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# ENDOGENOUS MINIMUM PARTICIPATION IN INTERNATIONAL ENVIRONMENTAL TREATIES

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## ABSTRACT

# Endogenous Minimum Participation in International Environmental Treaties*

Many international treaties come into force only after a minimum number of countries have signed and ratified the treaty. Why do countries agree to introduce a minimum participation constraint among the rules characterizing an international treaty? This question is particularly relevant in the case of environmental treaties dealing with global commons, where free-riding incentives are strong. Is a minimum participation rule a way to offset these free-riding incentives? Why do countries that know they have an incentive to free-ride accept to ‘tie their hands’ through the introduction of a minimum participation constraint? This Paper addresses the above questions by analysing a three-stage non-cooperative coalition formation game. In the first stage, countries set the minimum coalition size that is necessary for the treaty to come into force. In the second stage, countries decide whether to sign the treaty. In the third stage, the equilibrium values of the decision variables are set. At the equilibrium, both the minimum participation constraint and the number of signatories - the coalition size - are determined. This Paper shows that a non-trivial partial coalition, sustained by a binding minimum participation constraint, forms at the equilibrium. This Paper thus explains why in international negotiations all countries often agree on a minimum participation rule even when some of them do not intend to sign the treaty. The Paper also analyses the optimal size of the minimum participation constraint.

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# ENDOGENOUS MINIMUM PARTICIPATION IN INTERNATIONAL ENVIRONMENTAL TREATIES

## 1. Introduction

Several articles have recently provided a thorough economic analysis of a country's incentives to sign an international treaty.[1] Particular attention has been given to international environmental treaties, because they are often aimed at providing a global public good and are therefore characterised by strong free-riding incentives. This recent literature, by using a non-cooperative game-theoretic approach, has also explored which policy strategies and negotiation rules can be designed to increase the number of signatories of an international environmental treaty (Cf. Carraro and Galeotti, 2003 for a survey).

A feature of many international treaties that has been largely neglected by the theoretical literature is the clause that a treaty will only come into force if a minimum number of signatories or a minimum degree of effectiveness is achieved. For example, in the case of the Kyoto Protocol, the clause is twofold: the Protocol comes into force only if at least 55 countries sign it and the signatories represent at least 55% of total emissions. More generally, almost all international environmental treaties contain a minimum participation clause. According to Rutz (2001), only 2 out of the 122 multilateral environmental agreements provided by the Center for International Earth Science Information Network do not contain any minimum participation rule. In 81 cases, the participation rule asks for a minimum number of signatories. In 22 cases, unanimity is required for the treaty to come into force, namely all negotiating countries must sign and ratify the agreement for it to be effective. In the remaining 17 cases, the minimum participation rule is coupled to other requirements, i.e. for these agreements it is not sufficient that a certain number of countries ratify the treaty, but these countries have to satisfy other, additional criteria.[2]

Despite the importance of the minimum participation rule (and of the unanimity rule as a particular case), very few theoretical studies have analysed this issue. A previous study by Black, Levi and de Meza (1992) shows that the introduction of a minimum participation constraint increases the number of signatories of an international environmental agreement. However, it does not prove that countries actually have an incentive to introduce a minimum participation constraint among the rules of a given treaty. Similarly, Rutz (2001) shows, in a very specific case, that a minimum participation rule, if it exists, can result in an increase in the number of signatories. However, the rule is imposed exogenously and is therefore not an equilibrium outcome of the game. In addition, in Black, Levi and de Meza (1992) the minimum participation constraint is designed to solve a profitability problem (cooperation becomes profitable only if a minimum number of

[1] Good recent surveys are in Barrett (2002), Carraro and Marchiori (2003), Finus (2002).

[2] For example, the Montreal Protocol on the ozone layer asks for 11 instruments of ratification representing at least two-thirds of 1986 estimated global consumption of the controlled substances.

countries sign the agreement), whereas in this paper the goal is to solve a stability problem (cooperation is undermined by the presence of free-riders).

This paper aims to address the following questions: Why do countries agree to have a minimum participation constraint among the clauses characterising an international treaty? Is a minimum participation rule a way to offset free-riding incentives? Why do countries that know they have an incentive to free-ride, accept to "tie their hands" through the introduction of a minimum participation constraint? What is the endogenous equilibrium level of the minimum participation constraint?

This paper addresses the above questions by analysing a non-cooperative game of coalition formation. In the recent theoretical literature on international agreements, the decision of countries to sign a treaty is often modelled as a two-stage game (see Barrett, 1997b, 2002; Carraro and Siniscalco, 1998; Tulkens, 1998; Carraro and Galeotti, 2002; Carraro and Marchiori, 2002; Finus, 2002, for a few surveys). In the first stage (the *coalition stage*), countries non-cooperatively decide whether or not to sign the treaty by anticipating the consequences of their decision on the economic variables under their control. Then, in the second stage of the game (the *policy stage*), the equilibrium value of these variables is set. In this paper, an additional stage precedes the coalition and policy stages. In this first stage, called the *minimum participation stage*, countries select the number of countries that must sign the treaty for it to come into force. This decision is taken non cooperatively and unanimously by anticipating its implications on the second and third stage of the game. Therefore, in this paper, the minimum participation rule is endogenous.

Using the above theoretical framework, this paper shows that, at the equilibrium, a non-trivial coalition will form, and will be sustained by a binding minimum participation constraint. Therefore, it also shows that the number of signatories is increased by the presence of a minimum participation rule, even when this rule is endogenous. Consequently, the paper proves that there is an incentive for countries to adopt a minimum participation rule. In addition, the paper explores under what conditions it is optimal for countries to adopt the unanimity rule (we have seen that, in many treaties, minimum participation coincides with unanimous participation).

The idea that a non-trivial partial coalition can belong to the equilibrium structure of a coalition formation environmental game is not new. The aforementioned literature on international environmental agreements has already achieved this conclusion. In particular, it shows that (see Carraro and Marchiori, 2002):

(i) Even in cases where there are positive spillovers (e.g. in the case of public good provision) and even without any commitment to cooperation, countries may form a coalition, i.e. may decide to sign a treaty in order to cooperate to achieve a common target (Cf. Carraro and Siniscalco, 1992; Barrett, 1994 among others).

(ii) This coalition is usually formed by a subgroup of the n negotiating countries (Cf. Barrett, 1994).

(iii) The sometimes small initial coalition can be expanded by means of transfers or through "issue linkage", but only under some restrictive conditions (Cf. Carraro and Siniscalco, 1993, 1995; Botteon and Carraro, 1997a,b).

(iv) The outcome of the game strictly depends on the membership rules (open membership, exclusive membership, coalition unanimity, …) that are adopted by the n negotiating countries (Carraro and Marchiori, 2002).

(v) When multiple coalitions can and do form, the equilibrium is characterised by several, often small, coalitions (Bloch, 1997; Ray and Vhora, 1996, 1997; Yi, 1997, 2002).

The novel feature of this paper is the endogenisation of the minimum participation constraint and an analysis of a country's incentives to adopt it despite the presence of incentives to free-ride on the other countries' emission abatement.

In the following sections, the minimum participation rule will be denoted by $\alpha$, where $\alpha$ is the share of the n negotiating countries that must sign the treaty for it to come into force. The value of $\alpha$ can vary between 0 and 1. If $\alpha$=0, no restriction is introduced and a treaty comes into force whatever the number of its signatories. This is the so-called "open membership" rule, one of the most commonly assumed membership rules (see Yi, 1997, 2002; Carraro and Marchiori, 2003). If $\alpha$=1, a treaty comes into force only if all countries decide to sign the treaty. In this case, we have what is termed the "coalition unanimity" rule (Tulkens, 1998; Carraro and Marchiori, 2003) or full participation constraint. If $\alpha$=0.55, and countries are symmetric, we will have the 55% rule introduced in the Kyoto Protocol. Therefore, by endogenising $\alpha$, we can determine whether it is optimal for countries to opt for the open membership rule, the coalition unanimity rule or any other minimum participation rule defined by $\alpha \in [0,1]$.

The structure of the paper is as follows. Section 2 provides the main assumptions and definitions. Section 3 analyses the coalition game for a given value of $\alpha$. Section 4 endogenises $\alpha$ and determines its equilibrium value. A concluding section summarises the main results and describes the scope for further research.

## 2. Assumptions and Definitions

Assume negotiations take place among n countries, $n \geq 3$, each indexed by $i = 1, ..., n$. Let $c \in [1,n]$ denote the number of cooperating countries.[3] As stated above, countries play a three-stage game. In the first stage – the *minimum participation stage* – countries unanimously choose the minimum participation rule $\alpha$, $\alpha \in [0,1]$,

[3] When c=1, the coalition structure is trivial. All players are singleton and play non-cooperatively against each other.

i.e. the share of the n countries that must sign the treaty for it to come into force. As a consequence, only if c $\geq \alpha n$, can a coalition form at the equilibrium. In the second stage – the *coalition stage* – countries decide non-cooperatively whether or not to sign the environmental treaty (i.e. to join the coalition). In the third stage, they play the non-cooperative *policy stage*, where countries that signed the agreement play as a single player and divide the resulting payoff according to a given burden-sharing rule (any of the rules derived from cooperative game theory). The remaining countries play non cooperatively against the coalition and against each other.[4]

This three-stage game can be represented as a *game in normal form* denoted by $\Gamma = (N, \{X_i\}_{i\in N}, \{u_i\}_{i\in N})$, where N is a finite set of players, $X_i$ the strategy set of player i, and $u_i$ the payoff function of player i, assigning to each profile of strategies a real number, i.e. $u_i : \Pi_{i\in N} X_i \to R$. The payoff function is a twice continuously differentiable function. A *coalition C* is any non-empty subset of N. A *coalition structure* $\pi = \{C_1, C_2, ..., C_m\}$ is a partition of the player set N, i.e. $C_i \cap C_j = \varnothing$ for $i \neq j$ and $\cup^m_{i=1} C_i = N$.

Since the formation of a coalition creates externalities, the appropriate framework to deal with this game is a *game in partition function form*, in which the payoff of each player depends on the entire coalition structure to which he belongs (Bloch, 1997; Ray and Vohra, 1997, 1999; Yi, 2003). This is why we convert the game in normal form into a game in partition function form. The set of all feasible coalition structures is denoted by $\Pi$. A *partition function* P: $\Pi \to R$ is a mapping which associates each coalition structure $\pi$ with a vector in $\Re^{|\pi|}$, representing the worth of all coalitions in $\pi$. In particular, $P(C_i; \pi)$ assigns a worth to each coalition $C_i$ in a coalition structure $\pi$. When the rule of payoff division among coalition members is fixed, the description of gains from cooperation is made by a *per-member partition function* p: $\Pi \to \Re^n$, a mapping which associates each coalition structure $\pi$ with a vector of individual payoffs in $\Re^n$. In particular $p(C_i; \pi)$ represents the payoff of a player belonging to the coalition $C_i$ in the coalition structure $\pi$ [5].

Under suitable assumptions (A.2 and A.3 below), the third stage of the game can be reduced to a partition function (Bloch 1997; Yi, 1997, 2003). Therefore, the study of coalition formation consists of the study of the second stage of the game, i.e. of a country's decision of whether or not to join the group of cooperating countries. To compute the equilibrium of the game, we assume that:

[4] These behavioural assumptions coincide with those defining the PANE equilibrium of Eyckmans and Tulkens (2001). They can be contrasted with the traditional cooperative game approach (e.g. Chander and Tulkens, 1995, 1997) and with the repeated game approach (Barrett, 1994, 1997). Moreover, note that the regulatory approach often proposed in public economics is not applicable given the absence of a supranational authority.

[5] Bloch (1997) denotes the per-member partition function by the term "valuation".

*A.1. All players decide simultaneously at all stages;*[6]

*A.2. The third stage emission game has a unique Nash equilibrium for any coalition structure.*

This assumption is necessary for the second stage of the game to be reduced to a partition function. In order to convert the strategic form into a partition function, the competition among the coalition and the singletons has also to be specified. The common and perhaps the most natural assumption is that:

*A.3. Inside each coalition, players make their policy decisions cooperatively in order to maximise the coalitional surplus, whereas the coalitions and the singletons compete with one another in a non-cooperative way.*

The partition function is then obtained as a Nash equilibrium payoff of the game played by the coalition and the singletons. Formally, for a fixed coalition structure $\pi = \{C_1, C_2, \ldots, C_m\}$, let $x^* \in X = \Pi_{i\in N} X_i$ be a vector of strategies such that:

$$\forall C_i \in \pi, \qquad \sum_{j\in C_i} u_j\left(x^*_{C_i}, x^*_{N\setminus C_i}\right) \geq \sum_{j\in C_i} u_j\left(x_{C_i}, x^*_{N\setminus C_i}\right) \qquad \forall x_{C_i} \in \Pi_{j\in C_i} X_j$$

Then define $P(C_i; \pi) = \sum_{j\in C_i} u_j(x^*)$. In order to simplify the derivation of the partition function, we introduce a further assumption:

*A.4. All players are ex-ante identical, which means that each player has the same strategy space in the third stage policy game.*

This assumption allows us to adopt an equal-sharing payoff division rule inside a coalition, i.e. each player in a given coalition receives the same payoff as the other members[7]. Furthermore, the symmetry assumption implies that a coalition $C_i$ can be identified with its size $c_i$ and a coalition structure can be denoted by $\pi = \{c_1, c_2, \ldots, c_m\}$, where $\sum^n_{i=1} c_i = n$. As a consequence, the payoff received by players depends only on the coalition size and not on the identities of the coalition members. The per-member partition function (partition function hereafter) can thus be denoted by $p(k; \pi)$, which represents the payoff of a player belonging to the size-k coalition in the coalition structure $\pi$. Finally, let us denote by $\pi = \{a_{(1)} \ldots a_{(r)}\}$ r size-a coalitions in the coalition structure $\pi$.

[6] By contrast, Barrett (1994) assumes that the group of signatories is Stackelberg leader with respect to non-signatories. In Bloch (1997), it is assumed that players play sequentially.

[7] We consider the equal sharing rule as an assumption, since it is not endogenously determined in the model. However, Ray and Vohra (1999) provides a vindication for this assumption.

Recent developments of the theory of endogenous coalition formation (Cf. Bloch, 1997; Yi, 2003) have stressed the implications of allowing players to join different coalitions (see also Carraro, 1998b). However, in many environmental cases (e.g. the case of climate change or the case of the Montreal protocol), the negotiating agenda focuses on a single agreement. Here we assume that:

*A.5. Players are invited to sign a single agreement. Hence, those that do not sign cannot propose a different agreement. From a game-theoretic viewpoint, this implies that only one coalition can be formed, the remaining defecting players playing as singletons.*

We also need to introduce a technical assumption which is useful to simplify the analysis of the coalition formation game:

*A.6. Each player's payoff function increases monotonically with respect to the coalition size (the number of signatories).*[8]

This last assumption is quite natural in the case of international environmental agreements. Since the global environment is a public good, a country that finds it convenient to reduce its own emissions provides a positive contribution to the welfare of all countries (both inside and outside the coalition).

Finally, the first stage of our game is a sort of constitutional stage in which the rules of the game are set. Therefore, decisions are taken under unanimity and, in addition:

*A.7. Unanimous decisions taken in the first stage of the game are irreversible, i.e. once a minimum participation rule is set, it cannot be modified in the subsequent stages of the game.*

This last assumption is useful to avoid that in the second stage countries ask to renegotiate the minimum participation constraint set in the first stage.

In the next sections, we will analyse the equilibrium of the three-stage game with endogenous minimum participation. Given the partition function described above, we can directly focus on the second stage of the game and then move, by backward induction, to the first stage, in which the optimal minimum participation constraint is determined.

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[8] This assumption excludes the possibility of "exclusive membership equilibria" where the group of cooperating players can refuse entry to a player which wants to join the coalition (Yi, 1997). Moreover, this assumption is useful to distinguish the minimum coalition size endogenised in this paper from the minimum participation proposed in Black *et al*. (1992). In this latter paper, minimum participation is necessary to make the coalition profitable. In our paper, all non-trivial coalitions are profitable by assumption A.6. Hence, minimum participation can be chosen by countries only to increase the size of the stable coalitions (see below).

## 3. The coalition stage

The second stage of the game is a binary choice game (joining the coalition or behaving as a lone free-rider) whose outcome is a single coalition structure $\pi = \{c, 1_{(n-c)}\}$. The main distinctive feature of this game is the presence of positive spillovers, i.e. in any single coalition structure, if some players form a coalition, other players are better off. As a consequence, the partition function of any player outside the coalition (*non member function*) is increasing in c for all values of $c \in [1,n]$. Formally: $p(1; \pi)$, where $\pi = \{c, 1_{(n-c)}\}$, is an increasing function of c.

Let us denote by Q(c) the relative non-member partition function $p(1; \pi) - p(1; \pi^s)$, where $\pi^s = \{1_{(n)}\}$. Similarly, the relative per-member payoff function P(c) is equal to $p(c; \pi) - p(1; \pi^s)$. From A.6, we focus on the case in which P(c) and Q(c) are monotonic. As said, this case is relevant because it characterises environmental negotiations and more generally the provision of public goods. Let us start the analysis by considering the case in which no minimum participation rule is introduced. In this case, $\alpha = 0$ (open membership rule) and the equilibrium of the coalition stage is completely characterised by the following two properties, first derived in cartel literature (D'Aspremont *et al.*, 1983) and then often used also in environmental literature (Carraro and Siniscalco, 1993; Barrett, 1994, and many others).

<u>Profitability</u>. A coalition c is profitable if each cooperating player gets a payoff larger than the one he would obtain when no coalition forms. Formally:

(1) $$P(c) \geq P(1) = 0,$$

where P(c) is the relative payoff of a cooperating player when the coalition structure is $\pi=\{c,1_{(n-c)}\}$ and $P(1) = p(1; \pi^s)$ is the relative payoff associated to the singleton structure $\pi^S = \{1_n\}$.

- <u>Stability</u>. A coalition is stable if it is both internally and externally stable. It is internally stable if no cooperating player is better off by defecting in order to form a singleton[9]. Formally:[10]

(2a) $$P(c) \geq Q(c-1).$$

It is externally stable if no singleton is better off by joining the coalition c. Formally:

(2b) $$Q(c) > P(c+1).$$

[9] Yi (1997) denotes this condition by the term "stand alone stable".

[10] We assume that if a player is indifferent as to joining the coalition or defecting, then he joins the coalition.

A useful tool to analyse the stability of a coalition is the stability function L(c) proposed in Carraro and Siniscalco (1992). This function:

(3) $$L(c) = P(c) - Q(c-1)$$

describes a player's incentive to join a coalition. If L(c) is positive, there is no incentive to free-ride on the coalition of size c.

The size of the stable coalition is determined by conditions (1)(2a)(2b), i.e. by the largest integer c* smaller than c^, where c^ is defined by L(c^) = 0 and L'(c^) < 0 (again assumption A.6 guarantees the uniqueness of c^).[11] The size c* identifies the minimal externally stable coalition and the maximal internally stable one. Hence, the equilibrium coalition structure is $\pi^* = \{c^*, 1_{(n-c^*)}\}$. Note that c* is not necessarily greater than one. However, it has been shown in several papers (Cf. Barrett, 1994) that a non-trivial ($c^* \geq 2$) equilibrium (stable) coalition generally exists under A.1-A.6.[12] Let us denote this coalition by $c^*(\alpha=0)$. Then:

**Proposition 1**: *Let A.1-A.7 hold. The equilibrium of the coalition game for any value of* $\alpha \in [0,1]$ *is the coalition structure:*

*(4a)* $\pi^*(\alpha) = \{c^*(\alpha=0), 1_{(n-c^*)}\}$ *for any minimum participation rule such that* $0 \leq \alpha \leq \alpha^*$

*(4b)* $\pi(\alpha) = \{c=\alpha n, 1_{(n-c)}\}$ *for any minimum participation rule such that* $\alpha^* < \alpha \leq 1$

Proof: If $\alpha \leq \alpha^* = c^*(\alpha=0)/n$, the equilibrium coalition is not modified by the presence of a minimum participation constraint $\alpha$. Indeed, if in the first stage players set a minimum participation rule $\alpha \leq c^*(\alpha=0)/n$, the number of signatories necessary for the treaty to come into force is smaller than or equal to the number of countries that would sign the treaty anyway. Hence, the equilibrium coalition remains $c^*(\alpha=0)$. If in the first stage players agree on a minimum participation rule $\alpha > \alpha^* = c^*(\alpha=0)/n$, then in the second stage they have the choice either to form a coalition of size $c = \alpha n$, or not to form any coalitions at all. Indeed, all coalitions larger than c are unstable, because all coalitions larger than $c^*(\alpha=0)$ are unstable and $c > c^*(\alpha=0)$. Moreover, no coalition smaller than $c = \alpha n$ can form, by definition of minimum participation. Given that $Q(c-1) > P(c) > P(1) = 0$ (by assumption A.6) players prefer to form the coalition $c = \alpha n$.

Q.E.D.

[11] This result, as well as many others on the size of stable coalitions, is shown in Carraro and Marchiori (2003).

[12] Again, see Carraro and Marchiori (2003) for a synthesis of the literature.

Proposition 1 identifies the relationship between the minimum participation rule decided in the first stage of the game and the equilibrium of the coalition stage. This relationship between the value of $\alpha$ and the equilibrium of the coalition stage, jointly with the incentive structure that supports the equilibrium coalition $c^*(\alpha=0)$, are crucial to determine the equilibrium value of $\alpha$ in the minimum participation stage.

## 4. The minimum participation stage

The goal of this section is to determine the equilibrium of the minimum participation stage, i.e. to identify which minimum participation constraint is chosen in the first stage of the game. When countries deal with the choice of the membership rule, they consider two aspects:

*1)* ***if*** it is convenient to introduce a minimum participation constraint rather than to negotiate under the open membership regime;

*2)* ***which*** minimum participation constraint is optimal.

As noted above, the decision in the first stage of the game is taken independently and simultaneously by all players. As no player can be forced to accept a minimum participation rule he does not agree upon, decisions in the first stage must be taken with the unanimous consensus of all players. In order to achieve a unanimous consensus on a given $\alpha$-rule in the first stage, all players must prefer the equilibrium supported by that rule to the one that would emerge without a minimum participation rule. This is the case if, whatever the choice of a player in the second stage, a player's payoff when the minimum participation constraint is introduced is larger than the payoff he would receive in the absence of any minimum participation constraint.

**Proposition 2**: *Let A.1-A.7 hold. In the first stage of the game, all players agree to introduce a minimum participation constraint $\alpha = c/n$ iff:*

$$(5) \qquad P(c) \geq Q[c^*(\alpha=0)]$$

Proof: For all players to agree on a minimum participation constraint, we must have:

- $P(c) \geq P(c^*)$, i.e. all players who cooperate in $\{c,1_{(n-c)}\}$ and in $\{c^*,1_{(n-c^*)}\}$ are better off in $\{c,1_{(n-c)}\}$;
- $Q(c) \geq P(c^*)$, i.e. all players who are free-riders in $\{c,1_{(n-c)}\}$ but cooperators in $\{c^*,1_{(n-c^*)}\}$ are better off in $\{c,1_{(n-c)}\}$;
- $P(c) \geq Q(c^*)$, i.e. all players who cooperate in $\{c,1_{(n-c)}\}$ but free-ride in $\{c^*,1_{(n-c^*)}\}$ are better off in $\{c,1_{(n-c)}\}$;
- $Q(c) \geq Q(c^*)$, i.e. all players who free-ride both in $\{c,1_{(n-c)}\}$ and in $\{c^*,1_{(n-c^*)}\}$ are better off in $\{c,1_{(n-c)}\}$.

If these four conditions are satisfied, all players find it convenient to agree on the minimum participation constraint $\alpha$ that sustains $\{c,1_{(n-c)}\}$. Notice that $c > c^*$ (otherwise the coalition structure is $\{c^*,1_{(n-c^*)}\}$) by Proposition 1. Hence, $P(c) > P(c^*)$ by Assumption A.6. Moreover, $Q(c)$ is also monotonically increasing, which implies $Q(c) > Q(c^*)$ when $c > c^*$. These two results, the definition of $c^*$, and $c > c^*$, imply $Q(c) > Q(c-1) > P(c) > P(c^*)$. As a consequence, eq. (5), i.e. $P(c) \geq Q(c^*)$, is a necessary and sufficient condition for all players to agree on the selection of a minimum participation rule such that the equilibrium coalition structure becomes $\{c, 1_{(n-c)}\}$.

Q.E.D.

Inequality (5) can be interpreted as a participation incentive constraint. Its geometric representation, when met for $c \geq c^*+2$, is provided by Figure 1.

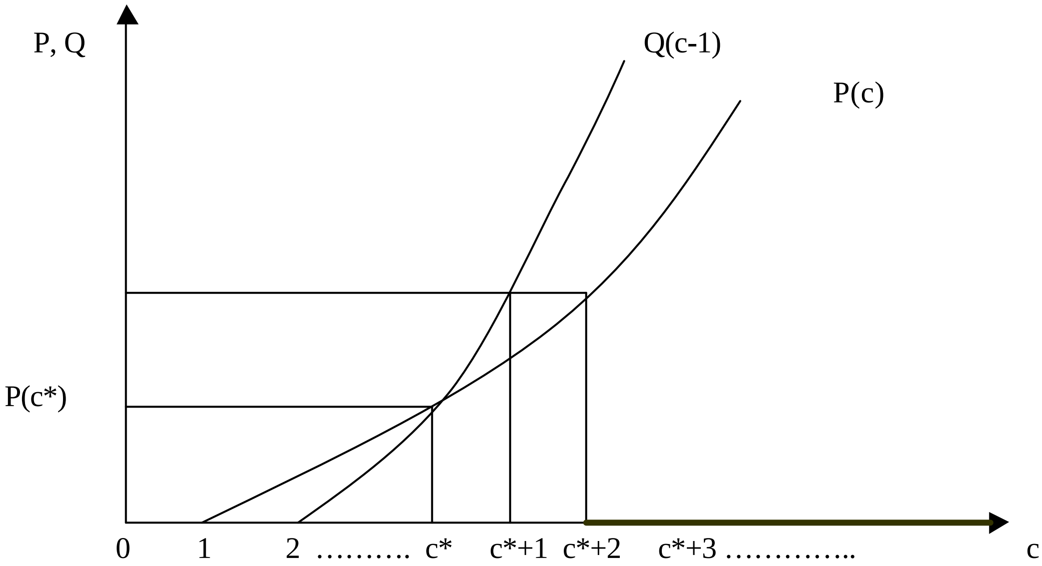


**Figure 1. Geometric representation of condition (5) when met for c ³ c*+2**

Is this condition feasible? The answer is certainly positive. Given the monotonicity of the functions $P(c)$ and $Q(c)$, it is possible – if n is sufficiently large – to find a coalition c large enough to satisfy $P(c) \geq Q(c^*)$. In particular, assume that n is such that there is a c' that satisfies $P(c') = Q[c^*(\alpha=0)]$. The monotonicity of $P(c)$ implies that (5) is met for all $c \in [c', n]$.

However, (5) is only a necessary condition to identify the minimum participation constraint which is chosen by the n countries. The inequality (5) defines the set of minimum participation rules that would be voted with the unanimous consensus of all countries. Which rule is actually going to be adopted?

To answer this question, we must write the optimisation problem that each country solves when deciding the optimal minimum participation rule. Given symmetry, in the first stage of the game, a country does not know whether in the coalition stage it will be a cooperator or a free rider. Therefore, it solves:

(6) $$\max_c \quad EP(c) = \frac{c}{n}P(c) + \frac{n-c}{n}Q(c)$$

$$\text{s.t.} \quad P(c) \geq Q[c^*(\alpha=0)] \qquad 1 \leq c \leq n$$

where EP(c) is a country's expected payoff in the first stage of the game, c/n is the probability of being a coooperator in the second stage (given that the rule $\alpha$ = c/n is chosen in the first stage), whereas (n-c)/n is the probability of being a free-rider in the second stage of the game.

The equilibrium minimum participation rule $\alpha°= c°/n$ is then the solution of the optimisation problem (6), i.e. c° is the maximand of EP(c) subject to (5). Note that (6) identifies the trade-off that countries face. On the one hand, a high value of c, namely of $\alpha$, increases the payoff of both cooperators and free-riders. On the other hand, a high value of $\alpha$ reduces the probability of being a free-rider in the second stage, thus reducing the probability of reaping the highest payoff.

Before providing a formal analysis of the above optimisation problem, let us consider a simple economic example. Using a linear quadratic model, and assuming n = 9, the payoffs of different coalition structures have been computed.[13] These payoffs are summarised in Table 1.

First of all, note that $c^*(\alpha=0) = 3$. Hence, when $\alpha=0$ (open membership), the stable coalition is formed by three players whatever n (this result was already shown in Carraro and Siniscalco, 1992). The inequality (5) is satisfied by all coalition sizes c larger or equal to 5. These coalition sizes make all players better off than in the coalition structure $\{c^*(\alpha=0), 1_{(n-c^*)}\}$.

[13] These quadratic cost and linear benefit functions are also used in Barrett (1994, 1997), Carraro and Siniscalco (1992), Chander and Tulkens (1997) and many others. See Carraro and Marchiori (2003) or Finus and Rundshagen (2001) for two recent surveys.

**Table 1. A single coalition game with orthogonal free-riding and linear-quadratic functions**

| Coalition structure | Per-member partition function (9 players) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1,1,1,1,1, 1,1,1,1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,1,1,1, 1,1,1,2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 0,5 | 0,5 |
| 1,1,1,1, 1,1,3 | 6 | 6 | 6 | 6 | 6 | 6 | 2 | 2 | 2 |
| 1,1,1,1, 1,4 | 12 | 12 | 12 | 12 | 12 | 4,5 | 4,5 | 4,5 | 4,5 |
| 1,1,1, 1,5 | 20 | 20 | 20 | 20 | 8 | 8 | 8 | 8 | 8 |
| 1,1,1,6 | 30 | 30 | 30 | 12,5 | 12,5 | 12,5 | 12,5 | 12,5 | 12,5 |
| 1,1,7 | 42 | 42 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| 1,8 | 56 | 24,5 | 24,5 | 24,5 | 24,5 | 24,5 | 24,5 | 24,5 | 24,5 |
| 9 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |

Let us solve the optimisation problem (6) for the example summarised by Table 1. The values of EP(c), for c = 5, 6, … , 9, are:

$$\mathrm{EP}(c=5) = \frac{5}{9}\cdot 8 + \frac{9-5}{9}\cdot 20 = \frac{120}{9}$$

$$\mathrm{EP}(c=6) = \frac{6}{9}\cdot 12{,}5 + \frac{9-6}{9}\cdot 30 = \frac{165}{9}$$

$$\mathrm{EP}(c=7) = \frac{7}{9}\cdot 18 + \frac{9-7}{9}\cdot 42 = \frac{210}{9}$$

$$\mathrm{EP}(c=8) = \frac{8}{9}\cdot 24{,}5 + \frac{9-8}{9}\cdot 56 = \frac{252}{9}$$

$$\mathrm{EP}(c=9) = \frac{9}{9}\cdot 32 = \frac{288}{9}$$

In this example, EP(c) increases with c for c $\in$ [5,9]. Therefore, the equilibrium minimum participation constraint is $\alpha° = 1$. As a consequence, in this example, all countries not only prefer to "tie their hands" in the first stage, but also decide to "tie all hands", thus giving up the possibility of free-riding in the second stage in order to reap the benefits arising from full cooperation. As said in the Introduction, 22 out of 122 multilateral environmental agreements share this feature.

Let us provide a more general analysis of the optimisation problem (6). The function EP(c) can be decomposed into four factors: c/n, P(c), Q(c) and (n-c)/n, because $EP(c) = (c/n)P(c) + Q(c)[(n-c)/n]$. The first three factors are increasing with c, because P(c) and Q(c) are monotonic and c is a positive number. Therefore, only the fourth factor, (n-c), is a decreasing function of c.

Under what conditions is EP(c) increasing with c for all values of c satisfying (5)? This question is relevant because it identifies the case in which c° = n or $\alpha° = 1$, i.e. in which the minimum participation rule requires the ratification by all countries and therefore full cooperation. The answer is provided by the following:

**Proposition 3**: *Let A1-A7 hold. The equilibrium minimum participation rule is $\alpha° = 1$, i.e. the treaty comes into force only when all countries sign and ratify it, iff:*

*(7a)* $\quad P(n) \geq Q[c^*(\alpha=0)]$

*(7b)* $\quad (1 + e_P)P(c)/Q(c) \geq 1$

*where $e_P$ is the positive elasticity of the function P(c).*

Proof: The first condition, (7a), is the necessary condition already established by Proposition 2. It is met for *n* sufficiently large. The second condition, (7b), can be proved as follows. By differentiating $cP(c)+(n-c)Q(c)$ with respect to c, we obtain:

(8) $$P(c) - Q(c) + cP'(c) + (n-c)Q'(c)$$

where P'(c) and Q'(c) are the first derivative of P(c) and Q(c) respectively. Let $c^+$ be the solution of $P(c^+) = Q(c^*)$. Then, (8) is positive for all $c \in [c^+,n]$ iff:

(9) $$\varepsilon_Q (n-c)/n + (1 + \varepsilon_P)P(c)/Q(c) \geq 1$$

where $\varepsilon_Q$ and $\varepsilon_P$ are the positive elasticities of the functions Q(c) and P(c) respectively. Note that both terms on the left hand side are positive. However, $(n-c)/n < 1$ because $c > c^*$ and $P(c)/Q(c) < 1$ for $c > c^*$ by definition of stability. Both (n-c)/n and P(c)/Q(c) decreases with c when P and Q are monotonic and $c^* \geq 2$. Therefore, unless the elasticities strongly increase with c, (9) is less likely to be met for high values of c. The strongest condition to be met for EP(c) to be increasing for all $c \geq c^+$, including c = n, is (7b), i.e.

$$(1 + \varepsilon_P)P(c)/Q(c) \geq 1$$

which coincides with (9) for c = n. This condition is satisfied only if $\varepsilon_P$ is sufficiently large, i.e. the profitability function increases sufficiently rapidly with c. The intuition is that high and increasing values of P(c) when c is close to n or equal to n offset the loss induced by the impossibility of free-riding in the second stage.[14]

Q.E.D.

If (7b) is not met, there may exist values of c for which (9) is negative. In this case, the optimal rule $\alpha° = c°/n$ is smaller than 1. A minimum participation constraint $\alpha° < 1$ implies that, at the equilibrium, some countries free-ride on the cooperative behaviour of the other ones. However, given the constraint $P(c) \geq Q[c^*(\alpha=0)]$, the minimum participation rule, even when chosen endogenously and strategically, achieves the goal of inducing an equilibrium coalition which is larger than or equal to the one that would form without minimum participation constraint.[15]

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[14] Assume P(c) concave. Its elasticity becomes smaller and smaller as c moves towards n. At the same time, by definition of stability, the difference between Q(c) and P(c) increases with c. Therefore, $P(c)/Q(c) < 1$ also becomes smaller and smaller. As a consequence, $(1 + \varepsilon_P)P(c)/Q(c)$ may become smaller than one and (7b) may not be met. By contrast, if $\varepsilon_P$ is large, e.g. because P(c) is convex, the ratio P(c)/Q(c) is closer to one and (7b) is more likely to be satisfied for c = n.

[15] The proof is easy. For all $c > c^*$, $Q(c) > P(c-1)$ by definition of stability (eqs. (2)). Therefore, $Q(c+1) > P(c) \geq Q[c^*(\alpha=0)]$ which implies $c+1 > c^*$ because Q(c) is monotonic. This implies $c \geq c^*$.

The intuition behind this result is as follows. Even if players perfectly anticipate the consequences of their decision, in the first stage they have an incentive to reduce their freedom to free-ride in order to achieve a larger payoff. However, this does not necessarily lead to the grand coalition (full cooperation), because all players also have an incentive to minimise this limitation to their freedom in order to increase the likelihood of being free-riders. The balance of these two incentives leads to the formation of a coalition which is larger than or equal to the one that would form when $\alpha = 0$ (no minimum participation constraint), but could be smaller than the grand coalition. The grand coalition is achieved only when the elasticity of P(c) for c close to n is sufficiently large (eq. (7b)).

As a further development of the example of Table 1, consider the following simple economic-environmental model. *n* identical countries emit a pollutant that damages a common environmental resource. The welfare $u_i$ of each country depends on the benefits arising from the use of the environment for production and consumption activities and on the damages resulting from polluting emissions:

(10) $$u_i = B(x_i) - D(X) \qquad i = 1, 2, \dots, n$$

where $x_i$ is country i's emission level and X is the total amount of polluting emissions ($X=\sum^n_{i=1} x_i$). Let the benefit function $B(x_i)$ be quadratic and the cost function (or damage function) be linear:

(11) $$B(x_i) = k(dx_i - x_i^2/2)$$

where d is the maximum level of emissions and k is a technological parameter which parametrizes total benefits from emissions (the larger k is, the larger the benefit)

(12) $$D(x_i, X) = \frac{m}{2}\left[x_i + (X - x_i)\right]$$

where m parametrizes the level of perceived damage from pollution. Using (10)-(12), a country's payoff function is:

(13) $$u_i = k\left(dx_i - \frac{x_i^2}{2}\right) - \frac{m}{2}\left[x_i + (X - x_i)\right]$$

In a coalition structure $\pi = (c, 1_{n-c})$, countries inside the coalition act cooperatively and choose their emission level by maximising the sum of the payoffs of all members. Hence, for a coalition structure $\pi$, the payoff of a cooperating player is:

(14) $$u_c = k\left(dx_c - \frac{x_c^2}{2}\right) - \frac{m}{2}\left[x_c + \left((c-1)x_c + (n-c)x_f\right)\right]$$

where $x_c$ and $x_f$ are the emission levels of cooperators and free-riders, respectively. Differentiating (14) with respect to $x_c$ yields $x^*_c = d - mc/2k$, which is the optimal emission level for a cooperating country. A free-rider's payoff function is given by the following expression:

(15) $$u_f = k\left(dx_f - \frac{x_f^2}{2}\right) - \frac{m}{2}\left[x_f + (n-c-1)\hat{x}_f + cx_c\right].$$

Differentiating (15) with respect to $x_f$ yields $x^*_f = d - m/2k$. By replacing the values of $x^*_c$ and $x^*_f$ into the payoff functions $u_c$ and $u_f$, we obtain the payoffs for cooperators and free-riders as a function of the coalition size c:

$$P(c) = k\left[d\left(d - \frac{mc}{2k}\right) - \frac{1}{2}\left(d - \frac{mc}{2k}\right)^2\right] + \frac{m}{2}\left[\left(d - \frac{mc}{2k}\right) + (c-1)\left(d - \frac{mc}{2k}\right) + (n-c)\left(d - \frac{m}{2k}\right)\right]$$

$$Q(c) = k\left[d\left(d - \frac{m}{2k}\right) - \frac{1}{2}\left(d - \frac{m}{2k}\right)^2\right] + \frac{m}{2}\left[\left(d - \frac{m}{2k}\right) + (n-c-1)\left(d - \frac{m}{2k}\right) + c\left(d - \frac{mc}{2k}\right)\right]$$

The values shown in Table 1 have been obtained by normalising to zero the payoff functions when c=0 (no-cooperation) and by assuming m=2k and k=d=1. The expected utility function EP(c) is then proportional to:

$$\left[c\left(d - \frac{mc}{2k}\right)\left(\frac{kd}{2} + \frac{mc}{4} - \frac{mN}{2}\right) + (N-c)\left(d - \frac{m}{2k}\right)\left(\frac{kd}{2} + \frac{m}{4} - \frac{mN}{2}\right)\right]$$

This function increases monotonically with c in the interval $[c^+, n]$ iff EP(c) – EP(c-1) > 0 for $c \in [c^+, n]$. This inequality holds because EP(c) – EP(c-1) =

$$c\left(d - \frac{mc}{2k}\right)\left(\frac{kd}{2} + \frac{mc}{4} - \frac{mn}{2}\right) - (c-1)\left(d - \frac{m(c-1)}{2k}\right)\left(\frac{kd}{2} + \frac{m(c-1)}{4} - \frac{mn}{2}\right) +$$

$$-\left(d - \frac{m}{2k}\right)\left(\frac{kd}{2} + \frac{m}{4} - \frac{mn}{2}\right) > 0$$

for $1 < c < 4/3n$. Therefore, the expected utility function EP(c) increases monotonically with c in the interval $\left(1, \frac{4}{3}n\right)$. As a consequence, the equilibrium minimum participation constraint is $\alpha° = 1$ (coalition unanimity) and the equilibrium coalition size is $c° = n$ (full cooperation).

This result is a generalisation of the conclusion already achieved when analysing Table 1. As already stated, when $\alpha = 1$, all countries join the coalition (sign the environmental treaty) in the second stage of the game. However, in the presence of structural asymmetries, some countries may balk from signing the agreement (the profitability condition is not met for all countries) and therefore the minimum participation constraint $\alpha = 1$ cannot guarantee full cooperation. In the presence of asymmetries, it may even be counterproductive, because it may lead to no cooperation, unless coupled with a transfer scheme that guarantees the profitability of the agreement for all countries.

## 5. Conclusions

In the previous sections, we analysed a coalition formation game in which, in the first stage of the game, players strategically decide whether to introduce a minimum participation constraint and the size of this constraint. At the equilibrium, the minimum participation constraint is binding and induces more countries to cooperate. This is consistent with the evidence provided by several international agreements. However, the two basic questions proposed in the Introduction were more stringent: (i) why do countries voluntarily decide to introduce a minimum participation constraint that must be met for a treaty to come into force?; and (ii) what is the equilibrium minimum participation rule ?

In words, the answer to the first question is as follows. Countries compare the incentives to cooperate within a larger coalition sustained by the minimum participation constraint with the incentives to free-ride on the public good (e.g. emission abatement) provided by a smaller coalition. If the former incentive dominates the second one, all countries prefer to “tie their own hands” and to introduce a minimum participation constraint.

As for the second question, the optimal minimum participation constraint is defined by the elasticity of the payoff function of cooperating countries. If this elasticity is sufficiently large and increasing for $c \leq n$, then all countries prefer a minimum participation constraint that induces full cooperation. The reason is as follows. If the benefits from cooperation are rapidly increasing with the number of cooperators, no player has an incentive to take the risk of being a free-rider. Note that this conclusion crucially depends on the assumption of symmetric countries.

These results could be used in the design of actual policy agreements. First, a minimum participation rule is generally helpful to enhance the environmental effectiveness of an international agreement. Therefore, international environmental treaties should contain this rule. We have seen that this is actually the case for most existing treaties. Second, the optimal rule is generally coalition unanimity, in particular when the number of negotiating countries is not too large. However, two factors of information are crucial. First, the unanimity constraint is effective only if the profitability condition is met for all countries. Otherwise, it may be counterproductive. Therefore, in real agreements, a minimum participation unanimity rule should be associated with a transfer mechanism that makes the agreement profitable to all countries (e.g. the one proposed in Chander and Tulkens, 1995, 1997). Secondly, the curvature of the coalition's payoff function is also crucial. If benefits from cooperation do not increase with the number of cooperators, or increase too slowly, then it is not optimal to set a minimum participation constraint such that all countries must sign and ratify the treaty for it to come into force.

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