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Dynamic Transfer Schemes and Stability of International Climate Coalitions

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Abstract

This paper examines the formation and stability of coalitions in international climate agreements with a combined game-theoretic and integrated assessment model. The empirical model comprises twelve regions and investigates partial coalition formation in a one-shot cartel game. We argue that a dynamic transfer scheme, based on a full path of emissions over the planning horizon, can overcome some of the major obstacles in international negotiations by incorporating the expected growth of emissions in developing countries in the distribution of emission permits. The simulation results show that permit trading based on grandfathering permits proportionate to a *static* base year level of emissions may lead to counter-intuitive transfer flows, and no stable coalitions emerge. This is resolved under a *dynamic* transfer scheme: we then find two small stable coalitions: a coalition between the European Union (EU15) and China, or a coalition between Japan and India.

JEL-Classification: C72, Q54

Keywords: International climate agreements, tradable emission permits, coalition formation game, dynamic optimization

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1. Introduction

Global warming problems entail externalities that extend beyond national borders. Each region's payoff and welfare derived from emission reduction (abatement) depends heavily on the arrangements enacted by international environmental agreements (IEAs) and the design of institutions. It remains a crucial research topic how such a voluntary agreement could be implemented and what incentives regions have to participate in an agreement. The difficulties with which the Kyoto protocol came into force in February 2005, but without ratification by the U.S.A., illustrate the importance of this topic.

Studies by Hoel (1992 and 1994), Barrett (1994), Fankhauser and Kverndokk (1996), Hoel and Schneider (1997), Peck and Teisberg (1999), Finus et al. (2004 and 2005) and others have proposed different settings to increase the environmental effectiveness and to stimulate voluntary initiatives to cooperate on IEAs. Some of the policy regimes apply the concept of transfer schemes between countries, such as emission permit trading or surplus sharing (e.g., Edmonds et al., 1995; Rose et al., 1998; Altamirano-Cabrera and Finus, 2006; and Weikard et al., 2006). Transfer schemes are especially suitable to compensate regions that contribute relatively much to abatement in the coalition, but that have relatively low benefits from abatement.

So far, little work has been done on the interaction between coalition formation and the optimal abatement paths, and on testing the stability of partial coalitions in a game theoretical approach with empirical inputs. In the framework of a non-cooperative game, Tol (2001) tested stability for all possible coalitions with and without side payment (transfer) using an integrated assessment model of climate change (FUND) including nine regions. FUND applies a fixed path of abatement instead of deriving the optimal abatement in each period. It turns out that the Grand Coalition is not stable under the side payment, and the largest emitters or the most affected regions are excluded in the largest stable coalition.

In the framework of a cooperative game with a dynamic, multi-regional integrated assessment model, Eyckmans and Tulkens (2003) calculated the optimal path of abatement and aggregated discounted welfare for each region. They apply the transfer scheme advocated by Germain et al. (1998) for the CLIMNEG world simulation (CWS) model with six regions. In CWS, the idea of surplus sharing is used for determining the transfer scheme, and they compute all possible partial agreement Nash equilibria (64 possible coalitions). They found that allocation in the full cooperation lies in the core of the emission abatement game under this specific transfer scheme.

In all these studies, the transfer schemes are based on a single year for assigning the permits or shares in the surplus. Such static transfer schemes are also often observed in reality, e.g. the reduction targets in the Kyoto Protocol are designed as reduction compared to 1990 levels. These static schemes, however, do not take into account that the future growth paths of emissions are expected to diverge substantially between regions. This leads to assignments where historically large emitters obtain relatively large shares of the permits / surplus, while fast-growing developing countries, such as China or India, obtain relatively small shares. This leads to increasing burdens on these developing countries to reduce theirs' emissions; a notion brought forward by many developing countries in their argumentation on why they do not agree on any reduction targets in the Kyoto protocol. Dynamic transfer schemes, that are based on expected paths of emissions[1], can overcome these obstacles and can therefore contribute to the stability of international climate agreements. Similarly, dynamic transfer schemes can be constructed that are based on other allocation rules, such as regional population trends.

It is clear that in practice, it will be hard to find a reference path of emissions for the coming decades that is acceptable for all parties. This topic is explored in detail in Böhringer and Lange (2005), who find that dynamic grandfathering schemes may be efficient. Moreover, there may be scope for strategic behavior by countries in the estimation of their future emissions. Nonetheless, expected emission paths are commonly used, for instance by Nakicenovic et al. (2000) and Carter et al. (2001). To use dynamic paths will not be easy in the international negotiations. To avoid strategic behavior as much as possible, it is necessary to very carefully check the reference emission paths as the basis for the dynamic transfer scheme. If the incentives for countries to cooperate increase with such dynamic transfer paths, countries may compromise on accepting the relevant reference emission paths.

The purpose of this paper is to test stability of climate coalitions in a non-cooperative, one-shot cartel game for twelve world regions by optimizing abatement paths under different transfer schemes, and to analyze the impact of implementing dynamic transfer paths on the stability of coalitions in an empirical setting. To this end, we have constructed a model for the stability of coalitions, STACO-2.1, that is capable of identifying the regional optimal abatement paths based on the stream of benefits and costs of abatement. The model is an update and dynamic extension of the STACO-1 model as described in Finus et al. (2005). As

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[1] Such reference emission paths are constructed assuming no implementation of (additional) climate policy. They are often refered to as Baseline Business-as-Usual projections.

each region's strategy depends on its abatement costs and benefits (avoided damages) in each period, each region can simultaneously decide which amount of CO2 emission should be reduced and when. We assume that undiscounted benefits in each period depends not only on current abatement but also on abatement in previous periods through reduced concentrations of CO_2 and correspondingly lower damage levels. Our model incorporates several transfer schemes, based on different allocation rules. The model calculates related economic variables such as benefits, abatement cost and payoffs (expressed year by year) and the discounted aggregates.

The paper is organized as follows. Section 2 provides the game theoretical and empirical framework of the STACO-2.1 model. Section 3 reports main results *without* emission permits and examines the findings *with* static and dynamic permit systems. In section 4, we investigate alternative transfer schemes. Section 5 concludes. The Appendix provides the parameters in our model.

2. The stability of coalitions model (STACO-2.1)

2.1. Game theoretic background

We consider a two-stage, non-cooperative game of coalition formation. Countries or regions (hereinafter referred to as regions) are denoted by $i = 1,...,N$. At the first stage, regions decide to join a coalition or not (membership of the coalition), and then a coalition is formed. Regions announcing not to join a coalition become a singleton, and those announcing to join the coalition become signatories of a cartel coalition. In our model, which comprises twelve regions, we can obtain 4084 (2^{12} -12) different coalition structures.

In the second stage, regions adopt their abatement strategies over the planning horizon $t = 1,\ldots,T$. The game at the second stage is a difference game. The strategies are based on the following payoff function (π):

$$\pi_i(q_1,...,q_T) = \sum_{t=1}^{T} \left\{(1+r)^{-t} \cdot (b_{it}(q_1,...,q_t) - c_{it}(q_{it}))\right\} + \sum_{t=T+1}^{\infty} \left\{(1+r)^{-t} \cdot b_{it}(q_1,...,q_T)\right\} \qquad [1]$$

where the model horizon to account for future benefits is infinity, r is the discount rate on the payoff, $\boldsymbol{q}$ is an abatement matrix of dimension $N \times T$.[2] b_{it} is a concave benefit function of

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[2] We adopt the common notation where subscripts are dropped to denote aggregation over that index.

past and current global abatement in period t, and c_{it} is a convex abatement cost function of regional current abatement. Benefit function and abatement cost function are specified in detail in Section 2.2. We calculate the optimal abatement paths over planning horizon, $t =$ 1,…, T . The abatement strategy space for each region is defined as $q_{it} \in [0, \bar{e}_{it}]$, where $\bar{e}_{it}$ denotes regional emission levels in the business-as-usual scenario with no abatement. Note that benefits for each region depend on *aggregated global emission reductions* and that abatement costs depend on the *emission reduction by region.*

Following Bloch (1997), we assume that signatories and singletons play a Nash equilibrium with regard to their abatement strategies, which is also called a partial agreement Nash equilibrium between signatories and singletons (Chander and Tulkens, 1995 and 1997). Non-signatories choose their abatement level by maximizing their own payoffs, taking the other regions' abatement levels as given. Signatories choose the abatement levels that maximize the sum of the payoffs of the signatories, taking the abatement levels of non-signatories as given. We call a coalition where none or one of the regions joins the coalition 'All Singletons', and a coalition where all regions cooperate 'Grand Coalition'. In the Grand Coalition, the highest global abatement levels and payoffs are obtained, as all spillovers from abatement on the benefits of other regions are taken into account.

Internal stability of a coalition means that no signatory has an incentive to withdraw from the coalition as a lower payoff is obtained by changing the strategy to not join the coalition. Similarly, external stability of a coalition means an equilibrium where no non-signatories have an incentive to participate in the coalition as a lower payoff is achieved by changing their strategy to join a coalition. We call a coalition structure K stable, if the coalition satisfies both internal and external stability. In the definition of external stability, it is implicitly assumed that non-signatories can join the coalition freely whenever they can obtain the higher payoff by joining the coalition, without the approval by other signatories. We call this 'stability under open membership' (cf. Finus et al., 2004). In this paper, we apply this concept of open membership, mainly because it seems in line with the procedures of the Kyoto protocol.

2.2. Empirical background – STACO-2.1 model with multi-periods in one-shot game

In this section, we explain the empirical module of our model which we label STACO-2.1 (Box 1). The model is an update and extension of the original STACO-1 model, described in Dellink et al. (2004) and Finus et al. (2005). Here, we focus on the main features of the model and on the differences with STACO-1. 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). We set the model horizon to account for benefits from abatement to infinity, but adopt a shorter planning horizon of 100 years, ranging from 2011 to 2110, for determining abatement levels. Together, this ensures a proper reflection of the intertemporal aspects of climate change, while the period for which the international agreement holds is limited. Essentially, in 2010 the signatories strike an agreement that sets their abatement path until 2110, while taking into account all future benefits and costs from that abatement path.

We calibrate the payoff function for each region expressed in equation [1]. Payoff for region i in t period, π_{it}, depends on the abatement path until t. Benefit, b_{it}, from abatement is the function of avoided damages which is derived from the damage module of the DICE model (Nordhaus, 1994) and the climate module by Germain and Van Steenberghe (2003). For CO_2 concentrations, the model bases its calibration on DICE model developed by Nordhaus (1994). In contrast to STACO-1, we use the data for CO_2 emission derived from EPPA model (Reilly, 2005) to calibrate the regional BAU emission paths[3] in our model; these paths are represented in Appendix 2. The damage function is a function of the stock of CO_2 and can be approximated by a linear function. In equation [3], y_t denotes global GDP in year t as given in Nordhaus (1994), and γ_1 and γ_2 are estimated by OLS-regression (Dellink et al., 2004). For the global damage parameter γ_D, 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, that is, $\gamma_D = 0.027$. Global benefits are allocated according to the share θ_i for each region, as displayed in Appendix 2.

We specify an abatement cost function following the estimates of the EPPA model by Ellerman and Decaux (1998). In our model, we assume exogenous technological progress for 0.5 percent annually that is modelled as a reduction of current abatement costs. STACO-1 assumed that each region chooses a constant abatement level over planning time horizon. Here, we use a specification in which abatement levels for each period are endogenously determined in the model by maximizing the net present value of the stream of payoffs. Each region has perfect foresight of the future and can plan its abatement path for the current and

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

all future years within the planning period. Finally, we implement a transversality condition for the future impacts from abatement by assuming that marginal global benefits reflect all current and future benefits from abatement in period t, discounted back to period t.

Box 1. Equations in STACO-2.1

Payoff function (objective function)

$$\max\ \pi_i(q_1,\ldots,q_T) = \sum_{t=1}^{T}\left\{(1+r)^{-t}\cdot(b_{it}(q_1,\ldots,q_t) - c_{it}(q_{it}))\right\} + \sum_{t=T+1}^{\infty}\left\{(1+r)^{-t}\cdot b_{it}(q_1,\ldots,q_T)\right\} \qquad \forall i \in \boldsymbol{N} \tag*{[1]}$$

Stock of CO_2

$$M_t(M_{t-1}, q_1,\ldots,q_t) = \overline{M} + (1-\delta)\cdot(M_{t-1}(q_1,\ldots,q_{t-1}) - \overline{M}) + \omega\cdot\sum_{i=1}^{n}\left(\overline{e}_{it} - q_{it}\right) \tag*{[2]}$$

Damages

$$d_t(M_t) = \left[\gamma_1 + \gamma_2\cdot\left(\frac{M_t(q_1,\ldots,q_t)}{\overline{M}}\right)\right]\cdot(\gamma_D\cdot y_t) \tag*{[3]}$$

Benefits

$$b_t(q_1,\ldots,q_t) = d_t(M_t(\mathbf{0})) - d_t(M_t(q_1,\ldots,q_t)) \tag*{[4]}$$

$$b_{it}(q_1,\ldots,q_t) = \theta_i\cdot b_t(q_1,\ldots,q_t) \tag*{[5]}$$

Abatement costs

$$c_{it}(q_{it}) = \tfrac{1}{3}\cdot\alpha_i\cdot(1-\varsigma)^t\cdot q_{it}^3 + \tfrac{1}{2}\cdot\beta_i\cdot(1-\varsigma)^t\cdot q_{it}^2 \tag*{[6]}$$

Discounted benefits

$$B_i(\mathbf{q}) \equiv \sum_{t=1}^{\infty}\left\{(1+r)^{-t}\cdot b_{it}(\mathbf{q})\right\} \tag*{[7]}$$

Discounted abatement costs

$$C_i(\mathbf{q_i}) \equiv \sum_{t=1}^{\infty}\left\{(1+r)^{-t}\cdot c_{it}(q_{it})\right\} \tag*{[8]}$$

Marginal benefits from current abatement

$$B'_{it}(q_t) \equiv \sum_{s=t}^{\infty}\left\{(1+r)^{t-s}\cdot\frac{\partial b_{is}(q_1,\ldots,q_s)}{\partial q_t}\right\} \tag*{[9]}$$

Marginal abatement costs

$$C'_{it}(q_{it}) \equiv \frac{\partial c_{it}(q_{it})}{\partial q_{it}} \tag*{[10]}$$

Discounted marginal benefits

$$B'_i(\mathbf{q}) \equiv \frac{\partial B_i(\mathbf{q})}{\partial q_t} = (1+r)^{-t}\cdot B'_{it}(q_t) \tag*{[11]}$$

Discounted marginal abatement costs

$$C'_i(\mathbf{q_i}) \equiv \frac{\partial C_i(\mathbf{q_i})}{\partial q_{it}} = (1+r)^{-t}\cdot C'_{it}(q_{it}) \tag*{[12]}$$

2.3. Transfer schemes

We incorporate an emission permit trading system in the model to allow for transfers among regions in the coalition. Following the permits trading scheme of Altamirano-Cabrera and Finus (2006) who apply several allocation-based rules[4] for distributing the permits, we focus on the pragmatic scheme which distributes permits in proportion to emissions. This allocation scheme is presented in the Kyoto protocol as 'Grandfathering' where the allocation of permits is based on the historical emission for each region. Emission permits can be traded only among signatories, so after trade payoffs ($\hat{\pi}_{it}^{K}$) for signatories are calculated as

$$\hat{\pi}_{it}^{K} = \pi_{it}^{K}(q_t^*(K)) - p_t \cdot (\tilde{q}_{it} - q_{it}^*(K)) \ , \qquad [13]$$

where p_t is the permit price at t period and $\tilde{q}_{it}$ is the assigned abatement for i player at period t under the permit trading system in a coalition structure K. The first term on the right hand side of equation [13] is the payoff from the optimal abatement level q_{it}^*, without trading permits. The second term implies that if a region reduces emission more than assigned ($\tilde{q}_{it} < q_{it}^*$), the region can sell the permits to other signatories. On the other hand, if a region reduces emissions less than the assigned abatement level ($\tilde{q}_{it} > q_{it}^*$), the region has to compensate the difference by purchasing permits. The price of a permit, p_t, equals marginal abatement costs.

In the permits market, the emission permits of region *i* at period *t*, $\tilde{e}_{it}$, are calculated as a share λ_{it} of the total amount of permits among signatories *K* with $\sum_{i \in K} \lambda_{it} = 1$, such that

$$\tilde{e}_{it} = \lambda_{it} \cdot \sum_{i \in K} \tilde{e}_{it} \ , \qquad [14]$$

where *K* denotes the set of signatories.

As the total amount of emission permits for signatories is equal to the emission level in equilibrium, $\sum_{i \in K} \tilde{e}_{it} = \sum_{i \in K} e_i^*$, expressed as $\sum_{i \in K} \tilde{e}_{it} = \sum_{i \in K} \overline{e}_{it} - \sum_{i \in K} q_{it}^*$, the assigned abatement can be defined as

$$\tilde{q}_{it} = \overline{e}_{it} - \lambda_{it} \left(\sum_{i \in K} \overline{e}_{it} - \sum_{i \in K} q_{it}^* \right) . \qquad [15]$$

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[4] For criteria of rules for allocating permits see Edmonds et al. (1995) and Rose et al. (1998).

For the static transfer scheme, share λ_{it} is calculated based on the ratio of 2010 emissions for region i ($\bar{e}_{i,2010}$) over the total 2010 emissions of all signatories. Thus, the share is constant over time:

$$\lambda_{it} = \lambda_i = \frac{\bar{e}_{i,2010}}{\sum_{i \in K} \bar{e}_{i,2010}} \ . \qquad [16a]$$

For the dynamic transfer scheme, we use the full path of reference emissions without abatement to determine the time-dependent shares:

$$\lambda_{it} = \frac{\bar{e}_{it}}{\sum_{i \in K} \bar{e}_{it}} \ . \qquad [16b]$$

3. Results

We start this section with an examination of the case without permit trading in Section 3.1. This case can serve as a reference point for the analysis of the various transfer schemes in the following sections. Section 3.2 presents results for emission-based permit trading, while Sections 4.1 and 4.2 discuss the alternative transfer schemes of population-based permit trading and emission-based surplus sharing, respectively.

3.1. Coalition formation without emission permits

Table 1 shows the results of the non-cooperative case for reducing emissions where all players act as singletons. In this All Singletons structure, marginal abatement costs equal marginal benefits for each region. The results for this case give good insights into the incentive structure of the different regions. The percentage of annual abatement compared to BAU emission tends to be decreasing over time and leads to a stock of CO_2 of 1,448 Gton by the year 2110. This is about 1.7 times the stock level in 2010.

At the individual region level, abatement differs from region to region, as the abatement level is determined by marginal benefits and marginal costs. The USA, a region with a low marginal abatement cost curve, and high share of global benefits (cf. Appendix 2), has an incentive to make substantial abatement efforts even in the All Singletons case, and in 2011 USA reduces 9.9 percent of BAU emissions. Regions with higher marginal abatement cost and lower share of global benefits, such as energy exporting countries, Brazil, and dynamic Asian economies, have hardly any incentive to reduce emission on their own. Japan, which has a relatively high share of global benefits, does not make much abatement efforts due to higher marginal cost. In 2011, it only reduces about 2.5 percent of emissions in the BAU case and total abatement amounts to 2 Gton over time.

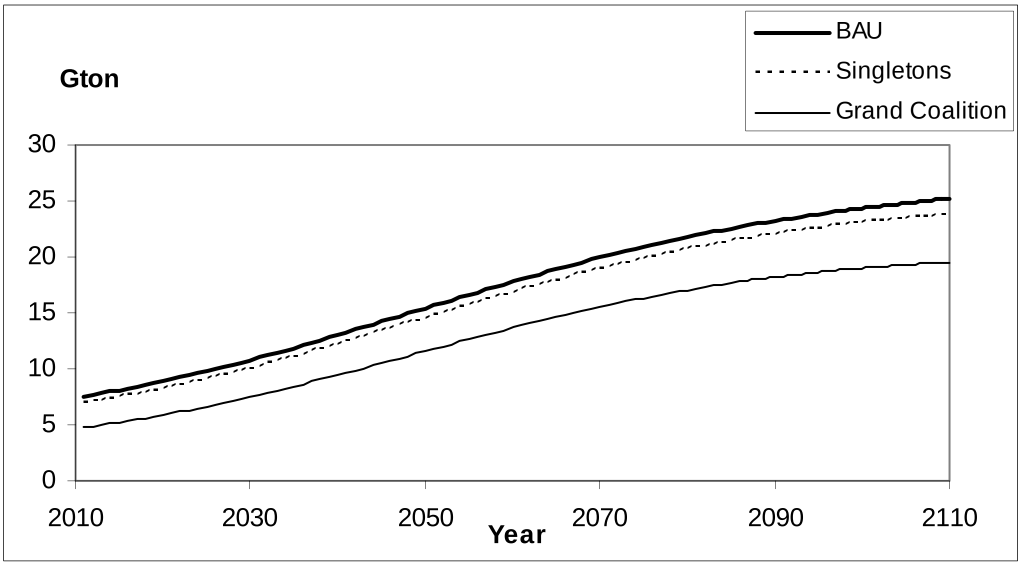
Table 1: All Singletons Structure

Regions	Annual abatement (% of BAU emissions)		Net present value (NPV) of payoff	Marginal costs in 2011	Marginal benefits from abatement in 2011
	2011	2110	Billion US$ over 100 years	US$/ton	US$/ton
USA	9.9	5.5	1,117	22.4	22.4
JPN	2.5	3.0	943	17.1	17.1
EU15	7.6	5.6	1,240	23.4	23.4
OOE	5.6	2.6	188	3.4	3.4
EET	4.4	2.9	71	1.3	1.3
FSU	6.7	5.3	362	6.7	6.7
EEX	1.9	2.0	164	3.0	3.0
CHN	14.8	10.8	298	6.1	6.1
IND	10.5	5.3	268	4.9	4.9
DAE	1.9	2.1	136	2.5	2.5
BRA	0.1	0.2	84	1.5	1.5
ROW	6.3	4.5	365	6.7	6.7
Global	8.0	5.5	5,238		

Global stock of CO_2 in 2110 = 1,448 Gton

Figure 1 depicts the global emission paths over time horizon for respectively the BAU case, All Singletons and Grand Coalition.

Figure 1: Global emission paths for BAU, All Singletons, and Grand Coalition (without transfers)



In the BAU scenario, no abatement takes place. BAU emissions grow in the form of an S-shaped curve, and the pace of growth slows down at the end of the century, reaching a level of almost 25 Gton by 2110. In the case of All Singletons, emissions reach about 24 Gton by 2110. Emissions in the Grand Coalition are about 20 percent lower than in the All Singletons case, and reach around 19 Gton by 2110.

We compute all possible cartel coalitions and examine stability for all 4084 coalition structures with an algorithm programmed in Matlab. Without permits, 14 non-trivial coalitions are internally stable, of which only the one between Japan & EU15 is also externally stable. Table 2 shows the results for stable coalition, Japan & EU15. EU15 reduces emissions about 30 percent more than in the All Singletons structure. Japan makes abatement efforts twice as high as in the All Singletons structure. As a result of their cooperation, both regions can obtain slightly higher net present payoff than in the All Singletons case.

Table 2: Coalition of Japan and EU15 (without transfers)

Regions	Annual abatement (% of BAU emissions)		Net present value (NPV) of payoff	Marginal costs in 2011	Incentive to change membership (NPV)
	2011	2110	Billion US$ over 100 years	US$/ton	Billion US$ over 100 years
USA	10	6	1,199	22.4	-143
JPN	***6***	***6***	***975***	***40.4***	***-32***
EU15	***11***	***8***	***1,244***	***40.4***	***-4***
OOE	6	3	201	3.4	-70
EET	4	3	76	1.3	-78
FSU	7	5	386	6.7	-121
EEX	2	2	175	3.0	-107
CHN	15	11	321	6.1	-725
IND	10	5	286	4.9	-159
DAE	2	2	145	2.5	-89
BRA	0	0	90	1.5	-7
ROW	6	5	389	6.7	-126
Global	8.6	5.8	5,486		

Global stock of CO_2 in 2110 = 1,445 Gton

Incentive to leave the coalition is shown in the last column of Table 2 and is calculated as the difference between the net present value of regional payoff when the region leaves the coalition and net present value of regional payoff for the coalition including the region. Similarly, for singletons the incentive to join the coalition is calculated and represented in Table 2. Both coalition members have interest in cooperation, because of their higher marginal benefits from abatement, while none of the other regions want to join, as their abatement costs would increase too much if they have to take the benefits in Japan and EU15 into account.

Other coalitions are not stable, implying that free-rider incentives are strong and regions are often better off when they stay outside a coalition.

3.2. Emission-based permit trading

3.2.1. A static transfer scheme

In this section, we incorporate a transfer scheme based on emission permit trading across regions in the coalition, as explained in Section 2.3. In the static transfer scheme, emission permits are divided over the coalition members based on their respective emissions in the base year 2010.[5] Table 3 shows the results of the Grand Coalition without and with a static emission-based permit trading scheme.

Table 3: Grand Coalition (with emission-based permit trading)

Regions	Abatement in 2110 (% of BAU emissions)		Net present value (NPV) of payoff Billion US$ over 100 years		Incentive to change membership (NPV) Billion US$ over 100 years	
	efficient level	assigned level for static transfers	no transfers	static transfers	no transfers	static transfers
USA	12	31	4,158	2,090	52	2,120
JPN	11	3	3,930	4,011	-281	-362
EU15	12	15	5,062	4,724	-432	-94
OOE	14	38	518	-325	261	1,103
EET	29	20	-1	187	297	109
FSU	21	-5	1,031	1,721	423	-268
EEX	21	14	248	395	420	274
CHN	54	25	-1,777	1,255	2,727	-305
IND	29	45	482	-217	588	1,287
DAE	26	11	209	454	352	107
BRA	5	21	333	-16	27	376
ROW	20	18	1,019	932	442	530
Global	23	23	15,211	15,211	4,877	4,877

Global stock of CO_2 in 2110 = 1,304 Gton

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[5] Using 1990 emission levels instead of 2010 does not influence the main qualitative results (results available from the authors upon request).

In the Grand Coalition, total gain of cooperation in terms of the net present value of payoff compared to the All Singletons case is 9,973 billion US$. Even though at the global level, substantially higher net present value of payoff can be achieved, some regions are worse off when the Grand Coalition is formed. For instance, China, which has the lowest abatement costs, has to contribute much to reduce emissions. This leads to the large difference in the net present value of payoff, from 298 billion US $ in the All Singletons case to -1,777 billion US $ in the Grand Coalition without transfers.

At the global level, transfers such as the emission permit trading scheme do not affect payoff, but the allocation of payoff over regions is changed. With regard to the net present value of transfers, a positive number implies that the region pays a transfer (is a permit buyer), and a negative number means that the region receives a transfer (is a permit seller). Japan, Eastern European countries, Former Soviet Union, Energy exporting countries, China and dynamic Asian economies become permit sellers and the other regions become permit buyers. The incentive to leave the coalition increases for permit buyers and reduces for permit sellers. Thus, if the permit buyers are those regions that have a high stake in collaboration, i.e. they have high marginal benefits, tradable permits may stabilize the coalition. In the Grand Coalition, permits can solve the problem of the high reduction burden for China, but the coalition is not stable, as most regions still have an incentive to leave the coalition.

The coalition between Japan and European Union is no longer stable under the transfer scheme. The European Union no longer desires to stay in this coalition, as it would have to pay more for buying permits from Japan than its gain from collaboration provides. A more likely coalition for stability is a combination of a region with high marginal benefits, such as Japan or European Union, together with a region with low marginal abatement costs, such as China or India. The basic idea is that the former regions could finance emission reductions in the latter regions. However, under a static emission-based permit trading scheme, the number of permits issues to China and India is relatively small, and their reference emissions grow relatively fast, and hence these regions need large abatement efforts to reach their targets. In contrast, a region like Japan will, relatively speaking, obtain many permits under a static scheme, whereas their emissions are expected to hardly grow over the century.

As the reduction target for the coalition of, for instance, Japan and India is limited to a rather low level, Japan will actually have excess permits to sell in the later decades. India will demand these permits to be able to attain their target. Thus, India is not compensated by Japan for carrying out the relatively large share of coalitional abatement, but rather punished for growing fast. Clearly, the coalition is not beneficial for India and it is not surprising that this coalition is unstable.

3.2.2. A dynamic transfer scheme

A possible way out of this dilemma is to base the distribution of emission permits on the whole path of reference emissions. This will overcome the counter-intuitive situation obtained in the static transfer scheme, as fast-growing regions such as India will obtain more permits over time. Thus, dynamic transfer schemes are much better aligned with the changing incentive structures of regions over time and may be a key determinant in persuading developing countries to sign an international climate agreement.

Table 4: Stable coalitions (with dynamic emission-based permit trading)

Regions	Efficient abatement in 2110		Net present value (NPV) of payoff		Incentive to change membership (NPV)	
	(% of BAU emissions)		Billion US$ over 100 years		Billion US$ over 100 years	
	(a) EU15 & China	(b) Japan & India	(a) EU15 & China	(b) Japan & India	(a) EU15 & China	(b) Japan & India
USA	6	6	1,780	1,240	-654	-126
JPN	3	***4***	1,448	***975***	-23	***-32***
EU15	***6***	6	***1,512***	1,368	***-272***	-71
OOE	3	3	289	207	-176	-44
EET	3	3	109	78	-63	-7
FSU	5	5	559	398	-251	-52
EEX	2	2	252	180	-197	-56
CHN	***28***	11	***401***	332	***-103***	-13
IND	5	***13***	415	***287***	-105	***-18***
DAE	2	2	209	150	-123	-33
BRA	0	0	129	93	-84	-31
ROW	5	5	564	402	-235	-52
Global	8	6	7,667	5,709	-2,284	-536

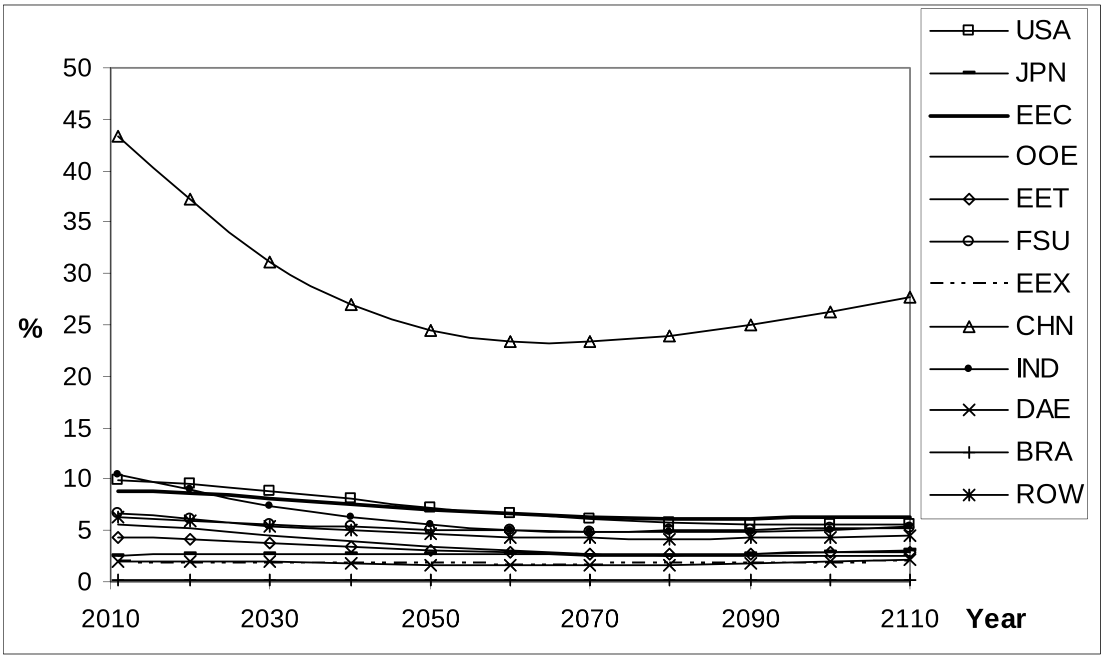
Global stock of CO_2 in 2110 = 1,425 Gton (EU15 – China) and 1,444 Gton (Japan and India)

Under the dynamic tradable emission permit scheme, twelve coalitions are internally stable of which two are also externally stable. Table 4 displays the results of the two stable coalitions; (a) EU15 & China, and (b) Japan & India. In the case without permits, China and India have incentive to leave the coalition because of higher abatement burden compared to EU15 and Japan respectively, and they have lower payoffs. This makes the coalition internally unstable.

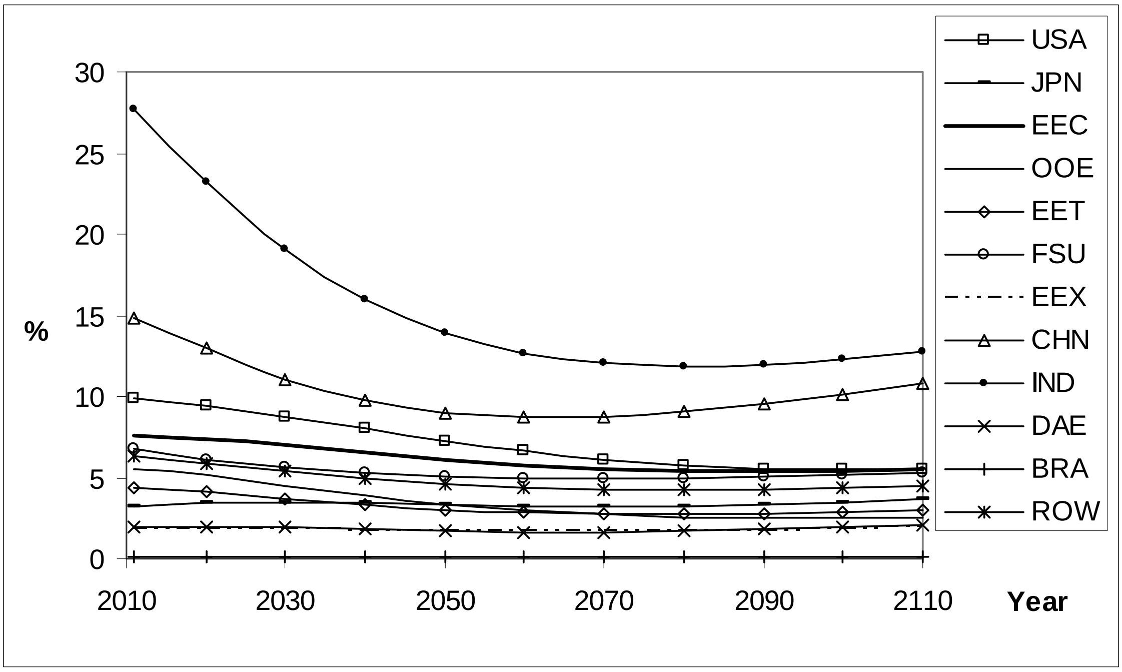
Under the dynamic transfer scheme, these situations are improved. China and India respectively have lower assigned abatement (more emission permits), and they can sell their permits to each partner, EU15 and Japan, respectively. China can obtain transfers from EU15 amounting to a Net Present Value (NPV) of about 392 billion US $, and India from Japan amounting to an NPV of about 57 billion US $. These transfers would encourage China and India to make a coalition with respectively EU15 and Japan, and not to leave the coalition.

Figure 2: Annual abatement (percent of emission in BAU) for stable coalitions

(a) EU15 & China



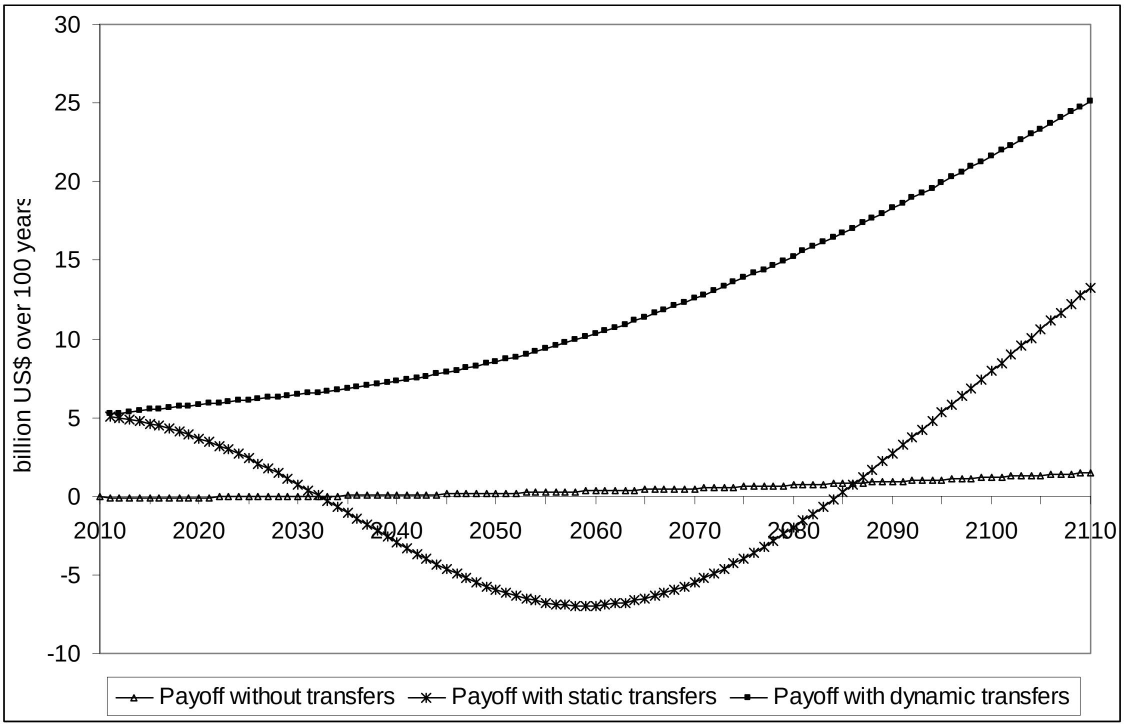
(b) Japan & India



The panels (a) and (b) in Figure 2 clearly show that signatories will undertake a substantial part of global abatement, especially China and India, but as they are sufficiently compensated through the transfer scheme, this no longer violates their interests.[6]

As an illustration, Figure 3 shows how the transfer schemes affect the stream of payoffs for China in a coalition of EU15 and China. Without transfers, the payoff for China is slightly negative for the first two decades, but is clearly positive for the later decades (as Chinese emissions are expected to stabilize), leading to a small but positive NPV of payoff (9 billion $). With the static transfer scheme, the payoff decreases rapidly and turns negative after two decades. This is due to the fast growth of reference emissions and thus the large need for emission reductions by China; in these periods, China buys permits from the EU15. In later decades, the payoff turns positive again, as Chinese emissions stabilize and China is able to sell some permits. In net present value terms, the coalition is not beneficial for China (NPV of payoff equals -5 billion $). Note that the stream of transfers can be read from the figure by subtracting the payoff without transfers from the payoff with transfers.

Figure 3: Undiscounted payoff path for China in the coalition of EU15 and China



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[6] Note also that due to their low marginal abatement costs, China will reduce emissions substantially as a singleton as well; cf. panel (b).

With the dynamic transfer scheme, China is able to sell permits to the EU15 in all periods, as the difference in growth rates between the two regions is taken into account in the allocation of the emission permits. Thus, the negative payoff in the middle of the century is prevented and China earns a NPV of almost 400 billion US$ on the sale of excess permits. These additional earnings overcome the free-rider incentives of China, and while they reduce the gains from cooperation for the EU15, the outcome is beneficial for both, and thus the coalition is internally stable. Larger coalitions will violate the interests of some members, because the emission permit price will be too high due to excess demand or too low due to excess supply. Thus, the coalition of EU15 and China is also externally stable.

4. Alternative transfer schemes

4.1. Population based permit trading

We apply a different transfer scheme, using the data on population over our planning horizon from the EPPA model as reported by Babiker et al. (2001). In the static transfer scheme, we use population shares in 2010 to determine the shares of signatories in the emission permits trading scheme, while for the dynamic transfer scheme we use the entire path. For the population-based transfer schemes, only the sharing rule needs to be revised. In this case, the static transfer scheme shares are given by

$$\lambda_{it} = \lambda_i = \frac{\overline{pop}_{i,2010}}{\sum_{i \in K} \overline{pop}_{i,2010}} \tag{16c}$$

where $\overline{pop}_{i,2010}$ denotes the regional population in 2010. The dynamic shares are calculated as

$$\lambda_{it} = \frac{\overline{pop}_{it}}{\sum_{i \in K} \overline{pop}_{it}} \tag{16d}$$

The static population based permits imply that regions with large population in 2010 such as the Energy exporting countries, China, and India, will obtain more permits to sell and higher payoffs than in the absence of the tradable permits. However, other signatories will not be better off under the population based transfer scheme. For the dynamic transfer scheme, regions with high expected population growth will benefit from the dynamic transfer path; these include for example, Energy exporting countries, China and India.

Under the population-based emission permit trading scheme, we find no stable coalitions, using either a static or dynamic transfer scheme. Table 5 reports the Grand Coalition. It is clear that the transfers involved are huge, especially for the USA and Energy exporting countries.

Table 5: Grand Coalition (with population-based permit trading)

Regions	Abatement in 2110			Net present value (NPV) of payoff			Incentive to change membership (NPV)		
	(% of BAU emissions)			Billion US$ over 100 years			Billion US$ over 100 years		
	efficient level	assigned level for static transfers	assigned level for dynamic transfers	no transfers	static transfers	dynamic transfers	no transfers	static transfers	dynamic transfers
USA	12	86	90	4,158	-11,233	-12,096	52	15,443	16,307
JPN	11	60	80	3,930	2,117	1,567	-281	1,531	2,082
EU15	12	61	79	5,062	-79	-1,665	-432	4,709	6,295
OOE	14	72	80	518	-2,176	-2,495	261	2,955	3,274
EET	29	51	71	-1	-634	-1,175	297	930	1,471
FSU	21	55	65	1,031	-2,457	-2,977	423	3,911	4,430
EEX	21	-241	-359	248	13,461	17,855	420	-12,793	-17,187
CHN	54	-3	25	-1,777	5,248	2,096	2,727	-4,299	-1,147
IND	29	-112	-95	482	9,038	8,317	588	-7,968	-7,247
DAE	26	33	39	209	-272	-421	352	833	982
BRA	5	-42	-24	333	907	690	27	-547	-330
ROW	20	13	-50	1,019	1,291	5,513	442	171	-4,052
Global	23	23	23	15,211	15,211	15,211	4,877	4,877	4,877

Global stock of CO_2 in 2110 = 1,304 Gton

4.2. Emission-based surplus sharing

Transfer schemes based on surplus sharing are proposed for instance by Weikard et al. (2006), who consider various sharing rules for the gains from cooperation. One of the main advantages of surplus sharing is that individual rationality is always satisfied as long as a coalition is at all profitable, i.e. countries cannot be worse off with the transfer scheme than without.

The sharing rule assigns a share λ_{it} of the coalition surplus S_t^K (as defined below in equation 17) to every coalition member $i \in K$ such that $\lambda_{it} \cdot S_t^K = s_{it}^K$; s_{it}^K can also be called the claim of member *i*. The coalition surplus S_t^K is defined as the joint gain of the coalition members compared with their joint payoff in the benchmark situation of the All Singletons structure (q_{it}^N), *i.e.*

$$S_t^K = \sum_{i\in K}\pi_{it}(q_t^*) - \sum_{i\in K}\pi_{it}(q_t^N). \quad [17]$$

Then, the payoff of a coalition member is given by its benchmark payoff plus its share of the coalition surplus:

$$\hat{\pi}_{it}^K = \pi_{it}(q_t^N) + s_{it}^K. \quad [18]$$

Although it is possible to apply different rules to the sharing problem (such as equal sharing, proportional sharing and combinations), we adopt a proportional sharing rule, based on emission levels. Thus, this transfer scheme is the outcome-based analogue to our emission-based (grandfathering) scheme in the context of permit trading.

For the static transfer scheme, the shares are based on 2010 emission levels:

$$s_{it}^K = \lambda_{it}\cdot S_t^K = \lambda_i \cdot S_t^K = \frac{\bar{e}_{i,2010}}{\sum_{i\in K}\bar{e}_{i,2010}}\cdot S_t^K \quad [19a]$$

For the dynamic transfer scheme, we use the full path of reference emissions without abatement to determine the time-dependent shares:

$$s_{it}^K = \lambda_{it}\cdot S_t^K = \frac{\bar{e}_{it}}{\sum_{i\in K}\bar{e}_{it}}\cdot S_t^K \quad [19b]$$

Table 6 presents the main results of the emission-based surplus sharing scheme for the only stable coalition, USA and China. This coalition is stable under both the static and dynamic transfer scheme. When transfers are based on a division of the gains from cooperation rather than division of tradable emission permits, internal stability is less of a problem. Therefore, though the static transfer scheme is not entirely matching the development of the regions, the scheme is sufficient to stabilize this coalition. The incentives to change membership are for most regions more strongly negative under the dynamic transfer scheme, indicating that the dynamic transfer scheme is more robust than the static scheme.

Table 6: Coalition of USA and China (with emission-based surplus sharing)

	Abat. in 2110	Claim in 2110		Net present value (NPV) of payoff			Incentive to change membership (NPV)		
Regions	(% BAU)	Million US$		Billion US$ over 100 years			Billion US$ over 100 years		
	efficient level	static transfers	dynamic transfers	no transfers	static transfers	dynamic transfers	no transfers	static transfers	dynamic transfers
USA	***6***	***11,342***	***11,704***	***1,731***	***1,332***	***1,319***	***-613***	***-215***	***-201***
JPN	3	-	-	1,454	1,454	1,454	312	-399	-421
EU15	6	-	-	1,940	1,940	1,940	541	-350	-388
OOE	3	-	-	290	290	290	-27	-45	-42
EET	3	-	-	110	110	110	-44	-5	-7
FSU	5	-	-	562	562	562	-19	-58	-78
EEX	2	-	-	253	253	253	-51	-15	-23
CHN	***27***	***7,249***	***6,887***	***37***	***436***	***449***	***261***	***-137***	***-151***
IND	5	-	-	417	417	417	-63	-80	-64
DAE	2	-	-	210	210	210	-44	-25	-30
BRA	0	-	-	130	130	130	-1	-29	-30
ROW	5	-	-	566	566	566	-21	-79	-87
Global	8	18,591	18,591	7,700	7,700	7,700	232	-1,437	-1,523

Global stock of CO_2 in 2110 = 1,425 Gton

5. Conclusions

In this paper, we incorporate a dynamic emission-based permit trading scheme to examine the stability of all possible climate coalitions in a cartel game. We argue that a dynamic transfer scheme, based on the full path of reference emissions, rather than based on a single (historical) base year, can overcome some of the major obstacles in international negotiations by incorporating the fast growth of emissions in developing countries in the division of emission permits. We investigate to what extent the dynamic transfer scheme can contribute to the stability of an international climate agreement, using our empirical model STACO-2.1.

We find that under a static emission-based permit trading scheme, historically large emitters get a disproportionately large share of the permits that they can sell while fast-growing regions, such as China and India, need to buy emission permits. This leads to the counter-intuitive situation that historically large emitters are permit-sellers, while the developing countries are permit-buyers. Given the relatively large benefits in regions like Japan and EU15, such transfers do not match the incentive structures of the coalition members, and such coalitions will not be stable.

This situation is improved under the dynamic permit trading scheme. We then obtain two stable coalitions; EU15 and China, and Japan and India. China and India will be better off because those regions have more emission permits and can sell their permits to the respective partner. As the gains from cooperation for this partner are sufficiently large, they also have an incentive to stay in the coalition. Dynamic transfer schemes are much better aligned with the changing incentive structures of regions over time and may be a key determinant in persuading developing countries to sign an international climate agreement. It should be noted that these coalitions are small and fall considerably short of filling the gap between no agreement and the Grand Coalition. The Grand Coalition of all regions leads to substantially higher abatement efforts and obtains large gains from cooperation, as marginal abatement costs vary widely between regions. However, the Grand Coalition is not stable, irrespective of the transfer scheme. The free-rider incentives are huge in the case without transfers and too large to be overcome by a transfer scheme, be it static or dynamic.

Alternative transfer schemes, such as population-based permit trading or emission-based surplus sharing, show that a dynamic transfer scheme will perform better than a static transfer scheme in terms of aligning regional incentives, but this does not automatically imply that larger stable coalitions will be found under the dynamic scheme: in the case of population-based emission permits, the dynamic transfer scheme is insufficient to stabilize any coalition, while in the surplus sharing scheme a coalition of USA and China is stable under both the static and dynamic transfer scheme.

For future research, we would like to investigate the possibilities of exclusive membership rules, technology transfers and one or more rounds of renegotiations. These mechanisms may contribute to the stability of climate coalitions, especially in combination with dynamic transfer schemes as discussed in this paper.

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Appendix 1: Global parameters

Symbol	Description	Value	Unit	Source
$\overline{M}$	Pre-industrial level of CO_2 stock	590	Gton	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 Appendix 2, column 3		own calculation based on Fankhauser (1995)
α_i	abatement cost parameter of region i	see Appendix 2, column 4		own calculation based on Ellerman and Decaux (1998)
β_i	abatement cost parameter of region i	see Appendix 2, column 5		own calculation based on Ellerman and Decaux (1998)
ς	technological progress parameter	0.005	-	assumption
γ_D	scale parameter of damage and benefit function	0.027	-	Tol (1997)

Appendix 2: Regional parameters in the benefit and abatement cost function

Regions	Emission in 2010 Gton (share)	Share of global benefits θ_i	Parameter of abatement cost α_i	Parameter of abatement cost 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 $\left(\sum=1\right)$	$\left(\sum\theta_i=1\right)$		

Regional emission paths