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The incentives to participate in and the stability of international climate coalitions: a game-theoretic analysis using the WITCH model

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1. Plan of the Lecture

1. Introduction to key concepts in non-cooperative coalition formation theory

2. Introduction to the WITCH model

3. Analysis of the incentives to participate in and the stability of international climate coalitions

2. Introduction

Long-lived Greenhose Gases (GHGs) have two peculiar characteristics:

1. they mix up perfectly in the atmosphere and therefore they represent a perfect global negative externality

2. they remain in the atmosphere from decades to centuries and therefore they represent an inter-temporal (inter-generational) externality

Game theory has emerged as the natural tool to study a problem in which strategic behavior is dominant

3. A Simplified Setting

- Players bargain over the provision of a global public good, which here is assumed to be emission (and climate change) control
- Emissions of GHG are associated with higher welfare because they allow production of useful goods and services
- However, the build up of emissions in the atmosphere has negative consequences on welfare of all countries
- Reducing GHG emissions is assumed to be costly because new technologies have to developed and adopted

4. The Cooperative Approach

- Interactions among countries are modeled as a one-shot simultaneous game with only two possible outcomes
    1. full cooperation
    2. free-riding

- Free-riding inevitably prevails: “tragedy of the commons”

- Strategic interactions rather crude:
    1. non-cooperative outcome not optimal
    2. absence of bargaining strategies

- Although weak, international cooperation to protect global commons exists

5. Non-cooperative Coalition Theory

- Countries interact repeatedly
  - they learn
  - they commit
  - can design mechanisms to enhance cooperation and deter non-compliance

- These issues are at the core of non-cooperative coalition theory

- Simplest case: simultaneous one-shot game
  - coalition game: cooperate or not
  - policy game: optimal level of emissions

6. Non-cooperative Coalition Theory

- Carraro and Siniscalco (1993) show that cooperation is fully rational and can emerge as the outcome of the non-cooperative game

- Different degrees of cooperation:
  - full cooperation
  - partial cooperation

- Lines of research:
  - characterization of coalitions at equilibrium
  - optimal size and optimal number of coalitions
  - mechanisms to foster coalition formation and stability

7. Profitability and Stability

- A coalition $\gamma \in \Gamma$ is said to be *profitable* if coalition members have a higher welfare than in a scenario where the coalition is not formed (Nash equilibrium):

$$W_i(\gamma) \geq W_i(Nash) \quad \forall i \in \gamma$$

- Profitability is a necessary, but not sufficient condition for the coalition to be formed. A second requirement concerns *stability*

8. Stability

- A coalition is said to be *stable* if it is *internally* and *externally* stable.

- A coalition is *internally stable* if signatory countries do not have the incentive to defect and to behave non-cooperatively when other coalition members cooperate:

$$\forall i \in \gamma \quad W_i(\gamma) \geq W_i(\gamma \setminus i)$$

- A coalition is *externally stable* if there is no incentive to enlarge the coalition by including non-signatory countries:

$$\forall i \in \gamma \quad W_i(\gamma) \geq W_i(\gamma / j)$$

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9. Stable Coalitions

- Under fairly general conditions stable coalitions exist (Donsimoni *et al*, 1986).

- However, stable coalitions are generally small and might well not address satisfactorily the environmental problem, especially when they deal with a global externality as in the case of climate change (D'Aspremont *et al*, 1983; D'Aspremont and Gabszewicz, 1986; Carraro and Siniscalco, 1991; Hoel 1992)

- The optimal reaction of non-signatory countries to the environmental coalition might imply higher emissions compared to the case in which no coalition is formed (carbon leakage)

10. The *Characteristic Function*

1. the *core* – set of stable coalitions that emerges as a strategic equilibrium
2. *characteristic* function – describes the payoff achievable by each possible coalition of players

- Chander and Tulkens (1997):
  - in games with externalities, in order to define the *core* of the emissions game, it is necessary that the *characteristic* function reflects the actual behaviour of players which are not members of the coalition

- Describing the actual response of non coalition members to coalition strategies is not an easy task

11. The γ-Characteristic Function

- *α-characteristic function:* players outside the coalition behave in the least favourable manner to coalition members (see Maler, 1989)

- not realistic because it does not guarantee that the choice to make the highest damage to coalition members is optimal for players which are outside the coalition.

- *γ-characteristic function:* countries inside the coalition assume that their non-signatory counterparts respond optimally to the equilibrium choice of the coalition (Chander and Tulkens 1997)

12. γ-Characteristic Functions

- The equilibrium of the emissions game is a Nash equilibrium
- Realistic γ *-characteristic functions*
- International knowledge or technological spillovers
  - positive spillovers
  - negative spillovers
- Useful analysis by means of large numerical models

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13. The Emissions Game

- In the first stage, players decide non cooperatively whether or not to join a coalition
- In the second stage, agents set their policy/decision variables by maximizing their welfare function given the decision taken in the first stage
- The standard assumption is that coalition members act as a single player maximising he aggregate payoff to their coalition, but behave non-cooperatively towards outsiders
- Equilibrium coalition structures are then determined by applying the concept of internal and external stability

14. Equilibrium Structures and Rules

- Simultaneous games
  - open membership
  - exclusive membership
  - coalition unanimity

- Sequential games
  - immediate exit
  - continuous renegotiations

15. The Enlargement of Coalitions

- Coalitions that are profitable and stable may easily be too small to have a meaningful impact on the stock of the global public good (Hoel, 1991, 1992; Carraro and Siniscalco, 1993; Barrett, 1994, 1997; Heal, 1994)

- Enlarging coalitions:
  - transfers
  - issue linkage (treaty on club or quasi-club good)

16. Potential Internal Stability

- A coalition $\gamma \in \Gamma$ is *potentially internally stable* if it can be turned into a stable coalition through a set of self-financed transfers among coalitions members

- This requires that there exists a matrix of financial transfers $\mu = (\mu_1(t), \mu_2(t), \ldots)$ with $\sum_t \sum_{i \in \gamma} \mu_i(t) e^{-rt} = 0 \quad \forall i \in \gamma$ and such that the following condition is met:

$$W_i(\gamma, \mu) \geq W_i(\gamma \setminus i) \quad \forall i \in \gamma$$

17. Transfers

- Empirical models that simulate negotiations among countries
- A wide range of papers has shown that transfers can foster coalition enlargement and lead to the construction of self-enforcing agreements (e.g. Botteon and Carraro, 1997; Altamirano-Cabrera and Finus, 2006; Bosello et al., 2003, 2004; Carraro and Siniscalco, 2001; Eyckmans and Finus, 2003, 2004a; Finus et al., 2004; Weikart et al., 2006)
- This strand of the literature has also taken into account complex transfer schemes which include many possible patterns of burden sharing

An Introduction to the WITCH model

www.witchmodel.org

www.policysimulator.org

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19. The WITCH Model

WITCH: World Induced Technical Change Hybrid model

Hybrid I.A.M.:

- **Economy**: Ramsey-type optimal growth (inter-temporal)
- **Energy**: Energy sector detail (technology portfolio)
- **Climate**: Damage feedback (global variable)

- 12 Regions (“where” issues)
- Intertemporal (“when” issues)
- Game-theoretical set-up (free-riding incentives)

- Bosetti, V., E. Decian, A. Sgobbi and M. Tavoni (2009). “The 2008 WITCH Model: New Model Features and Baseline.” FEEM Working Paper 85.09 .
- Bosetti V., E. Massetti, M. Tavoni (2007). “The WITCH Model, Structure, Baseline, Solutions”, FEEM Working Paper 10.2007.
- Bosetti, V., C. Carraro, M. Galeotti, E. Massetti and M. Tavoni (2006). “WITCH: A World Induced Technical Change Hybrid Model”, The Energy Journal, Special Issue. Hybrid Modeling of Energy-Environment Policies: Reconciling Bottom-up and Top-down, 13-38.

20. Distinguishing Features

- Focus on **energy sector**
- Focus on **technological change**:

  Learning-by-Doing in W&S

  Energy intensity R&D

  Breakthrough Technologies (two factors learning curves)
- Focus on channels of **interactions among regions**:

  Technological spillover

  Environmental externality

  Exhaustible common resources (coal, natural gas and uranium)

  Trade of emission permits

  Trade of oil (not in the version used for this work)
- Focus on **strategic behaviour (open loop Nash game)**

21. WITCH as a Game

- The scenarios produced using WITCH are the outcome of a game in which world regions interact in a setting of strategic interdependence (climate, exhaustible natural resources, technology)
- The model can be solved either in a cost-benefit or in a cost minimizing framework
- In the cost-minimizing framework a cap on emissions or a carbon tax are imposed
- In a cap-and-trade program different assumptions on the size of the carbon market can be made

22. The Players

World countries, aggregated into 12 regions

Regional Aggregation:

- United States (USA)
- Western EU countries (WEURO)
- Eastern EU countries (EEURO)
- Canada, Japan and New Zealand (CAJANZ)
- Korea, Australia and South Africa (KOSAU)
- Non-EU Eastern European countries, including Russia (TE)
- Latin America, Mexico and Caribbean (LAM)
- Middle East and North Africa (MENA)
- South Asia, including India (SASIA)
- China, including Taiwan (CHINA)
- Sub−Saharan Africa excluding South Africa (SSA)
- South East Asia (EASIA)

23. The Players

- WITCH can simulate all degrees of cooperation:
  - Decentralized, non-cooperative solution
  - Coalitions that co-exist with free-riders
  - Fully co-operative solution (technically, not a game)
- World countries can form coalitions to control externalities
- When formed, coalitions become players of the game
- Regions that do not join the coalition are said to behave as singletons or as free-riders

24. Actions and Outcomes

- The action of each player consists in choosing the path of investments in key economic variables governing the economy and the energy sector
- The economies are modeled coherently with a Ramsey-type optimal growth framework
- Investments in the energy sector and in research and development determine regional GHG emissions
- Economic activity is affected by global mean temperature, which depends on global concentrations of GHG
- The outcome of the game is a consumption path over the whole simulation horizon

25. Payoffs

- Players express their preferences over the outcomes of the game using a monotonous, twice continuously differentiable utility function on discounted consumption

- In particular, players evaluate the discounted sum of log per capita consumption over the entire simulation horizon

- Coalitions evaluate the weighted sum of discounted per capita consumption, with weights calibrated to equate marginal utilities across members (Negishi weights)

26. Utility Function

$$W_i(\gamma) = \sum_t w\left(C_{i,t}(\gamma)\right) e^{-\delta_t t} \qquad \frac{\partial w\left(C_{i,t}(\gamma)\right)}{\partial C_{i,t}} > 0 \qquad \frac{\partial^2 w\left(C_{i,t}(\gamma)\right)}{\partial C_{i,t}^{\ 2}} < 0$$

- Utility functions represent a complete preference ordering over a given set of goods or on an aggregate consumption level. They can be used to assess if a given consumption level $\overline{C}_{i,t}$ is preferred or not with respect to $\tilde{C}_{i,t}$.

- Monotonicity: $\overline{C}_{i,t} \geq \tilde{C}_{i,t} \Leftrightarrow w\left(\overline{C}_{i,t}\right) \geq w\left(\tilde{C}_{i,t}\right)$

- Utility cannot be compared directly among players

27. Transferable Utility

- Literature on coalition formation has usually simplified the analysis assuming that utility is transferable – i.e. comparable between different levels of consumption and between different players.

- The property of transferable utility requires that utility grows at a constant pace as consumption grows, as in linear or quasi-linear utility functions, which are in fact typically used in the literature of coalition formation.

28. Transferable Utility

- However, while linear utility is an acceptable simplification in theoretical analysis of coalition theory, it is not acceptable when studying long term growth dynamics and when players are asymmetric

- The rate at which utility grows when consumption grows is clearly different at different stages of economic development

- Analogously, the same amount of consumption in regions that are at very different levels of economic development, has very different implications on welfare

29. Social Welfare Aggregator

- Social welfare aggregator that assigns a social preference to every possible profile of individual preferences

$$S(\gamma) = S(W_1(\gamma), W_2(\gamma), \ldots, W_n(\gamma)) = \sum_{i=1}^{n} \sum_t \omega_{i,t} w(C_{i,t}(\gamma)) e^{-\delta_t t}$$

- where $\omega_{i,t} = \left(\frac{\partial w(C_{i,t}(\gamma))}{\partial C_{i,t}(\gamma)} \right)^{-1}$

30. Allocation of Abatement Effort

- The weights "linearize" the contribution of players utility functions to social welfare and avoids wealth transfers from wealthy players to poor players and from the future to the present

- Therefore, abatement effort is distributed with the sole objective to minimize coalition's emissions reduction costs, i.e. so that marginal abatement costs are the same in all regions

- The social welfare aggregator that we use produces the same actions as in a decentralized solution which internalizes the environmental externality among coalition members and uses an international market of carbon to distribute abatement effort.

31. Potential Internal Stability

- Literature: transfer of utility

- Utility is not transferable, only revenue/consumption can be transferred

$$\sum_t w\left(C_{i,t}(\gamma)+\mu_{i,t}\right)e^{-\delta_t t} = W_i(\gamma,\mu) \geq W_i(\gamma \setminus i) \qquad \forall i \in \gamma$$

- Efficient transfer scheme:

$$\mu^* = \left(\mu_1^*, \mu_2^*, \ldots\right) \qquad \mu_i^* = \sum_t \mu_i(t) e^{-r_i(t)t}$$

- A practical way to check potential internal stability is to verify if

$$\sum_t \left(C_{i,t}(\gamma)+\mu_{i,t}\right)e^{-r_i(t)\,t} \geq \sum_t C_{i,t}(\gamma \setminus i)\, e^{-r_i(t)\,t}$$

32. The Rules

- The WITCH model analysis assumes a…
  - Non-cooperative
  - Simultaneous
  - Open membership
  - Full information

  …game that leads to a Nash equilibrium

- Open-loop Nash game

- It allows for the possibility of international transfers to enlarge climate coalitions

- In essence, the framework considers immediate, irreversible and self-enforcing participation to climate change mitigation action

33. The Rules

- In order to simulate coalition formation in a cost-benefit setting, the model is solved as a one-shot meta-game:
  - First Stage: countries decide on their participation and coalitions are formed
  - Second Stage: countries choose their optimal emission levels internalizing only the environmental externality
  - The game is solved backward
- In the second stage, coalition members maximize aggregate joint welfare, whereas non participants behave as singletons and maximize individual welfare

34. The Rules

Equilibrium is found employing the **γ-characteristic** function approach (Chander and Tulkens, 1997):

- In the unique Nash equilibrium coalition members jointly play their best response to non-coalition members, who adopt individually their best-reply strategies

The game exhibits positive spillovers. When a new member joins the coalition all countries outside the coalition are better off because they benefit from:

- A better environment
- Technology spillovers (knowledge is not a club good)
- Lower fossil fuel prices

The Incentives to Partecipate in and the Stability of International Climate Coalitions

Bosetti, V., C. Carraro, E. De Cian, R. Duval, E. Massetti and M. Tavoni. 2009. “The Incentives to Participate in and the Stability of International Climate Coalitions: a Game Theoretic Approach Using the WITCH Model” OECD Economics Department Working Papers No. 702, June 2009.

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36. Participation Incentives

- Broad-based country participation is required for any coalition to be environmentally effective.

- At the same time, wide coalitions may be harder to achieve, reflecting stronger incentive to free ride.

⇒ Drivers of individual incentives to participate in international climate coalitions include *inter alia:*

1. The expected impacts of climate change;
2. Abatement costs;
3. The influence of distant impacts on current policy decisions (*i.e.* the discount rate);

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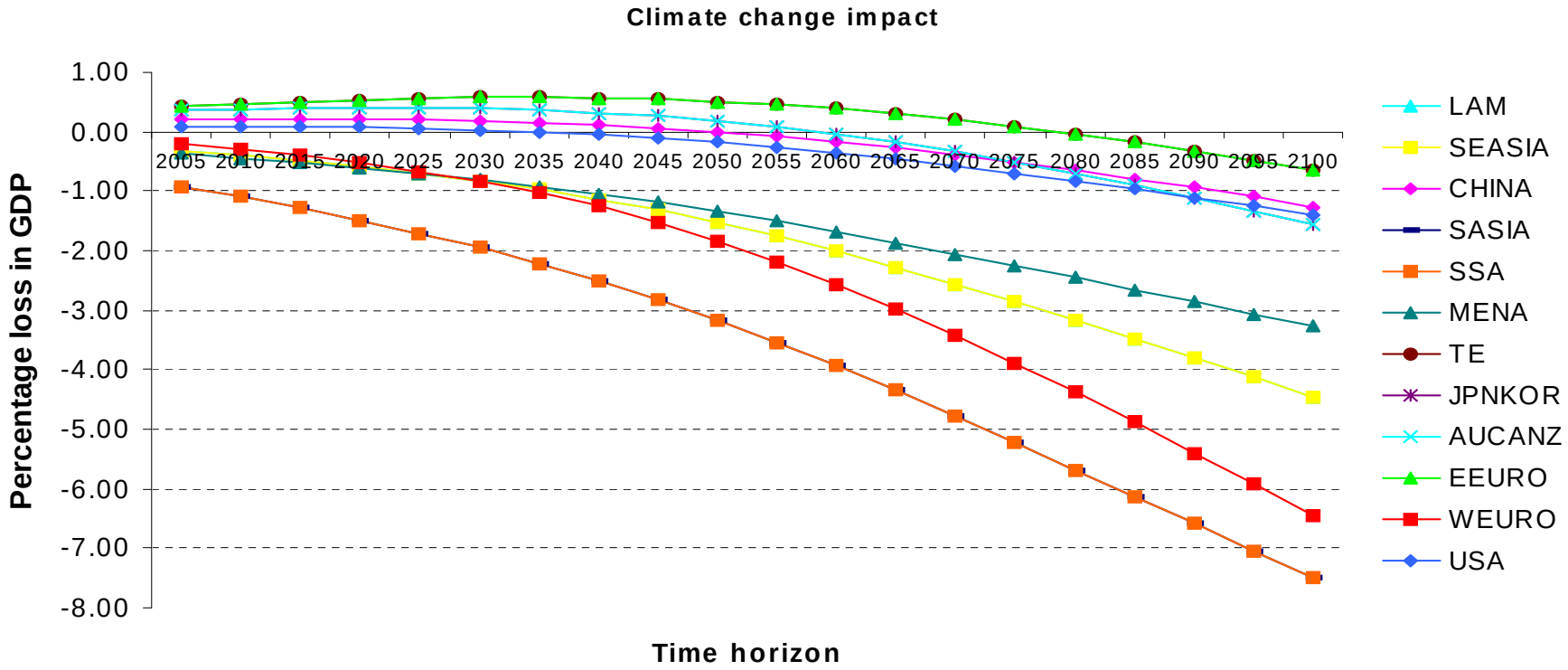
37. Climate Change Impacts in WITCH



- The impacts of climate change are expected to vary widely across regions.
- Developing countries would be more affected than their developed counterparts
- Uncertainties are large, however, as reflected by the wide variance in damage estimates across studies

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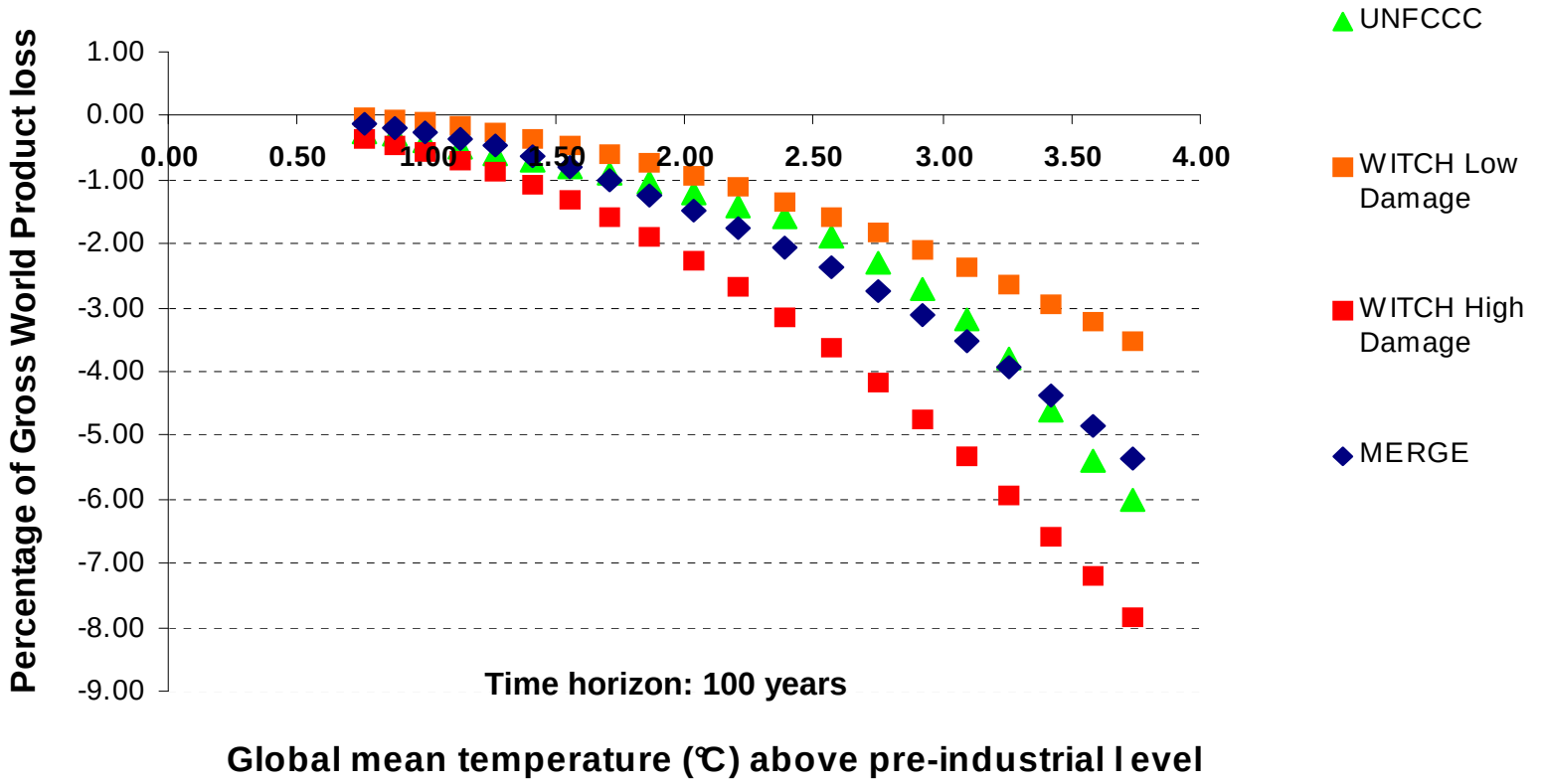
38. Climate Change Impacts



- A higher damage function reflecting upward revisions of recent estimates (UNFCCC, 2007; Stern et al. 2006) has been considered, so as to define an upper and lower bound around estimates available in the literature

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39. Discount Rate

- In order to take into account the existing debate on the choice of the social discount rate, the analysis is performed here under two different assumptions regarding the pure rate of time preference, namely 3% and Stern's 0.1% assumption.

Pure rate of time preference (PRTP)	ρ= *3% declining* *(HDR)*	ρ= *0.1% declining* *(LDR)*

- In order to account for uncertainty regarding both damages and inter-temporal preferences, the analysis of climate coalition will consider four cases:

1. Low damage - high discount rate (3%) *LDAM_HDR*
2. Low damage - low discount rate (0.1%) *LDAM_HDR*
3. High damage - high discount rate (3%) *HDAM_HDR*
4. High damage - low discount rate (0.1%) *HDAM_HDR*

40. Abatement Costs

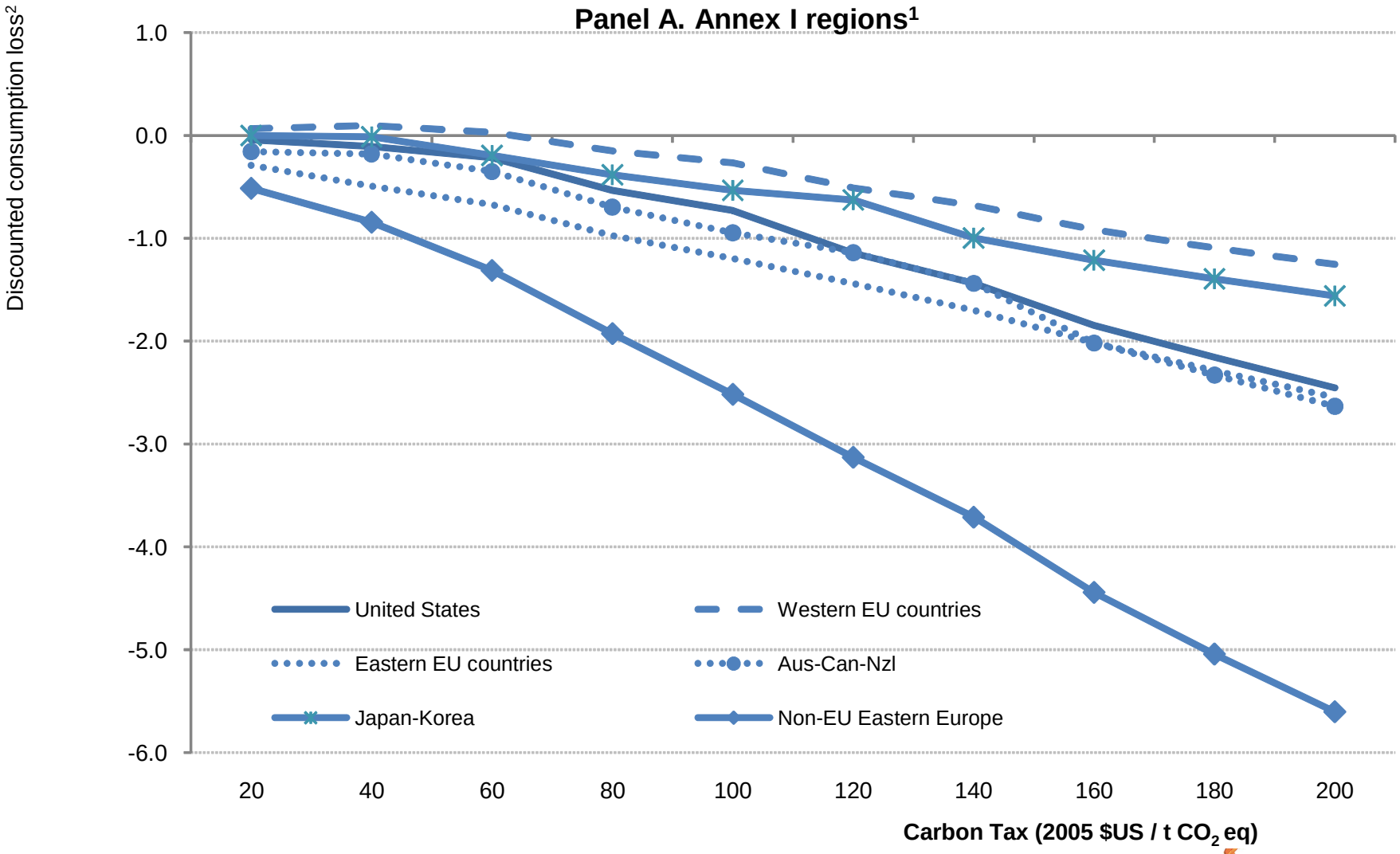
- The costs of mitigation policies are also expected to vary widely across regions.

- *Ceteris paribus,* the higher the overall carbon intensity of output
  - the flatter the aggregate marginal abatement cost curve
  - the larger the economy's abatement efforts
  - the larger the costs under a global carbon tax
  - the smaller its incentives to participate in a climate coalition

- Developing regions (China, South-East Asia, Africa and, to a somewhat lesser extent, South Asia (including India) and Latin America) incur larger costs than their developed counterparts in the absence of explicit or implicit financial transfers

- Economies that are both carbon-intensive and produce fossil fuels (non-EU Eastern Europe (including Russia), Middle East and North Africa) face the largest costs from broad-based mitigation action.

41. Abatement Costs - Carbon Tax



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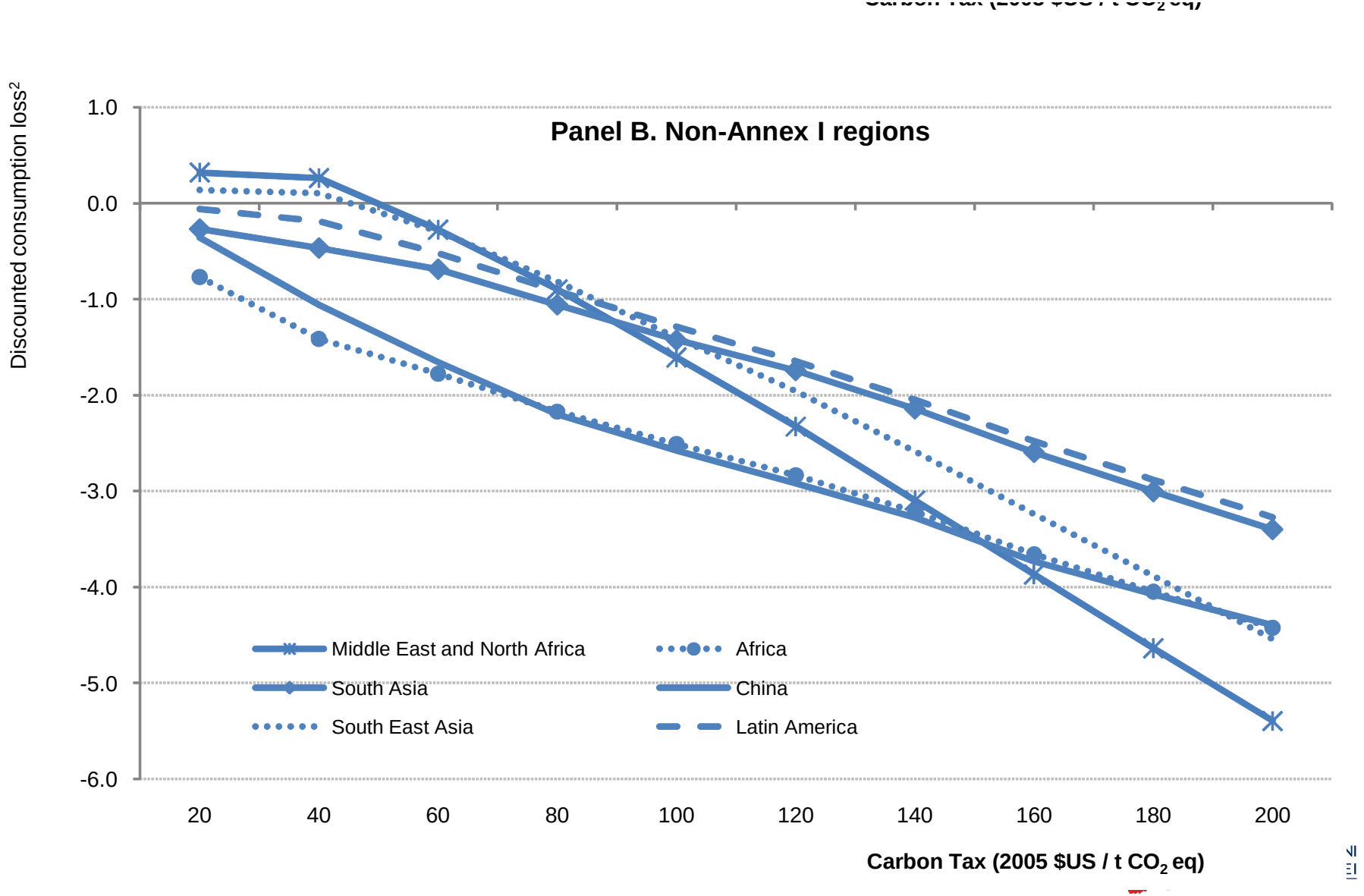
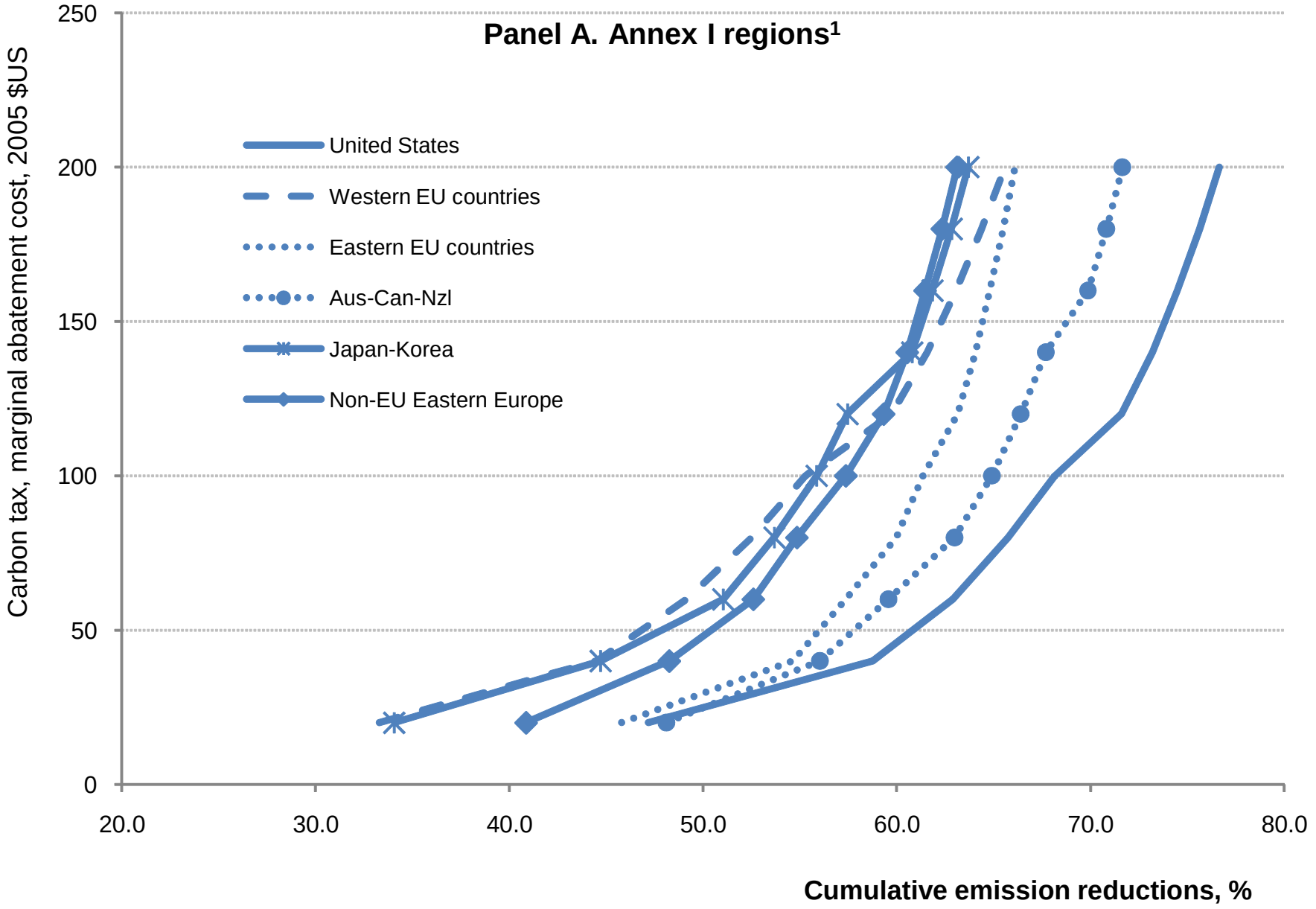
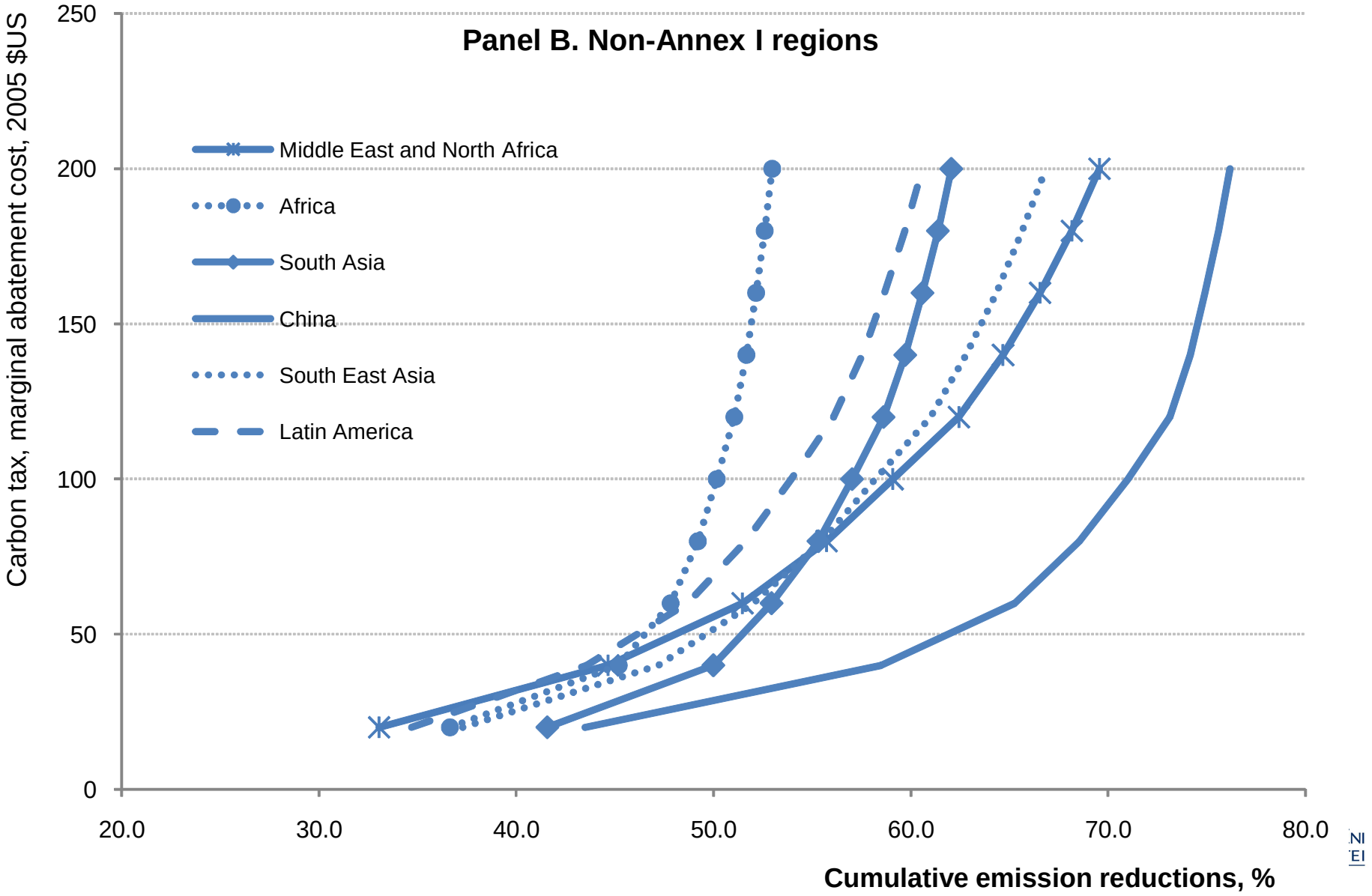
42. Abatement Costs - Carbon Tax



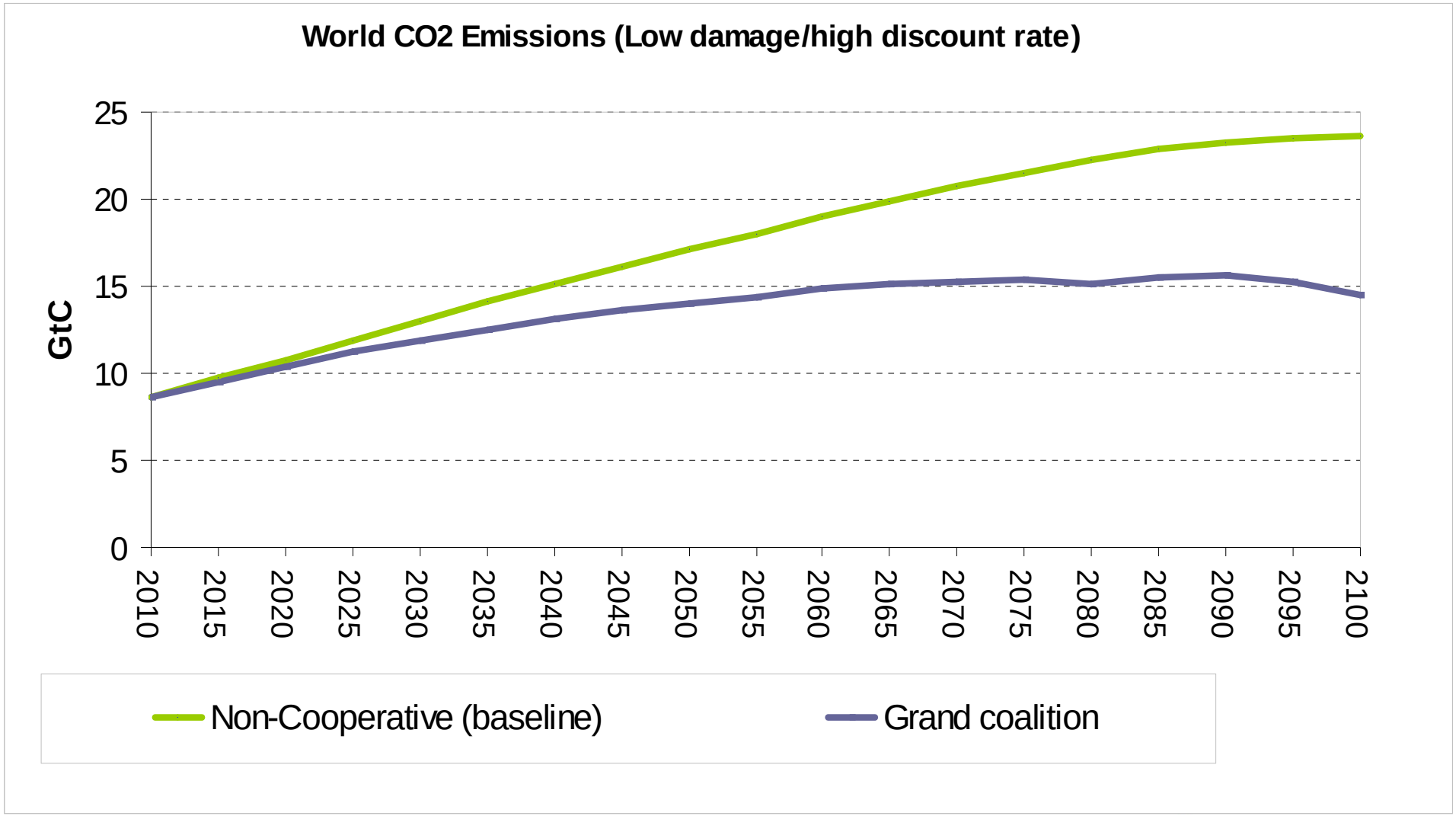
43. MACs


Panel A. Annex I regions[1]
Carbon tax, marginal abatement cost, 2005 $US
250
200
150
100
50
0
United States
Western EU countries
Eastern EU countries
Aus-Can-Nzl
Japan-Korea
Non-EU Eastern Europe
20.0
30.0
40.0
50.0
60.0
70.0
80.0
Cumulative emission reductions, %

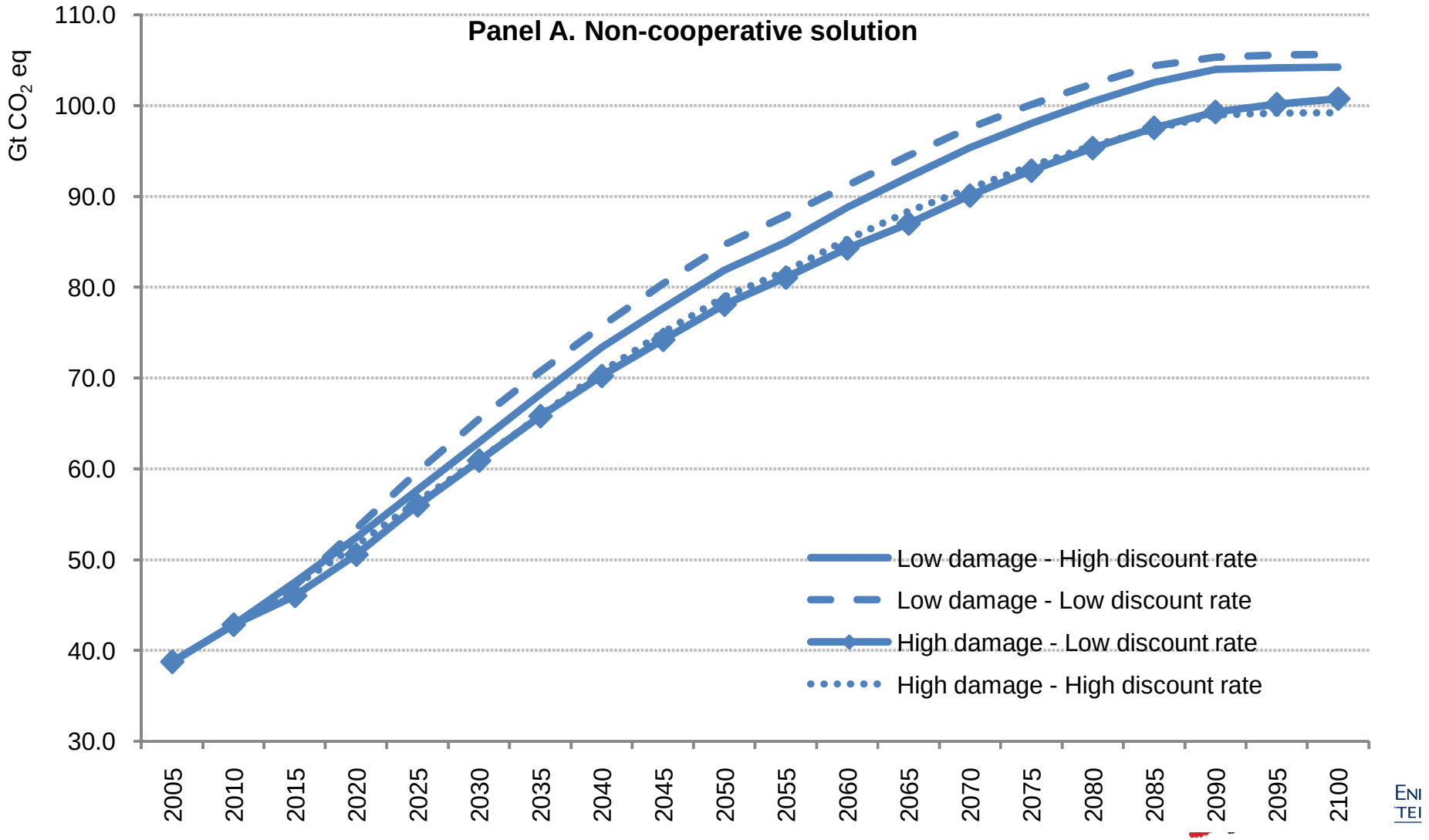
44. MACs


Panel B. Non-Annex I regions
Carbon tax, marginal abatement cost, 2005 $US
250
200
150
100
50
0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
Cumulative emission reductions, %
Middle East and North Africa
Africa
South Asia
China
South East Asia
Latin America

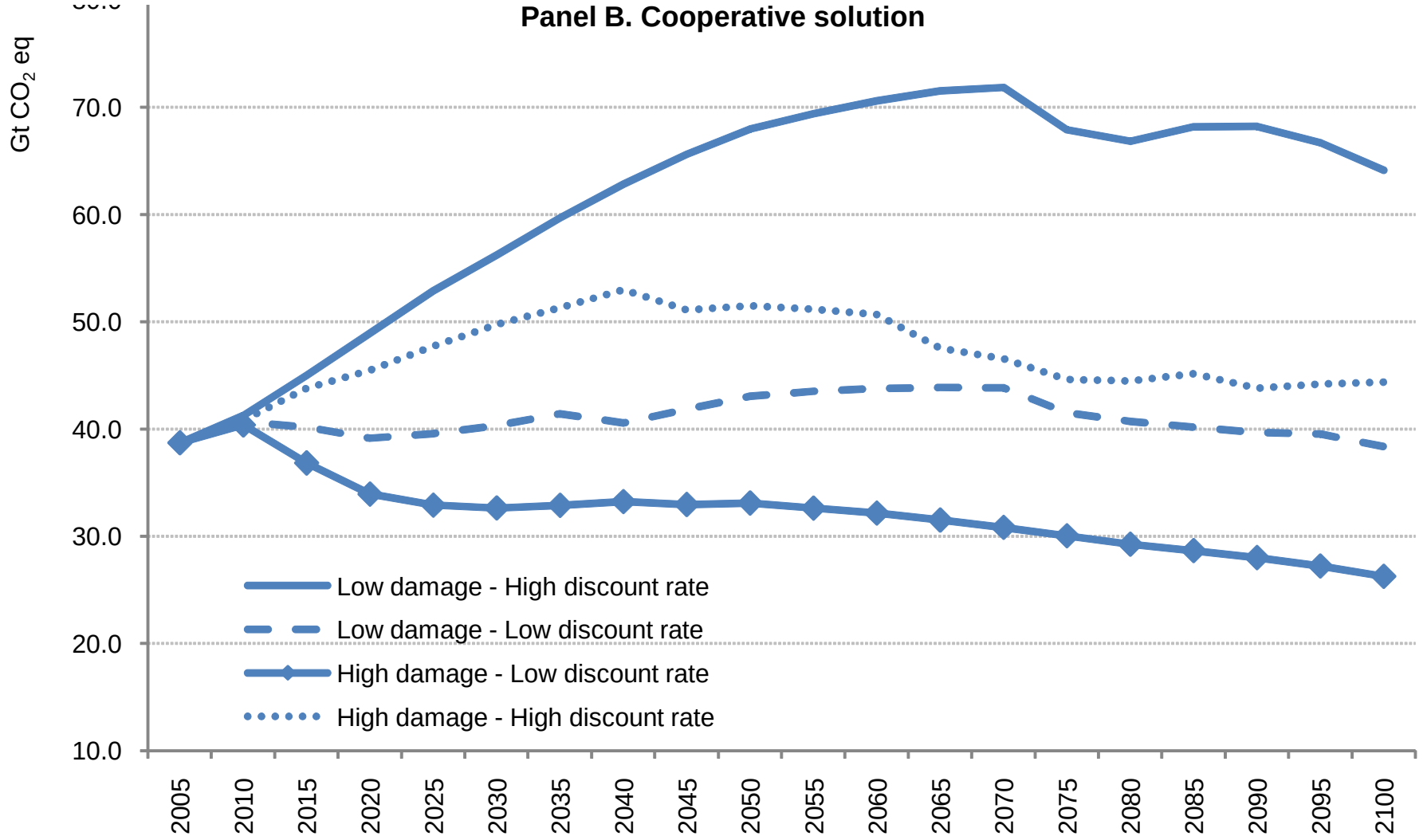
45. The Role of Cooperation



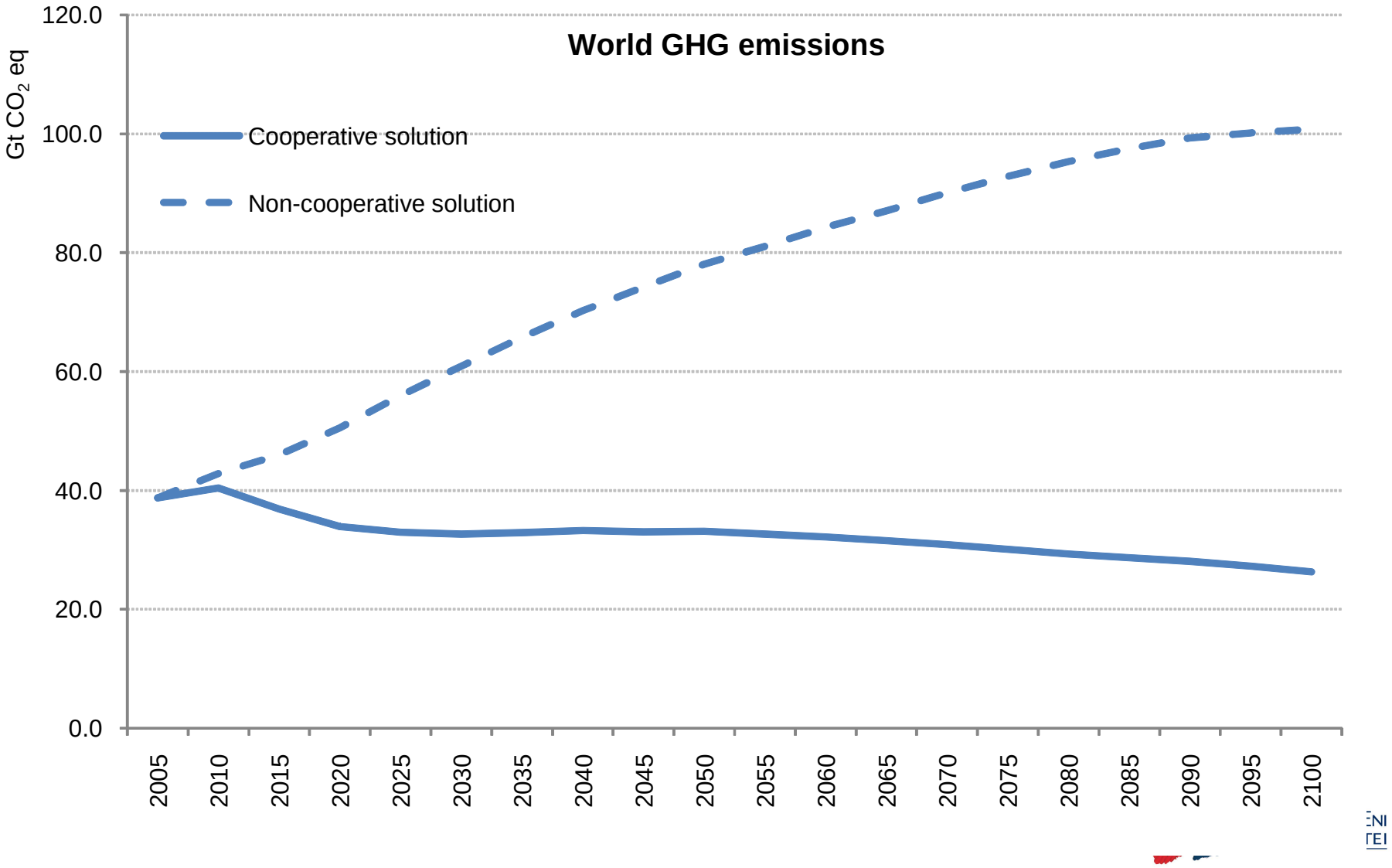
46. Non Cooperative Outcomes



47. Cooperative Outcomes



48. Focus on HD LDR



49. First Summary

- In a non-cooperative world, externalities dominate and equilibrium emissions are not very sensitive to different assumptions on damages and discount rates.

- In a cooperative world, the internalization of the externality through the climate damage component provides enough incentive to moderate pollution. In particular, the HDAM-LD case leads to stabilization of emissions and concentrations in line with a 550 ppm CO2 eq target.

50. Potentially Effective Coalitions

- Among the 4095 coalitions that are possible with 12 regions, only a subset is politically meaningful AND has the potential to stabilize GHG concentrations at a chosen target, in the present context, 550 ppm CO2eq

- A coalition is defined as a PEC if it could technically achieve a given world concentration target by bringing down its own emissions to zero and non-participating regions remain at their BAU levels.

- Being a PEC is a necessary (but not sufficient) condition for the 550 ppm CO2eq target to be attainable (there are free riding incentives for singletons and technical unfeasibility of zero emissions for coalition members).

51. Definition of the Target

2050 TARGET Emission reduction in 2050 w.r.t. 2005	2100 TARGET Emission reduction in 2100 w.r.t. 2005	Radiative Forcing in 2100 (W/m2)	Concentrations in 2100 (ppm eq.)
-25 %	-50 %	3.7	550

The two targets together define environmentally effectiveness: they ensure with high probability the stabilization of radiative forcing at 3.7 W/m2.

52. PECs: Methodology

- We defined two groups of PECs: a first group achieving only the 2050 target and a second group achieving both the 2050 AND the 2100 targets.

- For each of the four baseline scenarios (High and Low Damage, High and Low Discount Rate), we considered the minimum profile of global emissions for all coalitions (and related singletons) and computed the emission reductions that can be achieved both in 2050 and 2100.

- We considered the union of PECs in the 4 different scenarios. We identified 36 PECs that achieve the required reduction in 2050; only 7 match the 2100 target as well.

53. Potentially Important Coalitions

Politically important coalitions

i) **Grand coalition (2100)**

ii) **Industrialised countries + China + India + Russia + Latin America (2050)**

iii) **Industrialised countries + China + India + Russia (2050)**

iv) **Industrialised countries + China + India (2050)**

v) Industrialised countries + China;

vi) Industrialised countries only;

- Only 4 out of six politically important coalitions are PECs at 2050. None of them can achieve the 2100 target except for the Grand Coalition.

54. Main Insights from PECs Analysis

- If big emitters do not join the coalition, then the 2050 and 2100 targets cannot be achieved even under the extreme assumption of zero or negative emissions for coalition's members.

- All (politically relevant) PECs include all industrialised countries and both China and India by 2050, unless *all* other developing regions (except Africa) reduce their emissions below BAU levels.

- A coalition consisting of industrialised countries only cannot, even potentially, meet the target at the 2050 horizon.

55. Main Insights from PECs Analysis

- The participation of both China AND India is needed to attain the 2100 target.
- When the goal is GHG stabilization in 2100, PECs are subsets of the 12 regions in which at most three regions are not included.
- Generally, only SSA or SSA plus another region (LAM, TE, MENA, SEASIA) can be singletons.

56. Cost-Benefit Analysis (CBA)

- The identification of PECs is very robust: they hold under each of the four possible damage and discount rate scenarios

- Being a PEC is a necessary but not sufficient condition for the 550 ppm CO2eq target to be attainable
  - unfeasibility of zero emissions
  - free-riding incentives and carbon leakage, raising emissions in non-participating regions *above* their BAU levels.

- CBA analysis will illustrate how PECs underestimate the actual emission levels of both cooperating regions and singletons

- Policy implication: international coalitions will have to be larger than PECs in practice

57. Cost-Benefit Analysis of PECs

- Evaluate 36 PECs in a cost-benefit framework to check whether they actually attain the required environmental goal.

- 36 PECs:
  - 7 coalitions that are PECs in 2050 and 2100
  - 3 politically important coalitions that are PECs in 2050 only
  - 26 other coalitions that are PECs in 2050 only

- What does each coalition actually achieve in terms of emission reduction? How far from the stabilization goal is the equilibrium solution equalizing marginal costs and benefits?

- We start the analysis from the high damage and low discount rate (HDAM_LDR) case, again because if a coalition is not effective in this case, it cannot be effective in the other ones.

58. Environmental Effectiveness

	Emissions		Radiative Forcing (W/m2)		Concentrations (ppm)	
	2050 wrt 2005	2100 wrt 2005	2050	2100	2050	2100
Grand Coalition (GC)	**-25.9**	**-39.9**	**3.21**	**3.61**	**507**	**546**
GC_SSA	**-15.5**	**-23.0**	**3.33**	**3.93**	**518**	**579**
GC_SSA_LAM	-4.1	-6.1	3.47	4.22	532	612
GC_SSA_TE	-4.0	-14.7	3.46	4.14	531	603
GC_SSA_MENA	-4.5	-3.2	3.44	4.20	529	609
GC_SSA_SEASIA	-8.3	-9.5	3.41	4.09	526	598
GC_SSA_SEASIA_MENA	3.3	8.3	3.52	4.36	537	628
GC_SSA_SEASIA_TE	3.9	4.4	3.44	4.14	529	603
GC_SSA_SEASIA_MENA	**3.3**	**23.0**	**3.52**	**4.36**	**537**	**628**
GC_SSA_SEASIA_MENA_LAM	**11.5**	**26.6**	**3.64**	**4.61**	**549**	**659**
GC_SSA_SEASIA_MENA_LAM_TE	**17.5**	**8.3**	**3.67**	**4.66**	**552**	**665**

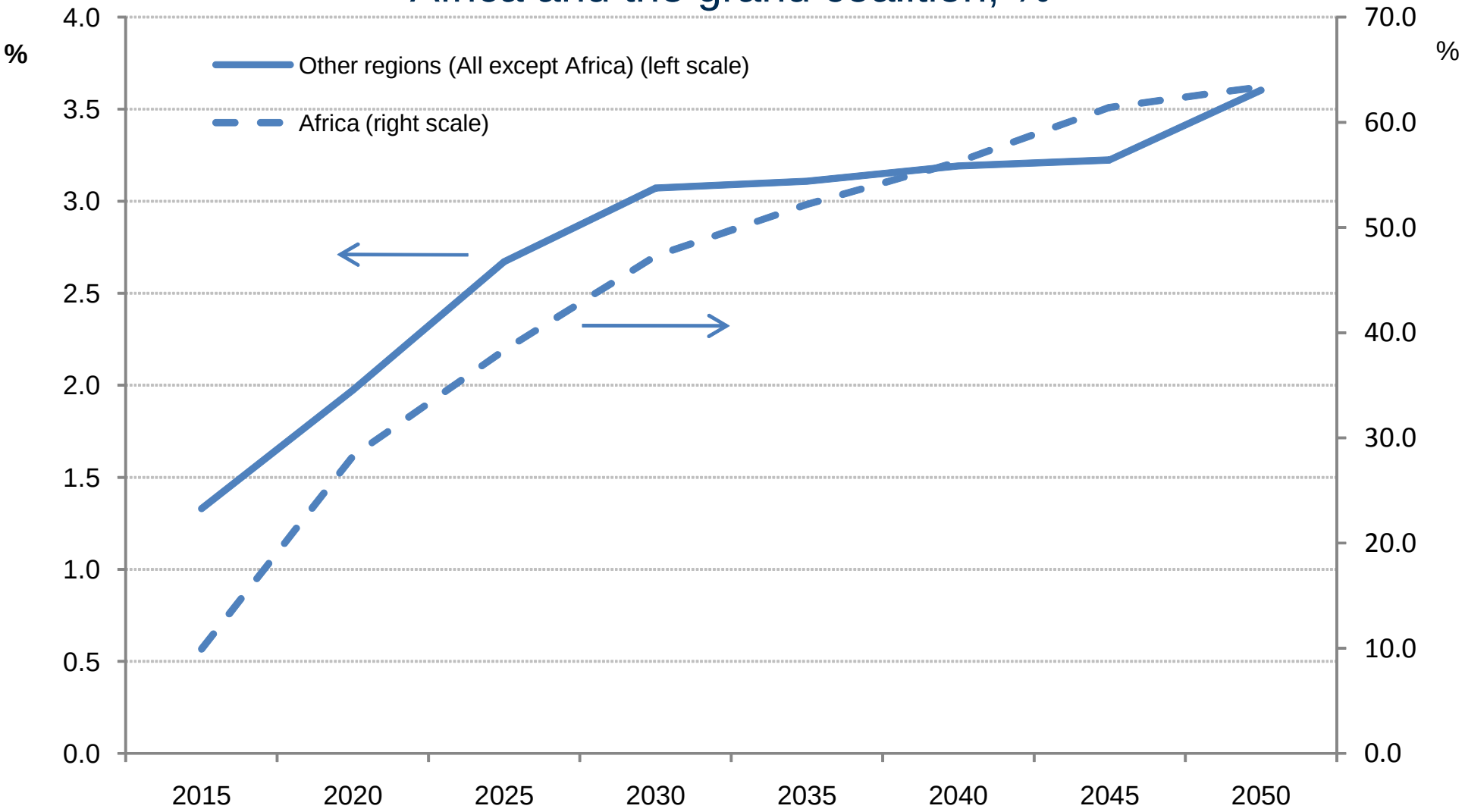
59. What Drives Coalition's Emissions?

- The major incentive from reducing emissions comes from the size of climate damage for coalition's members
- The composition of damages within the coalition determines the benefit from emission reductions and thus the degree of emission reductions
- For example, when we consider the coalition composed by all countries but SSA (GC_SSA) and consider the difference in emissions w.r.t. the grand coalition, two forces are at play

1. Countries in the coalition emit more because they do not internalize the high negative impact of climate change on SSA (damage effect).
2. As expected SSA emits more (free riding effect), BUT less than in the non cooperative baseline (technological spillovers).

60. Free Riding – the Case of SSA

Difference in GHG emissions between the grand coalition without Africa and the grand coalition, %



61. Effective and Profitable Coalitions

- Having identified the effective coalitions in a CB setting, we now turn to the analysis of their

1. Profitability
2. Internal Stability
3. Potential Internal Stability

- (Although only the Grand Coalition - and close to be the GC_SSA - has been shown to be effective, we evaluate profitability and stability also for other coalitions e.g. PECs and PICs)

62. Profitability and Stability

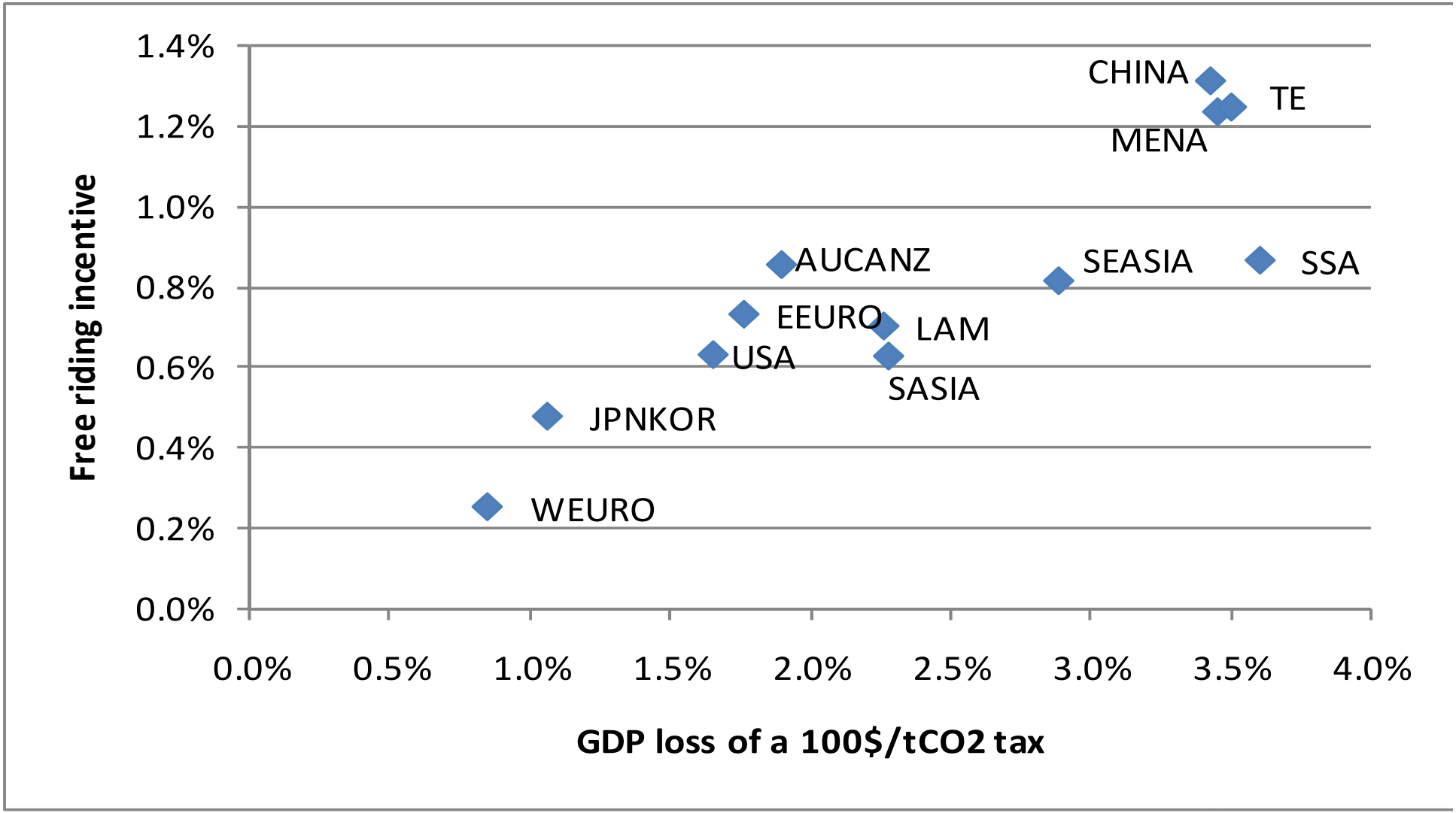
High Damage – Low Discount Rate	EFFECTIVE	PROFITABLE	STABLE	PIS
Grand Coalition (GC)	√	√		
GC_SSA		√		
GC_SSA_LAM		√		
GC_SSA_TE		√		
GC_SSA_MENA		√		
GC_SSA_SEASIA		√		+
GC_SSA_SEASIA_TE		√		
GC_SSA_SEASIA_MENA		√		+
GC_SSA_SEASIA_MENA_LAM		√		+
GC_SSA_SEASIA_MENA_LAM_TE		√		+

63. CBA: Gainers and Losers

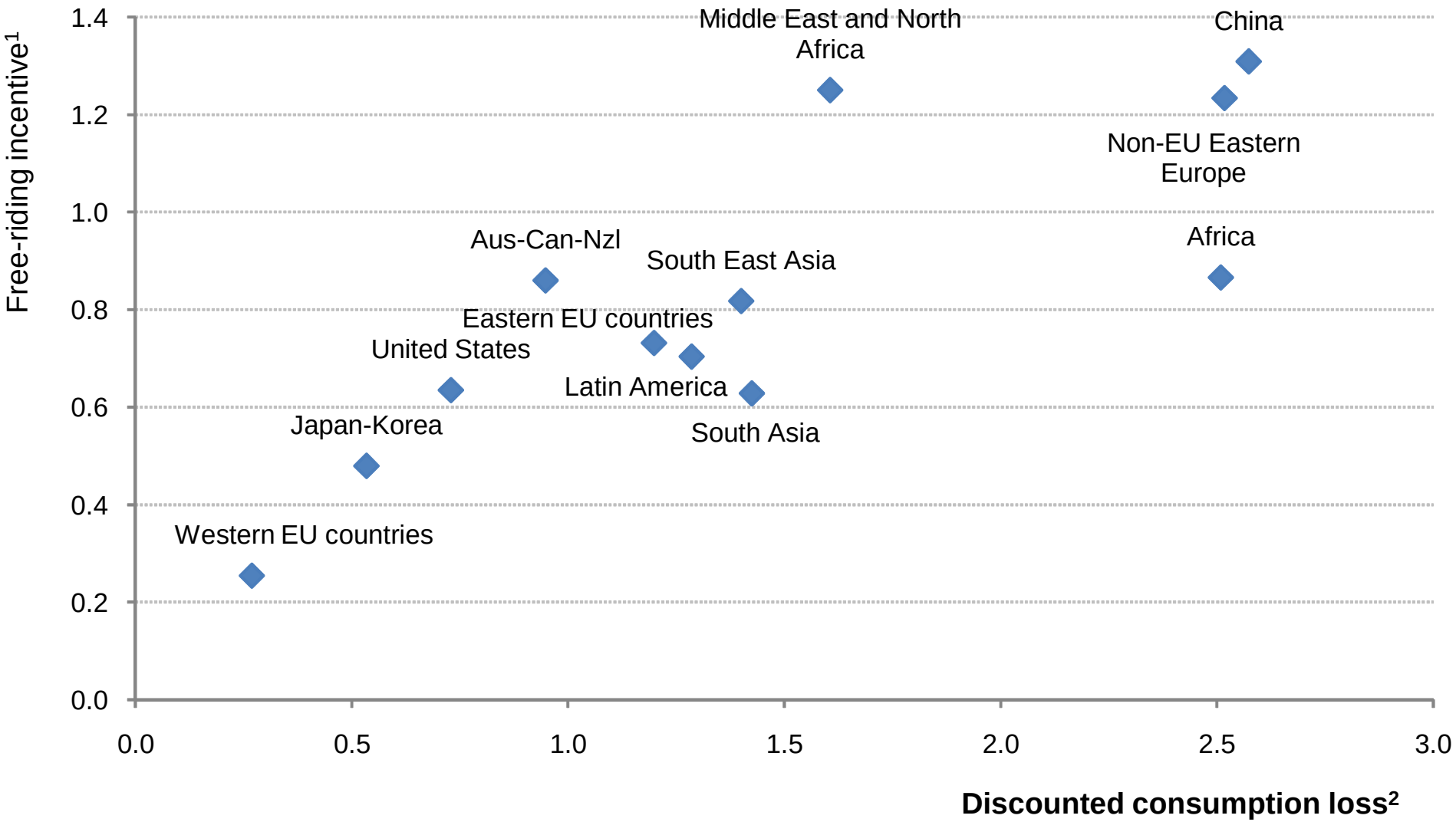
High Damage – Low Discount Rate	OECD	CHINA	TE	OTHERS
Grand Coalition	+	–	–	+
GC_SSA	+	–	–	+
GC_SSA_LAM	+	–	+	+
GC_SSA_TE	+	–	+	+
GC_SSA_MENA	+	–	+	+
GC_SSA_SEASIA	+	–	+	+
GC_SSA_SEASIA_TE	+	–	+	+
GC_SSA_SEASIA_MENA	+	–	–	+
GC_SSA_SEASIA_MENA_LAM	+	–	–	+
GC_SSA_SEASIA_MENA_LAM_TE	+	–	+	+

CHINA and TE are the major losers from climate cooperation, essentially because these regions, TE in particular, benefit from climate change for a large part of the century and their economies are or will be very fossil fuel intensive (China in particular).

64. Free Riding Incentive on the GC

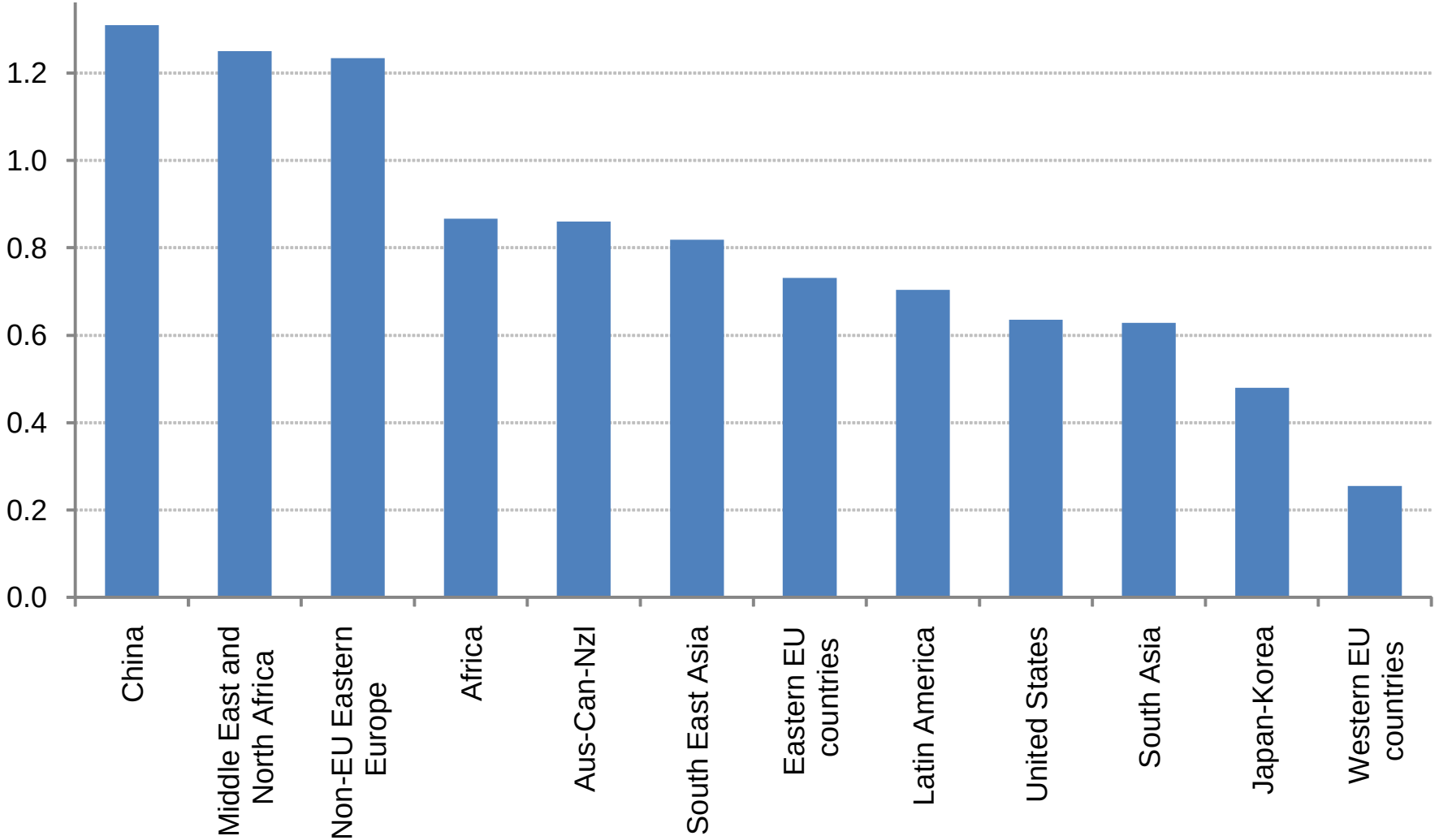


65. Free Riding Incentive on the GC



66. Free-riding and Welfare

Difference in welfare per capita between free-riding on and participating in the grand coalition, in %



67. Limitations

These findings are subject to a number of limitations:

- uncertainties in future emission trends
- the market and non-market impacts from climate change
- the likelihood and effect of catastrophic risks
- cross-country distribution of these damages and risks

68. Limitations

- The analysis focuses on immediate, irreversible and self-enforcing participation to mitigation action
- Other possible bargaining options include
  - delayed participation, renegotiation, sanctions or joint negotiation in multiple areas
- For instance, a major emitting country may have greater participation incentives than found here if it expects its withdrawal to prevent the formation of *any* coalition.

69. Limitations

- The co-benefits from mitigation action, *e.g.* in terms of human health, energy security or biodiversity, are not taken into account.

- Co−benefits are large, although the participation incentives they provide are dampened by the fact that some of these co-benefits could be reaped through direct policy action

- Local air pollution might be reduced at a lower cost through direct policy action than through reductions in GHG emissions (Bollen *et al.* 2009; Burniaux *et al.* 2008).

70. Conclusions

- Ambitious (?) mitigation action is economically rational at the world level in the high-damage/low-discounting case
- “Buying-in” all emitting regions will be challenging.
- This is in line with previous literature

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