Disputation of the Thesis

Endogenous Technological Change in Strategies for Mitigating Climate Change

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September 9th, 2009
Technology and Global Warming

- “Emissions from fossil fuels cause global warming”

![Graph showing global fossil carbon emissions and global temperature anomaly index from 1800 to 2000.](image)
Endogenous Technological Change

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

- In short: $\text{ETC} + \text{policy} \rightarrow \text{ITC}$
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?

\[ ETC + policy \rightarrow ITC \]
Outline

• Introduction and Motivation

1. Modeling ETC
   - Impact of ETC in climate-economy models
     • Mitigation Costs
     • Mitigation Strategies

2. Cooperative Climate Policy
   • Introduction of Model of International Climate Agreements
     - Solving MICA
     - Tariffs
     - R&D cooperation
   • Applications: linking with trade sanctions, research cooperation

• Summary and Conclusion
The Innovation Modeling Comparison Project

- 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

\[ \text{Emissions} = \text{Carbon Intensity} \times \text{Energy Intensity} \times \text{Income per capita} \times \text{Population of production} \]

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

\[ \text{CO}_2 = \frac{\text{CO}_2}{\text{PE}} \times \frac{\text{PE}}{\text{GWP}} \times \frac{\text{GWP}}{\text{POP}} \times \text{POP} \]

Kaya 1993
Mitigation Strategies

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

\[ \text{CO}_2 = \frac{\text{CO}_2}{\text{PE}} \times \frac{\text{PE}}{\text{GWP}} \times \text{GWP} \]
Mitigation Strategies

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

- 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

\[ ETC + policy \rightarrow ITC \]
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?
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

\[
W = \int_0^\infty L u(c/L) \exp\{-\rho t\} \, dt
\]
\[
c = F(aL, k) - i
\]
\[
\frac{d}{dt} k = i - \delta k
\]
Structure of MICA
Model of International Climate Agreements

\[ W = \int_0^\infty L u(c/L) \exp\{-\rho t\} dt \]
\[ c = F(aL, k) - i - i^a \]
\[ \frac{d}{dt} k = i - \delta k \]
\[ \frac{d}{dt} a = f(i^a) \]
Structure of MICA
Model of International Climate Agreements

\[ W = \int_0^\infty L u(c/L) \exp\{-\rho t\} \, dt \]
\[ c = F(aL, k) - i - i^a - i^m \]
\[ \frac{d}{dt} k = i - \delta k \]
\[ \frac{d}{dt} a = f(i^a) \]
\[ e = \sigma(km) \cdot F(L, k) \]
\[ \frac{d}{dt} km = f(i^m) \]
Structure of MICA
Model of International Climate Agreements

\[ W = \int_{0}^{\infty} L u(c/L) \exp{-\rho t} \, dt \]
\[ c = F(aL, k) - i - i^a - i^m \]
\[ \frac{dk}{dt} = i - \delta k \]
\[ \frac{d}{dt}a = f(i^a) \]

\[ e = \sigma(km) \cdot F(L, k) \]
\[ \frac{d}{dt}km = f(i^m) \]

\[ \Omega = \Omega \circ \text{temp} \circ \text{conc} \circ e \]

temp(\cdot), conc(\cdot): Petschel-Held et al. 1999
\( \Omega(\cdot): \) 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:

\[
\forall_i \max_{W_i, \{e_{it}\}} \text{subject to \textit{economy} and \textit{climate} equations and } e_{kt} = \bar{e}_{kt} \text{ for } k \neq i
\]
Numeric solution: Nash Equilibrium (trade + externality)

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

\[ \forall i \max_{\{e_{it}, m_{ijt}, x_{ijt}\}} W_i \]

subject to economy and climate equations

and \( e_{kt} = \bar{e}_{kt} \) for \( k \neq i \)

- Problem: \( m_{ijt}, x_{ijt} \): market price levels unknown

**Model of Intern'l Climate Agreements**
- Solving MICA
- Tariffs
- R&D cooperation

**2. Cooperative Climate Policy**
- Solving MICA
- Tariffs
- R&D cooperation

**Summary and Conclusion**
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 \(\delta_i\) such that the intertemporal budget constraint holds:

\[
\int_0^\infty \sum_{j \neq i} p_{ijt}^m m_{ijt} \, dt = \int_0^\infty \sum_{j \neq i} p_{ijt}^x x_{ijt} \, dt
\]
My solution algorithm: Nash Equilibrium (trade + externality)

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

\[
\begin{align*}
\max_{\{m_{ij}, x_{ij}\}} & \sum_i \delta_i W_i \\
\text{subject to } & \text{ economy and climate equations} \\
\text{and } & e_{jt} = \overline{e_{jt}}
\end{align*}
\]

\[
\forall_i \max_{\{e_{it}\}} W_i \\
\text{subject to } \text{ economy and climate equations} \\
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\]

- 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 $\tau$ on foreign goods (Stiglitz 2006)
Application 1: Trade Sanctions

- International disadvantage: Production costly due to abatement
- Offset by introducing an import \( \text{tariff } \tau \) on foreign goods (Stiglitz 2006)

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
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

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
  - Botteon/Carraro (1998): Production cost
  - Nagashima/Dellink (2008): Mitigation technology

- Identify difference between Productivity R&D, Mitigation R&D
Modeling Research Cooperation

- Formal description:
  - spillover intensity $\varepsilon_{ij}$

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

(Griliches 1992)

- Research cooperation on
  - (Labor) Productivity $a_i$
  - Mitigation Technology $km_i$
Modeling Research Cooperation

- Formal description:
  - spillover intensity $\varepsilon_{ij}
  \tilde{s}_{it} = \sum_j \varepsilon_{ij} s_{jt}$
  (Griliches 1992)

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

\[
\frac{d}{dt} a_{it} = \xi_a (ia_{it})^{\lambda_a} (a_{it})^{\Phi_a}
\]

\[
\frac{d}{dt} km_{it} = \xi_m (im_{it})^{\lambda_m} (km_{it})^{\Phi_m}
\]

\[
GWP \quad F(\tilde{a}L, K) \quad \text{CO}_2 \text{ Emissions} \quad \sigma(\tilde{km})
\]
Results: Research Cooperation

- Full cooperation achieved
Introduction and Motivation

1. Modeling ETC
   Impact of ETC: Costs
   Impact of ETC: Strategies

2. Cooperative Climate Policy
   Model of Intern'l Climate Agreements
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   - R&D cooperation

Summary and Conclusion

- 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?
   - ETC has potential to reduce the burden of mitigation
   - 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?
Summary and Conclusion

1. What is the role of ETC for climate change mitigation?
   - ETC has potential to reduce the burden of mitigation
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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
Ottnar Edenhofer, Carlo Carraro
Prof. Scherer and Prof. Hartje
My colleagues at PIK, Hermann, Elmar, Bob, Alexander, Matthias, Robert, Christian, Anne, Nico, Marian, Lavinia, Jutta
My friends, Theresa, Dominik, Frank
My parents
Britta

Max Planck Research School ESM, Volkswagen Stiftung, EU