Determinants of cooperative climate policy among heterogeneous countries – insights from numerical modeling

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Institut für Volkswirtschaftslehre, University of Kassel
UNFCCC Climate Negotiations
in five bullet points

● Framework Convention (1992)
● Kyoto Protocol (1997, COP3) entry into force 2005
  – »targets and time tables«
  – Europe: EU ETS
  – USA: non-ratification
  – Canada: withdrawal
● Copenhagen (2009, COP15) failed to deliver »Kyoto II«
  – »pledge and review« instead → new paradigm
● Paris Agreement (2015, COP21)
  – Nationally determined contributions, ambition mechanism
● Trumped?
A science of climate negotiations?

- Political science, Theory of Collective Action, Theory (and experimental economics) of public good provision, ...others?

- Game theoretic research on *International Environmental Agreements*
  - Focus on *incentive to cooperate*
  - Understanding what makes actors join/leave an agreement
  - Understanding the success of agreements
  - Treaty design

- ...and not so much:
  - Predicting the behavior of countries
  - Predicting the success of treaties
Basic theory

**Coalition** – a set of players \( S \subseteq N \)

**Internal stability** – nobody want to leave \( \forall i \in S: \pi_i(S) \geq \pi_i(S \setminus \{i\}) \)

**External stability** – nobody want to join \( \forall j \not\in S: \pi_j(S \cup \{j\}) < \pi_j(S) \)

**Stable:** internally stable \( \land \) externally stable

**Potentially internal stable (PIS):**

internally stable with optimal transfer scheme

\[ \sum_{i \in S} \pi_i(S) \geq \sum_{i \in S} \pi_i(S \setminus \{i\}) \]
Basic literature (very selective)

- »Meaningful coalitions are not stable«
    Cooperation fails when it is most needed (large coop./non-coop. Gap)

- »Fostering cooperation«
  - Treaty design, e.g. minimum participation clauses (Carraro et al. 2009)
  - Issue linking, e.g. with technology protocols or trade policy (Nagashima/Dellink 2008; Nordhaus 2015)
  - Burden sharing, with pragmatic, normative, incentive driven schemes (Altamirano-Cabrera/Finus 2006, Carraro/Eyckman/Finus 2006)
Determinants of cooperative climate policy among heterogeneous countries – insights from numerical modeling

Overview

- Numerical coalition modeling
  - Model of International Climate Agreements (MICA)
  - Numerical characterization of incentives (model comparison)
  - Transfer schemes
- Coalition formation at threshold damages
Model of International Climate Agreements (MICA)

(Equations in the appendix...)

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Model of International Climate Agreements (MICA)

(Equations in the appendix...)

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<table>
<thead>
<tr>
<th></th>
<th>MICA</th>
<th>STACO</th>
<th>CWS</th>
<th>WITCH</th>
<th>RICE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Modeling assumptions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time horizon (years)</td>
<td>190</td>
<td>95(^a)</td>
<td>330</td>
<td>145</td>
<td>245</td>
</tr>
<tr>
<td>Number of regions</td>
<td>11</td>
<td>12</td>
<td>6</td>
<td>13</td>
<td>6</td>
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<tr>
<td>Pure rate of time preference (%)</td>
<td>3.0</td>
<td>1.5(^b)</td>
<td>1.5</td>
<td>3.0</td>
<td>3.0</td>
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<tr>
<td>Elast. of marginal utility</td>
<td>1.0</td>
<td>1.0(^b)</td>
<td>0.0</td>
<td>1.0</td>
<td>1.0</td>
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<tr>
<td><strong>Non-cooperative equilibrium</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean GDP growth rate(^e)</td>
<td>2.06</td>
<td>1.97</td>
<td>1.54</td>
<td>1.56</td>
<td>1.24</td>
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<tr>
<td>Mean interest rate(^e,(^d)</td>
<td>5.26</td>
<td>4.17</td>
<td>1.50</td>
<td>5.35</td>
<td>4.98</td>
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<tr>
<td>GHG emissions (GtC) 2015–2100</td>
<td>1516</td>
<td>1827</td>
<td>1754</td>
<td>1963</td>
<td>1404</td>
</tr>
<tr>
<td>Non-cooperative GHG reductions (%)(^e)</td>
<td>9.8</td>
<td>12.1</td>
<td>10.2</td>
<td>13.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Mean GHG intensity (GtC/tn$)</td>
<td>0.12</td>
<td>0.14</td>
<td>0.13</td>
<td>0.15</td>
<td>0.13</td>
</tr>
<tr>
<td>Climate change damage in 2100 (%)(^f)</td>
<td>5.8</td>
<td>7.8</td>
<td>3.2</td>
<td>9.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Carbon price 2100: reg. mean ($/tC)</td>
<td>12</td>
<td>89</td>
<td>49</td>
<td>38</td>
<td>8</td>
</tr>
<tr>
<td><strong>Cooperative solution</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG emissions (GtC) 2015–2100</td>
<td>953</td>
<td>984</td>
<td>1094</td>
<td>1122</td>
<td>1242</td>
</tr>
<tr>
<td>Climate change damage in 2100 (%)(^f)</td>
<td>3.8</td>
<td>4.0</td>
<td>1.9</td>
<td>4.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Carbon price 2100: reg. mean ($/tC)</td>
<td>369</td>
<td>966</td>
<td>529</td>
<td>858</td>
<td>208</td>
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<tr>
<td>Carbon price growth rate to 2100 (%)</td>
<td>1.90</td>
<td>1.69</td>
<td>0.90</td>
<td>1.02</td>
<td>1.02</td>
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</table>
Stable coalitions
»Meaningful coalitions are not stable«

<table>
<thead>
<tr>
<th>Model</th>
<th>Number of stable coalitions</th>
<th>Number of members</th>
<th>Closing of welfare gap non- vs. fully-cooperative</th>
</tr>
</thead>
<tbody>
<tr>
<td>MICA</td>
<td>1</td>
<td>3</td>
<td>0.09</td>
</tr>
<tr>
<td>STACO</td>
<td>1</td>
<td>2</td>
<td>0.03</td>
</tr>
<tr>
<td>CWS</td>
<td>1</td>
<td>2</td>
<td>0.77</td>
</tr>
<tr>
<td>WITCH</td>
<td>1</td>
<td>2</td>
<td>0.05</td>
</tr>
<tr>
<td>RICE</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Characterization of regions

1. Common measure of abatement costs
2. Common measure of damages from climate change
Characterization of regions

1. Common measure of abatement costs

   »abatement potential«
   Regional emissions reduction when the same, globally uniform CO2 tax is applied

2. Common measure of damages from climate change

   »marginal damage indicator«
   Change in CO2 price when this region defects from the grand coalition

(Both indicators are normalize to [-1, 1])
## Characterization of regions

<table>
<thead>
<tr>
<th></th>
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<th>RICE</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>0</td>
<td></td>
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</table>
Characterization of regions: abatement costs

Abatement costs represented rather similarly across models

<table>
<thead>
<tr>
<th>MICA</th>
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</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>USA</td>
<td>China</td>
<td>USA</td>
<td>China</td>
</tr>
<tr>
<td>Japan</td>
<td>Japan</td>
<td>Japan</td>
<td>CAJAZ</td>
<td>USA</td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

Abatement costs represented rather similarly across models.
### Characterization of regions: damages

**Variation in damages large**

<table>
<thead>
<tr>
<th>MICA</th>
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<th>RICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Japan</td>
<td>USA</td>
<td>China</td>
<td>USA</td>
</tr>
<tr>
<td>USA</td>
<td>Japan</td>
<td>USA</td>
<td>CAJAZ</td>
<td>China</td>
</tr>
<tr>
<td>Japan</td>
<td>China</td>
<td>Japan</td>
<td>USA</td>
<td>USA</td>
</tr>
<tr>
<td>Tol</td>
<td>Fankhauser</td>
<td>Nordhaus</td>
<td>OHI</td>
<td>Nordhaus</td>
</tr>
</tbody>
</table>

**Determinants of cooperative climate policy among heterogeneous countries, Kai Lessmann**
Full set of indicators
Incentive to stay inside coalition: OECD-example

- Incentives for common regions differ

Incentive to stay [utility]
Transfers: distribution between winners and losers

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Transfers: normative or incentive driven

- Transfers: Allocation of emission permits to address distributional questions (Altamirano-Cabrera & Finus 2006)
  - Transfers based on normative/pragmatic principles
  - Selection: grandfathering, equal-per-capita, historic responsibility

No increase in cooperation
Reasons?
Transfers: normative or incentive driven

- Transfers based on incentives:
  - large number of internally stable agreements
  - close cooperation gap about half

![Graph showing number of internally stable coalitions with and without transfers]
Transfers: normative or incentive driven

Reasons for transfers failing:

1. Pragmatic/normative transfers often flow in the wrong direction
   → Not designed along incentives

2. Equity-based transfers too large in magnitude also when direction right
Transfers: normative or incentive driven

Reasons for transfers failing:

1. Pragmatic/normative transfers often flow in the wrong direction → Not designed along incentives
2. Equity-based transfers too large in magnitude also when direction right
Determinants of cooperative climate policy among heterogeneous countries – insights from numerical modeling

Overview

• Numerical coalition modeling
  – Model of International Climate Agreements (MICA)
  – Numerical characterization of incentives (model comparison)
    • *Regional abatement potential/damages information is indicative*
    • *Empirical estimate differ, particularly for regional damages*
  – Transfer schemes
    • *Potential to improve cooperation if incentives are acknowledged*

• Coalition formation at threshold damages
Literature: Climate change thresholds

- Lenton et al. (PNAS 2008): Tipping points from expert elicitation

<table>
<thead>
<tr>
<th>Tipping element</th>
<th>Feature of system, $F$ (direction of change)</th>
<th>Control parameter(s), $\rho$</th>
<th>Critical value(s), $\rho_{\text{crit}}$</th>
<th>Global warming, $\Delta T_{\text{crit}}$</th>
<th>Transition timescale, $\Delta T$</th>
<th>Key impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic summer sea-ice</td>
<td>Areal extent ($-$)</td>
<td>Local $\Delta T_{\text{air}}$, ocean heat transport</td>
<td>Unidentified(^6)</td>
<td>$0.5$–$2^\circ\text{C}$</td>
<td>$10$ yr (rapid)</td>
<td>Amplified warming, ecosystem change</td>
</tr>
<tr>
<td>Greenland ice sheet (GIS)</td>
<td>Ice volume ($-$)</td>
<td>Local $\Delta T_{\text{air}}$</td>
<td>$3^\circ\text{C}$</td>
<td>$1$–$2^\circ\text{C}$</td>
<td>$300$ yr (slow)</td>
<td>Sea level $2$–$7$ m</td>
</tr>
<tr>
<td>West Antarctic ice sheet (WAIS)</td>
<td>Ice volume ($-$)</td>
<td>Local $\Delta T_{\text{air}}$, or less $\Delta T_{\text{Ocean}}$</td>
<td>$5$–$8^\circ\text{C}$</td>
<td>$3$–$5^\circ\text{C}$</td>
<td>$300$ yr (slow)</td>
<td>Sea level $5$ m</td>
</tr>
<tr>
<td>Atlantic thermohaline circulation (THC)</td>
<td>Overturning ($-$)</td>
<td>Freshwater input to Northern Atlantic</td>
<td>$0.1$–$0.5$ Sv</td>
<td>$3$–$5^\circ\text{C}$</td>
<td>$100$ yr (gradual)</td>
<td>Regional cooling, sea level, ITCZ shift</td>
</tr>
<tr>
<td>El Niño–Southern Oscillation (ENSO)</td>
<td>Amplitude ($+$)</td>
<td>Thermocline depth, sharpness in EEP</td>
<td>Unidentified(^6)</td>
<td>$3$–$6^\circ\text{C}$</td>
<td>$100$ yr (gradual)</td>
<td>Drought in SE Asia and elsewhere</td>
</tr>
</tbody>
</table>

- Cai, Lenton, Lontzek (NCC 2016): Stochastic modeling of thresholds
  - Eightfold increase in CO2 price from accounting for tipping points
Literature: Coalition formation

- Theoretical literature has established results with linear or quasi-linear utility functions
  - Symmetric players, static setting
  - Coalition members internalize all coalition externalities, non-members do not
  - Stable coalition $\equiv$ no incentive to leave/join
  - Very simple description of mitigation costs and benefits (Hoel, 1992; Carraro and Siniscalco, 1993; Barrett, 1994)

- Barrett (2013): *Approaching catastrophes*
  - Coordination game for high impacts
  - Cooperation needed: low catastrophic impact, high threshold (in abatement)
Literature: Uncertainty and tipping points

• Barrett (2013): *Approaching catastrophes*
  – With uncertainty about tipping point location, cooperation breaks down again

• Barrett/Dannenberg (2016): *Sensitivity of collective action to uncertainty about climate tipping points*
  – Cooperation more successful for smaller uncertainty
Research aim and design

- Study the impact of threshold impacts on cooperation and the stability of climate coalitions
  - Take into account
    - heterogeneity of players/regions
    - non-linearities
    - dynamics of the climate game
  - Study **impact of real-world climate thresholds**
- Use two numerically calibrated *Integrated Assessment Models* (IAM)
  - introduce threshold damages
  - study optimal and strategic behavior at the threshold
  - consider transfers and uncertainty
The numerical models

- **WITCH (World Induced Technological Change Model)**
  - Full scale *Integrated Assessment Model* (IAM)
    Heavily contributed to AR5 scenario database
  - Multi-region growth model, 13 world regions
  - Detailed GHG mitigation options: multi-gas, energy sectors

- **MICA (Model of International Climate Agreements)**
  Lessmann et al. (2009, 2011, 2013)
  - Stylized IAM (think Nordhaus's RICE)
  - Multi-region growth model, 11 world regions
  - CO2 mitigation function calibrated to REMIND-R
Threshold implementation

- Regional, aggregate damage functions (percent of GDP)
  \[ \Omega_i = \theta_{1i} T + \theta_{2i}(T)^{\theta_3} \]
  - \( T \) = temperature
  - \( \theta_{ji} \) = parameter

- Thresholds: “smooth step”
  \[ \Omega_i = \theta_{1i} T + \theta_{2i}(T)^{\theta_3} + d \cdot \text{erf}\left(\frac{T - T_S}{\sigma}\right) \]
  - \( \text{erf} \) = “error function”, cumulative distribution function of normal distribution
  - \( T_S, d, \sigma \) = location, level, and “sharpness” of threshold
  - Our standard value: \( \sigma = 0.04 \)
Threshold (»tipping point«) locations

<table>
<thead>
<tr>
<th>Tipping element</th>
<th>Hazard rate (% yr(^{-1}) K(^{-1}))</th>
<th>Transition time (yr)</th>
<th>Final damages (% of GDP)</th>
<th>Carbon cycle effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMOC</td>
<td>0.063</td>
<td>50 (10–250)</td>
<td>15 (10–20)</td>
<td>No effect</td>
</tr>
<tr>
<td>GIS</td>
<td>0.188</td>
<td>1,500 (300–7,500)</td>
<td>10 (5–15)</td>
<td>100 GtC over transition</td>
</tr>
<tr>
<td>WAIS</td>
<td>0.104</td>
<td>500 (100–2,500)</td>
<td>5 (2.5–7.5)</td>
<td>100 GtC over transition</td>
</tr>
<tr>
<td>AMAZ</td>
<td>0.163</td>
<td>50 (10–250)</td>
<td>5 (2.5–7.5)</td>
<td>50 GtC over transition</td>
</tr>
<tr>
<td>ENSO</td>
<td>0.053</td>
<td>50 (10–250)</td>
<td>10 (5–15)</td>
<td>0.2 GtC yr(^{-1}) permanent</td>
</tr>
</tbody>
</table>

Cai et al. (2016)
- 5-15% long term
- total of 38%
- 1.89% expected value

We choose
- Threshold level: 4% of GDP
- Threshold location \(\in [1.5, 4.5]\)
Threshold strategies

- **Grand coalition** = socially optimal

- **Strategic behavior**
  - **Avoidance** success
  - **Postponement** of exceeding the threshold
  - **Resignation** ignore the inevitable
Threshold strategies (2)

Temperature in 2100

Threshold Temperature (°C)

- Resignation
- Postponement
- Avoidance

Avoidance infeasible or too costly

Threshold not binding

Regular free-riding

Threshold kept

MICA
WITCH
Coalition reaction around thresholds

Change in emissions upon defection of ... (GtC)

Defector:

Abandon threshold

MICA

Counteract defection

1.5  2.0  2.5  3.0  3.5  4.0  4.5  no threshold
Coalition reaction around thresholds

Change in emissions upon defection of ... (GtC)

Abandon threshold: MICA

Defector:

- ROW
- AFR
- LAM
- IND
- CHN
- MEA
- OAS
- JPN
- RUS
- USA
- EUR

Counteract defection

Defector:

- CALI
- CHINA
- EASIA
- INDIA
- KOSAU
- LACA
- MENA
- NEWEURO
- OLDEURO
- SASIA
- SSA
- TE
- USA

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(1) Abandon threshold which was previously avoided

(2) Counteract defection to still keep below the threshold

(3) Reduced abatement incentive due to smaller coalition size and non-binding threshold level
Coalition reaction around thresholds

Change in emissions upon defection of ... (GtC)

**Defector:**

1. Abandon threshold which was previously avoided

2. Counteract defection to still keep below the threshold

(1) Abandon threshold

(2) Counteract defection to still keep below the threshold
Coalition reaction around thresholds

Change in emissions upon defection of ... (GtC)

(1) Abandon threshold which was previously avoided
   - Stability value *skyrockets* → defection unattractive

(2) Counteract defection to *still* keep below the threshold
   - Stability value *plummets* → defection very attractive

• Critical role for *pivotal* regions
Stable Grand Coalitions in threshold vicinity

- “Optimal” transfers among coalition members
  - OPTS → Carraro, Eyckman, Finus 2006, assumes transferable utility
    \[
    \sum_{i \in S} \pi_i(S) \geq \sum_{i \in S} \pi_i(S \setminus \{i\})
    \]
  - Non-transferable utility implementation → Kornek, Lessmann, Tulkens 2015
Stable Grand Coalitions in threshold vicinity

- “Optimal” transfers among coalition members
  (OPTS $\rightarrow$ Carraro, Eyckman, Finus 2006, NTU implementation $\rightarrow$ Kornek, Lessmann, Tulkens 2015)

<table>
<thead>
<tr>
<th>T$_S$ \ d</th>
<th>3%</th>
<th>3.5%</th>
<th>4%</th>
<th>4.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2.4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
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<td>2.5</td>
<td>1</td>
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<td>0</td>
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<td>2.6</td>
<td>0</td>
<td>0</td>
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<tr>
<td>2.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- Threat of threshold successfully encourages cooperation
- “Knife edge” result: sensitive to threshold location and level
Conclusions and outlook

• In a nutshell
  – “At the threshold” pivotal regions matter
    • Whether coalitions counteract defection or abandon the threshold
    • Whether free-riding costs skyrocket or plummet
  – Whether climate change thresholds enhance cooperation depends
    • On threshold location
    • Regional characteristics
  – Uncertainty about threshold location partially undermines threshold benefits

• Outlook
  – Ongoing work: Non-cooperative equilibrium to keep the threshold
  – Application to tipping point empirics/science (cf. Lenton et al. 2008)
Thank you for your attention!

Thanks to my coauthors
Johannes Emmerling
Ulrike Kornek
Valentina Bosetti
Massimo Tavoni
Appendix
Preferences

Social welfare of region \( i \)

\[
W_i = \int_0^\infty n_{it} U(c_{it}/n_{it}) e^{-\rho t} \, dt
\]

Instantaneous utility

\[
U(c_{it}/n_{it}) = \begin{cases} 
\frac{(c_{it}/n_{it})^{1-\eta}}{1-\eta} & \text{if } \eta \neq 1 \\
\log(c_{it}/n_{it}) & \text{if } \eta = 1.
\end{cases}
\]
Technology

Economic output net of abatement costs and climate change damages

\[ y_{it} = (1 - \Lambda_{it} - \Omega_{it}) F(l_{it}, k_{it}) \]  \hspace{1cm} (A.3)

Production technology

\[ F(l_{it}, k_{it}) = \alpha_{it} y_{i0} \left[ (1 - \gamma) \left( \frac{\lambda_{it} l_{it}}{\lambda_{i0} l_{i0}} \right)^{\rho_F} + \gamma \left( \frac{k_{it}}{k_{i0}} \right)^{\rho_{F^{-1}}} \right] \] \hspace{1cm} (A.4)

Accumulation of capital, initially \( k_{i0} \)

\[ \frac{d}{dt} k_{it} = i_{it} - \delta_{i} k_{it} \] \hspace{1cm} (A.5)
Emissions and Emission Allowances

Emissions as a byproduct of production, reduced by emission intensity and abatement effort

\[ e_{it} = y_{it} \sigma_{it} (1 - a_{it}) \]  \hspace{1cm} (A.6)

Abatement costs

\[ \Lambda_{it} = b_{it}^1 \cdot (a_{it})^{b_{it}^2} \]  \hspace{1cm} (A.7)

All emissions are covered by allowances net of allowance exports.

\[ e_{it} \leq q_{it} - z_{it} \]  \hspace{1cm} (A.8)

Trade in allowances is balanced in every time period.

\[ \sum_j z_{jt} = 0, \hspace{0.5cm} \forall t \]  \hspace{1cm} (A.9)
Climate Dynamics

CO2 concentration changes with total allowances (same as total emissions), initially $C_0$.

$$\frac{d}{dt} C_t = \zeta Q_t - \kappa (C_t - C_0) + \psi E_t \quad \text{(A.10)}$$

Definition of global total of emission allowances

$$Q_t = \sum_i q_{it} \quad \text{(A.11)}$$

Global emissions stock, initially $E_0$, rises with per period total allowances.

$$\frac{d}{dt} E_t = Q_t \quad \text{(A.12)}$$

Temperature change, initially $T_0$, is determined by CO2 concentration.

$$\frac{d}{dt} T_t = \mu \log(C_t/C_0) - \phi (T_t - T_0) \quad \text{(A.13)}$$

Climate change damages

$$\Omega_{it} = \theta_{2i} (T_t)^2 \quad \text{(A.14)}$$