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Summary

Cooperation in international environmental agreements appears difficult to attain because of strong free-riding incentives. This paper explores how different technology spillover mechanisms among regions can influence the incentive structures to join and stabilise an international agreement. We use an applied modelling framework (STACO) that enables us to investigate stability of partial climate coalitions. Technology spillovers to coalition members increase their incentives to stay in the coalition and reduce abatement costs, which leads to larger global payoffs and a lower global CO2 stock. Several theories on the impact of technology spillovers are evaluated by simulating a range of alternative specifications. We find that while spillovers are a good instrument to improve stability of bilateral agreements, they cannot overcome the strong free rider incentives that are present in larger coalitions. This conclusion is robust against the specification of technology spillovers.

Keywords: Climate Change Modelling, International Environmental Agreements, Non-cooperative Game Theory, Technology Spillovers

JEL Classification: C72, O33, Q54

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1. Introduction

Successful CO_2 emission abatement requires international cooperation. However, full cooperation in the international environmental agreements (IEAs) seems to be difficult to achieve because of free-riding incentives. Game theoretic approaches are widely used to explore the properties of IEAs (e.g., Barrett, 1994) and the effects of institutional settings aimed to stimulate voluntary participation in the IEAs, for example through transfers (e.g., Carraro and Siniscalco, 1993; Hoel and Schneider, 1997; and Weikard et al., 2006). A general observation from this literature is that rather small partial coalitions tend to emerge and the coalition with all members may not be attained. For example, Barrett (1994) proves that stable coalitions will be small if the difference between the non-cooperative outcome and the full-cooperative outcome for each region is large. Hoel and Schneider (1997) conclude that letting non-signatories reduce their emissions by means of transfers from signatories will not increase the number of signatories, which implies higher global emissions in the case of transfers than in the case of no transfer. Thus, even with transfers, full cooperation on emission abatement is hard to get established.

To improve these outcomes, a number of studies have proposed to link the agreements on emissions abatement to other economic issues, especially to technological cooperation. The main idea of this mechanism is that each region negotiates not only on emissions abatement but also negotiates on technological cooperation, which might induce regions to join a coalition. For example, Carraro and Siniscalco (1994) indicate that linkage of the IEAs on climate control and technological cooperation may stabilise an IEA, as payoffs of signatories will increase due to increased technological spillovers from other signatories. Carraro and Siniscalco (1997) show that linkage of the environmental agreement with an agreement on technological cooperation may overcome free-riding problems due to the fact that the negotiation on both climate control and technology is more profitable to signatories when benefits from technological cooperation are exclusive to them than the negotiation on climate control only. Kemfert (2004) shows in an applied coalition formation game with four regions that signatories can profit more when they cooperate on emissions abatement and technological innovation than in the case of non-cooperation. Furthermore, there exist incentives for non-cooperating countries, such as the U.S.A., to join an agreement in which countries cooperate both on emissions abatement and technological innovations, because they can obtain technology spillovers, which improve energy efficiency through trade with signatories.

Buonanno et al. (2003) define the international spillovers of knowledge generated by a stock of world knowledge. In their setting, international knowledge spillovers affect both the production function and the emission to output ratio. Golombek and Hoel (2005) assume that the technology level of the region depends on own investments in R&D and R&D investment in other countries (signatories) using a certain rate of technology diffusion, and R&D activities in cooperating countries will lower abatement costs in non-cooperating countries due to technology diffusion. The general insight that emerges from these studies is that there are a number of different channels through which technology spillovers may affect the payoffs of regions and thus the incentives to cooperate: (i) global spillovers from a "world stock of knowledge", (ii) spillovers that are directly derived from participation in the agreement (coalitional spillovers), and (iii) spillovers to outsiders. What all these studies lack, however, is a systematic analysis of the influence of technology spillovers on the stability of international climate agreements with heterogeneous players in an applied setting.

Technology spillovers can be (and are) specified in many different ways, depending on the answer to the essential questions such as how to measure technology and how to specify spillovers. Most existing models assume that the level of environmental technology can be approximated by looking at the emission intensity of production, that knowledge can be aggregated over regions through summation, and that spillovers have the effect of pivoting the marginal abatement cost (MAC) curve down. Recent literature suggests, however, that a 'best-shot' aggregation of technology may be more appropriate (Sandler, 2006). Furthermore, alternative indicators of technology, such as based on energy intensity or carbon intensity, are also found in the applied literature (e.g. Kemfert, 2004). Finally, Baker et al. (2007) and Bauman et al. (2007) challenge the conventional specification that spillovers (or learning, for that matter) pivot down the MAC curves. Baker et al. (2007) suggest two alternatives: an extension of the MAC curve to the right, and a change in the curvature of the MAC curve.

The purpose of this paper is to investigate how these various technology spillover mechanisms and specifications affect the formation and stability of climate coalitions in a non-cooperative game. To do this, we use an integrated assessment model, STACO (Finus et al., 2006; Nagashima et al., 2006). We explore the links between coalition formation and technology spillovers from both sides by investigating how technology spillovers that depend on the coalition that is formed influence the incentive structures to join the coalition. Moreover, we will examine whether the effects of technology spillovers are large enough to stabilise more ambitious coalitions by offsetting the incentive to free-ride. We simulate several spillover mechanisms and specifications that are available in the literature, to investigate the robustness of these links. To keep the analysis tractable, we leave the issues of a separate technology agreement and endogenous learning effects for further analysis; thus, the spillovers we investigate are all specified as externalities, and there are no endogenous feedback effects from abatement on the state of technology.

The paper is organized as follows. Section 2 provides the game theoretic and empirical framework of the STACO model, and introduces technology spillovers in the model. Section 3 reports the main results with technology spillovers, followed by the analysis of alternative specifications of technology in the Section 4. Section 5 provides sensitivity analysis, and Section 6 concludes. The Appendix provides the model parameter values.

2. The stability of coalitions model (STACO)

2.1. Game theoretic background

In this section, we describe the game theoretic model following Finus et al. (2006) and Nagashima et al. (2006). Our analysis uses a two stage game. In the first stage, regions denoted by $i \in N$, $N = \{1,...,n\}$ decide whether they sign the agreement or not. Signatories form a coalition and non-signatories remain singletons in the second stage of the game. Then, all regions simultaneously determine their emission abatement levels, The payoff for each region π_i is a function of regional benefits B_{it} and regional abatement costs AC_{it} at period t. Formally, we have:

$$\pi_i(\mathbf{q}) = \sum_{t=1}^{\infty} \left\{(1+r)^{-t} \cdot (B_{it}(q_1,...,q_t) - AC_{it}(q_{it}))\right\} \tag{1}$$

where $\mathbf{q}$ is an abatement matrix of dimension $N \times \infty$ and r is the discount rate. The payoff is calculated as the net present value of the stream of net benefits. We assume that the regional benefits depend on past and current global emission abatement, and the regional abatement costs depend on a region's own current abatement. The regional abatement levels is determined within the abatement strategy space $q_{it} \in [0, \bar{e}_{it}]$, where $\bar{e}_{it}$ denotes emission levels in the business-as-usual (BAU) scenario.

We apply the solution concept of a partial agreement Nash equilibrium between the signatories and singletons (Chander and Tulkens, 1995, 1997). We assume that signatories determine their abatement level by maximising the sum of the payoffs of the signatories taking the abatement levels of non-signatories as given. Non-signatories choose their abatement level by maximising their own payoffs taking the other regions' abatement levels as given. This abatement game has a unique interior solution under the STACO specification of benefit and cost functions (see Section 2.2). Moreover, an emission permit trading system is applied among signatories. We define a valuation function $V_i(K)$ which yields regional payoffs with permit trading given coalition K. The payoff for signatory *i* after permit trading is defined as follows:

$$V_{it}(K) \equiv \pi_{it}(q^*_{it}(K)) - p_t \cdot \ (\tilde{q}_{it}(K) - q^*_{it}(K)) \ , \tag{2}$$

where p_t is the permit price in period t, q^*_{it} is the optimal abatement in coalition K and $\tilde{q}_{it}$ is the assigned abatement under the permit trading system. The assigned abatement level is determined as the difference between regional BAU emissions and regional emission permits, which are distributed proportional to the regional emission paths (Nagashima et al., 2006). We refer to the situations where none or one of the regions joins a coalition as 'All Singletons', and a coalition where all regions cooperate as 'Grand Coalition'.

We call a coalition *K* stable if the coalition satisfies both internal and external stability. Internal stability of a coalition means that no signatory has an incentive to withdraw from the coalition. For external stability, we consider a unanimity voting system in which signatories vote on entry of singletons (cf. Bloch, 1997; Finus et al., 2005). This definition of external stability has two interpretations. First, none of the singletons has an incentive to join the coalition if they are worse off when they are joining. Second, if one has an incentive to join the coalition they are, however, not allowed to enter the coalition if at least one of the signatories becomes worse off.

Formally, the stability concepts are defined as:

Internal stability:

$$V_i(K) \geq V_i(K \setminus \{i\}) \qquad \forall i \in K \ , \tag{3}$$

External stability:

If $V_j(K) \geq V_j(K \cup \{j\}) \ \forall j \notin K$, or (4a)

if $V_j(K) < V_j(K \cup \{j\}) \ \exists j \notin K$ and then $V_i(K) > V_i(K \cup \{j\})$ if $k > 0$, $i = \{1,...,k\} \in K$. (4b)

Finus and Rundshagen (2003) suggest that exclusive membership may stabilise climate coalitions because coalition members can control the entry of non-signatories which may obstruct the existing internally stable coalition. If at least one of the regions outside the coalition is allowed to enter the coalition, the coalition is no more externally stable. Hence, once an internally stable coalition is attained, the entry of new members does not hamper the interest of forming a coalition for existing coalition members under the exclusive membership. Different membership rules have been investigated in the STACO framework by Finus et al. (2005), and we will also investigate the impact of open membership, where condition (4b) does not apply, in the sensitivity analysis.

2.2. The STACO model

In this section, we present the main issues in the numerical specification of our model, following Finus et al. (2006) and Nagashima et al. (2006). We consider twelve world regions: USA (USA), Japan (JPN), European Union - 15 (EU15), other OECD countries (OOE), Eastern European countries (EET), former Soviet Union (FSU), energy exporting countries (EEX), China (CHN), India (IND), dynamic Asian economies (DAE), Brazil (BRA) and rest of the world (ROW). Payoffs from abatement are given as the net present value of benefits minus abatement costs over the model horizon. We set the model horizon to infinity to capture future benefits from abatement, while adopting a planning horizon for abatement and coalition formation of 100 years, ranging from 2011 to 2110. Calibration of the regional BAU emission paths[1], represented in Appendix (Figure A1), is based on the data for CO_2 emission derived from the EPPA model (Babiker et al., 2001; Reilly, 2005) and the GDP path is also derived from the EPPA model. Our benefit function is based on avoided damages, calculated using the damage module of the DICE model (Nordhaus, 1994) and the climate module by Germain and Van Steenberghe (2003). For global damages, we apply the estimate by Tol (1997) that damages amount to 2.7 percent of GDP for a doubling of concentrations over pre-industrial levels. Global benefits are allocated according to a fixed share for each region, as displayed in Appendix (Table A2). We specify an abatement cost function based on the estimates of the EPPA model by Ellerman and Decaux (1998).

2.3 Technology spillovers

Based on the ideas of technology spillovers discussed in the introduction, we identify technology spillovers through three major channels. In the reference scenario, we consider coalition formation in the absence of technology spillovers, and do not assume any

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[1] We use data from World Bank (2003) to match the regional aggregation in EPPA to STACO.

technological progress. In the second scenario, we assume global spillovers, which mimics international spillovers of knowledge generated by 'the stock of world knowledge' as in Buonanno et al. (2003), although our model is much simpler and thus cannot capture the knowledge creation aspect; we rather focus on the link between technology spillovers and incentives to cooperate in an IEA. In this context, the essence of the global spillovers is that every region obtains technology spillovers, irrespective of membership of the coalition or not. In the third scenario, in addition to the global spillovers, signatories to the climate agreement gain spillovers from the other coalition members (cf. the 'coalition information exchange parameter' in Carraro and Siniscalco, 1997); this scenario also refers to the mechanism in Kemfert (2004) that participants cooperate on technological innovation. In the fourth scenario, following Golombek and Hoel (2005), we consider all possible technology spillovers, i.e., we extend the mechanism of the third scenario with spillovers to singletons.

In our model setting, the size of the technology spillover depends on which regions are member of the coalition. We assume that the spillovers will be higher when more regions are member of the coalition, and when regions with an advanced "state of technology" are member of the coalition. The "state of technology (SoT)" is expressed as the inverse of the regional emission intensity in the reference path, calculated as the Business-as-Usual amount of CO_2 emission per unit of GDP.[2] The rationale of this definition is that regions that have a low emission intensity have a high level of knowledge on GHG abatement strategies. To investigate the robustness of this definition of the state of technology, we introduce some alternative definitions in the next section. As we use the state of technology as an indicator for the level of knowledge, we refer to the emission intensity in the reference path and do not adjust for changes in the emission intensity due to abatement. This is because we feel that abatement primarily reflects a movement along the technology curve, i.e. adoption of existing knowledge, rather than a shift of the curve, i.e. creation of new knowledge. Figure 1 shows the state of technology. We see that throughout the century, Japan has the highest state of technology, followed by EU15. On the other hand, the U.S.A. and China have relatively low states of technology.

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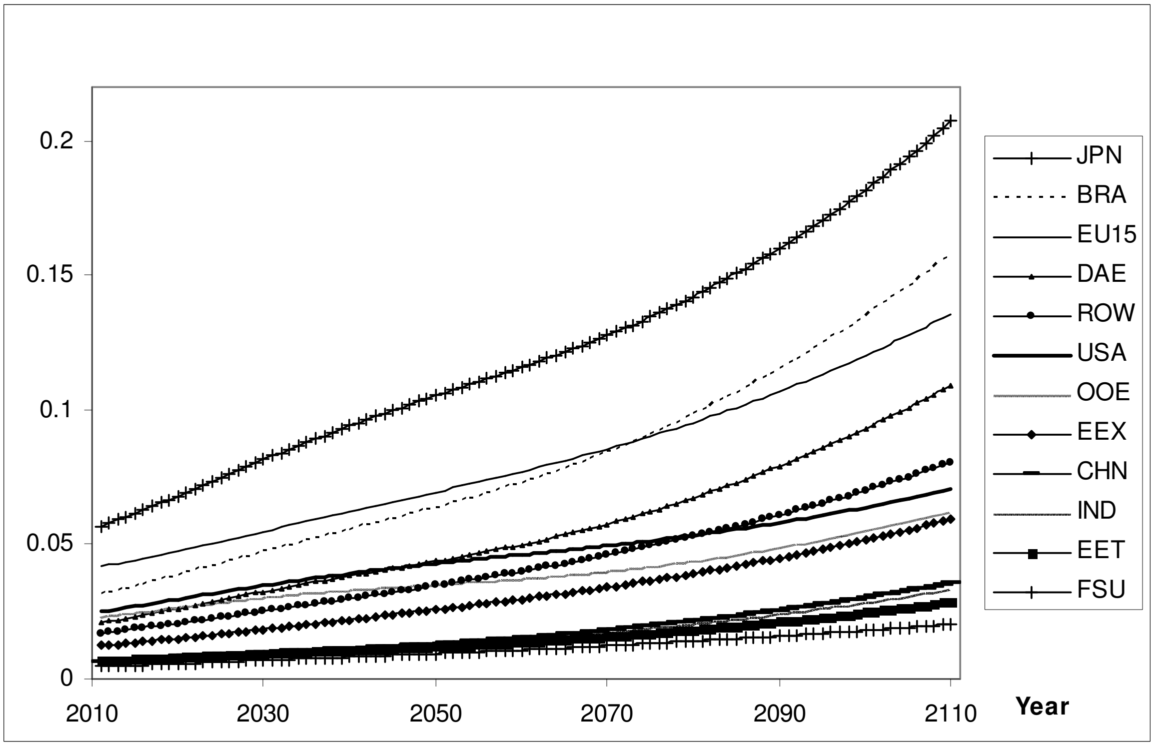
[2] We scale the SoTs such that global SoT equals 1 in 2110.

Figure 1: State of Technology based on emission intensity



In our base model, spillovers for region i in period t (ς_{it}) are expressed through a summation of state of technology:

$$\begin{cases} \varsigma_{it} = \xi_C \cdot \sum\limits_{\substack{j \in K \\ i \neq j}} SoT_{jt} + \xi_{global} \cdot \sum\limits_{j=1}^{N} SoT_{jt} & \forall i \in K, \qquad (5) \\[2em] \varsigma_{it} = \xi_{NC} \cdot \sum\limits_{j \in K} SoT_{jt} + \xi_{global} \cdot \sum\limits_{j=1}^{N} SoT_{jt} & \forall i \notin K. \qquad (6) \end{cases}$$

with $0 \leq \xi_{global}, \xi_C, \xi_{NC} < 1$ where ξ_c is coefficient of internal spillovers to coalition members, ξ_{NC} is coefficient of spillovers from coalition members to non-coalition members and ξ_{global} is coefficient of global spillovers. Unfortunately, there is no strong empirical base to calibrate the values of the different ξ. Therefore, we conduct a robustness analysis by changing the values of the spillover coefficient between coalition members (ξ_C) in Section 4.

In the different scenarios, some ξ are set to zero to reflect the absence of the corresponding spillover effect. Scenario 1 assumes no technology spillovers among regions:

$\xi_{global} = \xi_C = \xi_{NC} = 0$. For Scenario 2, we assume that every region can benefit from global spillovers, irrespective of the coalition membership, which lead to technological progress slowly increasing over the century to 1% per annum, that is, ξ_{global} equals 0.01 and ξ_C, ξ_{NC} are zero in equations 5 and 6. In Scenario 3, with internal coalitional spillovers, in addition to global spillovers, signatories can obtain spillovers from other signatories, that is, ξ_C=0.005 and still ξ_{global}=0.01. This scenario is expected to provide a stimulus for regions to join a coalition, as membership brings technology benefits, although the effect is assumed to be moderate, as it is on top of the global spillover effect. In Scenario 4, not only signatories benefit from internal coalition spillovers, but also singletons can obtain spillovers from signatories, that is ξ_C=0.005, ξ_{global}=0.01 and ξ_{NC}=0.001. In this case, we assume that a region can also benefit from its own contribution to the coalitional spillovers not as in the case of internal coalitional spillovers, and also outsiders can get some ratio of spillovers from the coalition. Following Carraro and Siniscalco (1997), we assume that the diffusion rate among coalitions is larger than the one towards outsiders.

In our base model, we adopt the most common assumption on the impact of spillovers and assume that technology spillovers reduce marginal abatement costs over time through a pivoting of the MAC curve:

$$MAC_{i,t+1} = (1 - \varsigma_{i,t}) \cdot MAC_{i,t} \tag{7}$$

where

$$MAC_{i,t} \equiv \frac{\partial c_{it}}{\partial q_{it}} = \alpha_i \cdot \left(\prod_{s=2011}^{t-1} \left(1 - \varsigma_{is}\right) \right) \cdot q_{it}^2 + \beta_i \cdot \left(\prod_{s=2011}^{t-1} \left(1 - \varsigma_{is}\right) \right) \cdot q_{it} \tag{8}$$

3. Results

As we cannot properly estimate the values of the different ξ, our analysis of the results focuses on the impact of spillovers on stability of partial climate coalitions, and a comparison of different specifications, rather than on the detailed numerical outcomes. Nonetheless, it is instructive to start with an analysis of the results of our base model and examine stability for all 4084 coalition structures.

Table 1: Global NPV of payoffs in the stable coalitions under four scenarios

Coalitions	Global net present value of payoffs (in billion US$)			
	No spillovers	Global spillovers	Internal coalitional spillovers	Extended coalitional spillovers
[USA-CHN]	6705	7560	7584	7590
[EU15-CHN]	6675	7528	7565	7574
[CHN-ROW]	5499	6223	6236	6241
[FSU-CHN]	5492	6214	6218	6221
[EU15-EET-IND]	5411	6118	6133	6146
[EU15-ROW]	4978	5638	5648	X
[EU15-FSU]	4968	5626	5633	5644
[JPN-IND]	4943	5602	5612	5628
[JPN-ROW]	4858	5507	5517	X
[JPN-FSU]	4851	5498	5507	X
[EU15-EET]	4826	5469	5473	5485
[JPN-EET]	4771	5409	5414	5430
[EEX-DAE]	4630	5259	5261	5271
[JPN-EU15-DAE]	X	X	5847	5876

X denotes instability of a coalition

Table 1 shows stable coalitions in all scenarios of technology spillovers and associated global net present value of payoffs in billion dollars. We obtain 13 stable coalitions in the cases of no spillovers and global spillovers. Global spillovers do not affect the set of stable coalitions because with global spillovers every region gets the same rate of technological spillovers, irrespective of coalition membership. Thus, while marginal abatement costs are lower and payoffs are higher in presence of the spillovers, the incentives to join or leave a coalition are not significantly influenced. The best performing coalition, in terms of global payoff, is formed by the USA and China: both regions have relatively flat marginal abatement cost curves and can thus abate substantially at relatively low cost. The high benefits accruing to the USA stimulate coalitional abatement, and China can obtain transfers from the USA by selling emission permits. Thus, these two coalition members nicely complement each other. Nagashima et al. (2006) show that a coalition between the USA and China is internally stable but externally unstable under open membership and in absence of spillovers, because Japan has a strong incentive to join the coalition. This accession is blocked, however, under exclusive membership.

Under the internal and extended coalitional spillovers, we have 14 and 11 stable coalitions, respectively. In the coalitional spillover scenarios, Japan and EU15 that have relatively high states of technology become attractive members of a coalition, as they generate large spillovers to other members; without spillovers, their steep marginal abatement cost curves and high damages form a substantial barrier for cooperation. A new stable coalition between Japan, EU15 and dynamic Asian economies emerges: in the case of coalitional spillovers, Japan and the EU15 can benefit from each other through high technological spillovers, thereby reducing the marginal abatement costs for the other coalition members. This overcomes the incentive for Japan to leave the coalition in absence of coalition spillovers, and demonstrates the use of coalition spillovers as a stabilising factor.

Moreover, three stable coalitions under no spillovers and global spillovers, namely {Japan and FSU}, {Japan and ROW}, and {EU15 and ROW}, become externally unstable under the extended coalitional spillovers. For example, in the coalition between Japan and FSU, and the coalition between Japan and ROW, singleton EU15 has an incentive to join the coalition as it can benefit from the coalitional spillovers. Furthermore, in these three coalitions, China and India have incentives to enter. The entry of China or India will shift a large part of the financial transfers away from the FSU or ROW, since China and India have lower marginal abatement costs. The relatively high State of Technology in the EU15, and the low marginal abatement costs in China and India, make them attractive partners in this setting, and thus their entry is not blocked by the existing members; this makes the smaller coalition externally unstable.

Clearly, the larger the spillovers are, the higher the net present value of global payoffs. Thus, global spillovers lead to higher payoffs than no spillover for any given coalition structure. Internal and extended coalitional spillovers further improve payoffs by reducing marginal abatement costs. In all of the stable coalitions, the highest global net present value of payoffs are achieved in the case of extended coalition spillovers since singletons can benefit from the spillovers generated by the coalition members; this boosts payoffs but may reduce incentives to join the coalition (though in our setting, these incentives are not changed sufficiently to alter the set of stable coalitions). For these four scenarios, we can conclude that only relatively small stable coalitions emerge, that achieve only small reductions in the stock of CO_2. Apparently, the spillovers are not strong enough to stabilise larger and more ambitious coalitions.

Next, we evaluate the impact of the technology spillovers on regional abatement levels. Table 2 show the stock of CO_2 and the optimal abatement levels in 2050 as percentage of BAU emissions for the All Singletons and top five stable coalitions (according to the global net present value of payoffs) in the four scenarios. The result for the All Singletons case is given as a reference, and provides good insight into the features of the heterogeneous regions where abatement levels vary widely between regions, indicating widely varying marginal benefits and marginal abatement costs. Without spillovers, the global stock of CO_2 in the All Singletons case is about 1,456 GtC by the year 2110, which is about 1.7 times the stock level in 2010. With spillovers, the global stock of CO_2 in the All Singletons case slightly decreases to 1,449 GtC by the year 2110, as we assume that at least global spillovers are available in the All Singletons case. Note that as there is no coalition, all three spillover scenarios are identical in the All Singletons case.

Table 2: Stock of CO_2 and abatement level in the All Singletons and top five Stable coalitions under four scenarios

	CO_2 Stock In 2110	Abatement in 2050 (% of BAU emissions)											
	(GtC)	USA	JPN	EU15	OOE	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
Without spillovers													
All Singletons	1456.2	6.48	2.24	5.40	3.05	2.69	4.61	1.43	7.78	4.86	1.41	0.10	4.08
1. No spillovers													
USA - CHN	1436.3	***7.44***	2.24	5.40	3.05	2.69	4.61	1.43	***21.31***	4.86	1.41	0.10	4.08
EU15 - CHN	1436.6	6.48	2.24	***6.24***	3.05	2.69	4.61	1.43	***21.74***	4.86	1.41	0.10	4.08
CHN - ROW	1448.0	6.48	2.24	5.40	3.05	2.69	4.61	1.43	***12.90***	4.86	1.41	0.10	***6.08***
FSU - CHN	1448.1	6.48	2.24	5.40	3.05	2.69	***6.41***	1.43	***12.87***	4.86	1.41	0.10	4.08
EU15 - EET - IND	1448.3	6.48	2.24	***6.26***	3.05	***15.08***	4.61	1.43	7.78	***14.70***	1.41	0.10	4.08
With spillovers													
All Singletons	1448.9	7.04	2.56	5.91	3.28	2.94	4.96	1.63	8.62	5.35	1.61	0.11	4.47
2. Global spillovers													
USA - CHN	1425.7	***8.07***	2.56	5.91	3.28	2.94	4.96	1.63	***23.25***	5.35	1.61	0.11	4.47
EU15 - CHN	1426.0	7.04	2.56	***6.82***	3.28	2.94	4.96	1.63	***23.72***	5.35	1.61	0.11	4.47
CHN - ROW	1439.3	7.04	2.56	5.91	3.28	2.94	4.96	1.63	***14.18***	5.35	1.61	0.11	***6.63***
FSU - CHN	1439.4	7.04	2.56	5.91	3.28	2.94	***6.90***	1.63	***14.14***	5.35	1.61	0.11	4.47
EU15 - EET - IND	1439.7	7.04	2.56	***6.83***	3.28	***16.26***	4.96	1.63	8.62	***15.98***	1.61	0.11	4.47
3. Internal spillovers													
USA - CHN	1425.4	***8.08***	2.56	5.91	3.28	2.94	4.96	1.63	***23.35***	5.35	1.61	0.11	4.47
EU15 - CHN	1425.5	7.04	2.56	***6.83***	3.28	2.94	4.96	1.63	***23.88***	5.35	1.61	0.11	4.47
CHN - ROW	1439.2	7.04	2.56	5.91	3.28	2.94	4.96	1.63	***14.23***	5.35	1.61	0.11	***6.64***
FSU - CHN	1439.4	7.04	2.56	5.91	3.28	2.94	***6.90***	1.63	***14.16***	5.35	1.61	0.11	4.47
EU15 - EET - IND	1439.5	7.04	2.56	***6.85***	3.28	***16.37***	4.96	1.63	8.62	***16.09***	1.61	0.11	4.47
4. Extended spillovers													
USA - CHN	1425.3	***8.09***	2.56	5.92	3.29	2.94	4.97	1.63	***23.36***	5.36	1.61	0.11	4.48
EU15 - CHN	1425.4	7.05	2.56	***6.84***	3.29	2.94	4.97	1.63	***23.88***	5.36	1.61	0.11	4.48
CHN - ROW	1439.1	7.04	2.56	5.92	3.28	2.94	4.96	1.63	***14.23***	5.36	1.61	0.11	***6.64***
FSU - CHN	1439.3	7.04	2.56	5.92	3.28	2.94	***6.90***	1.63	***14.16***	5.35	1.61	0.11	4.48
EU15 - EET - IND	1439.3	7.05	2.56	***6.86***	3.29	***16.38***	4.97	1.63	8.64	***16.10***	1.62	0.11	4.48

For each stable coalition, we observe that singletons are hardly affected by the spillovers. This is not surprising, as these are only linked to the coalition members indirectly through the benefits of global abatement; the exception is the scenario with extended coalitional spillovers, where the coalition affects marginal abatement costs of the singletons. In Table 2, it is clear that this latter effect is quite limited: it is only noticeable for regions EET, China and India who have higher optimal abatement levels in scenario 4 than in scenario 2. For coalition members, the joint welfare maximisation of the coalition implies that their abatement levels are substantially higher than when they act as singleton (although the highest abatement percentages are not necessarily obtained by coalition members). Coalitional spillovers further increase their abatement percentages by lowering marginal abatement costs. Regions such as China or India will contribute substantially to coalitional abatement, and receive transfers by selling their excess emission permits to their coalition partners.

Table 3: Incentive to change membership in the top five Stable coalitions

	USA	JPN	EU15	OOE	EET	FSU	EEX	CHN	IND	DAE	BRA	ROW
Without spillovers												
1. No spillovers												
USA - CHN	-106	76	-18	-107	-31	-144	-131	-205	-34	-78	-59	-133
EU15 - CHN	-560	-21	-246	-150	-53	-217	-174	-86	-88	-109	-74	-204
CHN - ROW	-31	178	170	-42	-16	-47	-56	-35	-12	-35	-22	-3
FSU - CHN	-25	179	174	-41	-16	-2	-55	-35	-11	-34	-22	-42
EU15 - EET - IND	-171	-30	-51	-56	-4	-66	-74	113	-32	-41	-43	-63
With spillovers												
2. Global spillovers												
USA - CHN	-107	87	-22	-124	-35	-161	-144	-239	-40	-85	-66	-148
EU15 - CHN	-643	-23	-268	-173	-62	-245	-193	-101	-103	-121	-83	-231
CHN - ROW	-49	197	182	-49	-19	-54	-62	-41	-15	-39	-25	-2
FSU - CHN	-42	198	188	-49	-19	-1	-62	-41	-14	-38	-25	-49
EU15 - EET - IND	-195	-30	-57	-65	-3	-73	-80	137	-35	-42	-48	-70
3. Internal spillovers												
USA - CHN	-109	101	-11	-124	-35	-161	-144	-242	-39	-85	-66	-148
EU15 - CHN	-646	-12	-273	-175	-62	-247	-195	-104	-103	-122	-83	-232
CHN - ROW	-46	207	190	-49	-19	-54	-63	-42	-15	-39	-25	-2
FSU - CHN	-40	208	195	-49	-19	-1	-62	-41	-14	-38	-25	-49
EU15 - EET - IND	-193	-25	-59	-66	-4	-73	-80	141	-36	-43	-48	-70
4. Extended spillovers												
USA - CHN	-110	103	-10	-124	-35	-161	-144	-243	-39	-85	-66	-148
EU15 - CHN	-646	-10	-276	-175	-62	-247	-195	-104	-103	-121	-83	-232
CHN - ROW	-46	209	192	-49	-19	-54	-63	-42	-15	-38	-25	-2
FSU - CHN	-39	210	197	-49	-19	-1	-62	-42	-14	-38	-25	-49
EU15 - EET - IND	-193	-23	-61	-66	-4	-73	-80	141	-36	-42	-48	-69

The incentive to change membership decision is shown in Table 3 and is calculated as a coalition member's gain when leaving the coalition (while other regions stick to their decision) or as a singleton's gain when joining the coalition (i.e. single deviations). We observe that none of the regions has an incentive to change their membership in the coalition of EU15 and China. For the stable coalitions of China and Rest of the World, and Former Soviet Union and China, some outsiders (Japan and European Union) would like to join the coalition in other stable coalitions, but entry of those regions is blocked under the exclusive membership rule. While absolute values of the incentives differ between the scenarios due to the differences in technology diffusion, the sign of the incentives are unchanged, and thus the set of stable coalition structures remains unchanged.

Figure 2: Regional undiscounted payoffs in 2110 in the coalition of USA and China

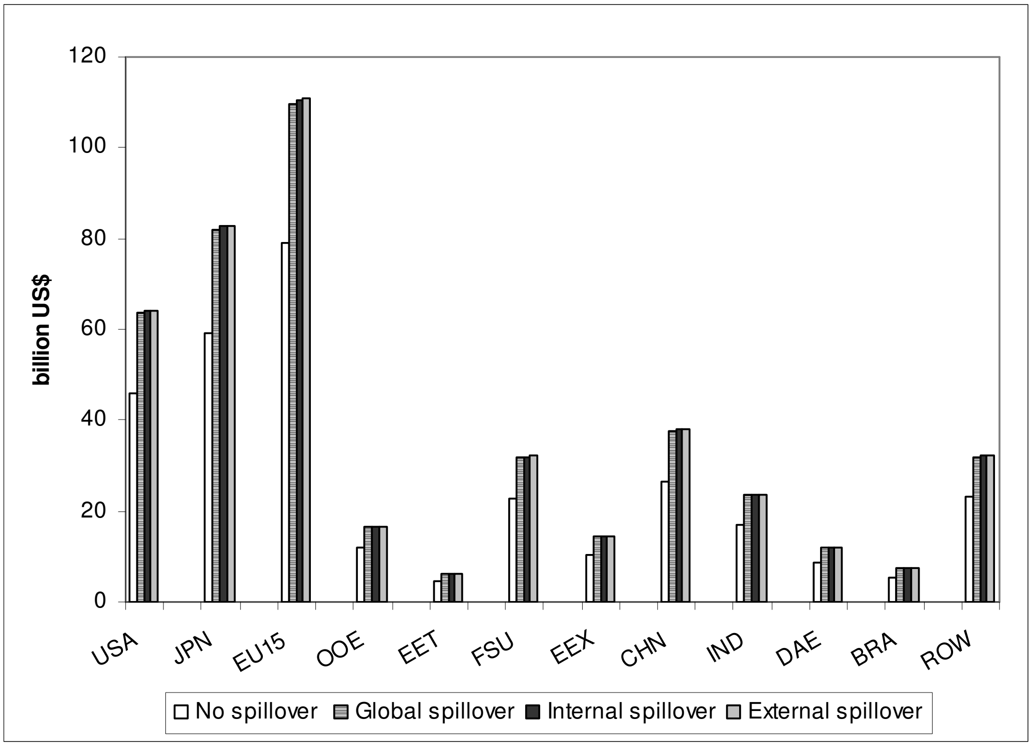


Figure 2 shows how the different types of technology spillovers affect regional undiscounted payoffs in a coalition of the USA and China. Every non signatory is better off through spillovers from signatories compared with the case of no spillovers or global spillovers.

4. Alternative specifications of technology spillovers

To investigate the robustness of our results, we simulate various alternative specifications of technology spillovers, by varying the aggregation of technology, using different indicators for the state of technology, changing the impact of spillovers on the MAC curve and, finally, calculating for different values of the main spillover parameter, i.e. the coefficient of technology spillovers among coalition members (ξ_C). For ease of comparison, we use the base model with extended spillovers as the reference case, and vary only one assumption in the alternative specifications.

4.1 Alternative aggregation of technology

In the simulations above, the assumption is made that knowledge (‘State of Technology’ in our terminology) can be summed over regions to identify the size of the spillovers. According to Sandler (2006), however, “Knowledge is the quintessential best-shot or better shot public good, where breakthroughs come from concentrating effort and building up research centers of excellence”. Therefore, we can construct an alternative spillover formulation where we follow Sandler’s definition and define spillovers through a best-shot aggregation of technology. The implication of the best-shot aggregation (Hirshleifer, 1983; Sandler, 2006) is that the technology spillovers depend on the maximum state of technology in a coalition, rather than the sum of technologies. In the field of GHG abatement technologies, the rationale for the best-shot aggregation is that the technologies that regions have to reduce emissions will have substantial (or even full) overlap with the technologies in other regions. Consequently, the region with the highest state of technology will not learn from others.

In this section, we explore the effects of best-shot aggregation on the stability of coalitions under the internal and extended coalitional spillovers. To reflect a region’s capability of adopting advanced technology, we modify the spillover specification in equations (5) and (6) such that the spillover depends on the difference between the highest state of technology and the region’s own state of technology.

Hence, the spillovers[3] can be defined as follows;

$$\begin{cases} \varsigma_{it} = \xi_{C} \cdot \left\{ \max_{j \in K}(SoT_{j,t}) - SoT_{i,t} \right\} + \xi_{global} \cdot \left\{ \max_{j \in N}(SoT_{j,t}) - SoT_{i,t} \right\} & \forall i \in K, \quad (9) \\ \varsigma_{it} = \xi_{NC} \cdot \left\{ \max_{j \in K}(SoT_{j,t}) - SoT_{i,t} \right\} + \xi_{global} \cdot \left\{ \max_{j \in N}(SoT_{j,t}) - SoT_{i,t} \right\} & \forall i \notin K\,. \quad (10) \end{cases}$$

Table 4: Global NPV of payoffs (billion US$) for stable coalitions under the alternative specifications of technology

Coalition	Base case	Alternative aggregation	Alternative state of technology		Alternative effect on MAC	
		Best shot	Energy intensity	Carbon intensity	Extend to right	Change curvature
[USA-CHN]	7590	7446	7594	8966	7265	6898
[EU15-CHN]	7574	7495	7569	8939	7242	6871
[CHN-ROW]	6241	6085	6242	7405	5934	5692
[FSU-CHN]	6221	6044	6222	7385	5921	X
[EU15-EET-IND]	6146	6011	6145	7297	5854	5594
[JPN-EU15-DAE]	5876	X	5866	7001	X	5341
[EU15-FSU]	5644	5507	5642	X	5362	5149
[JPN-IND]	5628	5520	5626	6661	5334	5132
[EU15-EET]	5485	5341	5483	6505	5202	5009
[JPN-EET]	5430	5308	5428	6431	5144	4956
[EEX-DAE]	5271	5104	5268	X	4976	X
[JPN-FSU]	X	5413	X	X	5235	X
[JPN-ROW]	X	5403	X	X	X	5047
[JPN-EU15-ROW]	X	X	X	7201	X	X
[JPN-EU15-FSU]	X	X	X	7173	X	X
[JPN-OOE]	X	X	X	6384	X	X
[EU15-ROW]	X	X	X	X	5373	X

Note: Base case indicates the case of extended coalitional spillovers. X denotes instability of the coalition.

Table 4 shows the global net present value (NPV) of payoffs with the best-shot technology aggregation (assuming extended coalitional spillovers). For each coalition, payoffs are somewhat lower than in the base case, because the spillovers are smaller (compare equations 9 and 10 with 5 and 6). In contrast to the base model specification, the highest global NPV of payoffs is obtained in the coalition between EU15 and China. The result suggests that as

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[3] All spillover coefficients are unchanged, and in the best-shot aggregation, we rescale the SoTs such that the maximum SoT equals 1 in 2110.

China can learn more from the EU15 than from USA, cooperation with the EU15 is now more successful (in terms of global abatement levels) than with the USA. We get twelve stable coalitions where the ten stable coalitions are the same as in the base case of extended coalitional spillovers, but the new coalitions Japan & FSU, and Japan & ROW emerge, while the coalition Japan & EU15 & DAE is not stable anymore. The results suggest that the best-shot technology induces participation if the partner is the highest state of technology holder, Japan. But the main conclusion is that the aggregation method does not change the qualitative outcomes of the analysis.

4.2 Alternative indicators for state of technology

In this section, we consider alternative indicators for state of technology, using energy[4] intensity or carbon intensity instead of emission intensity. Energy intensity is calculated as energy use per unit of GDP, whereas carbon intensity is calculated as the amount of CO_2 emitted per unit of energy. Emission intensity is used among others by Carraro and Siniscalco (1997), while Kemfert (2004) uses energy intensity. Table 4 also shows the stable coalitions with these alternative indicators of state of technology. With the state of technology based on energy intensity, we obtain the same stable coalitions as in the base case. This is because the regional trends of energy intensity are similar to the trends of the emissions-output ratio. In contrast, with the state of technology based on carbon intensity, some of the stable coalitions are the same but additionally different stable coalitions emerge. In our model, emission-output ratios and energy intensities decrease over time, but this is not the case for carbon intensity. This shows that while emission intensity and energy intensity are more or less interchangeable as indicator of the state of technology in addressing climate change, carbon intensity is a relatively poor indicator because of the missing link to economic activity, and using it may lead to misleading conclusions.

4.3 Alternative effects of spillovers on the MAC curve

The effect of technology spillovers and learning on the shape of the marginal abatement cost (MAC) curve is hardly ever subjected to a thorough analysis, even though suspicion of the effect of technical change on marginal abatement costs was already put forward more than 20 years ago by Downing and White (1986). Recently, two papers emerged, Baker et al. (2007)

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[4] The trajectory of the final energy is based on EPPA model (Reilly, 2005).

and Bauman et al. (2007), that challenge the conventional assumption that technical change will pivot the MAC curve down. Bauman et al. (2007) takes up the argumentation of Downing and White (1986) and show that in certain circumstances technical change may even increase marginal abatement costs. Baker et al. (2007) review the literature and derive that different technology options will have a different impact on marginal abatement costs. Following Baker et al. (2007), we adopt two alternatives to our base model: (i) technology spillovers will extend the MAC curve to the right, and (ii) technology spillovers will affect the curvature of the MAC curve.

In model terms, this implies that we separate the effects of the spillovers on the two parts of our MAC function (eq. (8) in Section 2.3). In the base case, a spillover will reduce both parameters α and β. We approximate an extension of the curve to the right as a spillover effect that will only affect parameter α (to the same extent as in the base model), leaving parameter β unchanged. This implies that the initial slope of the MAC curve is unchanged, but the curvature is reduced. In the alternative with a changed curvature, we assume that technology spillovers will reduce the initial slope of the MAC curve, but increase the curvature (where we assume the effect is smaller but not insignificant). In mathematical notation, we have:

Base model:
$$MAC_{i,t} \equiv \frac{\partial c_{it}}{\partial q_{it}} = \alpha_i \cdot \left(\prod_{s=2011}^{t-1} \left(1 - \varsigma_{is}\right) \right) \cdot q_{it}^2 + \beta_i \cdot \left(\prod_{s=2011}^{t-1} \left(1 - \varsigma_{is}\right) \right) \cdot q_{it} \tag{8}$$

Extension:
$$MAC_{i,t} \equiv \frac{\partial c_{it}}{\partial q_{it}} = \alpha_i \cdot \left(\prod_{s=2011}^{t-1} \left(1 - \varsigma_{is}\right) \right) \cdot q_{it}^2 + \beta_i \cdot q_{it} \tag{11}$$

Change curvature:
$$MAC_{i,t} \equiv \frac{\partial c_{it}}{\partial q_{it}} = \alpha_i \cdot \left(\prod_{s=2011}^{t-1} \left(1 + 0.1 \cdot \varsigma_{is}\right) \right) \cdot q_{it}^2 + \beta_i \cdot \left(\prod_{s=2011}^{t-1} \left(1 - \varsigma_{is}\right) \right) \cdot q_{it} \tag{12}$$

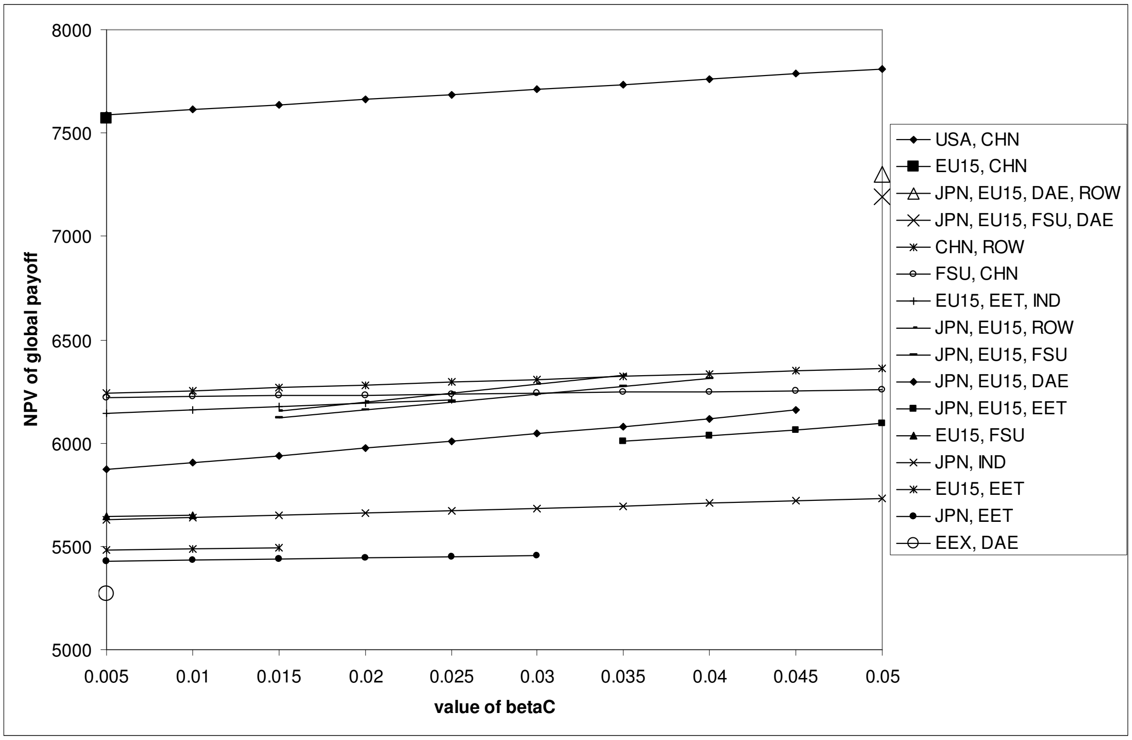
The main results of these alternative specifications can be found in the last two columns of Table 4. We observe that largely, the same stable coalitions emerge. In the alternative specifications the total spillover effect is somewhat smaller than in the base model (as the effect on β is missing, and the effect on α is reversed, respectively), but this does not affect stability of the coalitions substantially. In the first alternative, with extension of the MAC curve to the right, two new stable coalitions emerge (Japan & FSU and EU15 & ROW, respectively) and one stable coalition from the base model turns unstable (Japan & EU15 & DAE). Similarly, the second alternative (changing curvature) leads to one additional stable coalition (Japan & ROW) and the instability of FSU & China and EEX & DAE. The three best-performing stable coalitions are unaffected, however. Thus, we conclude that while the impact of the technology spillover cannot be ignored, the qualitative conclusions still hold.

4.4 Alternative levels of spillovers between coalition members (ξ_C)

We suspect that larger technology spillovers among signatories, by increasing the coefficient of intra-coalitional technology spillovers, may enhance larger stable coalitions. The larger spillovers induce signatories to stay in the coalition, and thus additional internally stable coalitions are expected to emerge. The large coalitional spillovers attract potential new entrants because coalition members can get higher benefits from increased abatement by reducing emissions at lower costs than in the base model.

We examine stability of all coalitions using different values of coalitional spillovers, moving from 0.005 to 0.05 in ten steps. The results of these calculations are summarized in Figure 3, which shows the net present value of global payoffs for all stable coalitions.

Figure 3: Global NPV of payoffs (billion US$) for all stable coalitions with different values of coalitional spillovers



As expected, global payoffs rise with increasing spillovers, as can be seen from the coalition of USA and China, which is stable for all values of spillovers that we specified. This coalition has only two members, but outperforms all other stable coalitions in terms of global abatement levels and payoffs. The reason is that these two regions both have very flat MAC curves and thus can abate more than other coalitions at low costs. As the damage estimate for the USA is rather large, a transfer scheme will induce that the USA is willing to finance some of the abatement in China. These two regions will block entrance of other regions that would like to join (for instance Japan or the EU15), as entrance of these new members would increase abatement efforts in the USA and China too much and disturb stability.

It appears that while larger coalitional spillovers do enhance stability, stable coalitions always consist of relatively few regions, one or two with a relatively high state of technology and high marginal costs /benefits (e.g., Japan and/or EU15), and one or two regions with a high state of technology and moderate marginal costs/low marginal benefits (e.g., FSU and/or DAE). For instance, for values of ξ_C up to 0.03 the coalition of Japan and EET is stable (and has very modest ambitions in terms of abatement levels), but for higher spillovers, the EU15 will successfully join these two regions to form a more ambitious stable coalition: the rather high level of technology in the EU15 makes it an attractive partner when the spillovers generated by this coalition are large enough.

The entry of regions with lower abatement costs, such as China, can be blocked by some of the coalition members because the entry decreases the payoffs for regions with moderate marginal costs/low marginal benefits, which makes the coalition externally stable. It should be noted however that this grouping of regions may be affected by the type of transfer mechanism adopted in the model (emission permits; as Nagashima et al., 2006, show, the type of transfer scheme does not affect the major qualitative conclusions, but does matter for which regions will successfully form a coalition). The conclusion can be drawn that larger coalitional spillovers may enlarge the coalition, but the effect is rather small and the most effective coalition is not affected at all by the level of spillovers.

5. Sensitivity analysis

We conduct a sensitivity analysis to examine how the main assumptions affect model results. We check stability of all coalitions using the open membership rule. In addition, as we believe that a crucial parameter in the model is the discount rate r, and this is subjected to a sensitivity analysis as well.

Table 5: Results of the sensitivity analysis

Coalition	Base case	Alternative membership rule Open membership	Higher discount rate 3% instead of 2 %	Lower discount rate 1% instead of 2 %
[JPN-EET]	O	X	O	O
[EU15-EET]	O	X	O	X
[EU15-FSU]	O	X	O	X
[USA-CHN]	O	X	O	O
[EU15-CHN]	O	O	O	O
[FSU-CHN]	O	X	O	X
[JPN-IND]	O	O	O	O
[EU15-EET-IND]	O	X	O	O
[JPN-EU15-DAE]	O	X	X	O
[EEX-DAE]	O	X	O	X
[CHN-ROW]	O	X	O	X
[[JPN-FSU]	X	X	O	X
[EU15-ROW]	X	X	O	X
[JPN-OOE]	X	X	X	O
[OOE-EET]	X	X	X	O
[JPN-EU15-FSU]	X	X	X	O
[USA-EET-IND]	X	X	X	O
[JPN-ROW]	X	X	X	O

Note: "O" indicates a stable coalition; X denotes instability of the coalition.

As in Section 4, we refer to the scenario with state of technology based on emission-output ratio, summation of technology over regions, a pivoting effect of spillovers on the MAC curve, exclusive membership and the case of extended coalitional spillovers (with $\xi_C = 0.005$) as the base case. Table 5 presents the results of the sensitivity analysis for the base case and the alternative specifications.

First, we assume an open membership rule where non-signatories can join the coalition freely whenever they can obtain a higher payoff by joining the coalition, without the approval by other signatories (d'Aspremont et al., 1983).[5] Under the open membership rule, only two stable coalitions, EU15 & China and Japan & India emerge. These results imply that, in line with previous studies (Finus et al., 2005), stability is sensitive to the membership rule and exclusive membership enhances stability but cannot make large coalitions stable.

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[5] Formally, the stability concept under open membership is defined as:
Internal stability: $V_i(K) \geq V_i(K \setminus \{i\})\ \ \forall i \in K$, External stability: $V_j(K) \geq V_j(K \cup \{j\})\ \ \forall j \notin K$.

Secondly, we change the base value of discount rate r from 2 % to 3% and 1%, respectively, reflecting a higher (lower) rate of time preference. Changing the value of r will decrease (increase) the amount of abatement and global net present value of payoffs as future benefits from abatement are valued lower (higher) , but the set of stable coalitions remains largely the same as the base case.

6. Discussions and conclusions

In this paper, we explore the effects of the technology spillovers among heterogeneous regions on the stability of possible climate coalitions under permit trading and the exclusive membership rules. We identify technology spillovers through three major channels, and investigate how technology spillovers can influence the region's incentive structure to join the coalition. Compared with the case of no spillovers, global spillovers can generate higher payoffs and global abatement levels, but global spillovers do not increase stability.

By and large, the technology spillovers to the coalitional members increase their incentive to stay in the coalition and their efforts to reduce emissions, which leads to larger global payoffs and lower global CO_2 stock. Moreover, Japan and EU15, with relatively high states of technology, are likely to be members of coalitions because other coalitional members are willing to form the coalition with them to receive the high technology spillovers. On the other hand, the spillovers to outsiders will not significantly influence the incentive to free-ride for outsiders, and thus the set of stable coalitions remains unchanged. To what extent coalitional spillovers will stabilise larger coalitions remains a question for empirical analysis: the stronger the spillovers, the larger the stable coalitions. But the analysis in this paper shows that spillovers between coalition members need to be extremely high to overcome the strong free rider incentives that prevail in the international climate negotiations.

References

Babiker, M.H., Reilly, J.M., Mayer, M., Eckaus, R.S., Wing, I.S., Hyman, R.C., 2001. The MIT Emissions Prediction and Policy Analysis (EPPA) model: revisions, sensitivities, and comparisons of results. MIT joint program on the science and policy of global change. Report No. 71. MIT, Cambridge.

Baker, E., E. Shittu and L. Clarke, 2007. Technical change and marginal cost of abatement. University of Massachusetts, Amherst.

Barrett, S., 1994. Self-enforcing international environmental agreements. Oxford Economic Papers 46, 878-894.

Bauman, Y., Lee, M., Seeley, K., 2007. Does technological innovation really reduce marginal abatement costs? Some theory, algebraic evidence, and policy implications. Environmental and Resource Economics, in press.

Bloch, F., 1997. Non-cooperative models of coalition formation in games with spillovers. In: Carraro, C., Siniscalco, D. (Eds.), New Directions in the Economic Theory of the Environment. Cambridge University Press, Cambridge, 311-352.

Buonanno, P., Carraro, C., Galeotti, M., 2003. Endogenous induced technical change and the costs of Kyoto. Resource and Energy Economics 25, 11-34.

Carraro, C., Siniscalco, D., 1993. Strategies for the international protection of the environment. Journal of Public Economics 52, 309-328.

Carraro, C., Siniscalco, D., 1994. Technical innovation and environmental protection Environmental policy reconsidered: The role of technological innovation. European Economic Review 38, 545-554.

Carraro, C., Siniscalco, D., 1997. R&D cooperation and the stability of international environmental agreements. In: Carraro, C. (Eds.), International Environmental Negotiations: Strategic Policy Issues. Edward Elgar, Cheltenham, pp. 71-96.

Chander, P., Tulkens, H., 1995. A core-theoretic solution for the design of cooperative agreements on transfrontier pollution. International Tax and Public Finance 2, 279-293.

Chander, P., Tulkens, H., 1997. The core of an economy with multilateral environmental externalities. International Journal of Game Theory 26, 379 – 401.

d'Aspremont, C., Jacquemin, A., Gabszewicz, J.J., Weymark, J.A., 1983. On the stability of collusive price leadership. Canadian Journal of Economics 16, 17-25.

Downing, P. B., White, L. J., 1986. Innovation in pollution control. Journal of Environmental Economics and Management 13, 18-29.

Ellerman, A.D., Decaux, A., 1998. Analysis of post-Kyoto CO_2 emissions trading using marginal abatement curves. MIT joint program on the science and policy of global change. Report No. 40. MIT, Cambridge.

Fankhauser, S., 1995. Valuing Climate Change: The Economics of the Greenhouse. Earthscan, London.

Finus, M., Altamirano-Cabrera, J.C., van Ierland, E., 2005. The effect of membership rules and voting schemes on the success of international climate agreements. Public Choice 125, 97-127.

Finus, M., Rundshagen, B., 2003. How the rules of coalition formation affect stability of international environmental agreements. Working Paper 62. 2003, Fondazione Eni Enrico Mattei.

Finus, M., van Ierland, E., Dellink, R., 2006. Stability of climate coalitions in a cartel formation game. Economics of Governance 7, 271-291.

Germain, M., van Steenberghe, V., 2003. Constraining equitable allocations of tradable CO_2 emission quotas by acceptability. Environmental and Resource Economics 26, 469-492.

Golombek, R., and Hoel, M., 2005. Climate policy under technology spillovers. Environmental and Resource Economics 31, 201-227.

Hirshleifer, J., 1983. From weakest-link to best-shot: The voluntary provision of public goods. Public Choice 41, 371-386.

Hoel, M., Schneider, K., 1997. Incentives to participate in an international environmental agreement. Environmental and Resource Economics 9, 153-170.

Kemfert, C., 2004. Climate coalitions and international trade: assessment of cooperation incentives by issue linkage. Energy Policy 32, 455-465.

Nagashima, M., Dellink, R., van Ierland, E., 2006. Dynamic transfer schemes and stability of international climate coalitions. Mansholt discussion paper 23, Mansholt, Wageningen.

Nordhaus, W. D., 1994. Managing the Global Commons: The Economics of Climate Change. The MIT Press, Cambridge.

Reilly, J.M., 2005. Emission, GDP and final energy paths in the MIT-EPPA model. Personal communication.

Sandler, T., 2006. Regional public goods and international organizations. Review of International Organization 1, 5-25.

Tol, R.S.J., 1997. A decision-analytic treatise of the enhanced greenhouse effect. Ph.D. thesis, Vrije Universiteit, Amsterdam.

Weikard, H.P., Finus, M., Altamirano-Cabrera, J.C., 2006. The impact of surplus sharing on the stability of international climate agreements. Oxford Economic Papers 58, 209-232.

World Bank, 2003. World Development Indicators 2003. CD-ROM edition. The World Bank. Washington D.C.

Appendix

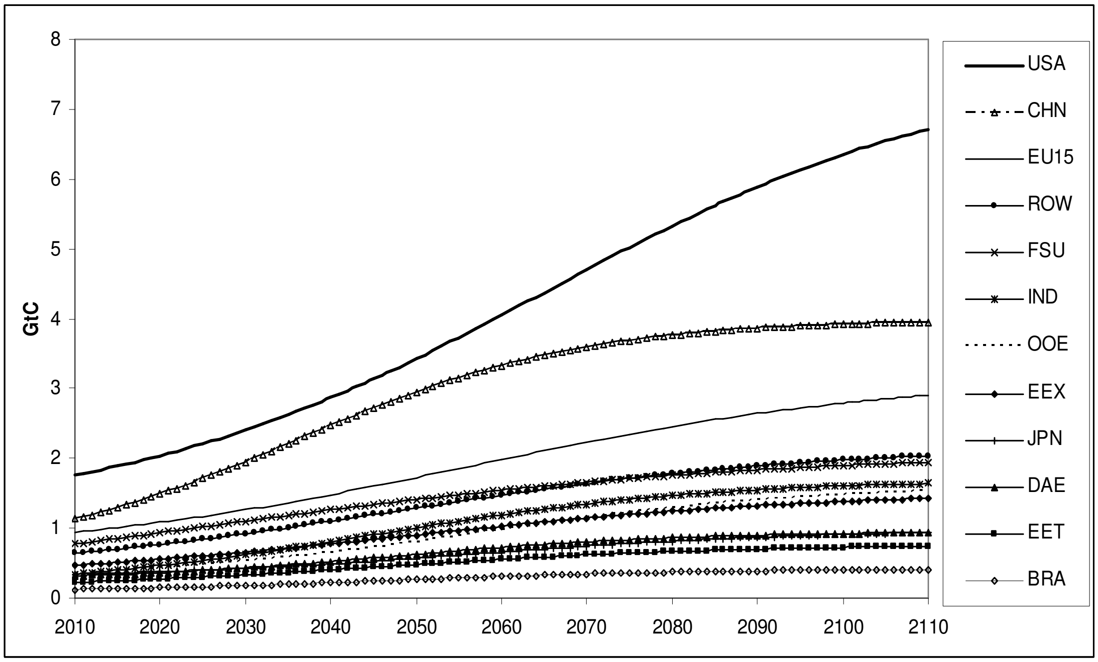
Table A1: Global parameters

Symbol	Description	Value	Unit	Source
$\overline{M}$	Pre-industrial level of CO_2 stock	590	GtC	Nordhaus (1994)
δ	natural annual removal rate of CO_2 stock	0.00866	-	Nordhaus (1994)
ω	airborne fraction of emissions remaining in the atmosphere	0.64	-	Nordhaus (1994)
r	discount rate	0.02	-	assumption
θ_i	share of region i in global benefits	see Table A2, column 3		own calculation based on Fankhauser (1995)
α_i	abatement cost parameter of region i	see Table A2, column 4		own calculation based on Ellerman and Decaux (1998)
β_i	abatement cost parameter of region i	see Table A2, column 5		own calculation based on Ellerman and Decaux (1998)
γ_D	scale parameter of damage and benefit function	0.027	-	Tol (1997)

Table A2: Regional parameters in the benefit and abatement cost function

Regions	Emission in 2010	Share of global benefits	Parameter of abatement cost	Parameter of abatement cost
	GtC (share)	θ_i	α_i	β_i
USA	1.763 (0.238)	0.226	0.0005	0.0398
JPN	0.344 (0.046)	0.173	0.0155	1.8160
EU15	0.943 (0.127)	0.236	0.0024	0.1503
OOE	0.360 (0.049)	0.035	0.0083	0
EET	0.226 (0.030)	0.013	0.0079	0.0486
FSU	0.774 (0.104)	0.068	0.0023	0.0042
EEX	0.469 (0.063)	0.030	0.0032	0.3029
CHN	1.127 (0.152)	0.062	0.00007	0.0239
IND	0.344 (0.046)	0.050	0.0015	0.0787
DAE	0.316 (0.043)	0.025	0.0047	0.3774
BRA	0.122 (0.016)	0.015	0.5612	8.4974
ROW	0.637 (0.086)	0.068	0.0021	0.0805
World	7.425 $\left(\sum=1\right)$	$\left(\sum\theta_i=1\right)$		

Figure A1: Regional BAU emission paths



Source: own calculations based on projections from the MIT-EPPA model (Reilly, 2005).

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