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Minimum Participation Rules with Heterogeneous Countries

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Almost all international environmental agreements include a minimum participation rule. Under such a rule an agreement becomes legally binding if and only if a certain threshold in terms of membership or contribution is reached. We analyze a cartel game with open membership and heterogeneous countries to study the endogenous choice of a minimum participation rule and its role for the success of international environmental agreements.

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1 Introduction

In February 2005 the Kyoto-Protocol entered into force, more than seven years after it had been negotiated. One reason for the delay is that a hurdle had to be overcome. It was agreed in Kyoto that the protocol would not become binding unless ratified by a minimum number of 55 countries that include Annex I countries[1] responsible for at least 55 percent of the emissions of greenhouse gases of all Annex I countries in 1990.[2] Similar requirements, called ‘minimum participation rules’ (MPRs), are very common in international environmental agreements (IEAs).[3] Rutz (2001) examined a sample of 122 IEAs and found that almost all (98 percent) contained some kind of participation clause.

As the abatement levels agreed in the Kyoto-Protocol are only binding until the end of 2012, negotiations about a post-Kyoto agreement will take place in December 2009 in Copenhagen. So far there is at least a consensus that in Copenhagen a new multilateral agreement with country-specific commitments to further reduce greenhouse gas emissions is aimed at. Our paper contributes to the discussion about optimal international policy coordination in general and the issue of an MPR for a post-Kyoto agreement in particular.

IEAs are set up to control transnational spillovers. By their very nature IEAs have to be *self-enforcing*, meaning that countries decide voluntarily to join the agreement or not. Spillovers imply that, even though countries can reap some gains from cooperation, there are strong incentives to free-ride on an agreement and unilateral action is inefficient. In the case of greenhouse gases, a failure to establish a sufficiently large (and effective) coalition may even trigger catastrophic risks (Stern et al. 2007, IPCC 2007).

The design of the agreement is important to overcome the problem of free-riding at the ratification stage. Our paper focuses on MPRs as a very common and potentially successful tool to increase IEA participation. MPRs can be designed in different ways. They can be linked to the number of signatory countries[4], to country characteristics (such as baseline emissions), contributions (such as an abatement target) or to combinations of these. In the Kyoto Protocol, for instance,

[1] Given by the UNFCCC definition from 1992.

[2] Article 25 of the Kyoto Protocol.

[3] The recent literature on IEAs has been surveyed by Barrett (2003, 2007), Carraro and Marchiori (2003) and Finus (2003 and 2008).

[4] In this paper, the term signatories refers to sovereign states that have ratified the agreement.

a twofold MPR rule has been implemented (55 countries representing 55 % of emissions).

We analyse the formation of an IEA as a coalition formation game with heterogeneous countries. We assume that each country is free to decide whether or not to join a unique IEA. Put more technically, we analyse a cartel formation game with open membership. We examine both, the choice of an MPR and its effects on equilibrium coalition formation among countries in this model. Our approach follows seminal work by Hoel (1992), Carraro and Siniscalco (1993) and Barrett (1994) who have proposed a sequential game where a transboundary pollution game at the second stage is preceded by a cartel formation game at the first stage.[5] Recently Carraro et al. (2009) have proposed an extension of this approach to study the endogenous choice of an MPR. A drawback of the analysis of Carraro et al. (2009) is that it relies on the assumption of identical countries. Our paper relaxes this assumption. We analyse a model with heterogeneous countries and we allow for transfers between coalition members that can be used to set incentives for participation. Following Carraro et al. (2009) we use a 3-stage game. First, there is a unanimous decision on the MPR. Second, each country individually decides whether to ratify the agreement or not. If countries agreed on the MPR the agreement enters into force if the MPR is satisfied. If the MPR is not satisfied, then the coalition breaks down into singletons. Third, given the MPR is satisfied, a transboundary pollution game between the coalition of signatories and the non-signatories is played. Else we have a standard transboundary pollution game.

Our analysis shows that an MPR will always improve stability. More precisely, a stricter MPR always performs at least as well as a less strict MPR. This does not imply that an equilibrium MPR will require the membership of all countries. We find that in any subgame perfect equilibrium the MPR will be set at a level that allows at least one country to free ride.

The structure of the paper is as follows. In the next section we describe the game. Section 3 provides the formal analysis of the game and determines key features of the equilibrium outcomes. In Section 4 we move to the discussion of our results. This section puts our results into a broader perspective and provides further details on how our paper is linked to the literature on minimum participation rules. Section 5 offers conclusions for international policy coordination.

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[5] A number of applied studies on stability of climate agreements have use this type of game, e.g. Finus et al. (2005).

2 A model of a IEA formation with minimum participation

We consider a 3-stage game with a set N of countries as players. As we wish to study coalition formation we assume $|N| \geq 3$. The three stages are (*i*) the minimum participation stage, (*ii*) the coalition formation stage, and (*iii*) the transboundary pollution game. We describe the game in more detail starting from the third stage going backwards.

Stage 3: The transboundary pollution game. At this stage an agreement has become binding for the group of signatories $S \subseteq N$. The case of failure to reach agreement is the special case where $S = \emptyset$. The signatories, acting as one single player, and the non-signatories play a transboundary pollution game. Hence we have $|N| - |S| + 1$ players. Each player *j* chooses a level of pollution abatement q_j. We assume a uniformly mixing pollutant, as in the case of greenhouse gases. Hence, individual benefits B_j depend on the aggregate level of abatement $q \equiv \sum_{i \in N} q_i$. Abatement costs C_j depend on country *j*'s own abatement. We assume that benefits are (weakly) concave and costs are (strictly) convex. Payoffs of player *j* (where *j* is the coalition *S* or a singleton player $i \notin S$) are given by

$$(1) \qquad V_j = B_j(q) - C_j(q_j).$$

We assume that countries choose abatement levels simultaneously to maximise payoffs, i.e. singletons maximise their individual payoff while the coalition maximises the aggregate payoff of coalition members. We allow for heterogeneous countries, i.e. countries may differ with respect to their benefits and cost functions. We assume that the game satisfies the conditions of the formal transboundary pollution game described by Folmer and von Mouche (2000) and that the pollution is uniformly distributed as mentioned before. Hence we assume that abatement is a global public good. Such a transboundary pollution game has a unique Nash equilibrium (Folmer and von Mouche 2000, Proposition 2), referred to as partial-agreement Nash equilibrium by Chander and Tulkens (1995).

The unique Nash equilibrium of the stage-3 game defines a partition function, i.e. for every coalition $S \subseteq N$ we have the payoffs for the coalition and for all non-signatories. We denote country *i*'s payoff under coalition *S* by $V_i(S)$. The coalition payoff is $V_S(S)$. A sharing rule must be applied to divide $V_S(S)$ between the members of *S*. This will be discussed below.

Stage 2: Coalition formation. At this stage each country $i \in N$ decides whether or not to join a unique IEA. Formally, each country *i* has a binary strategy space with strategies $\sigma_i \in \{0,1\}$. If country *i* chooses $\sigma_i = 0$, it will not be member of the

IEA; if i chooses $\sigma_i = 1$, it will be a signatory, $i \in S$. The group of signatories forms an IEA if and only if the MPR is satisfied. If the MPR is not satisfied, the agreement will not be binding and will be irrelevant. Then the transboundary pollution game will be played by all countries acting as singletons and payoffs are determined by the unique Nash equilibrium of that game. Hence $S \subseteq N$ is effective if the MPR is satisfied, else it is ineffective.

Stage 1: Setting the Minimum Participation Rule. We consider heterogeneous countries. In general, an MPR uses a set of measureable characteristics of countries and it defines a minimum requirement for the aggregate across signatory countries for each characteristic. A simple characteristic is “being a sovereign state”. This characteristic corresponds to a minimum number of countries, for example “55” in the case of the Kyoto protocol. With heterogeneous countries, however, setting a minimum number of signatories does not seem to be adequate. In our setting, where countries differ with respect to benefits and cost of abatement. Therefore a natural characteristic is countries’ abatement level in the non-cooperative (all singletons) Nash equilibrium of the transboundary pollution game which reflects countries’ respective marginal benefits and costs.

Let $q_i^{\varnothing}$ denote country i’s equilibrium abatement level in the non-cooperative Nash equilibrium of the stage-3 game. We refer to the vector $q_i^{\varnothing}\;_{i \in N}$ as benchmark abatement without an effective agreement. In the following we assume that an MPR refers to the sum of signatories’ benchmark abatements. We denote the minimum required level of benchmark abatement by $\bar{q}$. Hence, the MPR is satisfied and coalition S is effective if and only if

$$\text{(2)} \qquad \sum_{i \in S} q_i^{\varnothing} \geq \bar{q}\,.$$

In our game the MPR is set as follows. A randomly chosen country suggests $\bar{q}$ which the others accept or reject. As in Carraro et al. (2009) we require a unanimous decision, i.e. if a single country rejects, then no MPR applies and $\bar{q} = 0$.

3 Analysis

We conduct the analysis going backward.

Stage 3. As we have indicated before, the transboundary pollution game at stage 3 has a unique Nash equilibrium and determines a partition function. The partition function provides for any given coalition $S \subseteq N$ a coalition payoff $V_S(S)$ and payoffs $V_j(S)$ for all singleton countries $j \notin S$. Abatement is a public good in our transboundary pollution game. A larger coalition provides more of the public good as it internalises more externalities. Overall payoffs increase with coalition enlargement. If a player joins a coalition, the larger coalition will receive a larger payoff than the initial coalition and the joining player acting separately. Moreover, all other singleton countries are also better off. Using the shorthand notation $S_{+j} \equiv S \cup \{j\}$, these properties are formally defined as follows.

DEFINITION 1 (superadditivity): A cartel partition function is superadditive if and only if for all coalitions $S \subset N$ and all $j \in N \setminus S$, it holds that $V_{S_{+j}}(S_{+j}) \geq V_S(S) + V_j(S)$.

DEFINITION 2 (positive spillovers): A cartel partition function exhibits positive spillovers, if and only if for all coalitions $S \subset N$ and all $j,k \in N \setminus S$ with $j \neq k$, it holds that $V_j(S_{+k}) \geq V_j(S)$.

Note that in superadditive cartel games with positive spillovers the grand coalition of all players will choose an efficient abatement level and maximise overall payoffs. On the basis of what we just argued we can state our first result without formal proof.

RESULT 1 The partition function that results from the transboundary pollution game with a uniformly mixing pollutant described before is superadditive and exhibits positive spillovers.

In order to assess individual incentives to participate in a coalition, we need to determine how the coalition payoff is shared between members. Following Weikard (2009) we assume that a sharing rule is applied that satisfies the *Claim Rights Condition*. This condition requires that every coalition member $i \in S$ receives at least its outside option payoff, i.e. what *i* would receive under coalition $S_{-i} \equiv S \setminus \{i\}$ if this is feasible. Feasibility is warranted if the coalition payoff is at least as large as the sum of the outside option payoffs, i.e. if

$$(3) \qquad V_S(S) \geq \sum_{i \in S} V_i(S_{-i}) \, .$$

A particular sharing rule that satisfies the *Claim Rights Condition* is sharing proportional to outside option payoffs. In this case $V_i(S) = \frac{V_i(S_{-i})}{\sum_{j \in S} V_j(S_{-j})} V_S(S)$ for all $i \in S$. However, the remainder of the analysis holds for any sharing rule that satisfies the Claim Rights Condition. We refer to this class of sharing rules as "optimal sharing rules" for reasons that will become apparent below.

Stage 2. Now we can move to the coalition formation stage. A Nash equilibrium of the coalition formation game is a vector of ratification decisions $\sigma_i \;{}_{i \in N}$ such that no single country would prefer to change its decision. We call a coalition S a stable coalition if the strategy profile $\sigma_i{}_{i \in N}$ that corresponds to S is a Nash equilibrium. Stability can be decomposed into internal and external stability (d'Aspremont et al. 1983).

DEFINITION 3 (internal and external stability):
(*i*) A coalition S is internally stable if and only if for all $i \in S$ it holds that

$$(4) \qquad V_i(S) \geq V_i(S_{-i}).$$

(*ii*) A coalition S is externally stable if and only if for all $j \notin S$ it holds that

$$(5) \qquad V_j(S) \geq V_j(S_{+j}).$$

(*iii*) Coalition S is stable if and only if it is internally and externally stable.

To determine the equilibrium coalitions we proceed in two steps. First we discuss internal stability, then external stability. Note that our sharing rule implies that, if the coalition payoff exceeds the sum of outside option payoffs, then payoffs can always be shared such that the coalition is internally stable. Hence to check internal stability it is sufficient to check whether the Claim Rights Condition can be satisfied, i.e. to check condition (3). Next notice that if (3) is not satisfied for S, then S cannot be internally stable. Hence, sharing rules that satisfy the Claim Rights Condition will internally stabilise all coalitions that are possibly internally stable (Weikard 2009, Theorem 1). It is in this sense that these sharing rules are optimal. Also note that whether (3) holds is determined by the partition function alone and therefore it is not necessary to specify the sharing rule.

A transboundary pollution game with optimal sharing has been examined in McGinty (2007), Weikard and Dellink (2008), Nagashima et al. (2009) and Fuentes-Albero and Rubio (2009). The setting in this paper extends the analysis to include MPRs. In essence an MPR makes every coalition inadmissible that does not meet condition (2), the stated minimum requirements. Suppose coalition S forms such that $q_S^{\varnothing} \equiv \sum_{i \in S} q_i^{\varnothing} < \bar{q}$ and, hence, S is ineffective. In this case a non-cooperative transboundary pollution game is played where all countries $i \in N$ choose their benchmark abatements and payoffs are $V_i(\varnothing) = B_i(\sum_{j \in N} q_j^{\varnothing}) - C(q_i^{\varnothing})$. We refer to $V_i(\varnothing)$ as country i's benchmark payoff.

The following is straightforward.

RESULT 2 Every ineffective coalition is internally stable.

Proof. If coalition S is ineffective, then the smaller coalition S_{-i} will also be ineffective. Hence no country can gain by leaving an ineffective coalition. ♦

To obtain the next result we introduce the notion of a pivotal country.

> DEFINITION 4 (*i*) Country $i \in S$ is pivotal for an effective coalition S if and only if coalition S_{-i} is ineffective.

The next result follows by construction.

> RESULT 3 The outside option payoff of a pivotal member of S is its benchmark payoff.

To determine the impact of an MPR on coalition (internal) stability, we need to examine how an MPR affects coalition payoffs and outside option payoffs.

It holds that

> RESULT 4 Consider a given coalition S and two MPRs, one less strict $\overline{q}_L \geq 0$, the other more strict $\overline{q}_H > \overline{q}_L$. Moving from $\overline{q}_L$ to $\overline{q}_H$ will never increase coalition payoffs but may reduce them to benchmark payoffs for $\overline{q}_H$ sufficiently high.

Proof. If S is ineffective under $\overline{q}_L$, nothing changes if $\overline{q}_H$ applies instead of $\overline{q}_L$. Furthermore, if S is effective under $\overline{q}_H$, then it will be effective under $\overline{q}_L$ and nothing changes. If, however, $\overline{q}_L \leq q_S^{\varnothing} < \overline{q}_H$ (S is effective under $\overline{q}_L$ but ineffective under $\overline{q}_H$), then payoffs will be reduced to benchmark payoffs. ♦

The next result is the key to understanding how MPRs work in this model.

> RESULT 5 Consider again a given coalition S and two MPRs, $\overline{q}_L \geq 0$ and $\overline{q}_H > \overline{q}_L$. Moving from $\overline{q}_L$ to $\overline{q}_H$ will never increase outside option payoffs but may reduce them to benchmark payoffs for $\overline{q}_H$ sufficiently high.

Proof. First, if S is ineffective under $\overline{q}_L$, nothing changes if $\overline{q}_H$ applies instead of $\overline{q}_L$. Next, recall that country $i \in S$ is pivotal if and only if $q_{S_{-i}}^{\varnothing} < \overline{q} \leq q_S^{\varnothing}$ or equivalently $q_i^{\varnothing} > q_S^{\varnothing} - \overline{q}$. This implies that an increase of $\overline{q}$ may increase (but never decrease) the number of pivotal countries. If $\overline{q} = q_S^{\varnothing}$, every country in S is pivotal. As a country becomes pivotal, its outside option payoff is the benchmark payoff (RESULT 3) which is lower than the initial outside option payoff. The latter holds due to superadditivity and positive spillovers. Finally, if $\overline{q} > q_S^{\varnothing}$, then S is ineffective and, trivially outside option payoffs equal benchmark payoffs. ♦

The next result follows as a corollary of Results 2 and 5.

RESULT 6 Consider any two MPRs, $\bar{q}_L \geq 0$ and $\bar{q}_H > \bar{q}_L$. Then every coalition *S* that is internally stable under $\bar{q}_L$ will also be internally stable under $\bar{q}_H$. The converse does not hold.

Proof. First, from RESULT 2, if *S* is ineffective under $\bar{q}_H$ then it will be internally stable. If *S* is effective under $\bar{q}_H$ (and, of course under $\bar{q}_L$), then payoffs are unaffected if $\bar{q}_H$ applies instead of $\bar{q}_L$. Outside option payoff, however may fall (see RESULT 5). Hence, moving from $\bar{q}_L$ to $\bar{q}_H$ may internally stabilise *S* but it will never internally destabilise *S*. ♦

Loosely speaking, a stricter MPR will always offer more internal stability than a less strict MPR. Of course, an increase of $\bar{q}$ may make a given coalition *S* ineffective. However, under a well chosen MPR every possible coalition can be stable and effective as the next result shows.

RESULT 7 With a superadditive partition function, if $\bar{q} = q_S^{\varnothing}$, then *S* is effective and internally stable under optimal sharing.

Proof. It is clear that *S* is effective. But also every smaller coalition is ineffective and, hence, all countries in *S* are pivotal. By superadditivity it holds that $V_S(S) \geq V_S(\varnothing)$. Because every member is pivotal, $V_S(\varnothing)$ is the sum of the outside option payoffs and condition (3) is satisfied. Therefore optimal sharing guarantees internal stability. ♦

With these results we can move on to examine external stability. Under an optimal sharing rule the following result holds

RESULT 8 A coalition *S* is externally unstable if and only if there exists country $j \notin S$ such that S_{+j} is internally stable.

Proof. See Weikard (2009) proof of Lemma 1. ♦

The next result puts together external and internal stability.

RESULT 9 Consider any two MPRs, $\bar{q}_L \geq 0$ and $\bar{q}_H > \bar{q}_L$. A move from $\bar{q}_L$ to $\bar{q}_H$ may result in a larger coalition becoming stable. With superadditivity and positive spillovers, this will always improve payoffs.

Proof. This follows immediately from RESULTS 6 and 8. If a move from $\bar{q}_L$ to $\bar{q}_H$ internally stabilises coalition *S*, then either *S* is externally stable or, if externally unstable, there exist S_{+j} with $j \notin S$ and S_{+j} is internally stable. We call S_{+j} an internally stable enlargement of *S*. The argument can then be repeated. Hence, either S_{+j} is externally stable or there exists an internally stable enlargement of S_{+j}, and so on. ♦

Stage 1. With these results in place we can now turn to the minimum participation stage.

Since each country is characterised by $q_i^{\varnothing}$, we sort countries according to this criterion and adopt the following notational convention $q_1^{\varnothing} < q_2^{\varnothing} < ... < q_n^{\varnothing}$. It is only for mathematical convenience that we assume all inequalities to be strict. Clearly we have by construction

> RESULT 10 If country i is pivotal in S, then all countries $j > i$ are also pivotal in S.

Notice that, by comparison, in a game with identical countries, as considered by Carraro et al. (2009), either all countries or none of the countries are pivotal.

At the minimum participation stage, one country is randomly selected to propose the MPR. Then others are asked to accept or reject the proposal. A rejection results in $\bar{q} = 0$. In this case every coalition formed would be effective. Hence, a country would reject a proposal if its expected payoff under the proposed MPR would be less than the expected payoff under $\bar{q} = 0$. We denote a stable coalition under $\bar{q} = 0$ by S^*. As we will usually find a large set of stable coalitions, E_j^* denotes the expected payoff if j rejects the MPR proposed by i. Hence, we call a proposed MPR "acceptable" if it stabilises a coalition where each country receives at least E_j^*. Obviously an equilibrium proposal must be acceptable. We return to this issue below.

In the remainder of the analysis we assume that the grand coalition is unstable under $\bar{q} = 0$. Else an MPR has no force and the problem is not very interesting.

We know from RESULT 7 that the grand coalition will be internally stable and therefore stable under $\bar{q} = q_N^{\varnothing}$. Also we know that the grand coalition is efficient. The next question then is whether any country can get a higher payoff than in the grand coalition. For this it is important to note that individual payoffs in the grand coalition depend on outside option payoffs – note that the Claim Rights Condition must be met. The outside option payoffs will, in turn, depend on the MPR. Hence, the country that proposes the MPR will determine which countries are pivotal. This will impact the distribution of payoffs. Clearly the proposing country prefers to be non-pivotal as pivotal countries' payoffs are reduced to benchmark payoffs. If a country i is selected as proposer, it will try to set an MPR that stabilises the grand coalition such that i is non-pivotal while countries $j > i$ are pivotal. This minimises others' outside option payoff subject to i being non-pivotal. This implies that it could be optimal for the proposing country i to propose $\bar{q} = q_N^{\varnothing} - q_i^{\varnothing}$ rather than $\bar{q} = q_N^{\varnothing}$. Clearly if i is close to $|N|$ most countries will be non-pivotal, the sum of outside option payoffs is larger and this strategy will eventually undermine the internal stability of N . Still in this case it may be optimal to propose $\bar{q} = q_N^{\varnothing} - q_i^{\varnothing}$, provided that this proposal would be acceptable. To fix ideas, we first examine the "smallest" country, country 1.

RESULT 11 If country 1 is the proposer, it proposes

$$\bar{q} = q_N^{\varnothing} - q_1^{\varnothing}$$

and the grand coalition emerges, provided that this proposal is acceptable for all other countries.

Proof. First notice that all countries other than 1 are pivotal players and their outside option payoff is $V_i(\varnothing)$. Furthermore, by superadditivity we have $V_N(N) \geq V_{N_{-1}}(N_{-1}) + V_1(N_{-1})$ and $V_{N_{-1}}(N_{-1}) \geq \sum_{i \in N_{-1}} V_i(\varnothing)$. Hence condition (3) is satisfied and N is internally stable under optimal sharing. As N is externally stable by definition, N is stable. In addition, by positive spillovers, no other proposal will give a larger payoff to country 1 as it receives at least the outside option payoff $V_1(N_{-1})$. ♦

For a randomly selected proposer we have the following result.

RESULT 12 If country i is the proposer, it proposes

$$\bar{q} = q_N^{\varnothing} - q_i^{\varnothing}$$

provided that this proposal is acceptable by all other countries.

The grand coalition emerges if and only if $V_N(N) \geq \sum_{j=1}^{i} V_j(N_{-j}) + \sum_{j=i+1}^{n} V_j(\varnothing)$. Otherwise coalition N_{-i} emerges.

Proof. First notice that all countries $j > i$ are pivotal players for the grand coalition. Hence in N they must at least receive their outside option payoff $V_j(\varnothing)$. The non-pivotal countries $j \leq i$ must receive at least $V_j(N_{-j})$. Hence if $V_N(N) \geq \sum_{j=1}^{i} V_j(N_{-j}) + \sum_{j=i+1}^{n} V_j(\varnothing)$, condition (3) is satisfied and N is internally stable under optimal sharing. As N is externally stable by definition, N is stable. In addition by positive spillovers, no other proposal will give a larger payoff to country i as it receives at least the outside option payoff $V_i(N_{-i})$. If, however, condition (3) cannot be met under $\bar{q} = q_N^{\varnothing} - q_i^{\varnothing}$, then country i can still secure $V_i(N_{-i})$ by announcing $\sigma_i = 0$ in the stage 2 game. Others' best response is $\sigma_j = 1$ for all $j \neq i$. Hence, coalition N_{-i} is formed. N_{-i} is stable as all its members are pivotal under $\bar{q} = q_N^{\varnothing} - q_i^{\varnothing}$. ♦

Finally, it remains to be examined whether any country $j \neq i$ would reject i's proposal $\bar{q} = q_N^{\varnothing} - q_i^{\varnothing}$. The acceptability of the proposal can be guaranteed whenever

$$(6) \qquad V_{N_{-i}}(N_{-i}) \geq \sum_{j \in N_{-i}} E_j^* .$$

This will typically be the case in a superadditive game. If the number of countries is sufficiently large, coalitions S^* are "small" compared to N_{-i} and provide significantly less than the efficient level of abatement. If condition (6) is not met, then members of N_{-i} have an incentive to decline i's proposal. In this case $\bar{q} = 0$ results and some equilibrium coalition S^* emerges.

4 Policy coordination and IEAs

As IEAs are wide-spread and important for environmental policy making we turn now to discuss the significance of our theoretical results for environmental policy coordination. Also we provide a more in-depth review of previous contributions on MPRs in the literature. Even though, as we show, MPRs may have a decisive role for the stability of IEAs, only a few previous theoretical contributions exist in the literature with an explicit focus on MPRs. Closest to our research are models with perfect information. To these we turn first. Then we broaden the scope and discuss MPRs under uncertainty and incomplete information about payoff structures.

Rutz (2001) analyses the role of MPRs in the coalition formation game that has become canonical for the study of IEAs (Hoel 1992, Carraro and Siniscalco 1993, Barrett 1994). In this game a coalition forms at stage 1 and, at stage 2, the coalition and the non-signatories play the transboundary pollution game. Rutz considers identical countries and shows that the equilibrium number of signatories is equal to a number required by an exogenously given MPR. Rubio and Casino (2005) introduce a stock pollutant into the game. The partition function is generated by a differential game. They consider the effect of MPRs and arrive at the same conclusion: once an MPR is established, the size of a stable coalition is the number of countries required by the MPR. In these studies the MPR is exogenous. Carraro et al. (2009) have extended the model to analyse the endogenous choice of an MPR. The MPR is unanimously agreed in the first stage of the game. Once the MPR is established, the standard IEA formation game follows. Carraro et al. (2009) arrive at the result that there exists (among other equilibria) an equilibrium MPR that requires full participation such that the grand coalition is stable.

Our model is an extension of Carraro et al. (2009). While the basic set-up of our game is similar, we allow for heterogeneous players. This is an important step towards practical applicability of the theoretical analysis of MPRs. Introducing heterogeneous players poses three challenges for the analysis. First, if players differ with respect to benefits and costs of abatement, the design of transfer schemes (e.g. tradable permits) is an important determinant of the stability of coalitions. The benefits from cooperation can be shared in different ways. A sharing rule (or transfer scheme) that satisfies the Claim Rights Condition will support stability whenever it is feasible. Second, with heterogeneous players, the equilibria of the game cannot be described by the number of players anymore. The identity of players matters. Third, the different characteristics of players allow for the use of different types of MPRs. An MPR may require a minimum number of countries, but it may also require some other aggregate characteristics. In our analysis we choose for the equilibrium abatement level of countries in the non-cooperative equilibrium of the transboundary pollution game. This captures the "size" of the different countries. Addressing these three challenges together is a genuine novelty in the analysis of MPRs.

We now turn to a more detailed discussion of our results and link them to international environmental policy making.

First notice that, due to superadditivity, an increase in coalition size will always increase the gains from cooperation. With a sufficiently strict MPR it is more likely to stabilise larger coalitions than in the absence of an MPR (RESULT 9). An immediate implication is that a social planner would set an MPR sufficiently strict to stabilise the grand coalition. Hence, the result derived by Rutz (2001) generalises to heterogeneous countries. Comparing our findings to the results obtained by Carraro et al. (2009) we notice a difference. We find, in contrast to the result of Carraro et al. (2009), that the equilibrium MPR is generally not requiring full participation. The equilibrium proposal will allow the proposing country to free-ride on the coalition consisting of all other countries. Still the grand coalition will emerge if the country that proposes the MPR is sufficiently small as compared to other countries. With identical countries a grand coalition emerges in an equilibrium, as found by Carraro et al. (2009).

Our model underlines the importance of agenda-setting. We model the first stage of the game as a simple bargaining game with a take-it-or-leave-it offer. The country that can make a proposal, or sets the agenda, is able to exploit some bargaining power. Country i's equilibrium proposal ($\bar{q} = q_N^{\varnothing} - q_i^{\varnothing}$) makes i non-pivotal for the grand coalition. This establishes a larger claim and, hence, a larger payoff under any sharing rule that satisfies the Claim Rights Condition.

One interesting implication of our model is that if free-riding occurs in equilibrium, it will be a large country that free-rides. The equilibrium proposal of a large country ($\bar{q} = q_N^{\varnothing} - q_i^{\varnothing}$) makes all smaller countries non-pivotal and increases their claims such that condition (3) is not met for the grand coalition. The implication of this finding for environmental policy making is that large countries' power to the set the agenda is more likely to lead to inefficient results compared to small countries.

To summarise our results, we find that MPRs can play a significant role to establish successful coalitions that overcome the free-rider problem in the provision of public goods. In many cases an efficient grand coalition emerges. In some cases a single large player free-rides. Still in a setting with many players the largest part of the gains from cooperation can be reaped.

These optimistic results must be interpreted with care. Our model is a game with complete information, i.e. each player is informed about choice options (strategy spaces) and payoffs of all other players. However, the long-term environmental impacts that an IEA addresses and the technological abatement options are generally uncertain. This leads to uncertain payoffs –an issue that hampers, presumably, the formation of a global climate agreement. In addition coalition formation is a political process and there may be uncertainties about policy preferences as well.

Black et al. (1993) were the first to provide an analysis of the role of MPRs for IEAs under uncertainty. They include incomplete information in their model assuming that individual countries know their cost function but do not know their benefits from the agreement. Black et al. (1993) use this approach in order to assess the optimality of MPRs depending on different abatement costs as well as the number of participating countries. Countries are assumed to be symmetric and the binary choice about coalition formation is made simultaneously, or at least without knowledge about the decision of the other countries (Black et al. 1993, p. 284). Therefore, countries are uncertain about whether a coalition will be formed or not. According to the underlying assumptions of the model, coalition formation is only possible under the condition that an MPR is incorporated into the treaty. The motivation to sign an agreement "is the contribution that added commitment makes to the likelihood that the treaty is effected" (Black et al. 1993, footnote 9). Under incomplete information about the payoffs the grand coalition might not be efficient (individual marginal abatement costs may exceed the sum of expected marginal benefits). Therefore, in contrast to our model, a social planer would eventually choose a threshold below the grand coalition.

Harstad (2006) models uncertainty about the costs and benefits of the provision of a public good and discusses incentives for cooperation of heterogeneous countries to jointly provide the public good. Flexible participation (open membership) is compared with rigid cooperation (full membership) and minimum participation rules. The decision about the agreement on the MPR is endogenised assuming majority voting on the threshold defined by the MPR. Harstad (2006, proposition 5) shows that the voting game may not have a Condorcet winner and there may not be a stable equilibrium MPR.

The MPRs of most IEAs require less than full participation. The models of Black et al. (1993) and Harstad (2006) explain this by incomplete information and uncertainty. In our model less than full participation is explained by the bargaining power of the proposing country.

5 Conclusions

In this paper we show that the model of endogenous choice of minimum participation rules (MPRs) for international environmental agreements (IEAs) suggested by Carraro et at. (2009) can be generalised to heterogeneous countries. We find that MPRs are an effective tool to stimulate participation in IEAs. The grand coalition, full participation, can be established in cases where the country that puts a proposal for an MPR on the bargaining table is small. Large countries, however, can take a free-rider position if they have bargaining power when the MPR is negotiated. This implies that large countries bear a particular responsibility in the negotiation process of a new climate agreement.

Even though our findings shed new light on the formation of IEAs with an MPR, there remain open questions. Our model could be extended in various directions. An important issue is to gain a better understanding of the dynamics of coalition formation, in particular an understanding of the negotiation process (cf. Caparrós 2004) and of the role of renegotiations (cf. Weikard and Dellink 2008). As discussed in the previous section uncertainties are an important determinant of IEA formation. Uncertainties may unravel over time. When renegotiations are considered, learning becomes an important issue (Ulph 2004, Kolstad 2007). Furthermore, signing –and ratifying– an agreement just means that countries declare their intention to contribute to the public good. It is an additional step to incorporate the treaty into national law. Clearly, the important issue here is enforcement. Barrett (2009) argues that the lack of an enforcement mechanism is a decisive failure of Kyoto protocol. McEvoy and Stranlund (2009) incorporate enforcement into the standard IEA formation game.

Models of IEA formation have been looking at these aspects one by one – a comprehensive model of IEA formation that combines MPRs, renegotiations and enforcement is still missing.

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