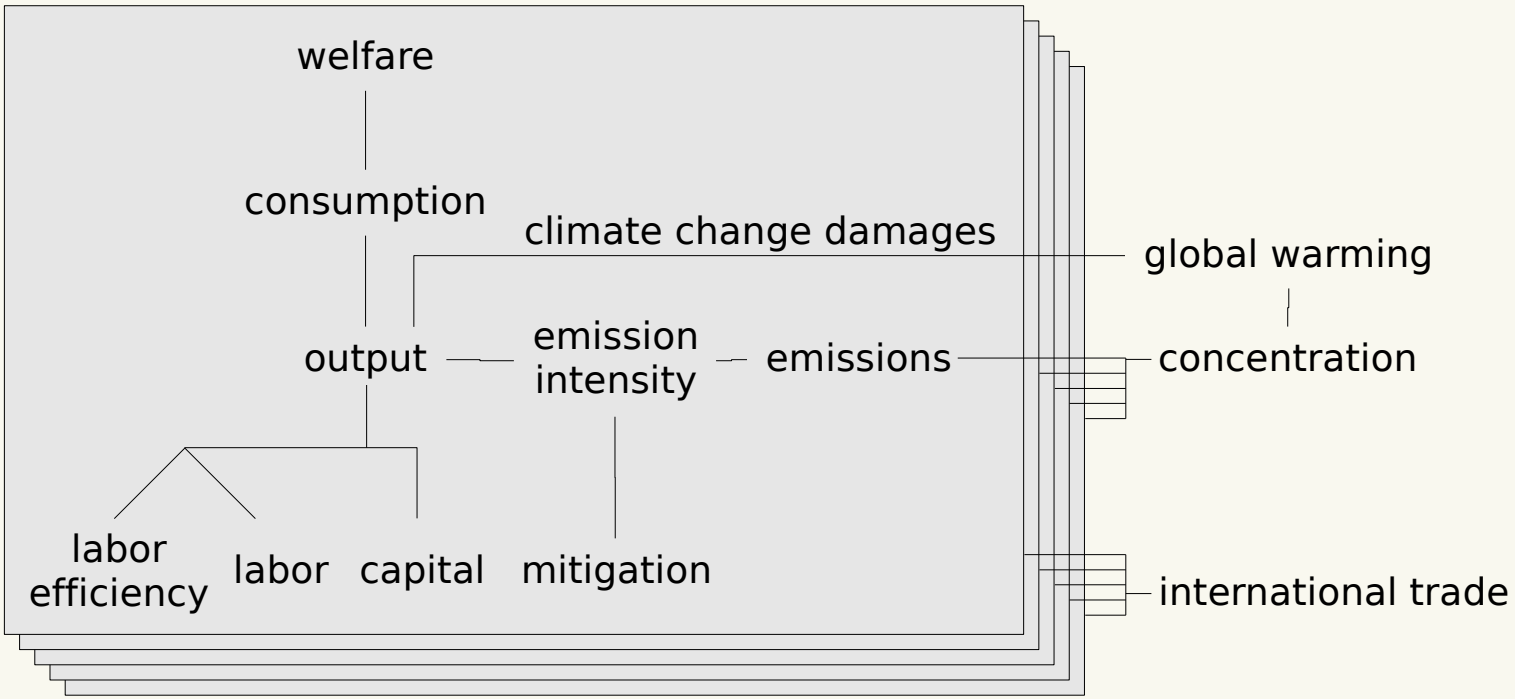
\end{aligned}
$$

$$
\Omega = \Omega \circ \mathrm{temp} \circ \mathrm{conc} \circ e
$$

temp(·), conc(·): Petschel-Held et al. 1999
Ω(·): Nordhaus/Yang 1996

Structure of MICA
Model of International Climate Agreements

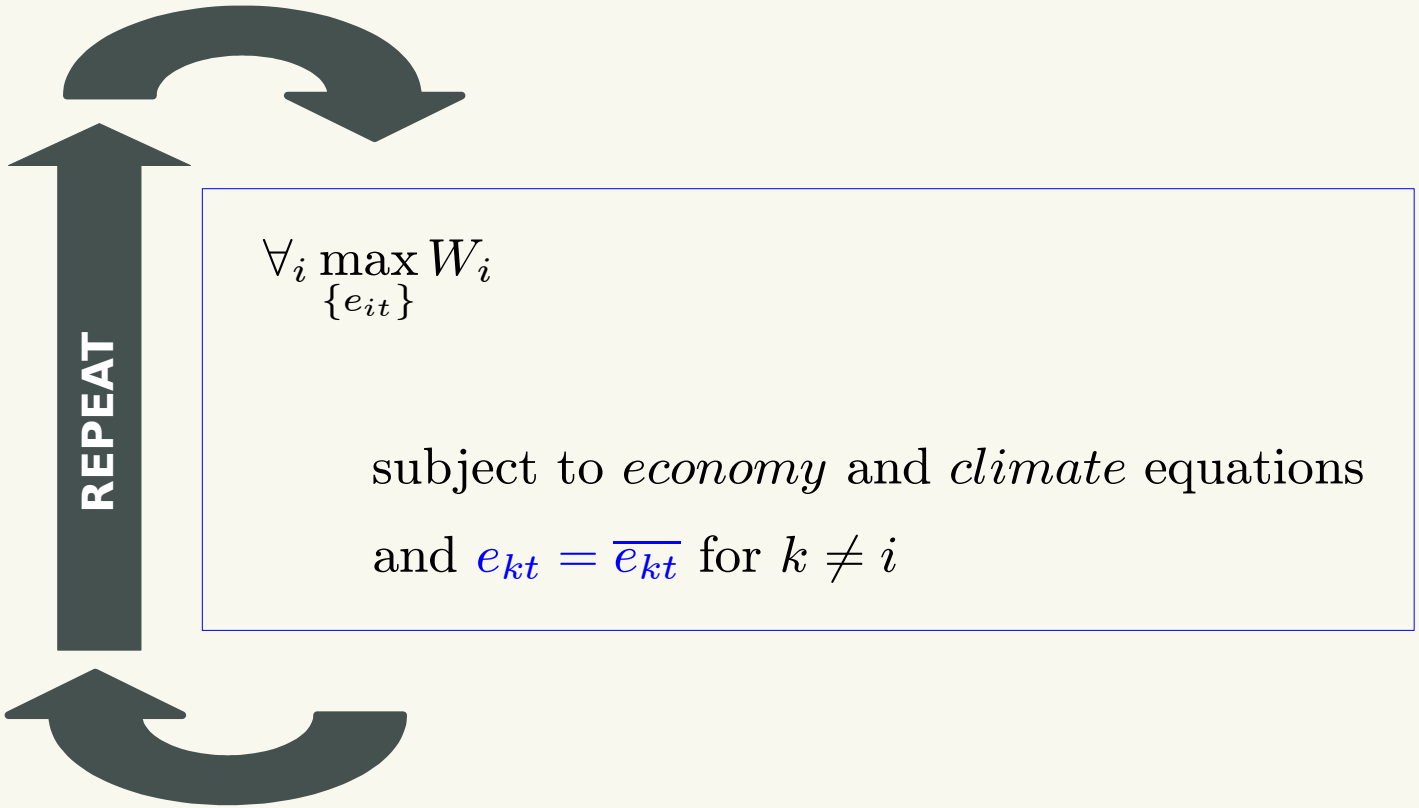
- Multiple regions (here: 9)
- International trade
  with national product differentiation



- Solving multi-actor intertemporal optimizations with trade + external effects is numerically challenging

Numeric solution: Nash Equilibrium (no trade, externality)

- *Fictitious Play:* Search for Nash Equilibrium as a fixed point of the iteration:



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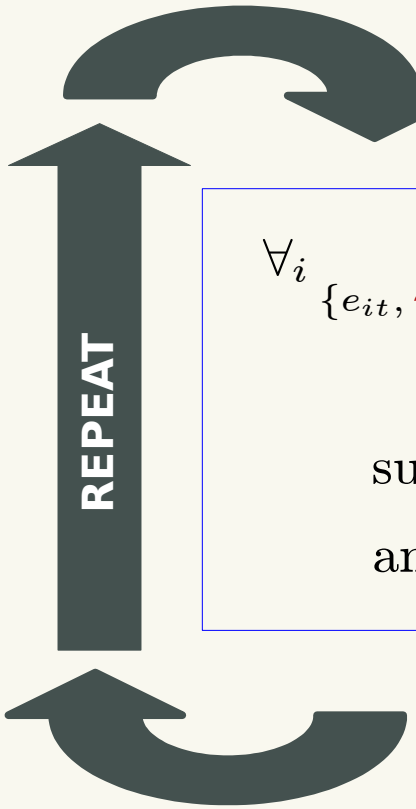


$$\forall_i \max_{\{e_{it},\, m_{ijt},\, x_{ijt}\}} W_i$$

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

Numeric solution: Nash Equilibrium (trade, no externality)

- Determine competitive equilibrium using Negishi's Approach

$$\max_{\{e_{it},\, m_{ijt},\, x_{ijt}\}} \sum_i \delta_i W_i$$

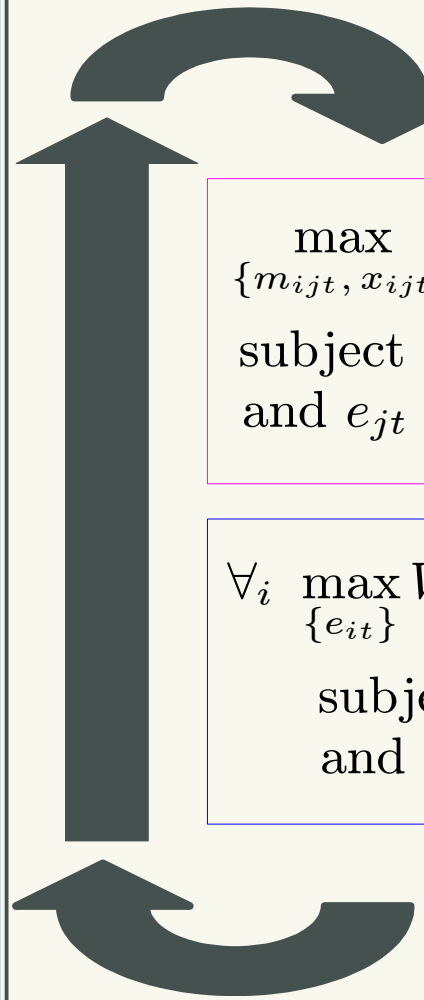
subject to *economy* and *climate* equations

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

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

My solution algorithm: Nash Equilibrium (trade + externality)

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



$$\max_{\{m_{ijt},\, x_{ijt}\}} \sum_i \delta_i W_i$$

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

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

$$\forall_i \quad \max_{\{e_{it}\}} W_i$$

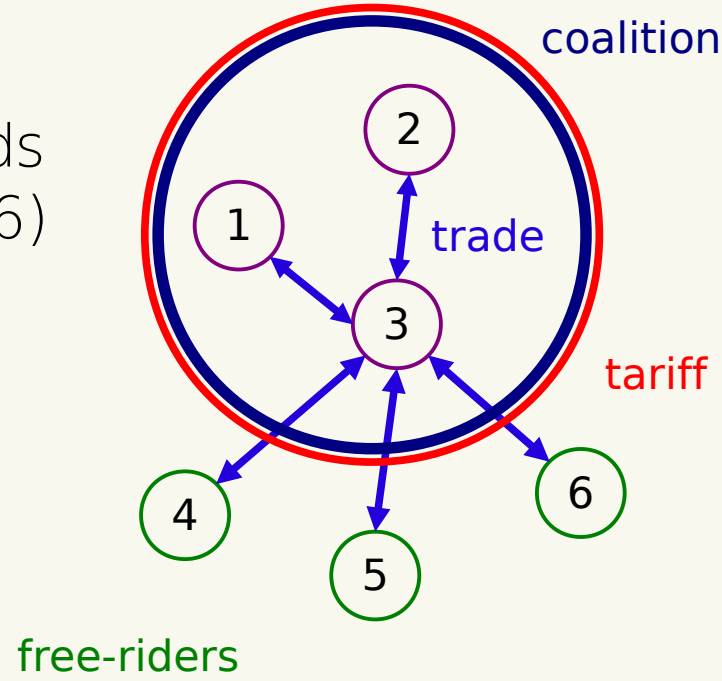
subject to *economy* and *climate* equations and $m_{ijt} = \overline{m_{ijt}}, x_{ijt} = \overline{x_{ijt}}, e_{kt} = \overline{e_{kt}}$ for $k \neq i$

$\Rightarrow \quad e_{it}$

- Published as Lessmann et al. 2009, *Economic Modelling*

Application 1: Trade Sanctions

- International disadvantage: Production costly due to abatement
- Offset by introducing an import tariff τ on foreign goods (Stiglitz 2006)



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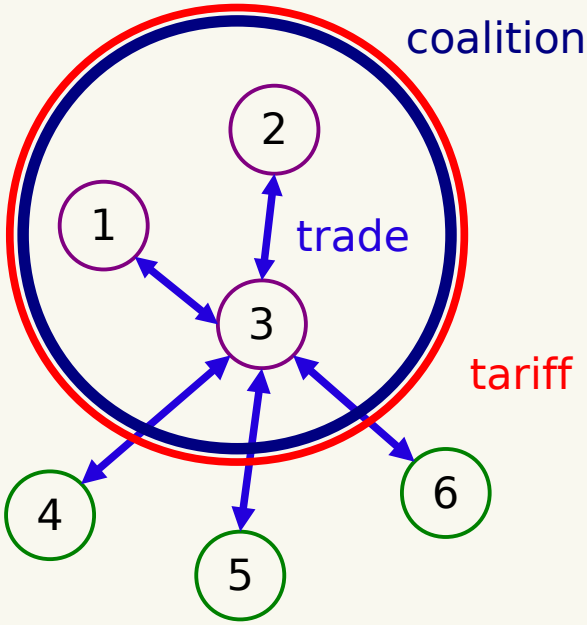


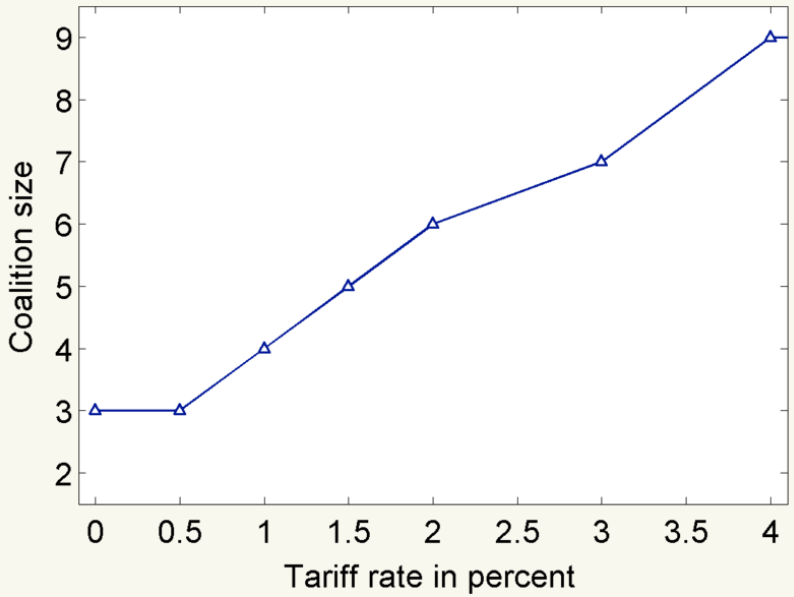
- Research Questions:
  - Will tariffs work when goods are highly substitutable?
  - Will tariffs do more harm than good?

Application 1: Trade Sanctions

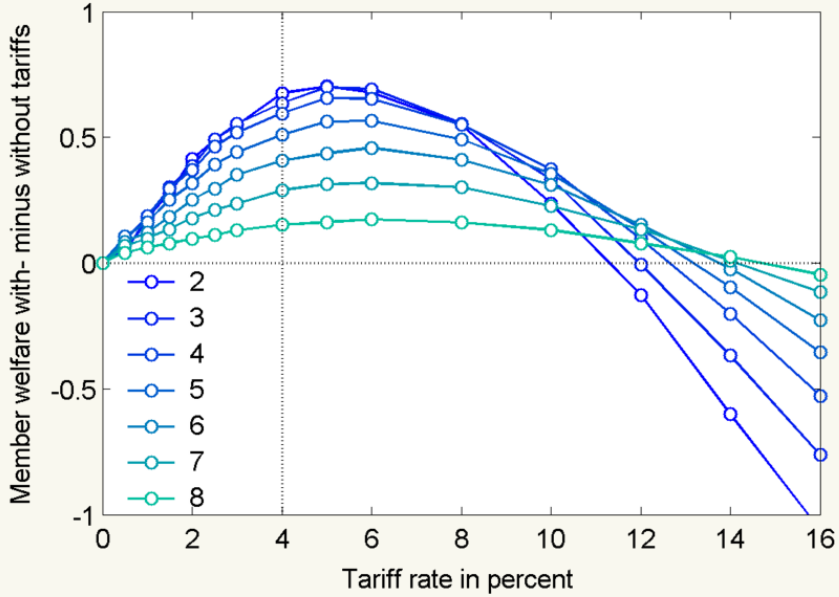
- Tariffs increase participation

- Coalition welfare with tariffs minus without
- Members benefit when tariffs are not too high

Participation



Member gain from tariff



Conclusions Tariffs

- Linking climate agreements to trade sanctions
  - raises participation in the linked agreement
- Tariffs are
  - individually rational
    i.e. members benefit from tariffs
  - socially rational
    i.e. global welfare is increased

- Lessmann et al. 2009, *Economic Modelling*

Application 2: Research Cooperation

- Benefits of R&D spill over to research partners (Griliches 1992)
  - transfer of technology/technical knowledge
  - networks synergies
  - economies of scale
  - sharing R&D costs
- Climate-Research Agreements

	Participation
– Botteon/Carraro (1998): Production cost	*full cooperation*
– Nagashima/Dellink (2008): Mitigation technology	*only marginal increases*

- Identify difference between Productivity R&D, Mitigation R&D

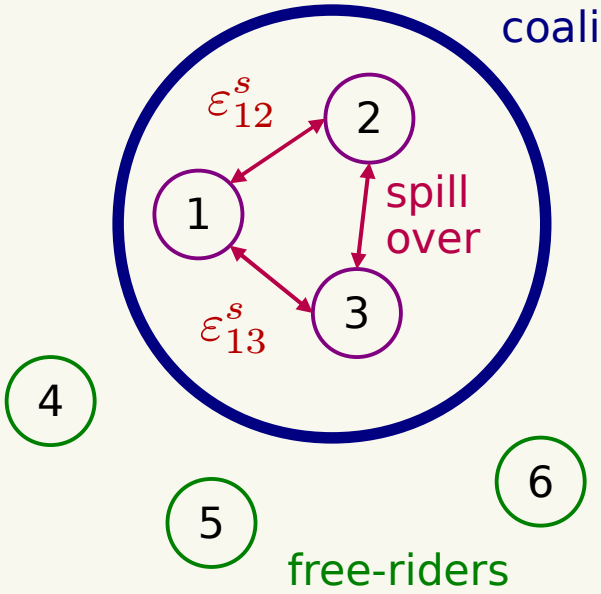
Modeling Research Cooperation

- Formal description:
  - spillover intensity ε_{ij}

$$\tilde{s}_{it} = \sum_j \varepsilon_{ij}^s s_{jt}$$

(Griliches 1992)

- Research cooperation on
  - (Labor) Productivity a_{it}
  - Mitigation Technology km_{it}



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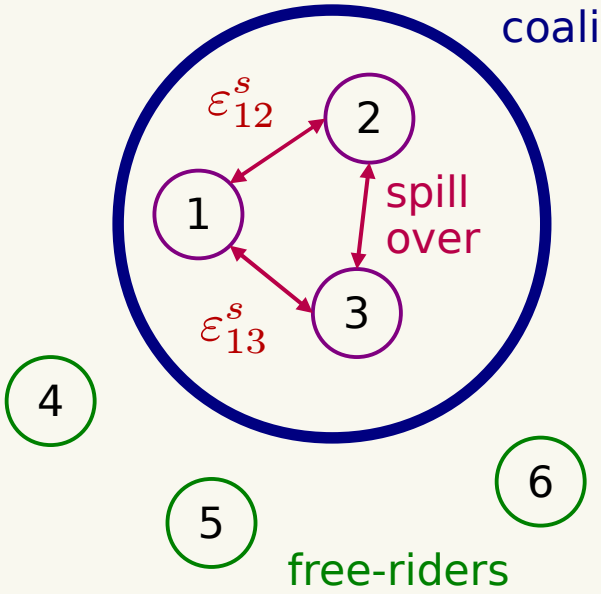


$$\frac{d}{dt} a_{it} = \xi_a \left(ia_{it}\right)^{\lambda_a} \left(a_{it}\right)^{\Phi_a}$$

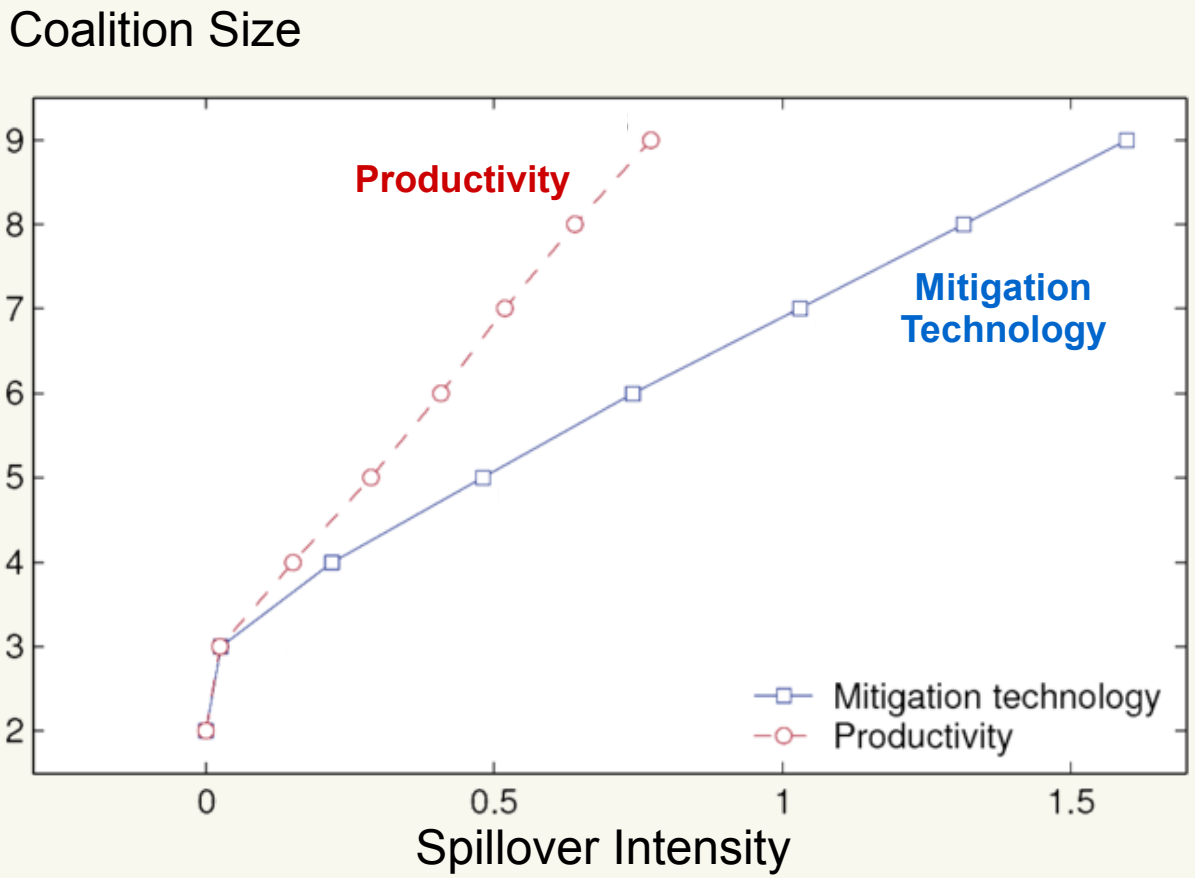
$$\frac{d}{dt} km_{it} = \xi_m \left(im_{it}\right)^{\lambda_m} \left(km_{it}\right)^{\Phi_m}$$

GWP $F(\tilde{a}L, K)$

$\sigma(\widetilde{km})$ CO_2 Emissions

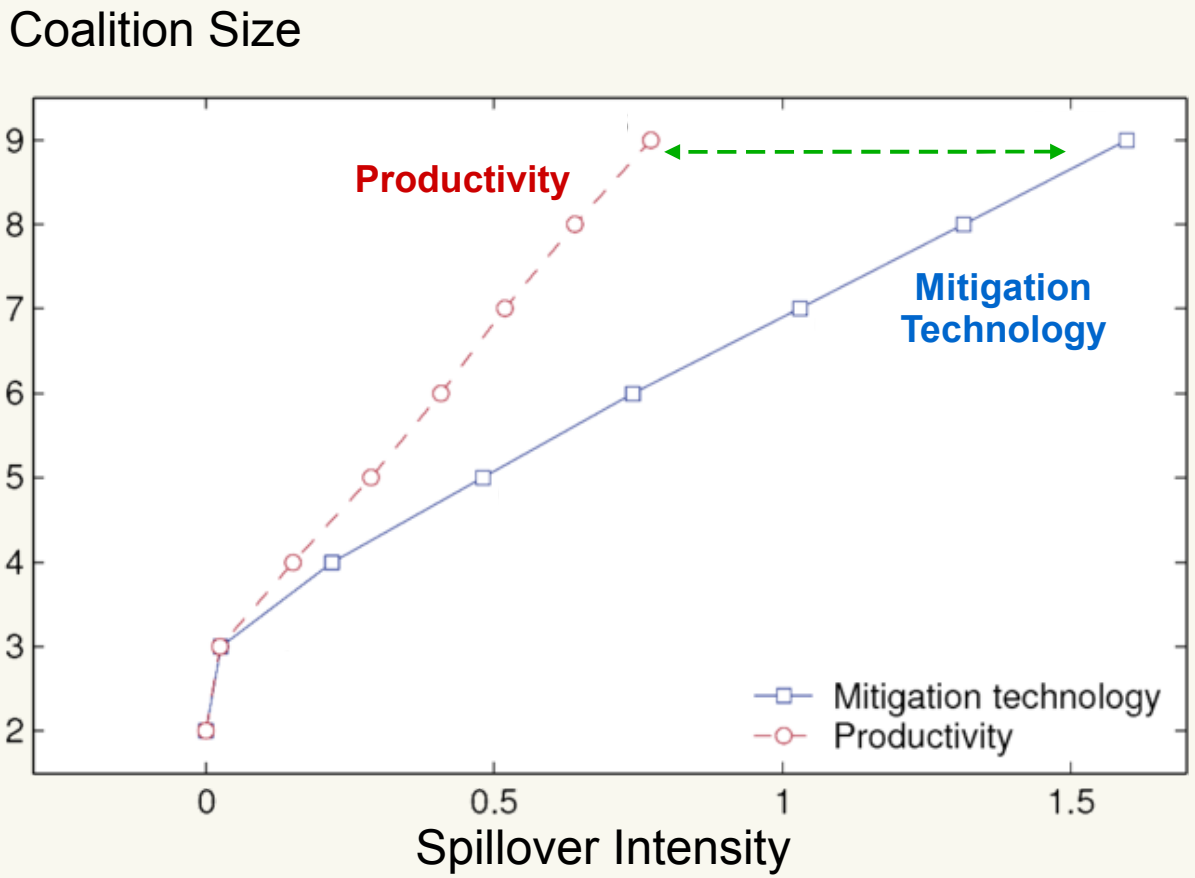
Jones/Williams (1998)

Results: Research Cooperation



- Full cooperation achieved

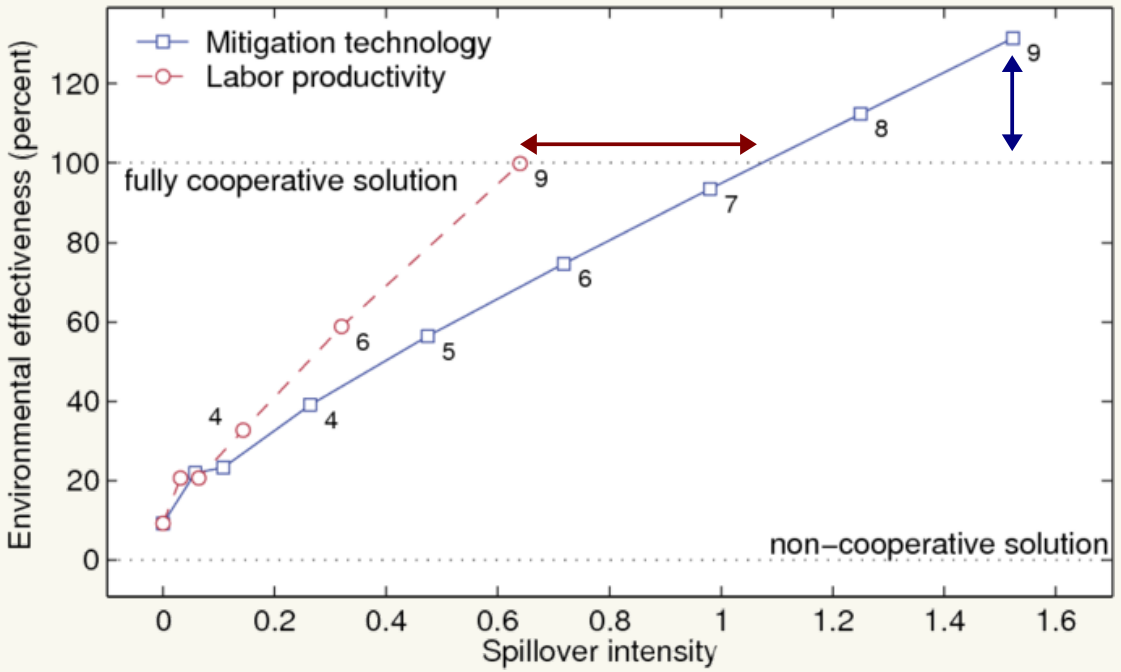
Results: Research Cooperation



- Full cooperation achieved
- Cooperation on Productivity R&D is stronger as an incentive

Environmental Effectiveness

- Effective = low cumulative Emissions



- Mitigation R&D *exceeds* the (previous) Optimum
  - reduced abatement costs → cleaner atmosphere optimal
- Similar emission levels are reached more effectively with Productivity R&D

Conclusions R&D Cooperation

- Research cooperation may raise
  - participation
  - environmental effectiveness
- Cooperation on productivity improvement: lower spillover needed to reach
  - Full cooperation
  - High environmental effectiveness
- Cooperation on mitigation improvement:
  - Reaches higher absolute environmental effectiveness

- Lessmann / Edenhofer, under revision for *Resource and Energy Economics*

Summary and Conclusion

1. What is the role of ETC for climate change mitigation?

2. How to implement global policies to trigger such ETC?

Summary and Conclusion

1. What is the role of ETC for climate change mitigation?
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   - Low-cost mitigation prefers on carbon intensity reduction
   - Low-carbon energy technologies important for decarbonization
     → hybrid modeling

2. How to implement global policies to trigger such ETC?

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   - Low-carbon energy technologies important for decarbonization
     → hybrid modeling
2. How to implement global policies to trigger such ETC?
   - Issue Linking increases participation in climate agreements
     - linking with trade sanctions (tariffs)
     - linking with research cooperation

Thank you!

I would like to thank
Ottmar Edenhofer, Carlo Carraro
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Matthias, Robert, Christian, Anne, Nico, Marian, Lavinia, Jutta
My friends, Theresa, Dominik, Frank
My parents
Britta

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