



# NOTA DI LAVORO

5.2014

---

## The Stability and Effectiveness of Climate Coalitions: A Comparative Analysis of Multiple Integrated Assessment Models

---

By **Kai Lessmann** and **Ulrike Kornek**, Potsdam Institute for Climate Impact Research (PIK)

**Valentina Bosetti**, Università Bocconi and Fondazione Eni Enrico Mattei (FEEM)

**Rob Dellink** and **Hans-Peter Weikard**, Environmental Economics and Natural Resources Group, Department of Economics, Wageningen University

**Johannes Emmerling**, Fondazione Eni Enrico Mattei (FEEM) and Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)

**Johan Eyckmans**, KU Leuven – Center for Economics and Corporate Sustainability (CEDON)

**Miyuki Nagashima**, Research Institute of Innovative Technology for the Earth

**Zili Yang**, Department of Economics, State University of New York at Binghamton

# Climate Change and Sustainable Development

Series Editor: Carlo Carraro

## The Stability and Effectiveness of Climate Coalitions: A Comparative Analysis of Multiple Integrated Assessment Models

By Kai Lessmann, Potsdam Institute for Climate Impact Research (PIK)

Ulrike Kornek, Potsdam Institute for Climate Impact Research (PIK)

Valentina Bosetti, Università Bocconi and Fondazione Eni Enrico Mattei (FEEM)

Rob Dellink, Environmental Economics and Natural Resources Group, Department of Economics, Wageningen University

Johannes Emmerling, Fondazione Eni Enrico Mattei (FEEM) and Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC)

Johan Eyckmans, KU Leuven – Center for Economics and Corporate Sustainability (CEDON)

Miyuki Nagashima, Research Institute of Innovative Technology for the Earth

Hans-Peter Weikard, Environmental Economics and Natural Resources Group, Department of Economics, Wageningen University

Zili Yang, Department of Economics, State University of New York at Binghamton

### Summary

In this paper we report results from a comparison of numerically calibrated game theoretic integrated assessment models that explore stability and performance of international coalitions for climate change mitigation. Specifically, by means of this ensemble of models we are able to identify robust results concerning incentives of nations to commit themselves to a climate agreement, and to estimate what stable agreements can achieve in terms of greenhouse gas mitigation. We also assess the potential of transfers that redistribute the surplus of cooperation in order to foster stability of climate coalitions. In contrast to much of the existing analytical game theoretical literature, we find substantial scope for self-enforcing climate coalitions in most models that close much of the abatement and welfare gap between complete absence of cooperation and full cooperation. This more positive message follows from the use of transfer schemes that are designed to counteract free riding incentives.

**Keywords:** Coalition Stability, International Environmental Agreements, Numerical modeling, Transfers

**JEL Classification:** Q5, Q58, C7

*Address for correspondence:*

Kai Lessmann

Potsdam Institute for Climate Impact Research (PIK)

PO Box 60 12 03

D-14412 Potsdam

Germany

E-mail: lessmann@pik-potsdam.de

The opinions expressed in this paper do not necessarily reflect the position of  
Fondazione Eni Enrico Mattei

Corso Magenta, 63, 20123 Milano (I), web site: [www.feem.it](http://www.feem.it), e-mail: [working.papers@feem.it](mailto:working.papers@feem.it)

1           The stability and effectiveness of climate  
2 coalitions: A comparative analysis of multiple  
3 integrated assessment models

4           Kai Lessmann\*     Ulrike Kornek\*     Valentina Bosetti†  
5           Rob Dellink‡     Johannes Emmerling§     Johan Eyckmans¶  
6           Miyuki Nagashima||     Hans-Peter Weikard‡     Zili Yang\*\*

7                                   October 2, 2013

8 **Abstract:** In this paper we report results from a comparison of numerically calibrated  
9 game theoretic integrated assessment models that explore stability and performance of  
10 international coalitions for climate change mitigation. Specifically, by means of this  
11 ensemble of models we are able to identify robust results concerning incentives of na-  
12 tions to commit themselves to a climate agreement, and to estimate what stable agree-  
13 ments can achieve in terms of greenhouse gas mitigation. We also assess the potential  
14 of transfers that redistribute the surplus of cooperation in order to foster stability of  
15 climate coalitions. In contrast to much of the existing analytical game theoretical lit-  
16 erature, we find substantial scope for self-enforcing climate coalitions in most models  
17 that close much of the abatement and welfare gap between complete absence of co-  
18 operation and full cooperation. This more positive message follows from the use of  
19 transfer schemes that are designed to counteract free riding incentives.

20 **Keywords:** coalition stability, international environmental agreements, numerical mod-  
21 eling, transfers

---

\*Potsdam Institute for Climate Impact Research (PIK), PO Box 60 12 03, D-14412 Potsdam, Germany

†Università Bocconi and Fondazione Eni Enrico Mattei (FEEM) Milan, Italy

‡Environmental Economics and Natural Resources Group, Department of Economics, Wageningen Uni-  
versity, The Netherlands

§Fondazione Eni Enrico Mattei (FEEM) and Centro Euro-Mediterraneo sui Cambiamenti Climatici  
(CMCC), Italy

¶KU Leuven – Center for Economics and Corporate Sustainability (CEDON), Warmoesberg 26, B-1000  
Brussels, Belgium

||Research Institute of Innovative Technology for the Earth, Kyoto, Japan

\*\*Department of Economics, State University of New York at Binghamton, Binghamton, New York, USA

## 22 **1 Introduction**

### 23 **1.1 Motivation**

24 This paper reports results from a comparison of models that explore international coalitions for climate policy. Specifically, these models investigate the incentives of nations  
25 to commit themselves to a climate agreement, and what makes climate agreements stable  
26 in the sense that participation is enforced by the self-interest of its members. Since  
27 climate change is a global externality and thus not fully taken into account, national  
28 actions are in general not globally efficient. How much a climate coalition improves  
29 upon this dilemma depends on the costs and benefits of the individual nations.  
30

31 All models in this study use a numerical approach to explore climate coalition  
32 formation in a cost-benefit structure that reflects real-world regions and their dynam-  
33 ics. Three topics where these numerical models give particularly valuable insights  
34 beyond those from their analytical counterparts are (i) the impact of asymmetry, i.e.  
35 the regional heterogeneity observed across the world; (ii) quantitative estimates (of the  
36 order-of-magnitudes), in particular when trade-offs leave the net effects on, say, coalition  
37 stability or free-riding incentives ambiguous; and (iii) the impact of sophisticated  
38 (non-orthogonal) reaction functions implicit in the models, for example related to the  
39 effects of carbon leakage that add to those incentives directly related to the environmen-  
40 tal externality. For these topics, both the mechanics and the calibration of the models  
41 are of central importance, but the uncertainties both within and between models are  
42 large. The strength of our comparison exercise using multiple models is threefold: it  
43 will make uncertainty more transparent, help to identify robust results across modeling  
44 assumptions and parameterizations, and enable learning from the differences.

45 Early theoretical investigations resulted in a rather pessimistic assessment of the  
46 scope of self-enforcing agreements to cope with international environmental issues. In  
47 their seminal paper Carraro and Siniscalco (1993) find stable coalitions generally to be  
48 small, and while stable coalitions may be large in the model setup of Barrett (1994),  
49 this only holds if the gains from cooperating are small. Much of the ensuing research  
50 has investigated this dilemma and ways around it; for a survey of the literature see  
51 Finus (2008) and recent advances are discussed in Fuentes-Albero and Rubio (2010).

52 Transfer payments were identified as likely game-changers, and Barrett (2001)  
53 stresses their complementarity to the asymmetry of players: together, transfers and  
54 asymmetry may well improve cooperation. But not all transfer schemes have poten-  
55 tial to improve the success of environmental agreements: transfers that do not take  
56 the strategic implications into account are unlikely to improve an agreement and even  
57 may hurt its success (Nagashima et al., 2009; Weikard et al., 2006). In fact, transfers  
58 designed specifically to make cooperation more attractive than free-riding greatly im-  
59 prove the success of coalitions (Carraro et al., 2006; Nagashima et al., 2009; Weikard,  
60 2009). Similarly, McGinty (2007) shows the beneficial effect of such transfers within  
61 the framework of Barrett (1994).

62 Recently, studies have focused specifically on the role of asymmetry: Weikard  
63 (2009) shows that higher levels of participation under such transfers are spurred by  
64 stronger asymmetry among the coalition members, including the grand coalition. This  
65 is confirmed by Fuentes-Albero and Rubio (2010) who elaborate that differences in

66 marginal damages (rather than abatement costs or the level of damages) are key to this  
67 result. While these studies firmly establish a more optimistic prospect for cooperation  
68 and highlight the importance of heterogeneity, the degree of asymmetry often remains  
69 a conceptual assumption. Notable exceptions are Carraro et al. (2006) and Nagashima  
70 et al. (2009), which rely on integrated assessment models to quantify asymmetries.

71 This paper is unique in drawing on five (new or updated) projections of the un-  
72 derlying real-world heterogeneity from integrated assessment models of different com-  
73 plexity. These models relax limitations of the more stylized models such as linearity in  
74 damages and transferable utility that are common to all studies discussed above. More  
75 importantly, their joint assessment allows us to represent the large uncertainties in the  
76 estimates of the benefits and costs of climate change mitigation.

77 Our aim is to explore the implications of real-world asymmetry for coalition stabil-  
78 ity. To this end, we assess the regional abatement costs and climate change damages  
79 in the models, and how this cost-benefit structure translates into the incentive to en-  
80 gage in a climate agreement for specific regions of the world. Our contribution is a  
81 better understanding of the well-known cooperation failure, particularly in the hetero-  
82 geneous setting provided by these numerical models. In addition, we explore the role  
83 of transfers and assess their magnitude and direction when used as a tool to enhance  
84 cooperation.

## 85 1.2 International Climate Agreements

86 Central to this study is the concept of ‘self-enforcing agreements’ or ‘coalition sta-  
87 bility.’ A climate coalition is a subset of the world’s regions that agree to cooperate  
88 on climate change mitigation policies. More specifically, we stipulate that within the  
89 coalition climate change is addressed in an efficient manner, i.e. a manner that max-  
90 imizes coalitional welfare.<sup>1</sup> The coalition adopts a joint climate policy and interacts  
91 with the remaining regions as a single player each acting selfishly with respect to the  
92 other.

93 In our comparison exercise we apply the concept of cartel stability (d’Aspremont  
94 and Gabszewicz, 1986) to all models. A coalition is considered stable if it is both inter-  
95 nally stable, meaning that no member is willing to leave the coalition, and externally  
96 stable, meaning that all non-members prefer to remain singletons. Formally, any given  
97 coalition  $S$  is stable if for the payoff of player  $i$  facing coalition  $S$ ,  $\pi_i(S)$ , we have

$$\pi_i(S) \geq \pi_i(S \setminus \{i\}) \text{ for all } i \in S, \quad \pi_j(S) \geq \pi_j(S \cup \{j\}) \text{ for all } j \notin S \quad (1)$$

98 This notion of cartel stability was first applied to international environmental agree-  
99 ments by Hoel (1992), Carraro and Siniscalco (1993), and Barrett (1994).

100 Building on this concept, we aim at exploring the drivers of cooperation. In partic-  
101 ular we also examine the effects of transfer schemes on the prospects for cooperation.  
102 We employ the concept of potential internal stability (PIS) introduced in the litera-  
103 ture on international environmental agreements for transferable utility by Carraro et al.

---

<sup>1</sup>Most models implement Pareto-efficiency through maximization of the utilitarian sum of individual welfare per region. MICA computes a market-equilibrium with full internalization of the climate change externality.

104 (2006). A coalition is said to be potentially internally stable (PIS) if there exists a  
105 transfer scheme that redistributes payoffs within the coalition such that the coalition is  
106 internally stable. Formally, PIS requires the existence of a vector of transfers  $\tau_i$  such  
107 that

$$\pi_i(S) + \tau_i \geq \pi_i(S \setminus \{i\}) \text{ for all } i \in S \quad (2)$$

108 and the sum of all transfers is zero. Note that the simple addition of transfers in condi-  
109 tion (2) is only appropriate in models with transferable utility. For models that do not  
110 assume transferable utility but feature a transferable commodity (e.g. consumption),  
111 transfers can be implemented at the commodity level. Here, a transfer scheme compris-  
112 es in a redistribution of the commodity between regions at each time period. For  
113 details of the applied procedure see Kornek et al. (2013).

114 The rest of the paper is structured as follows. An overview of the different inte-  
115 grated assessment models used in this analysis is given in section 2. Section 3 focusses  
116 on the role of transfers. Section 4 summarizes results and concludes.

## 117 2 Characterization of the Models

118 All models in this study are built upon Ramsey’s dynamic model, four of them in-  
119 clude its optimal consumption/savings decision (Ramsey, 1928). This so-called opti-  
120 mal growth framework seems particularly apt for economic models with a long time  
121 horizon as required in the assessment of climate change impacts on the economy. An  
122 early model to generalize this approach to multiple regions in an application to global  
123 warming was the RICE model (Nordhaus and Yang, 1996), which participates in this  
124 study in an updated version (Yang, 2008). Closely related is the ClimNeg World Sim-  
125 ulation (CWS) model, a modified version of the RICE model, updated to new data in  
126 its cost and damage parameters (Bréchet et al., 2011; Eyckmans and Finus, 2006; Ey-  
127 ckmans and Tulkens, 2003). The Model of International Climate Agreements (MICA)  
128 follows the same economic framework but also with different assumptions about costs  
129 and benefits. Formally, its main distinction is to include international goods markets  
130 (Lessmann and Edenhofer, 2011; Lessmann et al., 2009). The fourth model abstracts  
131 from the consumption/savings decision: the Stable Coalitions model (STACO) takes as  
132 a starting point the balancing of marginal benefits and marginal costs of emission re-  
133 ductions and builds onto this a Ramsey-type dynamic abatement structure (Nagashima  
134 et al., 2009, 2011). All four, RICE, CWS, MICA, and STACO, remain relatively styl-  
135 ized in their description of the world economy. The World Induced Technological  
136 Change model (WITCH) is a state-of-the-art integrated assessment model of global  
137 warming (Bosetti et al., 2006). In contrast to the aforementioned models, which rely  
138 on stylized abatement cost functions to model emissions reductions, WITCH incorpo-  
139 rates an explicit representation of mitigation options, particularly in the energy system.  
140 There is, of course, a trade-off: with increasing computational complexity it becomes  
141 less feasible to explore all possible climate coalitions. For WITCH, our study must  
142 therefore resort to selected coalitions.

## 143 2.1 Non-cooperative and fully cooperative equilibria

144 The five models in this study represent quite different views of the world economy.  
145 This is evident from Table 1, which documents model assumptions and basic behavior  
146 in selected numbers.

147 A key difference of the models is how they value the present against the future.  
148 Concerning monetary values such as abatement costs or climate change damages, this  
149 is expressed in the models' endogenous interest rate. Simple Ramsey models suggest  
150 that this interest rate depends on the pure rate of time preference and, if the intertem-  
151 poral elasticity of substitution is strictly positive, on consumption growth.<sup>2</sup> Table 1  
152 shows how models differ in the assumed preference parameters. Together with dif-  
153 ferent projections about productivity growth, this results in growth rates of economic  
154 output ranging from 1.2 percent to 2.1 percent per year over the first century. The pure  
155 rate of time preference is highest for MICA, WITCH, and RICE at 3 percent, and con-  
156 sequently so are the interest rates in these models (around 5 percent).<sup>3</sup> For STACO,  
157 the pure rate of time preference is lower (at 2 percent) but the (exogenous) assumption  
158 of relatively strong growth in the coming decades leads to a fairly high initial discount  
159 rate, especially for emerging economies, which slowly declines over time to values of  
160 around 3 percent, and 4.2 percent on average. Finally, in CWS the interest rate is the  
161 same as the pure rate of time preference, 1.5 percent, which is the lowest among the  
162 models.

163 In the non-cooperative equilibrium (NC), i.e. where no coalition forms, greenhouse  
164 gas (GHG) emissions are of the same order of magnitude in all models, with mod-  
165 erately lower values in MICA and RICE. Non-cooperative emission reductions a of  
166 comparable magnitude in most models (about 10 percent of emissions), and about half  
167 of that in RICE. In the social optimum, emissions are strongly reduced relative to NC  
168 within the first century (again, with the exception of RICE). In the other models, mit-  
169 igation reduces climate change damages relative to GDP by several percentage points  
170 by the end of the century. Especially in STACO and WITCH, the high damages from  
171 the non-cooperative scenario are reduced by about four percentage points. In RICE,  
172 the formation of the grand coalition leaves climate change damages almost unchanged  
173 (we will see later that low damage estimates in RICE are the likely cause for this).

## 174 2.2 Cost/benefit information

175 In this section, we introduce two metrics to characterize abatement costs and the sever-  
176 ity of climate change damages in the models, both globally and on the regional scale.  
177 Perhaps the most intuitive metric would be to compare marginal cost and marginal  
178 damage functions. However, this information is not easy to extract from or compare  
179 between all different models. Our metrics are therefore based on model output of sce-  
180 nario runs rather than assumptions regarding functional forms and parameter values.

---

<sup>2</sup>This follows from the Keynes-Ramsey rule  $\dot{c}/c = 1/\eta (r - \rho)$  with per capita consumption  $c$ , elasticity of intertemporal substitution  $\eta$  and pure rate of time preference  $\rho$ . At the interest rate  $r$  households are indifferent between one unit now or  $(1+r)$  units later.

<sup>3</sup>Specifically, the pure rates of time preference are constant in RICE and MICA, but diminish in WITCH from 3 percent initially to 2 percent over the course of a century.

Table 1: Modeling assumptions and key numbers of non-cooperative and fully cooperative model dynamics

Modeling assumptions	MICA	STACO	CWS	WITCH	RICE
Initial year	2005	2011	2000	2005	2000
Time Horizon (years)	190	95	330	145	245
Pure rate of time preference (percent)	3.0	2.0	1.5	3.0	3.0
Intertemp. elast. of subst.	1.0	–	0.0	1.0	1.0
Non-cooperative model behavior	MICA	STACO	CWS	WITCH	RICE
RICE					
Mean GDP growth rate <sup>b</sup>	2.06	1.97	1.54	1.56	1.24
Mean interest rate <sup>c</sup>	5.26	4.17	1.50	5.35	4.98
CO2 emissions (GtC) 2015-2100	1516	1827	1754	1963	1404
Non-cooperative CO2 reductions (percent) <sup>d</sup>	9.8	12.1	10.2	13.0	5.0
Mean CO2 intensity (GtC/tn\$)	0.12	0.14	0.13	0.12	0.13
Climate change damage in 2100 (percent) <sup>e</sup>	5.8	7.8	3.2	9.3	1.6
Carbon price 2100: reg. mean (\$/tC)	13	89	49	38	8
Cooperative model behavior	MICA	STACO	CWS	WITCH	RICE
CO2 emissions (GtC) 2015-2100	953	984	1094	1122	1242
Climate change damage in 2100 (percent) <sup>e</sup>	3.8	4.0	1.9	4.9	1.5
Carbon price 2100: reg. mean (\$/tC)	391	966	529	858	208
Carbon price growth rate to 2100 (percent)	1.90	1.69	0.90	1.02	1.02

a STACO derives the interest rate for discounting payoffs using the Keynes-Ramsey rule to ensure consistency with a logarithmic utility function and a pure rate of 2 per cent

b Using a time horizon of 100 years

c The endogenous rate at which monetary values are discounted in the model, averaged over regions and time

d Emission reduction in the non-cooperative scenario relative to a business-as-usual scenario without climate change damages

e Damages are reported as a share of 2100 economic product



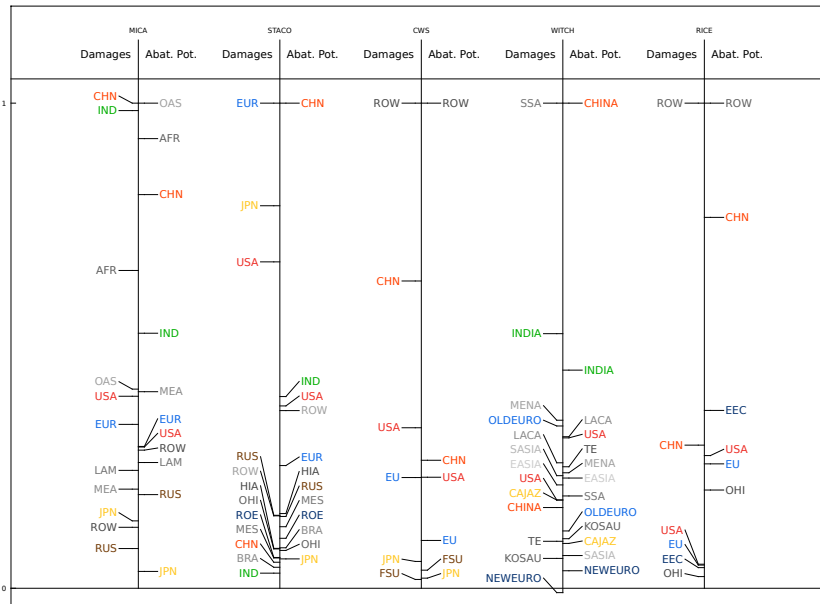


Figure 1: Abatement potential and climate change damages indicators scaled to  $[-1, 1]$ . Abatement potential was calculated by in every model a common carbon tax trajectory for all regions. The resulting abatement trajectory (measured in tons) was integrated over model’s time horizon and scaled relative to the maximum abatement level. The climate change marginal damage indicator for a particular region was calculated by taking the average of the difference in carbon price of the grand coalition and the grand coalition price of the particular region at hand. This indicator was normalized relative to the maximum average difference over all regions. Model regions are specified in Tables 7-11.

181 **Measuring regional abatement costs**

182 Regional abatement costs are inversely related to the regional reductions of emissions  
 183 at a uniform global carbon price – the higher the emissions reduction at this price, the  
 184 lower the associated average costs per unit of reduction. We therefore take cumulative  
 185 regional abatement from a common tax scenario (which results in a uniform global  
 186 carbon price) as an indicator for a region’s abatement potential.<sup>4</sup>

187 Figure 1 shows for each model the abatement potential indicator, i.e. the abatement  
 188 undergone by each region in the tax scenario normalized to the maximum abatement

<sup>4</sup>For the common tax scenario, all models implement the same global emissions tax trajectory while climate change damages were disabled. The cumulative abatement is the absolute emissions reduction, summed over the models time horizon. We find the global abatement potential to be largest in case of STACO, followed by MICA, CWS, WITCH, and RICE in declining order. The range of costs is large: in WITCH and RICE only about two thirds of the abatement triggered in STACO is achieved. Still, abatement costs are in the same order of magnitude for all five models.

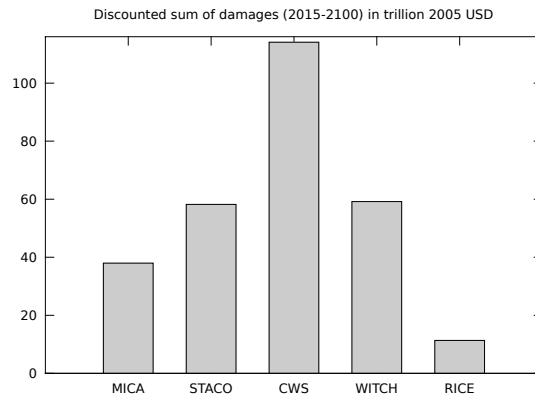


Figure 2: Aggregate total damages 2015–2100 (discounted) in the non-cooperative scenario (NC)

189 level over all regions. The indicator shows, for example, that China and India always  
 190 rank high on abatement potential while for Japan the mitigation costs are perceived to  
 191 be among the largest. We will use the information from this table extensively when dis-  
 192 cussing the main objectives of this note: incentives of specific regions to join a climate  
 193 agreement and the characterization of transfers. In general, one can say that the models  
 194 seem to be in good agreement about their assumptions on the costs of abatement.

195 **Measuring climate change damages**

196 Figure 2 compares aggregate discounted damages (total, not marginal) in the non-  
 197 cooperative equilibrium across models. Of course, the underlying dynamics of the  
 198 models are quite different as discussed above: different temperature profiles, economic  
 199 growth and damage assumptions lead to the dissimilarities in the bars. The figure nev-  
 200 ertheless highlights the fact that the damage calibration is low in RICE, resulting to a  
 201 relatively low carbon price in the cooperative scenario (see Table 1).<sup>5</sup>

202 In order to compare the marginal damages from climate change between regions for  
 203 each model, we take a slightly different approach than the total damages shown in Fig-  
 204 ure 2. Instead, we identify those regions as exhibiting higher marginal damages from  
 205 climate change that strongly raise the carbon price when joining the grand coalition.  
 206 The impact on the coalitional carbon price is a good indicator for the way that a joining  
 207 region suffers from climate externalities because by definition these externalities are  
 208 now internalized in the grand coalition’s carbon price.

209 To normalize, we take the average of the difference in discounted carbon prices  
 210 before and after the grand coalition is completed by a joining region. The resulting

<sup>5</sup>It should be noted that the STACO model considers only benefits from abatement and results do not rely on the level of damages. Thus, the STACO model is consistent with different damage estimates. The damage value shown here is based on the assumption that for low levels of temperature change, there are net gains from climate change.

211 measure, normalized to the maximal difference over all regions, is shown in Figure 1  
212 next to the indicator for abatement potential discussed before.

213 One can see that the assumptions on which players would incur the highest marginal  
214 damages from climate change differ greatly between the models. Each model sees  
215 a different player to be ranking highest. These differences concerning the marginal  
216 damage assumptions will be a main driver of the results of the comparison. We will  
217 highlight this point in the separate analyses hereafter.

218 The characterization of regions in Figure 1 will subsequently be used for describing  
219 their behavior in the coalitions.

### 220 **2.3 Incentives of regions**

221 The different assumptions about model structure and regional characteristics outlined  
222 in the previous sections jointly determine the strategic behavior of the regions. This  
223 section looks at the incentive of regions to participate in a climate coalition.

224 The incentive to remain in a coalition is described by the incentive to stay, which  
225 is defined as the payoff received as a member of a given coalition minus the payoff  
226 outside the coalition (i.e. as a free-riding non-member). For the following discussion,  
227 we want to structure the driving forces that determine the incentive to stay for a given  
228 region in the following way:

229 1. First, the benefit of joining the coalition for this region, which is in turn influ-  
230 enced by

231 (a) the extent of the externality in this region. When a player joins, this player's  
232 externality is henceforth internalized by all coalition members. Thus, the  
233 higher the marginal damages in the joining region, the more the coalition  
234 abates as a whole. This positive effect is enforced, as a high marginal  
235 damage region benefits all the more from additional abatement.

236 (b) the reaction functions of the non-members. The free-riding non-members  
237 may raise their emissions in reaction to the reduced emissions of the coaliti-  
238 on. Such leakage emissions offset the abatement of the coalition and  
239 therefore have a negative impact on the benefit of joining.

240 2. Second, the additional costs incurred by this region upon joining the coalitions.  
241 We distinguish the abatement costs of a coalition member and other opportunity  
242 costs

243 (a) Abatement costs are a result of the distribution of emission reductions  
244 which are determined by efficiency in abatement (i.e. the lower the marginal  
245 costs, the more a region needs to do), and the overall ambition of the coaliti-  
246 on, which depends on the collective marginal climate change damages of  
247 all coalition members.

248 (b) Other opportunity costs emerge when regions are coupled through more  
249 channels than just the externality. For example, when carbon pricing affects  
250 the world demand for fossil resources, net exporters of resources will take

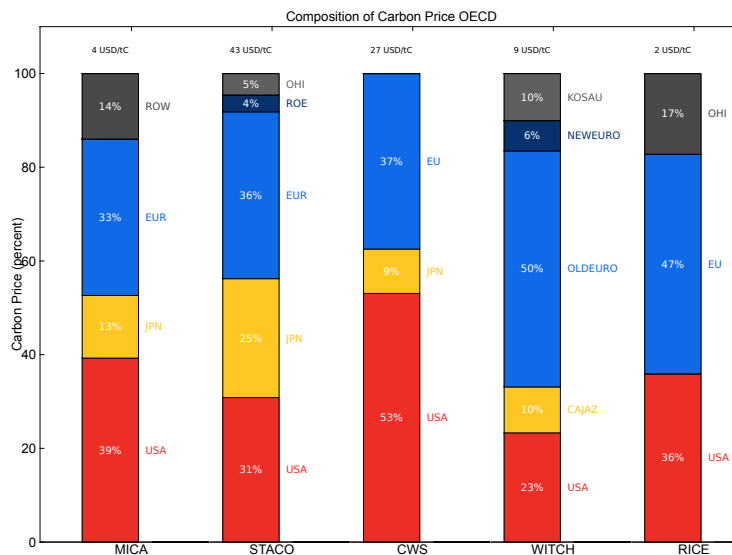


Figure 3: Carbon price in the OECD coalition (as average net present value). Percentages indicate how climate change damages in the member regions contribute to the overall carbon price.

251                   the effect of participating in a coalition on their fossil resource revenues  
 252                   into account.

253                   Some of these drivers of stability were covered above (i.e. in the discussion of  
 254 models' assumption on costs and benefits) and are summarized in Figure 1. Before  
 255 we take a look at the incentives, we discuss the distribution of damages, emissions  
 256 abatement and emission leakage exemplary for the coalition of OECD countries. This  
 257 coalition is one of the few larger coalitions that can be described in all models. Still,  
 258 in some cases, we include "mixed" regions of OECD and non-OECD countries. The  
 259 guiding criterion was whether more than half of the region's economic output was  
 260 achieved by OECD countries.

### 261 **Distribution of Damages**

262                   The extent to which a region benefits from abatement is measured via the carbon price  
 263 (see discussion of Figure 1). Figure 3 reports the average net present value carbon  
 264 price of the first century for each model within the OECD and how individual members  
 265 contribute to it: when a player leaves this coalition, by what percentage does the price  
 266 decrease?<sup>6</sup>

<sup>6</sup>Since marginal damages are not entirely flat in all models, this procedure is just an approximation of the decomposition of the cooperative carbon price but since the abatement of the OECD coalition is unambitious

267 The absolute level of the carbon price, given above each bar, shows differences in  
268 the ambition in emissions reduction that this coalition will have across models. While  
269 for STACO the OECD coalition consists of regions with high damages leading to a  
270 very high carbon price, the OECD coalition is much less ambitious e.g. in MICA, and  
271 hence free-riding on the OECD is much less attractive in this model.

272 Second, for the OECD-countries, models agree relatively well who contributes the  
273 most to damages: both the USA and Europe score high in every model, and Japan plays  
274 a minor role (except in STACO). From the benefit side, these two players therefore gain  
275 much from the abatement undergone in the coalition. However, one has additionally to  
276 consider their burden from abatement when joining the agreement to determine their  
277 net benefit, which we turn to next.

## 278 **Distribution of Abatement**

279 There are numerous ways to distribute the overall abatement among the members of a  
280 climate coalition. Criteria that guide this decision may, for example, be normative or  
281 pragmatic criteria, or incentive compatibility considerations. The default distribution  
282 of abatement in coalition models is driven by efficiency in the sense of maximizing  
283 the social welfare function of the coalition.<sup>7</sup> Efficiency determines first and foremost  
284 where how much of the emission reductions ought to be achieved to be efficient. This  
285 approach was taken for the models participating in this exercise.

286 For the OECD coalition, Figure 4 shows that its total abatement over the first centu-  
287 ries is quite different across models (model regions are specified in Tables 7-11). This  
288 is in part because not quite the same countries are covered. But since differences turn  
289 out to be large even when regions are identical (e.g. in case of single country regions),  
290 we conclude that a large part of the differences is due to different cost and benefit as-  
291 sumptions resulting in different carbon prices of the coalition as well the associated  
292 abatement potential of its members.

293 The distribution of abatement is diverse across models, e.g. the share of USA falls  
294 anywhere within the range 20-60 percent, for Japan within 1-18 percent, and for Eu-  
295 rope within 10-30 percent. The large differences in the cost-benefit assumptions also  
296 translate to the efficient burden sharing schemes. All models agree, however, that the  
297 largest share of abatement ought to be achieved in the USA, often followed by Europe.<sup>8</sup>

## 298 **Leakage Emissions**

299 Leakage is the reaction of non-members to the coalition's behavior in terms of in-  
300 creased emissions. As such, we can only discuss leakage for incomplete cooperation,  
301 and this section therefore focuses on the OECD coalition.

302 The sensitivity of the reaction functions depends largely on model features that  
303 determine the ways in which non-members are affected by the coalition.

---

and therefore leakage is small, the error is negligible.

<sup>7</sup>Some models use a weighted sum in the social welfare function, see footnote , hence emission choices are Pareto-efficient.

<sup>8</sup>In MICA, the largest share falls onto the rest-of-the-world region, which includes several non-OECD countries and therefore plays a special role.

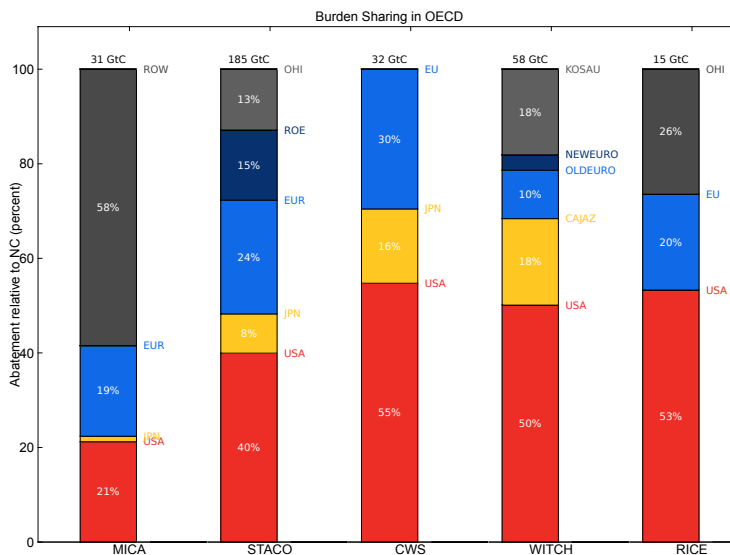


Figure 4: Allocation of emission reductions in the OECD coalition as percentages of overall emissions reduction (time horizon is a century)

304 On the one extreme, there is zero leakage in STACO. This is a consequence of as-  
 305 suming constant marginal damages, which implies that abatement is chosen indepen-  
 306 dently in the regions. In all other models, the regions react to the abatement decisions  
 307 of the others.

308 MICA, CWS, and RICE show only very moderate leakage: for these models, leak-  
 309 age emissions per region are less than one percent of the coalition's abatement.

310 Regions in WITCH show the strongest free-riding behavior in terms of leakage,  
 311 with total leakage emissions of 16 percent of the OECD's abatement. In WITCH, the  
 312 coalition affects non-members through an additional channel, namely energy markets  
 313 (see Bosetti and De Cian, 2013, for details). A coalition drives down oil prices and  
 314 free-riders increase their consumption especially of the carbon-intensive oil grades. In  
 315 addition, climate change damages are especially high in WITCH.

### 316 Incentives

317 The interplay of all the drivers discussed above jointly determines the incentive to join  
 318 or leave a given coalition. We consider the OECD coalition and the grand coalition in  
 319 turn.

320 Figure 5 shows the incentive to stay inside the OECD coalition for all its members.  
 321 If the incentive to stay was positive for all members, the coalition would be internally  
 322 stable. Conversely, the figure shows which regions are responsible when the OECD

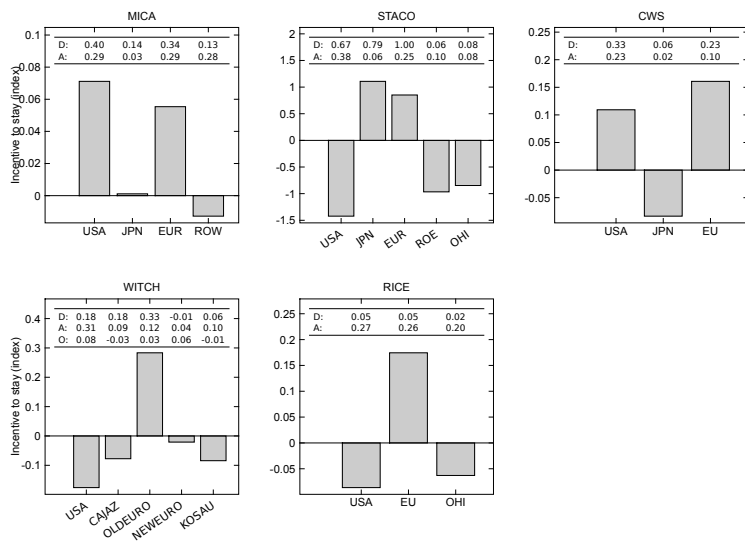


Figure 5: Incentive to stay in the OECD coalition, calculated as the difference of inside and outside payoff and scaled to the gap in global aggregated payoff between no cooperation (=0) and full cooperation (=100). The inset tables list the regional indicators for climate change damages and abatement potential, denoted 'D' and 'A', respectively.

323 coalition fails to be internally stable in any of the models. For easy reference, the indi-  
324 cators of abatement potential and climate change damages from Figure 1 are repeated  
325 in Figure 5.

326 While all models agree that the OECD coalition is not stable, they identify different  
327 culprits. For example, while the USA player would support the OECD coalition in  
328 MICA and CWS, the other three models, STACO, WITCH, and RICE, indicate a strong  
329 incentive to leave for this region. In the following, we will use the major players in the  
330 OECD coalition (USA, Europe, and Japan) as examples to explain how the drivers  
331 discussed above interact to form the incentive to join or leave the coalition.

332 The USA have a strong motivation to defect from the OECD coalition: their es-  
333 timated abatement potential is the highest of all OECD players in all models but one  
334 where it is second to only one other region (to ROW in MICA). This implies that the  
335 USA would carry a large burden of the emission reductions in this coalition and would  
336 not join for this reason, which is what three of the models find (STACO, WITCH, and  
337 RICE). This is overcompensated by the large gains for the USA in this coalition in  
338 the remaining models (MICA and CWS), where the USA incur the highest marginal  
339 damages of all coalition members and thus has an incentive to remain in the coalition.  
340 In these two models it also helps that the ambition level of the OECD coalition is low,  
341 implying a low burden for its members as most high marginal damage regions are out-  
342 side the OECD coalition. Conversely, none of the models estimates an incentive for the  
343 USA to stay in the grand coalition where joint climate change damages imply a much  
344 higher burden (not shown).

345 The incentives of Europe (in the sense of EU-15 countries due to model aggrega-  
346 tion, i.e. regions EUR, EU, and OLDEURO) are a relatively simple case: in all models  
347 Europe is a typical happy coalition member, characterized by relatively high marginal  
348 damages and low abatement potential. Such players have much to gain from coopera-  
349 tion, but pay little as their burden share remains small. The models therefore agree that  
350 Europe would want to remain in the OECD coalition.

351 Japan is modeled as a single country region except for WITCH, where it is part of  
352 Canada/Japan/New Zealand (CAJAZ), and in RICE. The models unanimously see little  
353 abatement potential in Japan by itself. Thus Japan would carry only a small burden,  
354 which makes it better off in MICA and STACO. In CWS, the estimated marginal dam-  
355 ages are also very low for Japan. Japan can therefore defect (and save on abatement  
356 costs) without substantially lowering the ambition level of the coalition, which turns  
357 out to be preferential. The larger aggregate region CAJAZ of WITCH incurs substan-  
358 tial abatement costs, tipping the balance towards defection as marginal damages are  
359 only average compared to the other OECD players.

360 Going from the OECD coalition to the grand coalition, positive net incentives to  
361 join become rare (not shown). Of course, this is a consequence of more ambitious  
362 emission reductions in this coalition, which places a larger burden on all members.  
363 The few exceptions are either of the high damage/low burden type discussed above (e.g.  
364 Japan and Europe in STACO, and SSA in WITCH) or very large players (ROW in CWS  
365 and RICE), which aggregate a lot of the world's damages and abatement potential due  
366 to their sheer size. In WITCH, an additional driver of incentives becomes important  
367 for very ambitious coalitions: here, in contrast to other models, net revenues from  
368 trade in oil are part of the region's income. Coalitions that strongly abate emissions



369 consume substantially less oil leading to a price drop which increases the outsiders’  
370 consumption. Therefore oil-rich regions, while cutting their own oil consumption when  
371 joining the coalition, receive large revenues. Interestingly, extraction does not change  
372 very much and also the price differences are only minor. However, the pattern of  
373 consumption changes between the different grades of oil leading to increased exports  
374 of low carbon intensive ones. The top three regions that show the strongest increase  
375 in oil revenues (MENA, TE, and SSA) are the three players that prefer to stay in the  
376 grand coalition while this effect is negative for CAJAZ and KOSAU.

### 377 **3 Transfers**

#### 378 **3.1 Stable coalitions in IES, IS, and PIS**

379 In this section, we consider the three stability concepts defined in the introduction:  
380 internal/external stability (IES), internal stability (IS), and potential internal stability  
381 (PIS).<sup>9,10</sup> Table 2 reports the number of stable coalitions for each stability concept,  
382 along with maximum coalition size, maximum abatement achieved and maximum welfare  
383 achieved. For the latter two, we use the closing the gap indicator to characterize  
384 the performance of coalitions, which relates global emission reductions (“environmen-  
385 tal effectiveness”) and welfare to the gap between the non-cooperative scenario –set to  
386 zero– and to full cooperation, set to unity (cf. Eyckmans and Finus, 2007).

387 Not surprisingly, coalitions that are IES without transfers are small and achieve  
388 little, which is in line with the existing literature. RICE and CWS are interesting ex-  
389 ceptions: here the best IES coalitions achieve 33 and 77 percent of the global welfare  
390 gains of the GC, respectively. For CWS, this is caused by the very large region ROW  
391 which enables even a two player coalition to achieve much. The best performing coal-  
392 ition that does not include ROW achieves only a closing the gap indicator for welfare  
393 of 21 percent.

394 When we focus on IS, more coalitions are stable, and the performance improves.  
395 We want to highlight two interesting observations: (i) participation remains almost  
396 unchanged (with the only exception of an increase from 3 to 4 players in one model,  
397 MICA), and (ii) the performance improvement of IS coalitions over IES coalitions is  
398 substantial for some models, and negligible in others.

399 Introducing the transfers that are implicit in PIS has a strong impact: the number  
400 of stable coalitions increases by 1-2 orders of magnitude, and the corresponding im-  
401 provement in the closing the gap indicators is also large. Three of the models find that  
402 the grand coalition is PIS, the other two “close the gap” about half. When superaddi-  
403 tivity prevails (e.g. in STACO), the PIS coalition generating the highest global welfare  
404 is not only IS after receiving the implied transfers but also externally stable (ES) and  
405 hence IES (Eyckmans et al., 2010). In other words, the model comparison shows that  
406 transfers exist that make it possible to stabilize coalitions that close the welfare gap  
407 substantially. This is a considerably more optimistic message than the traditional con-

<sup>9</sup>The analysis could be extended to include blocking power (or core stability).

<sup>10</sup>For the models WITCH and RICE, the consumption discount rate was fixed at the one inside the coal-  
tion, which leaves the optimization procedure from Kornek et al. (2013) very constraint.

Table 2: Stable coalitions for internal/external stability and potential internal stability.

Model	Concept <sup>a</sup>	Number stable	Max. size	Max. abat. <sup>b</sup>	Max. welf. <sup>c</sup>
MICA	IES	1 (0.05%)	3	0.06	0.09
	IS	54 (2.64%)	4	0.17	0.24
	PIS	480 (23.45%)	6	0.31	0.47
STACO	IES	1 (0.02%)	2	0.03	0.03
	IS	23 (0.56%)	2	0.07	0.07
	PIS	2142 (52.31%)	9	0.59	0.68
CWS	IES	1 (1.59%)	2	0.67	0.77
	IS	5 (7.94%)	2	0.67	0.77
	PIS	61 (96.83%)	6	1.00	1.00
WITCH <sup>d</sup>	IES	1	2	0.03	0.05
	IS	1	2	0.03	0.05
	PIS <sup>e</sup>	5	4	0.17	0.38
RICE	IES	0 (0.00%)			
	IS	3 (4.76%)	2	0.03	0.06
	PIS <sup>e</sup>	7 (11.11%)	2	0.12	0.11

a Stability concepts are abbreviated IES (internal/external stability), IS (internal stability), and PIS (potential internal stability)

b The maximum global abatement achieved by a coalition is measured by the *closing the gap* indicator from 0=no-cooperation to 1=full-cooperation.

c Maximum global welfare is measured by the *closing the gap* indicator.

d In WITCH, only seven selected coalitions were analyzed.

e For the maximization procedure, the discount-rate was held fixed at the level of the PANE-solution.

Table 3: Permit allocation schemes. The permit allocation for a coalition  $S$  is determined as follows: each member  $i$  of  $S$  receives  $q_{it} = \omega_{it} \cdot Q_t$  where  $Q_t = \sum_{j \in S} e_{jt}$  are the available permits within  $S$ . Population, emissions and economic product are abbreviated pop,  $e$ , and  $y$ .

Scheme	Distribution key
Egalitarian	$\omega_{it} = \text{pop}_{it} / \sum_{j \in S} \text{pop}_{jt}$
Grandfathering	$\omega_{it} = e_{i,t_0} / \sum_{j \in S} e_{j,t_0}$
Quota Nash	$\omega_{it} = e_{it}^{NC} / \sum_{j \in S} e_{jt}^{NC}$
Quota BAU	$\omega_{it} = e_{it}^{ND} / \sum_{j \in S} e_{jt}^{ND}$
Historic responsibility	$\omega_{it} = (e_{it}^{ND})^{-1} / \sum_{j \in S} (e_{jt}^{ND})^{-1}$
Ability to pay	$\omega_{it} = (y_{it} / \text{pop}_{it})^{-1} / \sum_{j \in S} (y_{jt} / \text{pop}_{jt})^{-1}$
Ability to pollute	$\omega_{it} = (e_{it} / \text{pop}_{it})^{-1} / \sum_{j \in S} (e_{jt} / \text{pop}_{jt})^{-1}$
Energy efficiency	$\omega_{it} = (e_{it} / y_{it})^{-1} / \sum_{j \in S} (e_{jt} / y_{jt})^{-1}$

408 clusion derived from analytical models so far. In addition, our multi-model approach  
 409 allows us to conclude that this claim is robust with respect to modeling approaches and  
 410 parameterizations.

### 411 3.2 Transfers and stable coalitions

412 The previous section already introduced PIS, which implicitly relies on transfers that  
 413 are designed to make coalitions internally stable wherever this is possible by an ex post  
 414 reallocation of payoff within the coalition. We complement this “incentive driven”  
 415 transfer scheme by a list of “conventional” transfers implicitly defined by burden shar-  
 416 ing rules (Table 3). In contrast, these allocation rules are designed to be either eq-  
 417 uitable or pragmatic. The schemes in Table 3 are taken from Altamirano-Cabrera and  
 418 Finus (2006). To evaluate how burden sharing affects stability of coalitions, we convert  
 419 permit allocations to monetary transfers using the carbon price of the coalition. The  
 420 monetary transfers are added either to the consumption streams or payoff (in case of  
 421 STACO).<sup>11</sup>

#### 422 How do conventional transfers affect stability?

423 In a first look at the implications of the conventional transfer schemes, we analyze how  
 424 a selection of four schemes from Table 3 affects internal stability (IS). Table 4 reports  
 425 the number of IS coalitions under these transfers and how this number changes relative  
 426 to the scenario without transfers.

<sup>11</sup>In two models, there is no single carbon price within the coalition (WITCH and RICE) because maxi-  
 mization of social welfare for the coalition balances marginal value of emissions in terms of utility but not  
 monetary units. This is different in MICA (where international trade balances marginal utility of consump-  
 tion) and CWS (which uses a linear utility function). In WITCH and RICE, we use the social cost of carbon  
 for the conversion instead (computed as the marginal utility of carbon inside coalition divided by the average  
 per-capita consumption inside the coalition).

Table 4: How transfers affect coalition stability.

Transfer: Model	grandfathering coal <sup>a</sup>	$\Delta$ coal <sup>b</sup>	egalitarian coal <sup>a</sup>	$\Delta$ coal <sup>b</sup>	historic responsibility coal <sup>a</sup>	$\Delta$ coal <sup>b</sup>	ability to pay coal <sup>a</sup>	$\Delta$ coal <sup>b</sup>
MICA	6	-48	4	-50	5	-49	4	-50
STACO	3	-20	9	-14	0	-23	11	-12
CWS	16	11	0	-5	0	-5	3	-2
WITCH <sup>c</sup>	1	0	0	-1	0	-1	1	0
RICE	1	-2	0	-3	0	-3	0	-3

a Number of internally stable coalitions

b Number of internally stable coalitions relative to no-transfers

c Only selected coalition were analyzed in WITCH

427 The main conclusion is that transfer schemes that were designed without coalition  
428 stability in mind have an adverse effect on stability almost unanimously. This is evident  
429 from the decrease in the number of IS coalitions (cf. the almost exclusively negative  
430 numbers in the column  $\Delta\text{coal}$ ). An exception is “grandfathering” in CWS.

### 431 **Why do conventional transfer schemes fail to induce stability? (A comparison** 432 **with PIS-transfers)**

433 As we have seen above, the conventional transfer schemes fail to induce much stability  
434 in any model. In Table 5 we compare two additional statistics of the transfer schemes  
435 to the PIS-transfers in order to track the precise reasons for this in more detail.

436 The first column of each model displays the share of PIS coalitions where the sign  
437 of transfers coincides with PIS transfers, i.e. players that need a positive transfer are  
438 receivers, and players with a surplus according to PIS have to pay. Hence by definition,  
439 PIS transfers reach the perfect score of 100 percent and other transfers score lower.

440 We find that most conventional transfer schemes stay well below 100 percent for  
441 this indicator, getting the sign of the required transfer right only about half of the time.  
442 There are positive exceptions for four of the models (MICA, STACO, CWS, RICE),  
443 however the models disagree which of the transfer scheme performs best. This is due  
444 to the fact that these models significantly differ in the damage assumptions of players.  
445 Therefore the directions of PIS-transfers differ greatly.

446 The second column displays the average flow of money between the regions across  
447 the ensemble. PIS transfers are roughly in the order of magnitude of the “quota bau”  
448 and “grandfathering”. These two often also perform well for the direction indicator.

449 Thus, we have identified two problems of the conventional transfer schemes with  
450 respect to their negative effect on stability, namely the direction of the induced transfers  
451 and their magnitude. In view of these indicators, transfers that are based on business  
452 as usual (e.g. BAU Quota and Grandfathering) seem to do better than others. Espe-  
453 cially when looking at the magnitude of all transfers listed in the table, there is great  
454 agreement that stability-enhancing PIS-transfers only demand relatively low flows of  
455 money.

### 456 **How do PIS transfer schemes depend on the properties of coalition members?**

457 In this section, we characterize the PIS transfers that induce stability. To this end, we  
458 consider all coalitions in the ensemble and relate properties of coalition members (as  
459 given by the indicators abatement potential and damages from the model characteriza-  
460 tion) to the frequency with which they receive a positive transfer (Table 6).

461 Table 6 shows the correlation coefficient of the percentage of coalitions in which  
462 a player receives positive transfers to abatement potential, damages, and the ratio of  
463 damages to abatement potential.<sup>12</sup>

464 We find that there is significant agreement among the models that the more damages  
465 a region incurs from climate change, the more likely it will be that this region has  
466 a surplus to share with other members, i.e. PIS transfers will be negative (column 2).

<sup>12</sup>The significance of the one-sided correlation is indicated with a “\*” for the p=0.05 level and a “\*\*\*” for the p=0.01 level.

Table 5: Permit transfer schemes compared to PIS-transfer schemes

Transfer	MICA		STACO		CWS		WITCH		RICE	
	Direc- tion	Magni- tude	Direc- tion	Magni- tude	Direc- tion	Magni- tude	Direc- tion	Magni- tude	Direc- tion	Magni- tude
PIS-transfer	100	0.019	100	2.662	100	8.334	100	0.239	100	0.002
egalitarian	48	0.232	55	1.529	33	16.574	23	0.383	21	0.044
historic responsibility	71	0.544	56	3.946	71	52.702	54	1.511	64	0.144
grandfathering	50	0.166	40	0.861	72	10.941	54	0.279	50	0.008
quota bau	63	0.025	53	0.194	40	3.212	46	0.096	79	0.001
ability to pay	67	0.409	74	2.755	55	23.075	8	0.542	50	0.103

Table 6: Characterization of PIS transfers with properties of players

	Percentage of positive transfer received		
	Abatement Potential	Damages	Damages/ Abatement
MICA	-0.502	-0.802 **	-0.593
STACO	0.117	-0.918 **	-0.771 **
CWS	-0.857*	-0.914*	-0.114
WITCH	0.499	0.273	0.078
RICE	-0.014	-0.186	-0.357

467 The other two indicators do not give rise to significant correlation although the numbers  
 468 still indicate the same sign of the relationship in most cases.

## 469 4 Summary and Conclusions

470 In this study, we compared five structurally different models and make the modeling  
 471 assumptions on the costs and benefits of climate change mitigation comparable through  
 472 two indicators measuring (a) the regional abatement potential and (b) regional expo-  
 473 sure to climate change damages. While the models' estimates for abatement potentials  
 474 are in agreement for key world regions, we find large differences in the climate change  
 475 damage estimates that the models prescribe for certain regions. To a large extent, the  
 476 differences reflect the variations in the literature sources that the model parametriza-  
 477 tions are based on and therefore reflect the uncertainty about costs and benefits of  
 478 climate change mitigation in the literature (cf. Metz et al., 2007).

479 It is therefore not surprising that the models differ in their assessment whether cer-  
 480 tain coalitions are stable, and whether certain world regions or nations have an incentive  
 481 to be members of a given coalition. (A notable exception is the assessment of the EU,  
 482 for which the models unanimously attest an incentive to support a coalition of OECD  
 483 countries.) However, when we abstract from the identity of the players and instead  
 484 consider their cost-benefit characteristics in terms of the two indicators suggested in  
 485 this study, the models are remarkably consistent in their predictions. We find that the  
 486 indicators of a region's abatement potential and its exposure to climate change dam-  
 487 ages capture much of its incentives and allow us to understand the regions membership  
 488 preference for or against membership in a coalition. When either abatement potential  
 489 is low (implying a steep marginal abatement cost function) or marginal climate change  
 490 damages are high in a region, the likelihood for a positive incentive to stay is higher.

491 In absence of transfers, all models agree that stable coalitions tend to be small and  
 492 achieve little, due to a lack of internal stability of larger, more ambitious coalitions.  
 493 This is in accordance with the theoretical literature and therefore not surprising.

494 Transfers designed to minimize free riding incentives as much as possible achieve  
 495 much more: the models find that PIS coalitions are substantially larger and achieve  
 496 about half or more of what full cooperation would achieve both in welfare and GHG  
 497 abatement terms.

498 In contrast, conventional transfers do not improve cooperation, they often even un-  
499 dermine existing stable coalitions. The reason is, of course, that conventional transfers  
500 are not reflecting incentives: among other things they frequently induce transfers that  
501 are (a) too large in their magnitude and (b) transfer wealth in the wrong direction, i.e.  
502 regions that need transfers to be convinced to stay in a coalition are made to pay regions  
503 that have no incentive to defect from the coalition.

504 Finally, we examine how the properties of coalition members affect the PIS trans-  
505 fers necessary to stabilize the coalition. We find that players with high damages tend  
506 to benefit enough from cooperation such that they can share some of these gains.

507 The last two findings seem to be robust across the different specifications of the  
508 models concerning how an incentive-based transfer scheme should be designed and  
509 that its implementation will increase cooperation greatly. On the one hand, its mag-  
510 nitude is comparable to allocation schemes based on historic emissions; the financial  
511 flows demanded are therefore comparably small. On the other hand, players with high  
512 damages from climate change are eligible for compensating those players with high  
513 abatement potential that provide the necessary mitigation.

#### 514 **Acknowledgements**

515 We would like to thank all participants of the two workshops that led to this model  
516 comparison (Potsdam 8-9th of February, 2012, and Venice, 24-25th of January, 2013).  
517 We also benefited from feedback to presentations of the manuscript at Grantham Insti-  
518 tute, LSE, at IGIER, Bocconi, and at the EAERE2013 conference, which is gratefully  
519 acknowledged. Ingram Jackard contributed to the review of numerical coalition models  
520 an preparation of the initial workshop.

#### 521 **References**

- 522 Altamirano-Cabrera, J. and Finus, M. (2006). Permit trading and stability of interna-  
523 tional climate agreements. *Journal of Applied Economics*, 9(1):19–47.
- 524 Barrett, S. (1994). Self-enforcing international environmental agreements. *Oxford*  
525 *Economic Papers*, 46:878–894.
- 526 Barrett, S. (2001). International cooperation for sale. *European Economic Review*,  
527 45(10):1835–1850.
- 528 Bosetti, V., Carraro, C., Galeotti, M., Massetti, E., and Tavoni, M. (2006). WITCH:  
529 A World Induced Technical Change Hybrid model. *The Energy Journal*, Special  
530 Issue Hybrid Modelling of Energy Environment Policies: Reconciling Bottom-up  
531 and Top-down:13–38.
- 532 Bosetti, V. and De Cian, E. (2013). A good opening: the key to make the most of  
533 unilateral climate action. *Environmental and Resource Economics*, pages 1–22.
- 534 Bréchet, T., Gerard, F., and Tulkens, H. (2011). Efficiency vs. stability in climate  
535 coalitions: a conceptual and computational appraisal. *Energy Journal*, 32(1):49.



- 536 Carraro, C., Eyckmans, J., and Finus, M. (2006). Optimal transfers and participation  
537 decisions in international environmental agreements. *Review of International Orga-*  
538 *nizations*, 1(4):379–96.
- 539 Carraro, C. and Siniscalco, D. (1993). Strategies for the international protection of the  
540 environment. *Journal of Public Economics*, 52(3):309–328.
- 541 d’Aspremont, C. and Gabszewicz, J. J. (1986). *New Developments in the analysis of*  
542 *market structures*, chapter On the stability of collusion, pages 243–64. Macmillan,  
543 New York.
- 544 Eyckmans, J. and Finus, M. (2006). Coalition formation in a global warming game:  
545 how the design of protocols affects the success of environmental treaty-making. *Nat-*  
546 *ural Resource Modeling*, 19(3):323–358.
- 547 Eyckmans, J. and Finus, M. (2007). Measures to enhance the success of global climate  
548 treaties. *International Environmental Agreements: Politics, Law and Economics*,  
549 7(1):73–97.
- 550 Eyckmans, J., Finus, M., and Mallozzy, L. (2010). A new class of welfare maximizing  
551 stable sharing rules for partition function games with externalities. Working Paper.  
552 Department of Economics, University of Bath.
- 553 Eyckmans, J. and Tulkens, H. (2003). Simulating coalitionally stable burden shar-  
554 ing agreements for the climate change problem. *Resource and Energy Economics*,  
555 25:299–327.
- 556 Finus, M. (2008). Game theoretic research on the design of international environmental  
557 agreements: Insights, critical remarks, and future challenges. *International Review*  
558 *of Environmental and Resource Economics*, 2:29–67.
- 559 Fuentes-Albero, C. and Rubio, S. J. (2010). Can international environmental coopera-  
560 tion be bought? *European Journal of Operational Research*, 202(1):255–264.
- 561 Hoel, M. (1992). International environment conventions: The case of uniform reduc-  
562 tions of emissions. *Environmental and Resource Economics*, 2(2):141–159.
- 563 Kornek, U., Lessmann, K., and Tulkens, H. (2013). NTU implementations of PIS and  
564 core stability. Working Paper available upon request.
- 565 Lessmann, K. and Edenhofer, O. (2011). Research cooperation and international stan-  
566 dards in a model of coalition stability. *Resource and Energy Economics*, 33(1):36–  
567 54.
- 568 Lessmann, K., Marschinski, R., and Edenhofer, O. (2009). The effects of tariffs  
569 on coalition formation in a dynamic global warming game. *Economic Modelling*,  
570 26(3):641–649.
- 571 McGinty, M. (2007). International environmental agreements among asymmetric na-  
572 tions. *Oxford Economic Papers*, 59(1):45–62.

- 573 Metz, B., Davidson, O., Bosch, P., Dave, R., and Meyer, L., editors (2007). *Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental*  
574 *Panel on Climate Change*. Cambridge University Press, Cambridge, United King-  
575 *dom and New York, NY, USA.*  
576
- 577 Nagashima, M., Dellink, R., Van Ierland, E., and Weikard, H. (2009). Stability of in-  
578 *ternational climate coalitions—a comparison of transfer schemes. Ecological Eco-*  
579 *nomics*, 68(5):1476–1487.
- 580 Nagashima, M., Weikard, H., de Bruin, K., and Dellink, R. (2011). International cli-  
581 *mate agreements under induced technological change. Metroeconomica*, 62(4):612–  
582 *634.*
- 583 Nordhaus, W. D. and Yang, Z. (1996). A regional dynamic general-equilibrium  
584 *model of alternative climate-change strategies. The American Economic Review*,  
585 *86(4):741–765.*
- 586 Ramsey, F. (1928). A mathematical theory of saving. *Economic Journal*, 38:543–559.
- 587 Weikard, H. (2009). Cartel stability under an optimal sharing rule. *The Manchester*  
588 *School*, 77(5):575–593.
- 589 Weikard, H., Finus, M., and Altamirano-Cabrera, J. (2006). The impact of surplus shar-  
590 *ing on the stability of international climate agreements. Oxford Economic Papers*,  
591 *58(2):209–232.*
- 592 Yang, Z. (2008). *Strategic Bargaining and Cooperation in Greenhouse Gas Mitiga-*  
593 *tions: An Integrated Assessment Modeling Approach*. MIT Press.

## 594 **A Model regions**

Table 7: Regions as defined in MICA and corresponding world regions

Region	Countries
AFR	Sub-Saharan Africa without South Africa
CHN	China
EUR	EU-27
IND	India
JPN	Japan
LAM	All American countries except Canada and the United States
MEA	North Africa, Middle Eastern and Arab Gulf countries, resource exporting countries within the former Soviet Union, and Pakistan
OAS	South East Asia, North Korea, South Korea, Mongolia, Nepal, Afghanistan
ROW	Australia, Canada, New Zealand, South Africa and non-EU27 European states except Russia
RUS	Russia
USA	United States of America

Table 8: Regions as defined in STACO and corresponding world regions

Region	Countries
BRA	Brazil
CHN	China
EUR	European Union and European Free Trade Association
HIA	High-income Asia, including South Korea and Indonesia
IND	India
JPN	Japan
MES	Middle Eastern countries
OHI	Other high-income countries, including Canada, Australia, New Zealand
ROE	Rest of Europe
ROW	Rest of the world
RUS	Russia
USA	United States of America

Table 9: Regions as defined in CWS and corresponding world regions

Region	Countries
CHN	China
EU	EU-15
FSU	Former Soviet Union
JPN	Japan
ROW	Rest of the world
USA	United States of America

Table 10: Regions as defined in WITCH and corresponding world regions

Region	Countries
CAJAZ	Canada, Japan, New Zealand
CHINA	China, including Taiwan
EASIA	East Asia without China, Japan, Korea
INDIA	India
KOSAU	Korea, South Africa, Australia
LACA	Latin America and Caribbean
MENA	Middle East and Northern Africa
NEWEURO	Recent accessions to the European Union
OLDEURO	EU-15
SASIA	South Asia
SSA	Sub-Saharan Africa
TE	Non-EU East-Europe and Central Asia
USA	United States of America

Table 11: Regions as defined in RICE and corresponding world regions

Region	Countries
CHN	China
EEC	Eastern European countries and the former Soviet Union
EU	European Union
OHI	Other high-income countries
ROW	Rest of the world
USA	United States of America

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:

<http://www.feem.it/getpage.aspx?id=73&sez=Publications&padre=20&tab=1>  
[http://papers.ssrn.com/sol3/JELJOUR\\_Results.cfm?form\\_name=journalbrowse&journal\\_id=266659](http://papers.ssrn.com/sol3/JELJOUR_Results.cfm?form_name=journalbrowse&journal_id=266659)  
<http://ideas.repec.org/s/fem/femwpa.html>  
<http://www.econis.eu/LNG=EN/FAM?PPN=505954494>  
<http://ageconsearch.umn.edu/handle/35978>  
<http://www.bepress.com/feem/>

NOTE DI LAVORO PUBLISHED IN 2014

CCSD	1.2014	Erin Baker, Valentina Bosetti, Karen E. Jenni and Elena Claire Ricci: <a href="#"><u>Facing the Experts: Survey Mode and Expert Elicitation</u></a>
ERM	2.2014	Simone Tagliapietra: <a href="#"><u>Turkey as a Regional Natural Gas Hub: Myth or Reality? An Analysis of the Regional Gas Market Outlook, beyond the Mainstream Rhetoric</u></a>
ERM	3.2014	Eva Schmid and Brigitte Knopf: <a href="#"><u>Quantifying the Long-Term Economic Benefits of European Electricity System Integration</u></a>
CCSD	4.2014	Gabriele Standardi, Francesco Bosello and Fabio Eboli: <a href="#"><u>A Sub-national CGE Model for Italy</u></a>
CCSD	5.2014	Kai Lessmann, Ulrike Kornek, Valentina Bosetti, Rob Dellink, Johannes Emmerling, Johan Eyckmans, Miyuki Nagashima, Hans-Peter Weikard and Zili Yang: <a href="#"><u>The Stability and Effectiveness of Climate Coalitions: A Comparative Analysis of Multiple Integrated Assessment Models</u></a>