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

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PRESIDENT
RESIDENCE

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 $\forall j \notin S: \ \pi_j(S \cup \{j\}) < \pi_j(S)$

Stable: internally stable ∧ externally stable

Potentially internal stable (PIS):

internally stable with optimal transfer scheme

$$\sum_{i \in S} \pi_i(S) \geq \sum_{i \in S} \pi_i(S \setminus \{i\})$$

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Basic literature (very selective)

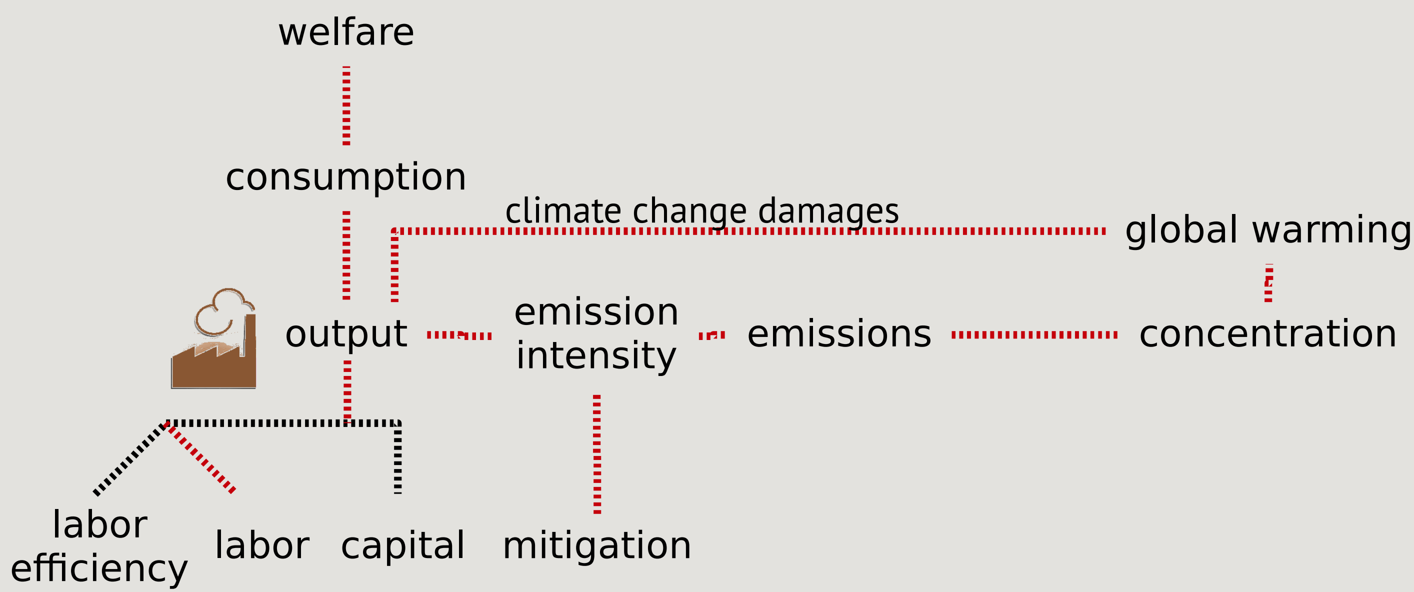
- »Meaningful coalitions are not stable«
  - Barrett's paradox (Barrett 1994, Hoel 1992, Carraro/Siniscalco 1993)
    Cooperation fails when it is most needed (large coop./non-coop. Gap)
- »Fostering cooperation«
  - Treaty design, e.g. minimum participation clauses (Carraro et al. 2009)
  - Issue linking, 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

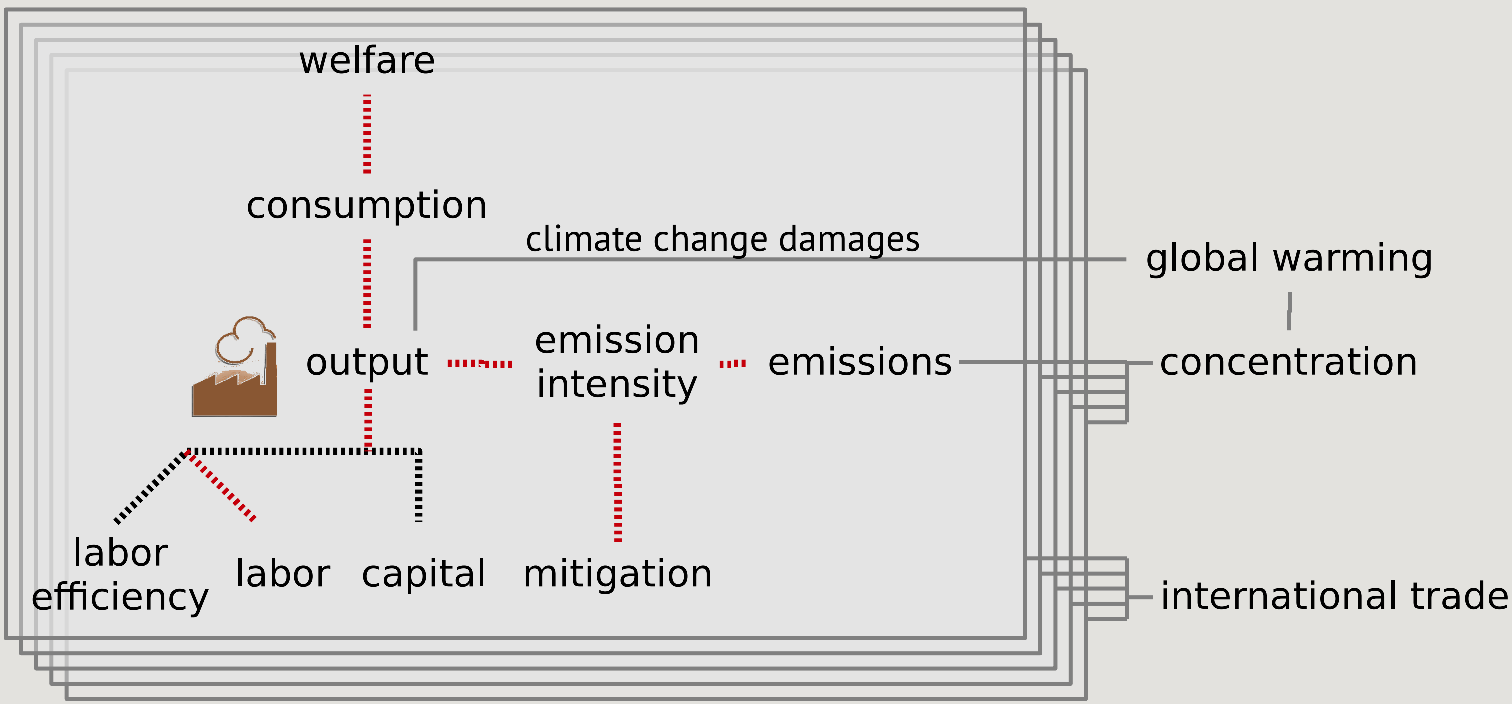
- Numerical coalition modeling
  - Model of International Climate Agreements (MICA)
  - Numerical characterization of incentives (model comparison)
  - Transfer schemes
- Coalition formation at threshold damages

Model of International Climate Agreements (MICA)



(Equations in the appendix...)

Model of International Climate Agreements (MICA)

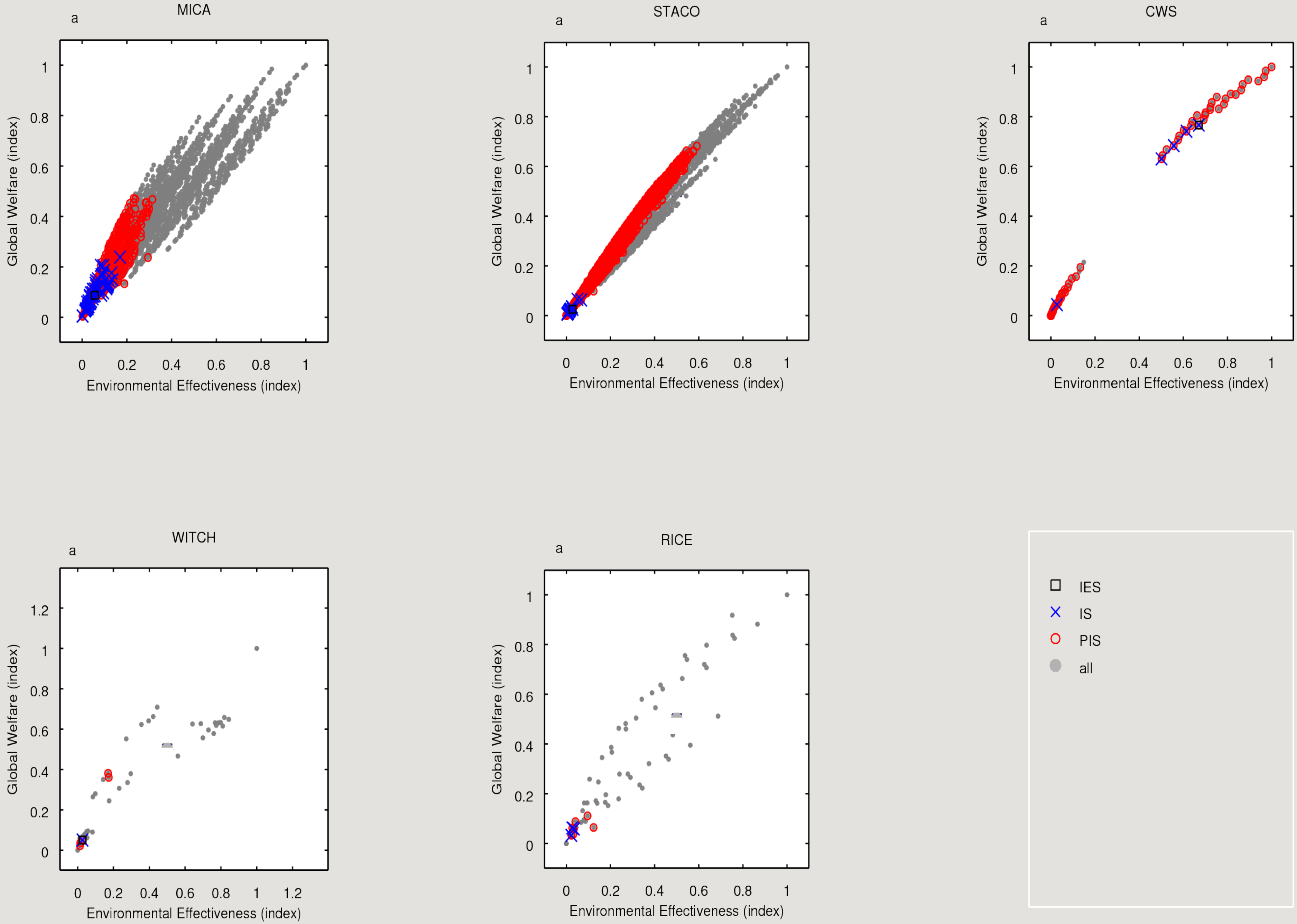


(Equations in the appendix...)

Coalition Model Comparison

	MICA	STACO	CWS	WITCH	RICE
Modeling assumptions					
Initial year	2005	2011	2000	2005	2000
Time horizon (years)	190	95[a]	330	145	245
Number of regions	11	12	6	13	6
Pure rate of time preference (%)	3.0	1.5[b]	1.5	3.0	3.0
Elast. of marginal utility	1.0	1.0[b]	0.0	1.0	1.0
Non-cooperative equilibrium					
Mean GDP growth rate[c]	2.06	1.97	1.54	1.56	1.24
Mean interest rate[c,d]	5.26	4.17	1.50	5.35	4.98
GHG emissions (GtC) 2015–2100	1516	1827	1754	1963	1404
Non-cooperative GHG reductions (%)[e]	9.8	12.1	10.2	13.0	5.0
Mean GHG intensity (GtC/tn$)	0.12	0.14	0.13	0.15	0.13
Climate change damage in 2100 (%)[f]	5.8	7.8	3.2	9.3	1.6
Carbon price 2100: reg. mean ($/tC)	12	89	49	38	8
Cooperative solution					
GHG emissions (GtC) 2015–2100	953	984	1094	1122	1242
Climate change damage in 2100 (%)[f]	3.8	4.0	1.9	4.9	1.5
Carbon price 2100: reg. mean ($/tC)	369	966	529	858	208
Carbon price growth rate to 2100 (%)	1.90	1.69	0.90	1.02	1.02

Stable coalitions



»Meaningful coalitions are not stable«

Stable agreements are **small** and **ineffective**

Model	Number of stable coalitions	Number of members	Closing of welfare gap non- vs. fully-cooperative
MICA	1	3	0.09
STACO	1	2	0.03
CWS	1	2	0.77
WITCH	1	2	0.05
RICE	0	0	0.00

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

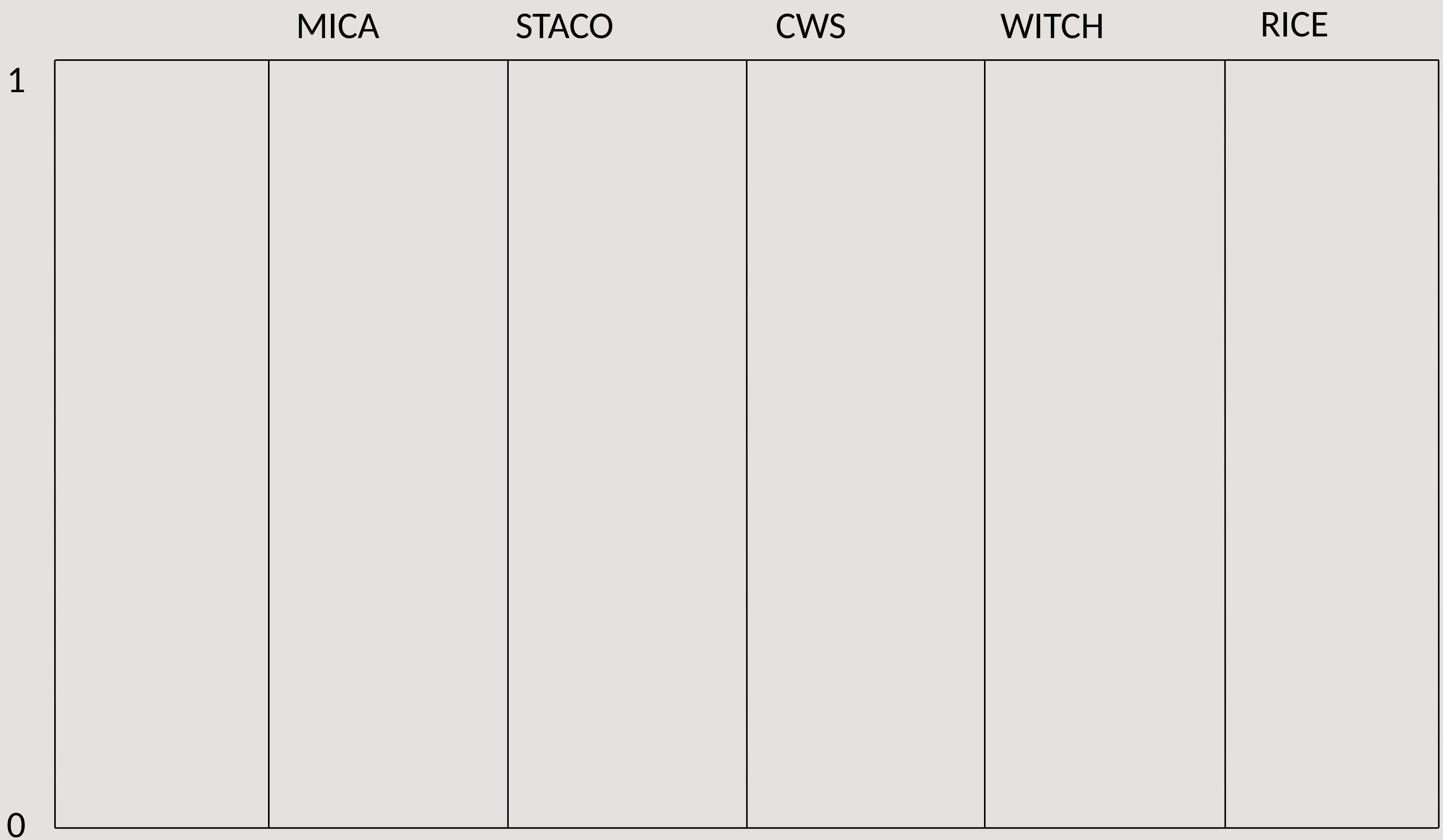
   »abatement potential«
   Regional emissions reduction when the same, globally uniform CO2 tax is applied

2. Common measure of damages from climate change

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

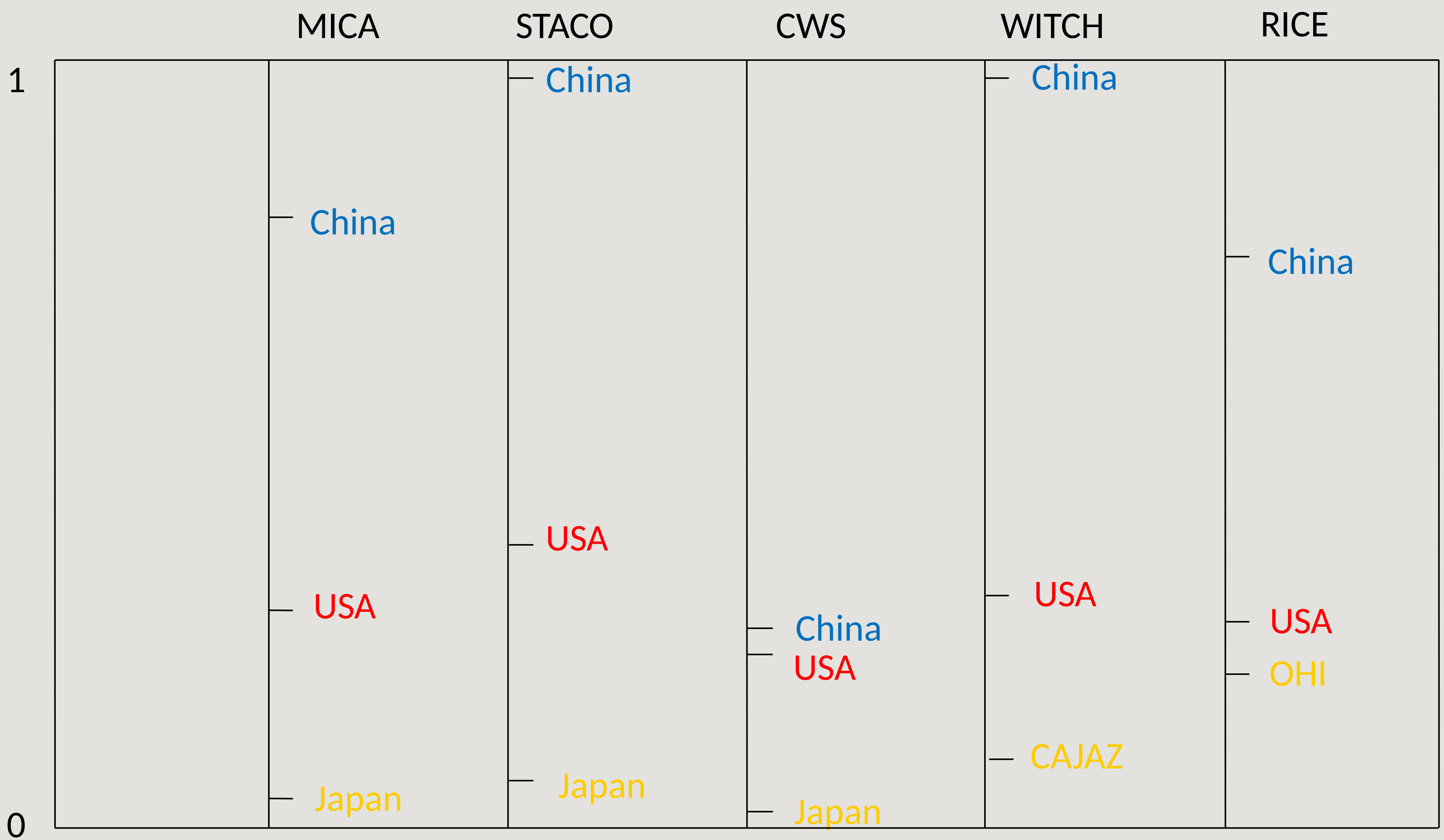
(Both indicators are normalize to [-1, 1])

Characterization of regions



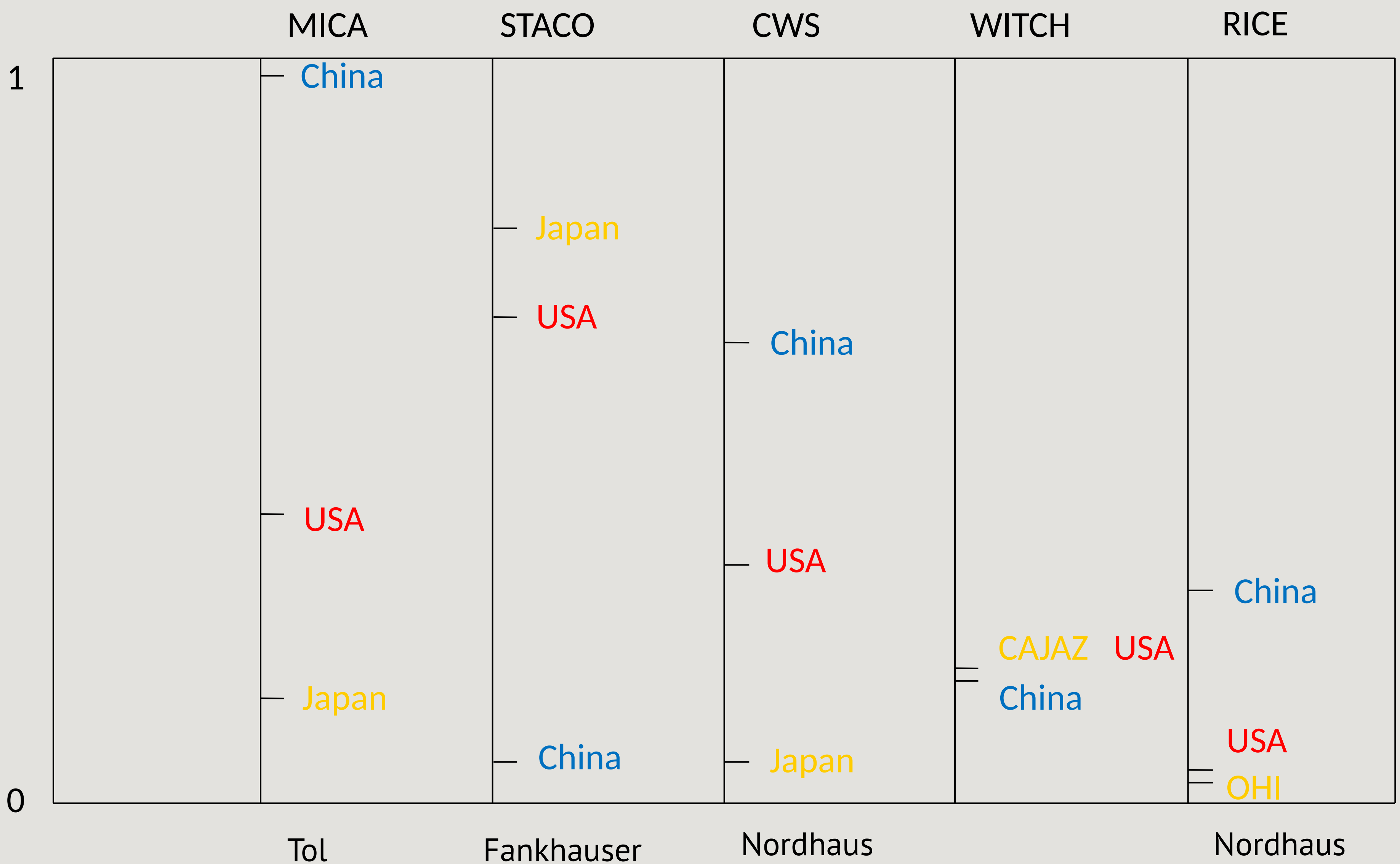
Characterization of regions: abatement costs

Abatement costs represented rather similarly across models

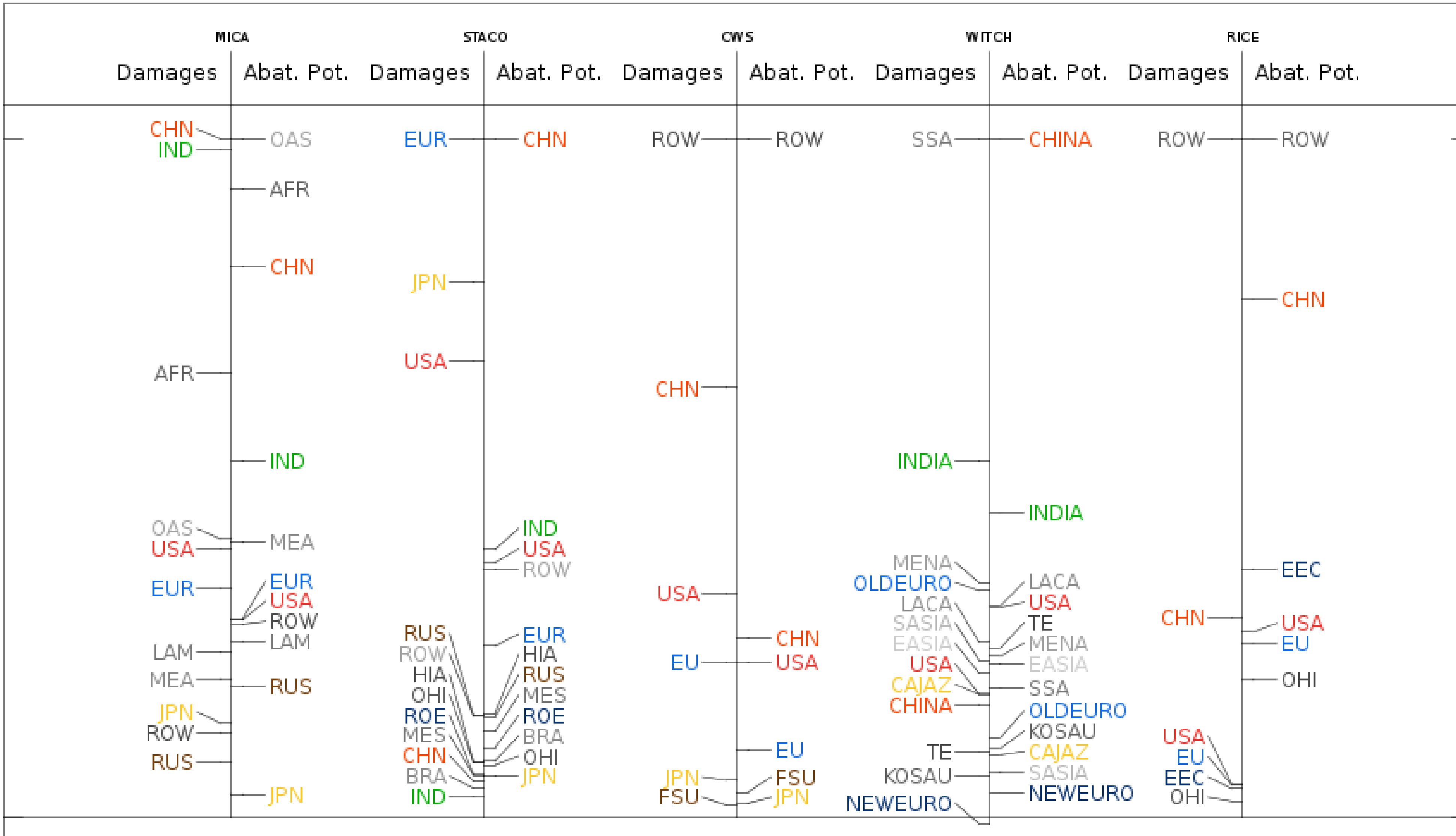


Characterization of regions: damages

Variation in damages large



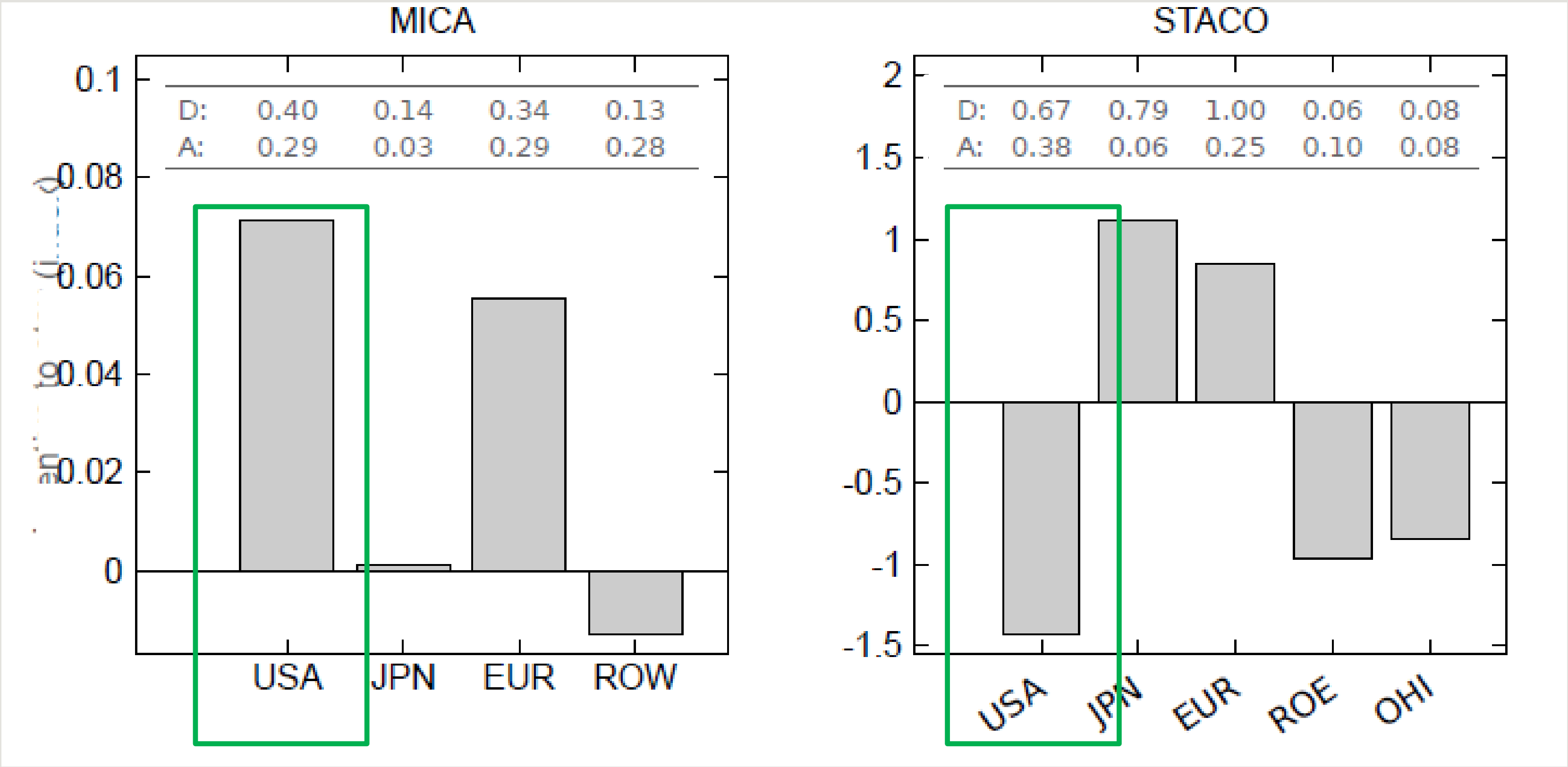
Full set of indicators



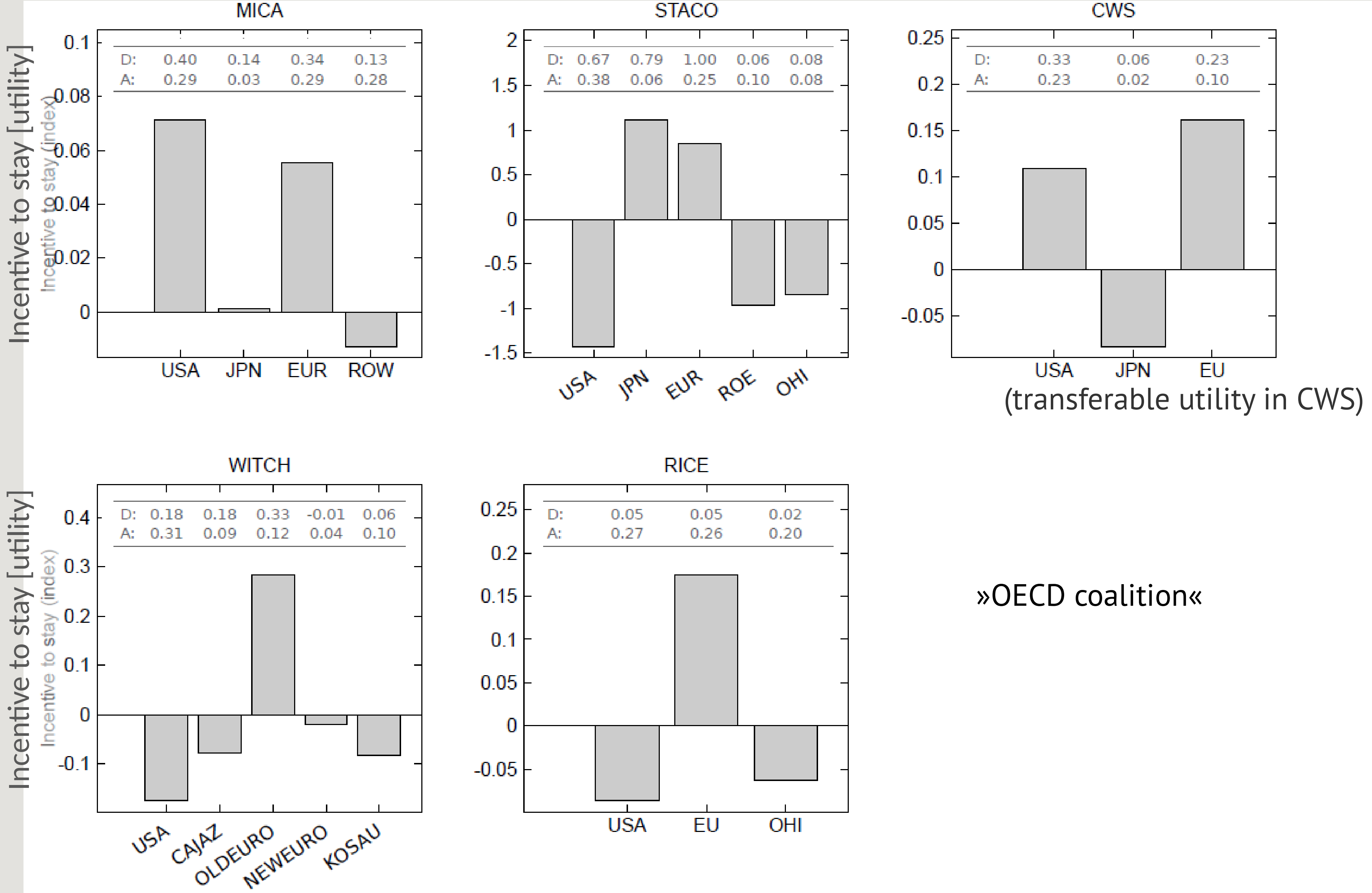
Incentive to stay inside coalition: OECD-example

- Incentives for common regions differ

Incentive to stay [utility]



Transfers: distribution between winners and losers



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

↓

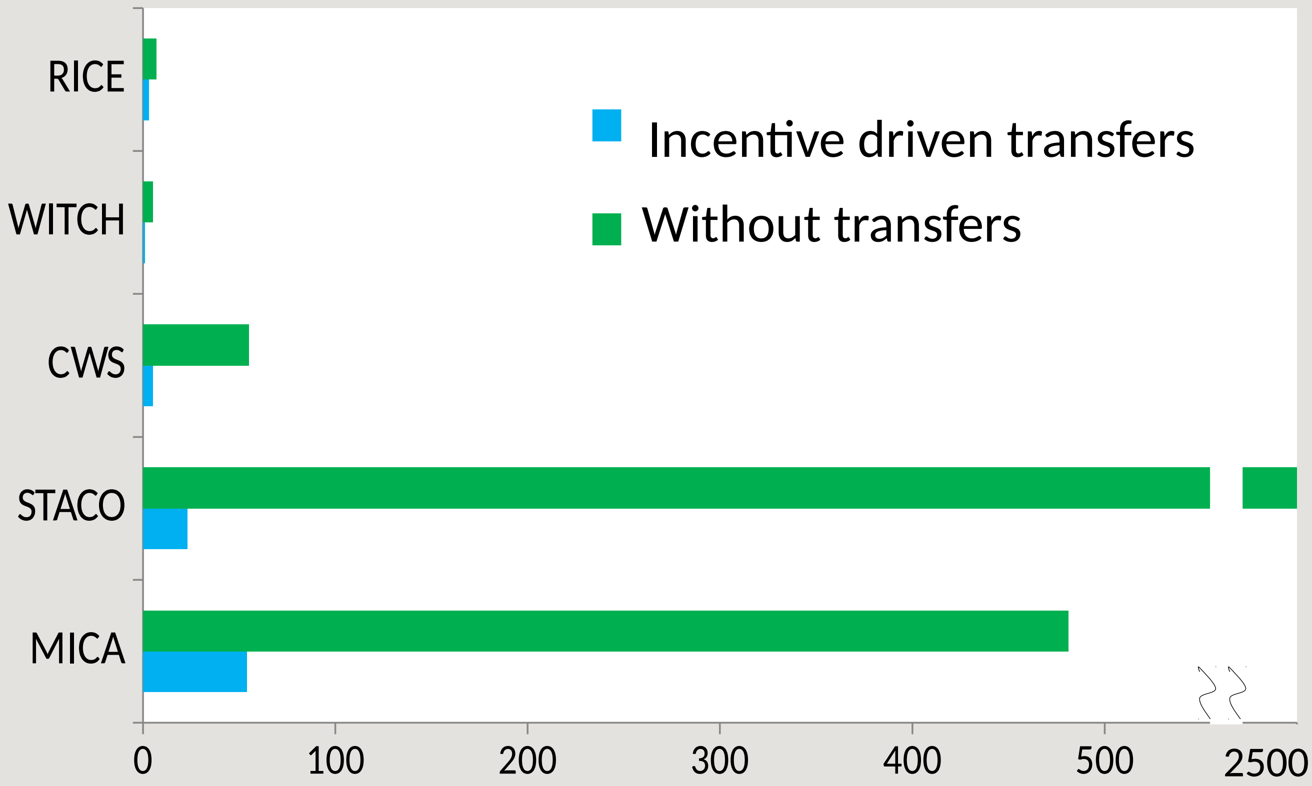
No increase in cooperation

Reasons?

Transfers: normative or incentive driven

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

Number of internally stable coalitions



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

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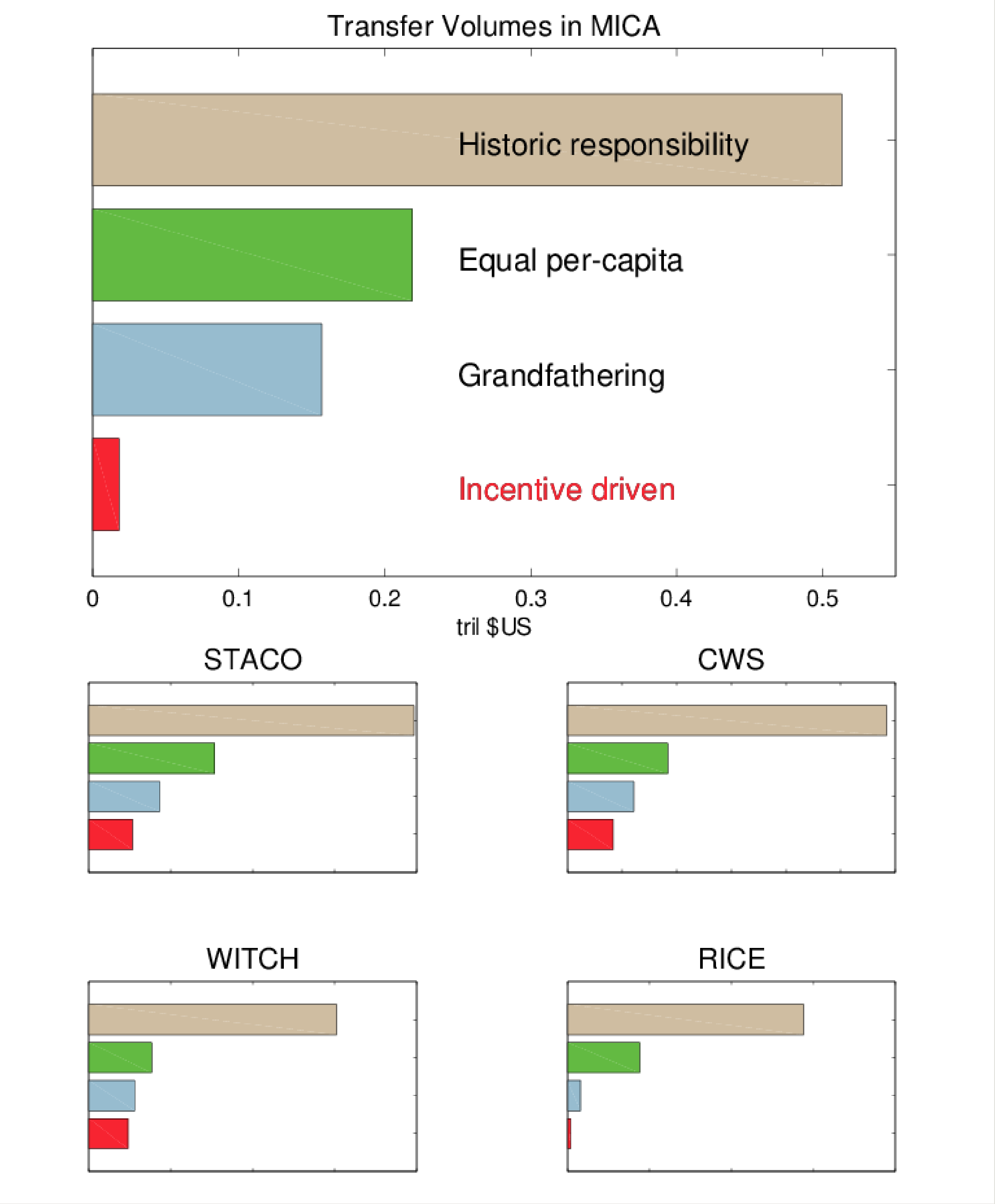

Determinants of cooperative climate policy among heterogeneous countries – insights from numerical modeling

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**

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Literature: Climate change thresholds

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

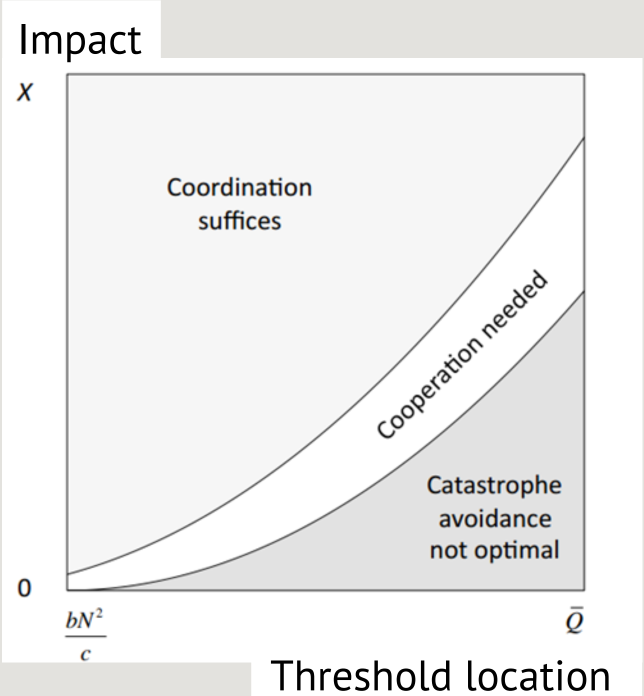
Tipping element	Feature of system, F(direction of change)	Control parameter(s), ρ	Critical value(s),[†] ρ_{crit}	Global warming[†],[‡]	Transition timescale,[†] T	Key impacts
Arctic summer sea-ice	Areal extent (−)	Local ΔT_{air}, ocean heat transport	Unidentified[§]	+0.5–2°C	≈10 yr (rapid)	Amplified warming, ecosystem change
Greenland ice sheet (GIS)	Ice volume (−)	Local ΔT_{air}	+≈3°C	+1–2°C	>300 yr (slow)	Sea level +2–7 m
West Antarctic ice sheet (WAIS)	Ice volume (−)	Local ΔT_{air}, or less ΔT_{ocean}	+≈5–8°C	+3–5°C	>300 yr (slow)	Sea level +5 m
Atlantic thermohaline circulation (THC)	Overturning (−)	Freshwater input to N Atlantic	+0.1–0.5 Sv	+3–5°C	≈100 yr (gradual)	Regional cooling, sea level, ITCZ shift
El Niño–Southern Oscillation (ENSO)	Amplitude (+)	Thermocline depth, sharpness in EEP	Unidentified[§]	+3–6°C	≈100 yr (gradual)	Drought in SE Asia and elsewhere

- 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 ≡ 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)



Source: Barrett (2013)

Literature: Uncertainty and tipping points

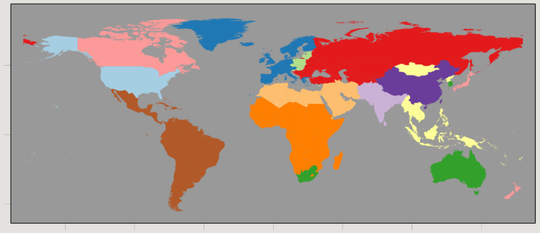
- Barrett (2013): *Approaching catastrophes*
  - With uncertainty about tipping point location, cooperation breaks down again
- Barrett/Dannenberg (2016): *Sensitivity of collective action to uncertainty about climate tipping points*
  - Cooperation more successful for smaller uncertainty

Research aim and design

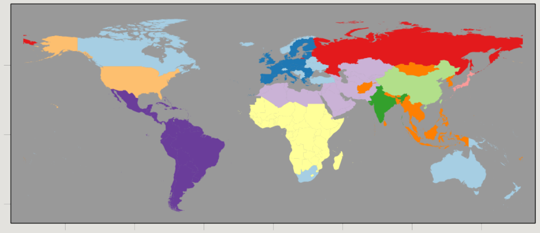
- Study the impact of threshold impacts on cooperation
  and the stability of climate coalitions
  - Take into account
    - heterogeneity of players/regions
    - non-linearities
    - dynamics of the climate game
  - Study **impact of real-world climate thresholds**
- Use two numerically calibrated *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)
  Bosetti et al. (2006, 2007, 2009)
  - 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



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Threshold implementation

- Regional, aggregate damage functions (percent of GDP)

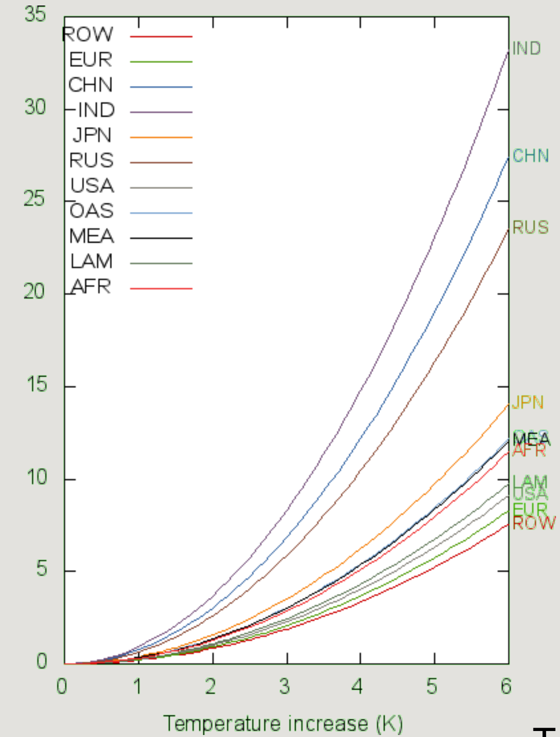
$$\Omega_i = \theta_{1i} T + \theta_{2i} (T)^{\theta_3}$$

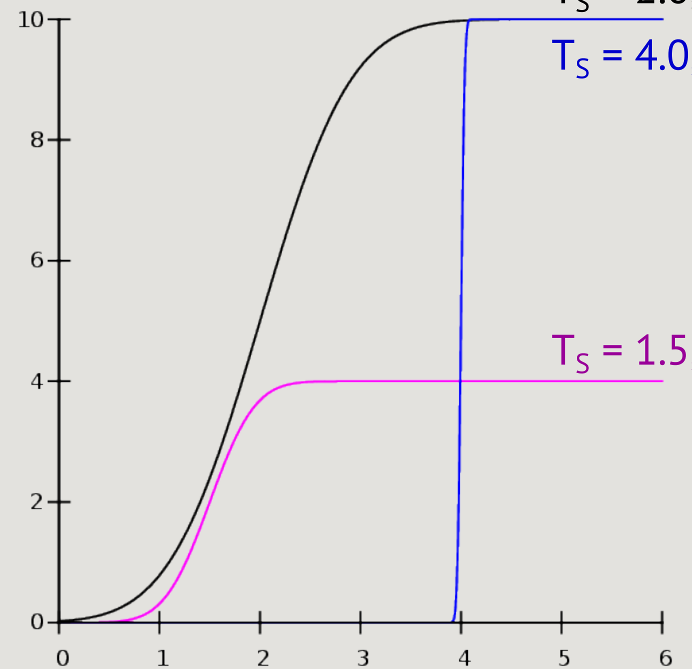
  - T = temperature
  - θ_{ji} = parameter

- Thresholds: "smooth step"

$$\Omega_i = \theta_{1i} T + \theta_{2i} (T)^{\theta_3} + d * erf\left(\frac{T - T_S}{\sigma}\right)$$

  - *erf* = "error function", cumulative distribution function of normal distribution
  - T_S, d, σ = location, level, and "sharpness" of threshold
  - Our standard value: $\sigma = 0.04$

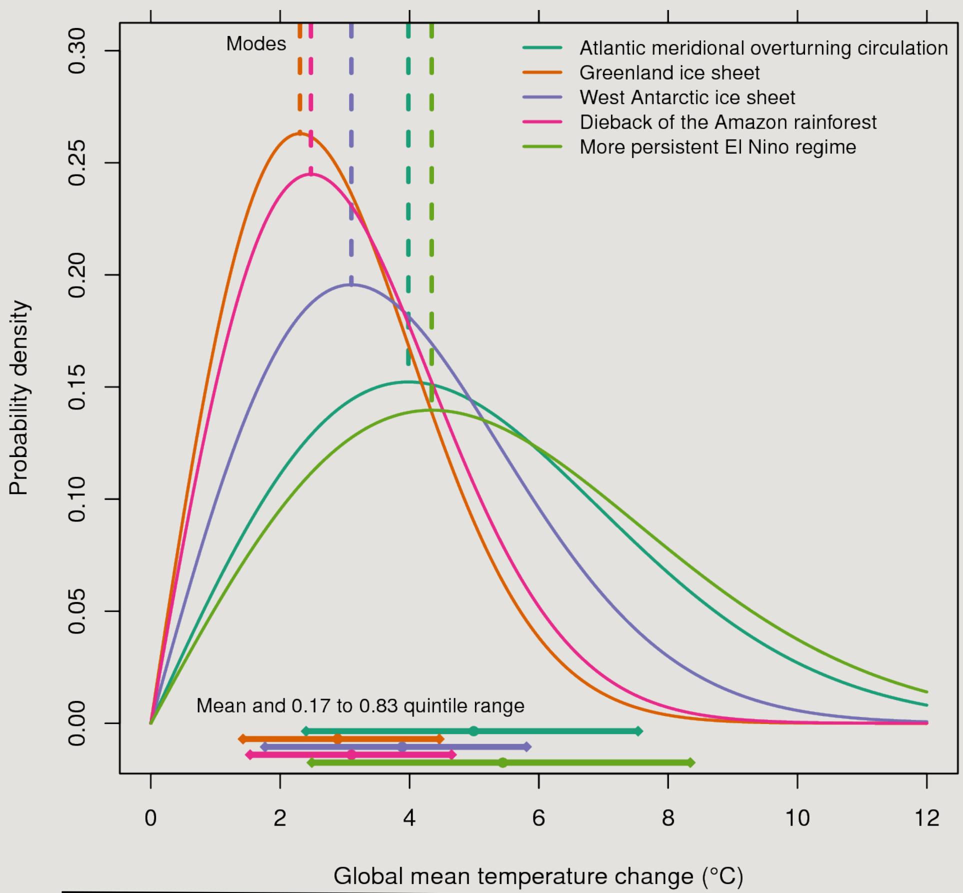




Threshold (»tipping point«) locations

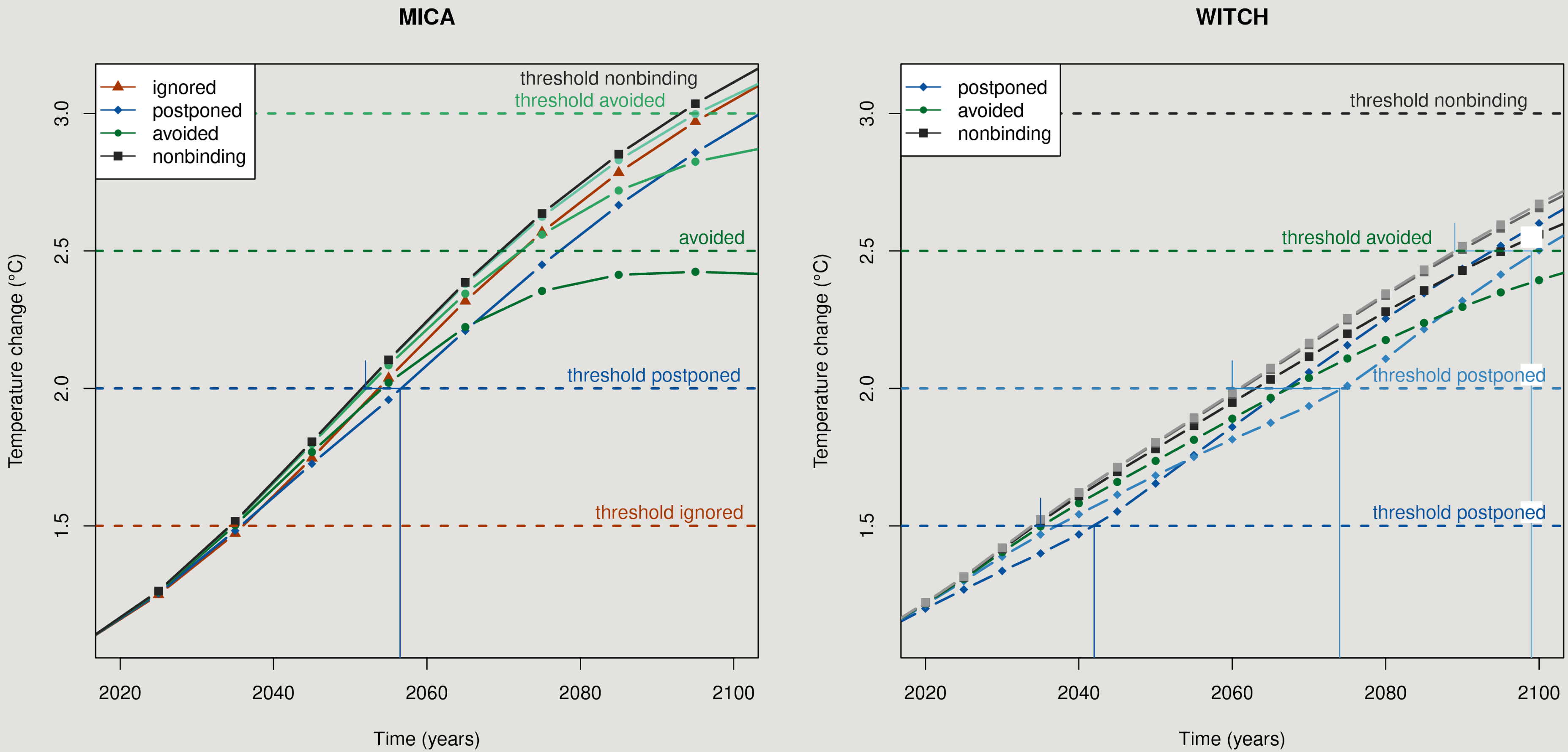
Table 1 | Hazard rate, transition time, final damages and carbon cycle effect for each tipping element, with uncertainty ranges (in parentheses) considered in the sensitivity analysis.

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



- 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

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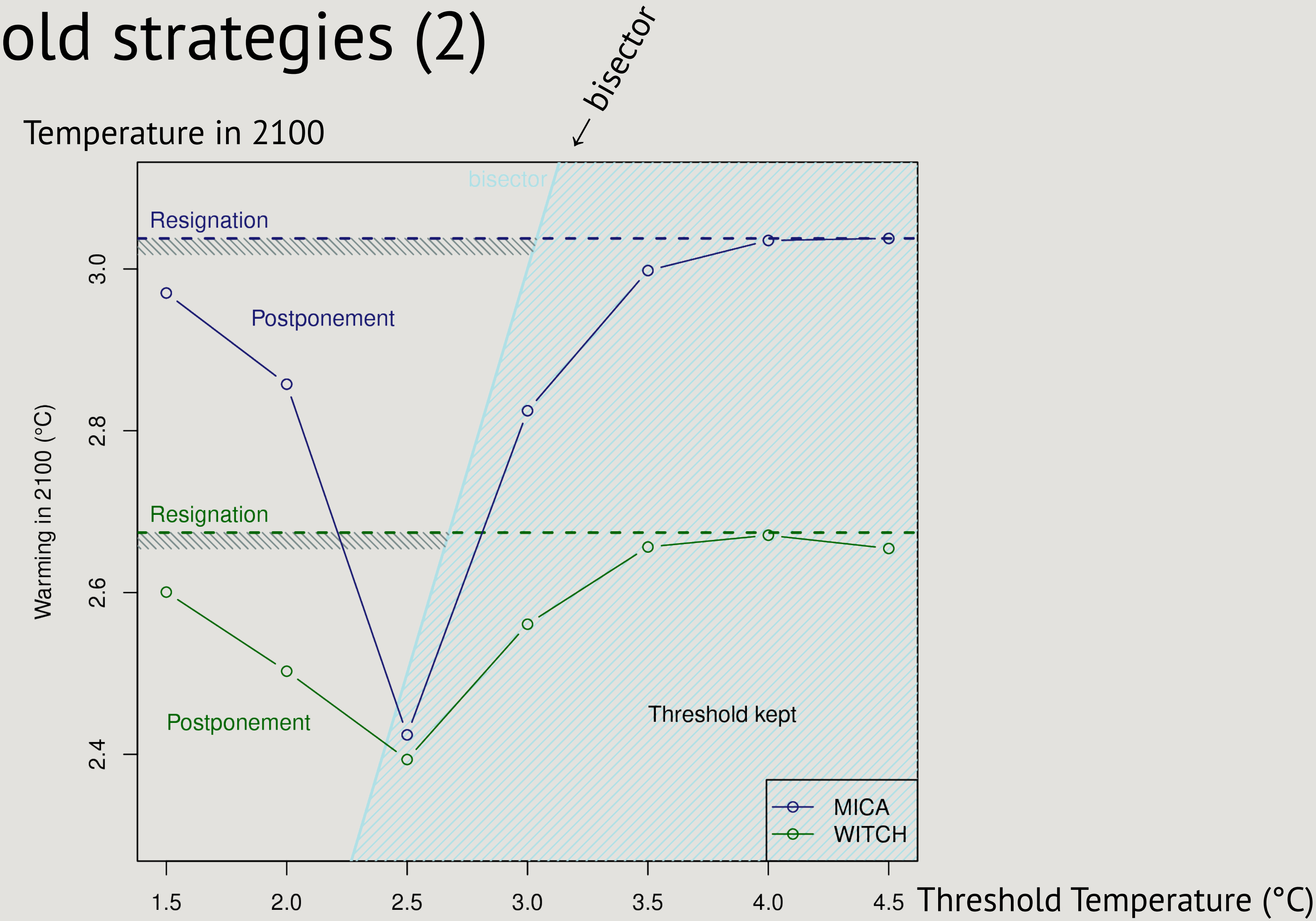
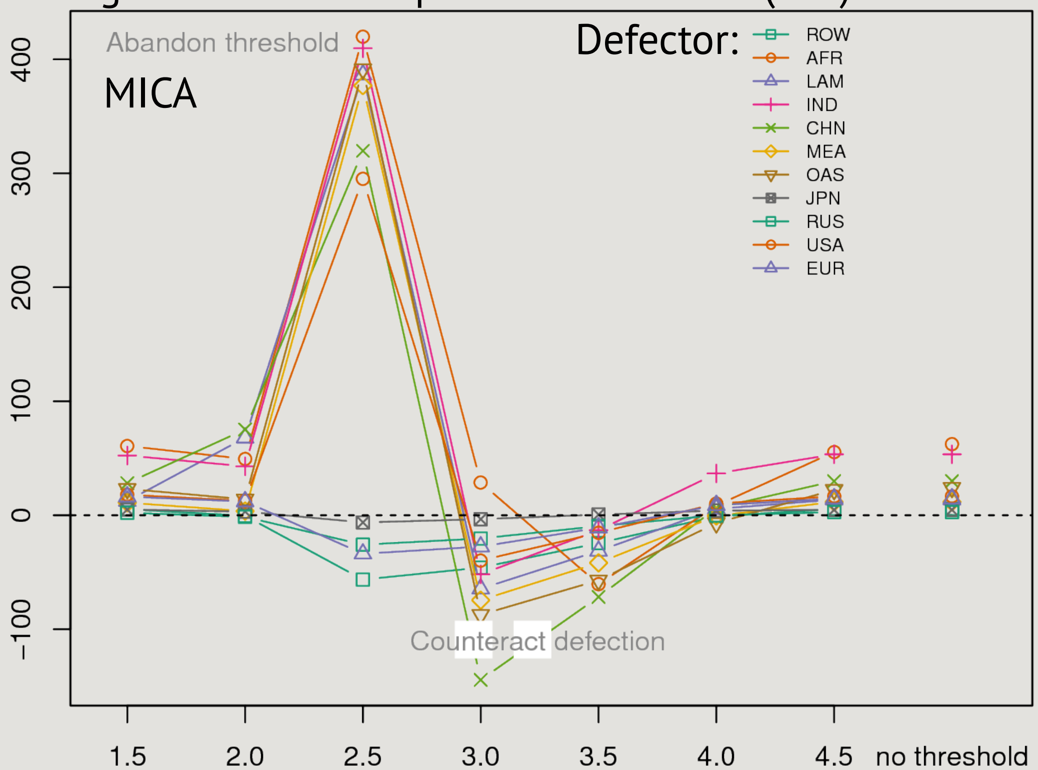
Threshold strategies (2)



Coalition reaction around thresholds

Change in emissions upon defection of … (GtC)



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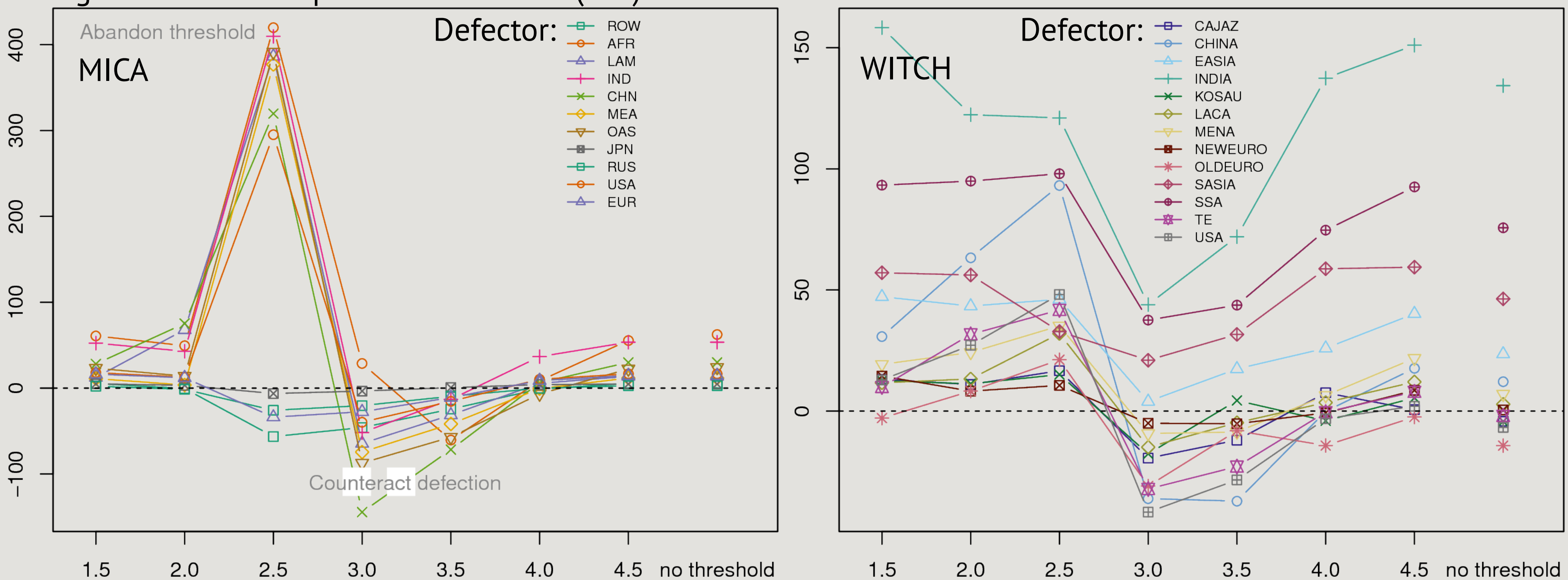

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Coalition reaction around thresholds

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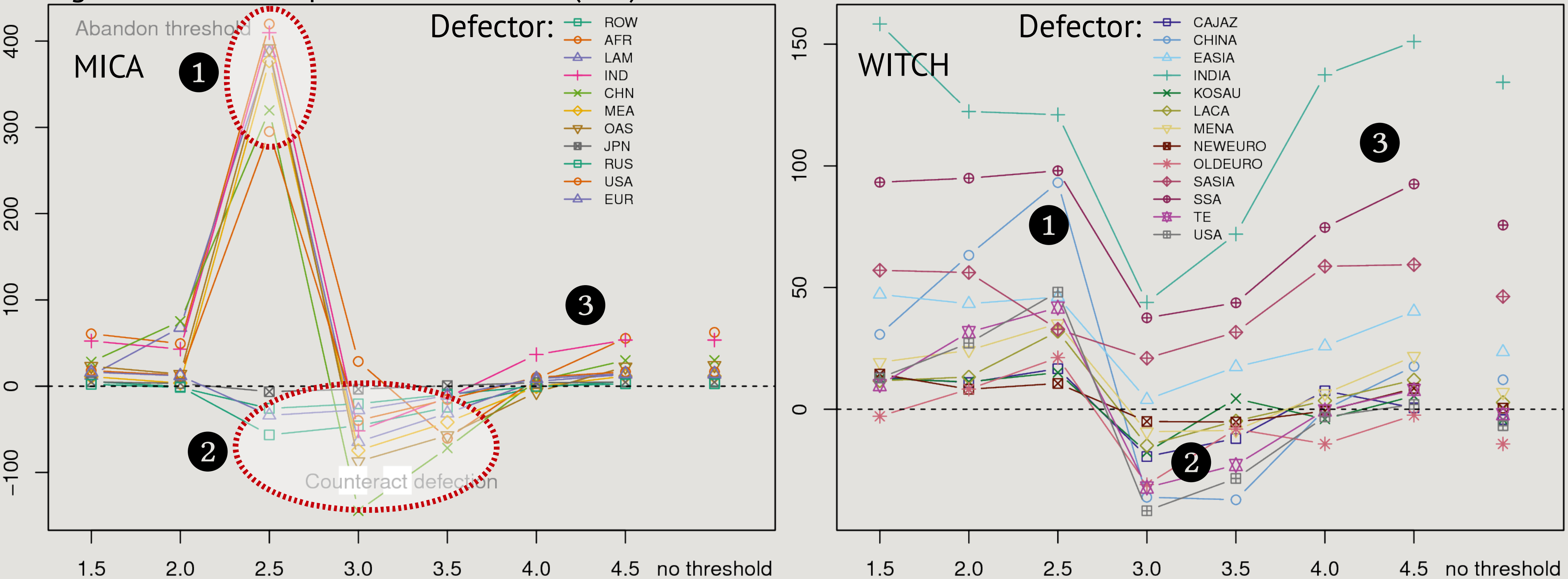

(1) Abandon threshold

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

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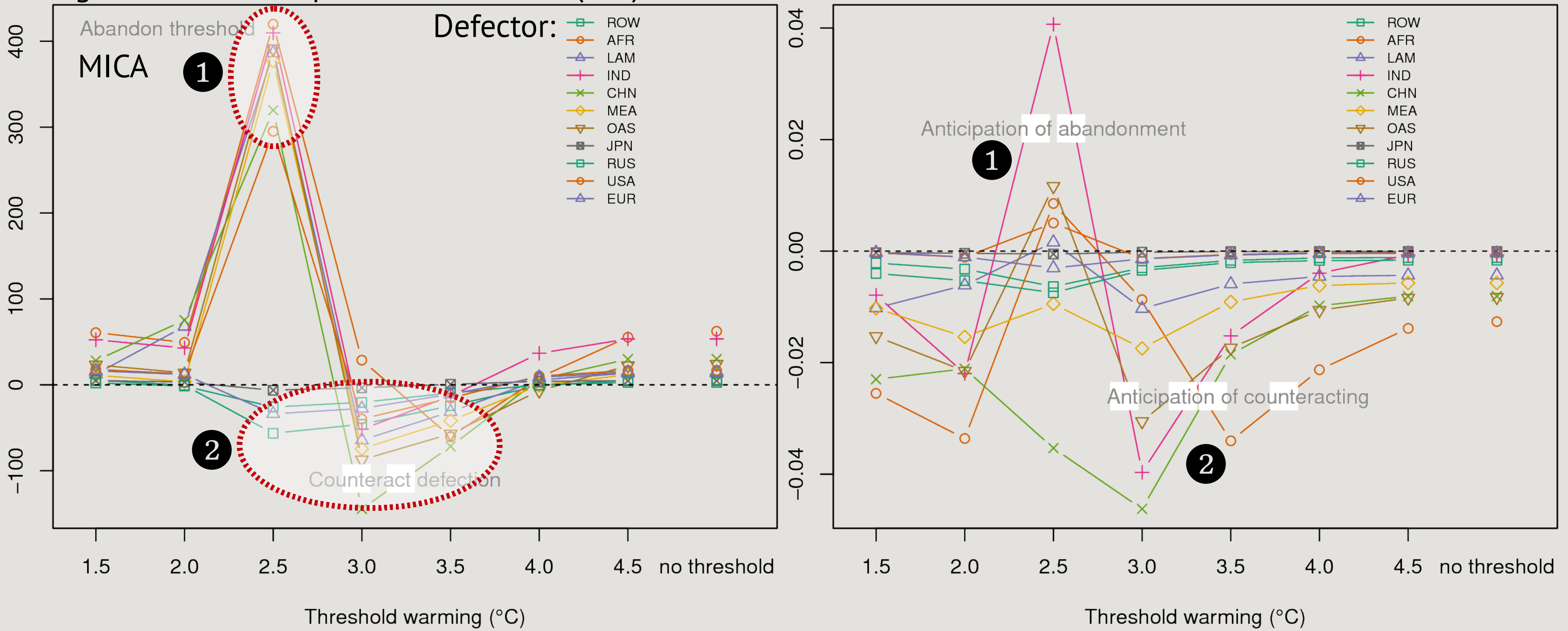
Coalition reaction around thresholds

Change in emissions upon defection of … (GtC)



(1) Abandon threshold
which was previously avoided

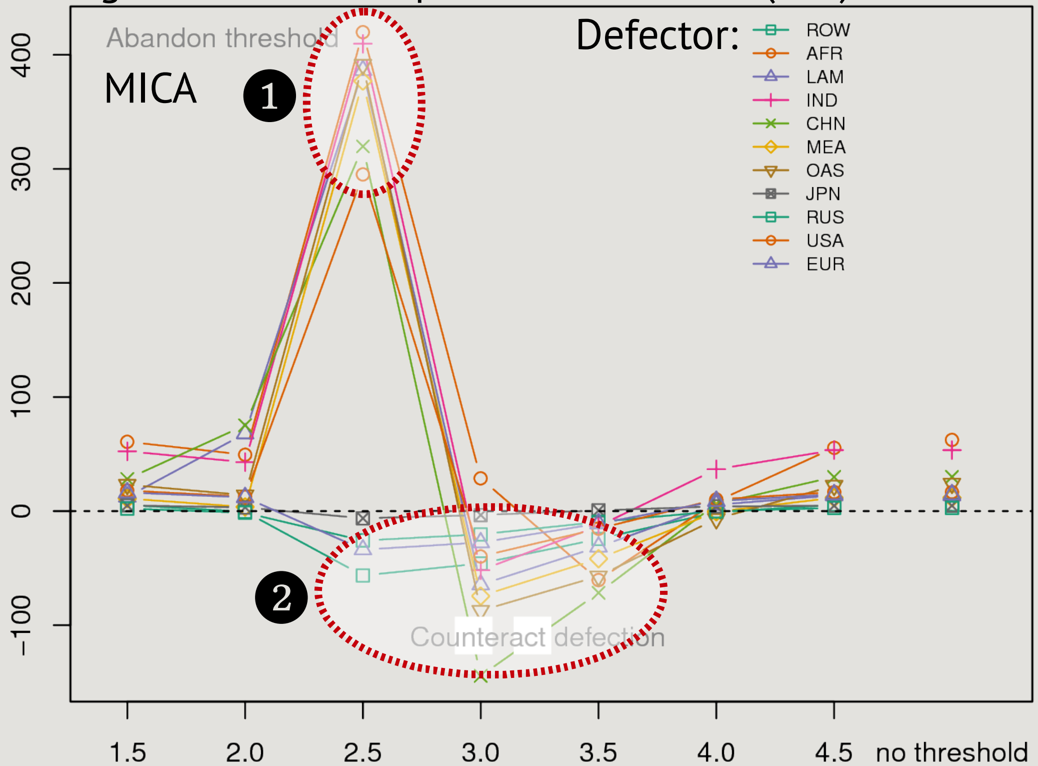
–

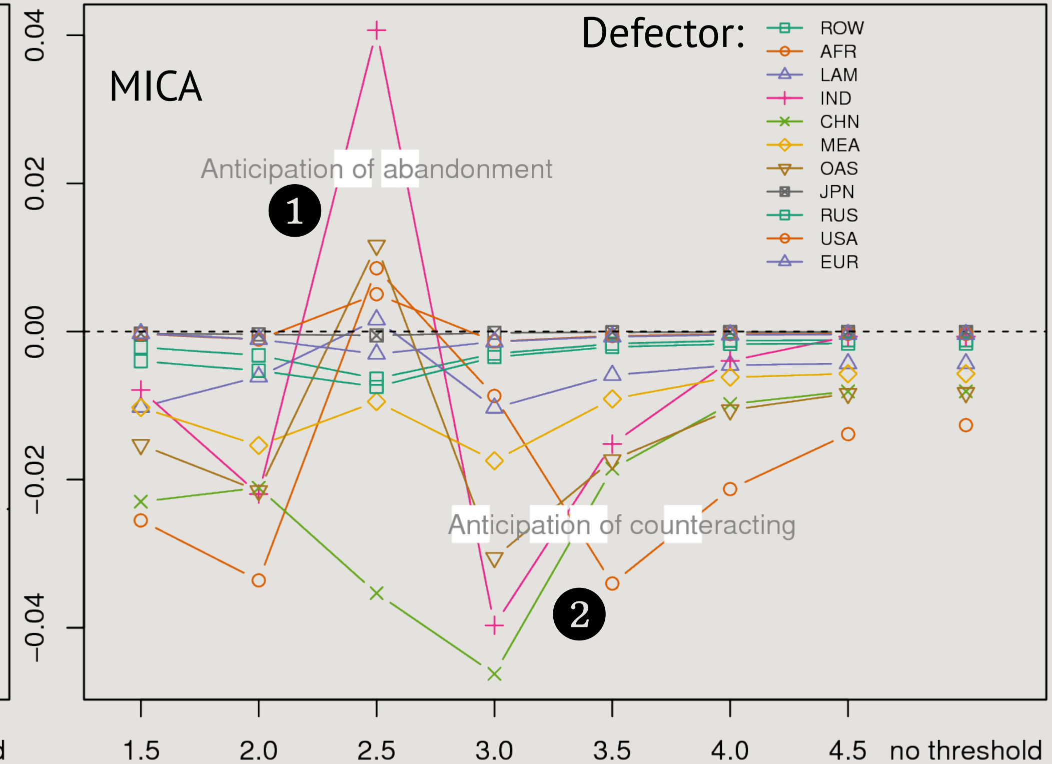
(2) Counteract defection
to *still* keep below the threshold

–

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

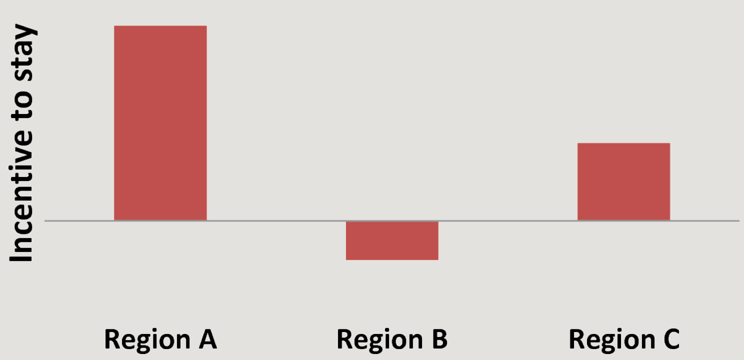
Stable Grand Coalitions in threshold vicinity

- "Optimal" transfers among coalition members
  - OPTS → Carraro, Eyckman, Finus 2006, assumes *transferable utility*

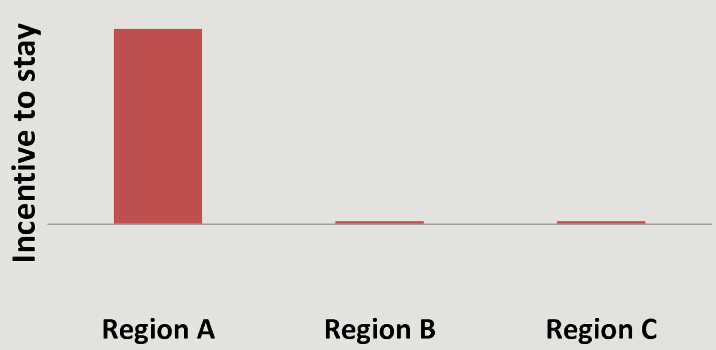
$$\sum_{i \in S} \pi_i(S) \geq \sum_{i \in S} \pi_i(S \setminus \{i\})$$

  - Non-transferable utility implementation → Kornek, Lessmann, Tulkens 2015

Potential internally stable coalition



Leftover of coalition



Stable Grand Coalitions in threshold vicinity

- "Optimal" transfers among coalition members
  (OPTS → *Carraro, Eyckman, Finus 2006*, NTU implementation → *Kornek, Lessmann, Tulkens 2015*)

Threshold level (addition damages)

Threshold location (temperature)

$T_S \setminus d$	3%	3.5%	4%	4.5%
2.3	0	0	0	0
2.4	0	0	0	0
2.5	***1***	***1***	***1***	0
2.6	0	0	0	0
2.7	0	0	0	0

- 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

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PIK

Appendix

Preferences

Social welfare of region i

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

Instantaneous utility

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

Technology

Economic output net of abatement costs and climate change damages

$$y_{it} = (1 - \Lambda_{it} - \Omega_{it})\, F(l_{it}, k_{it}) \tag{A.3}$$

Production technology

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

Accumulation of capital, initially k_{i0}

$$\frac{d}{dt} k_{it} = i_{it} - \delta_i k_{it} \tag{A.5}$$

Emissions and Emission Allowances

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

$$e_{it} = y_{it}\,\sigma_{it}\,(1 - a_{it}) \tag{A.6}$$

Abatement costs

$$\Lambda_{it} = b^1_{it} \cdot (a_{it})^{b^2_i} \tag{A.7}$$

All emissions are covered by allowances net of allowance exports.

$$e_{it} \leq q_{it} - z_{it} \tag{A.8}$$

Trade in allowances is balanced in every time period.

$$\sum_j z_{jt} = 0, \qquad \forall t \tag{A.9}$$

Climate Dynamics

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

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

Definition of global total of emission allowances

$$Q_t = \sum_i q_{it} \tag{A.11}$$

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

$$\frac{d}{dt}E_t = Q_t \tag{A.12}$$

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

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

Climate change damages

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