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THE STRUCTURE OF
INTERNATIONAL ENVIRONMENTAL AGREEMENTS

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Abstract

Since the framework convention of Rio, actual environmental negotiations on climate change aim at inducing all world countries to sign a global environmental agreements to reduce greenhouse gas emissions. Despite the past unsuccessful attempts, even current negotiations seem to pursue the same objective. This paper shows from a game-theoretic viewpoint that the emergence of agreements signed by all countries is quite unlikely, even in the presence of appropriate and multi-issues negotiation strategies and transfers. Either a single partial agreement or a coalition structure in which regional environmental agreements to control climate change are signed are the most likely outcomes. The paper compares these two cases and argue that regional agreements may increase both countries welfare and environmental quality.

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1. Introduction

Climate change (asymmetrically) affects all world countries. Hence, the reduction of C02 concentration in the atmosphere (asymmetrically) benefits most, if not all, world countries. However, each country individually bears the (sometimes relevant) cost of domestic policies designed to control greenhouse gases (GHG) emissions. Moreover, most world countries have only a minor impact on total global emissions. These asymmetries, in benefits vs. costs, in actions vs. outcomes, are the source of the many difficulties in achieving an international agreement on climate change.

These problems are not new to economists, and have been analysed in the area of externalities and public goods. What is new is the context where these problems take place. Currently, the atmosphere is managed as global common-property goods, and there is no institution which possesses powers to regulate their use by means of supra-national legislation, economic instruments, or by imposing a system of global property rights. Hence, the necessity to design negotiation mechanisms leading to self-enforcing agreements, i.e. agreements to reduce GHG emissions which are voluntarily signed by a large group of countries (large enough to keep climate change under control).

In the recent history of international agreements to protect the global environment, one can observe different attempts to achieve cooperation among countries. The first attempt has been to design world-wide agreements to cut emissions by bargaining solely on emissions. The result of these attempts has been usually frustrating. The conventions, whenever are signed by a great number of countries, are rather empty in terms of quantitative targets and/or deadlines. Precise commitments, on the other hand, are signed by small groups of "like-minded" countries.

The dissatisfaction with such an outcome, and in particular with small environmental coalitions, has been followed by attempts at expanding the agreements by bribing reluctant countries by means of transfers. Alternatively, but with the same goal, the negotiating experience is trying to link environmental protection to other international agreements: on technological cooperation (as in the case of the Climate Change Convention) and trade (as in the environmental clause in GATT/WTO).

There is therefore a problem of targets vs. instruments. Should countries agree on emission paths (e.g. stabilise emissions at the 1990 level) or on the value of policy instruments (an international carbon tax or a tradable permit system)? But there is also a problem of strategy. Should negotiation focus only on climate change policies or should they be linked to other policy issues? This paper aims at discussing the possible answers to this latter question, but it also raises a more fundamental question. Should country insist with their attempt to achieve a world agreement on GHG emission reduction? And if not, what could the target be? A partial coalition where only a sub-group of countries sign the environmental convention? Or a set of regional agreements specifically designed for the countries in each world region?

Sections 2 through 4 will focus mainly on the design of appropriate negotiation strategies, whereas Section 5 will address the basic issue of which coalition structure, i.e. which type of international agreement, should be pursued by countries negotiating on emission reductions to control climate change.

2. A Game-Theoretic Perspective

There are probably two reasons which explain the difficulty to achieve self-enforcing agreements with a large number of signatories. The first one is the large economic and environmental asymmetries across world regions. Less developed countries, for example, are quite reluctant to adopt measures to control global pollution because this could slow down their growth with high economic costs which are evaluated as larger than the environmental benefits resulting from emission reduction. In other words, signing an environmental agreement may not be profitable for all countries involved in the negotiation process.

The second problem is the intrinsic instability of environmental agreements. In words, some countries may prefer to free-ride, i.e. to profit from the emission reduction achieved by the signatory countries (because the environmental benefit is not excludable). This phenomenon is not related to the presence of asymmetries, even if asymmetries can strengthen it, and it occurs even if countries are identical. Therefore, even when all countries are conscious that gains from environmental cooperation are above the economic costs of abating pollution, i.e. that cooperation is profitable, most of them may not sign the environmental agreement because of the possibility to achieve the environmental benefit without paying the costs (i.e. cooperation is unstable).[1]

Let us provide a more formal description of the above two problems and of the solutions proposed in the environmental literature. Assume negotiations take place among n countries, $n \geq 3$, each indexed by $i=1, ..., n$. Let $P_i(s)$ denote the value of country i's welfare when it decides to join the coalition s, whereas $Q_i(s)$ is the value of its welfare when country i does not join the coalition s. The only argument of the payoff functions is the identity and number of cooperating countries. However, it is implicit that all other relevant variables, including emissions and policy decisions in other countries, enter country i's welfare function. Indeed, countries facing an international environmental problem play a two-stage game. In the first stage -- the coalition game -- they decide non cooperatively whether or not to sign the agreement (i.e. to join the coalition s). In the second stage, they play the non cooperative Nash emission game, where the countries which 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).[2] The functions $P_i(s)$ and $Q_i(s)$ are the value functions in the first stage of the game when the only decision to be taken is whether or not to join the coalition.

Moreover, let us assume that:

A1. All countries decide simultaneously in both stages;[3]

A2. Countries are proposed to sign a single agreement. Hence, those which do 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.[4]

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[1] This argument is well described in the early works on environmental cooperation. See Hardin (1968), Hardin and Baden (1977), Ostrom (1990).

[2] This approach has to be contrasted with the traditional cooperative game approach (e.g. Chander-Tulkens, 1993, 1997) and with a repeated game approach (Barrett, 1994, 1997b). Moreover, notice that the regulatory approach often proposed in public economics is not appropriate given the lack of a supranational authority.

[3] By contrast, Barrett (1994) assumes that the group of signatories is Stackelberg leader with respect to non-signatories in the second stage emission game. In Bloch (1997) it is assumed that countries play sequentially in the first stage coalition game.

[4] This assumption will be relaxed later on.

A3. When defecting from a coalition *s*, each country assumes that the other countries belonging to *s* remain in the coalition.[5]

A4. Each country's payoff function increases monotonically with respect to the coalition size (the number of signatories in the symmetric case).[6]

Given these assumptions, we say that:

- A coalition *s* is profitable when each country $i \in s$ gains from joining the coalition (with respect to its position when no countries cooperate). Formally, a coalition *s* is profitable iff $P_i(s) \geq P_i(\emptyset)$, $\forall i \in s$, where $P_i(s)$ is country i's payoff when coalition *s* forms.
- A coalition *s* is stable (i.e. self-enforcing) iff:

(i) there is no incentive to free-ride, i.e. $Q_i(s \backslash i) - P_i(s) < 0$ for each country i belonging to *s*, where $Q_i(s \backslash i)$ is country i's payoff when it defects from coalition *s;*

(ii) there is no incentive to broaden the coalition, i.e. $P_i(s \cup i) - Q_i(s) < 0$ for each country i which does not belong to *s*.[7]

- A profitable and stable coalition *s* is also Pareto optimal iff there exists no other profitable and stable coalition which provide all countries with a payoff larger than $P_i(s)$, $\forall i \in s$. Formally, $P_i(s) \geq P_i(s^*)$, $\forall i \in s$, $s \in S$, $\forall s^* \in S$ such that $i \in s^*$, where *S* is the set of all stable and profitable coalitions.

Notice that a profitable and stable coalition is also Pareto optimal under the assumption that a country's payoff function increases monotonically with the coalition size.

Most articles in the theoretical literature on environmental cooperation and conflict (Hoel, 1991, 1992; Carraro and Siniscalco, 1992, 1993; Barrett, 1994, 1997b; Heal, 1994) adopt the standard definitions of stability and self-enforcing agreements provided above (under assumptions A1-A4). There is a result which is common to most of this literature. The presence of asymmetries across countries and the incentive to free-ride makes the existence of self-enforcing agreements quite

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[5] This assumption is equivalent to the assumption of "Nash conjectures" in a simultaneous oligopoly game where a player assumes no change in the other players decision variable when it modifies its own decision variable. However, coalition theory often uses a different assumption, named coalition unanimity (Cf. Bloch, 1997), where the whole coalition is assumed to collapse when one of its members defects (see Chander and Tulkens, 1993, 1997).

[6] The implications of relaxing this assumption will be discussed in Section 4.

[7] This definition of stability coincides with the definition of a stable cartel provided in the oligopoly literature (D'Aspremont *et al*, 1983) and defines the Nash equilibrium of the first of the game (the one in which countries decide whether or not to sign the agreement). Notice that stability coincides with profitability under coalition unanimity.

unlikely. When they exist they are signed by a limited number of countries (Hoel, 1991; Carraro-Siniscalco, 1992; Barrett, 1994). When the number of signatories is large, the difference between the cooperative behaviour adopted by the coalition and the non cooperative one is very small (Barrett, 1997b).

These results, which are robust with respect to different specifications of countries' welfare function, and with respect to the burden-sharing rule[8] used in the asymmetric case (Barrett, 1997a, Botteon-Carraro, 1997a), suggest that the attempt to negotiate on emission reductions is unlikely to be successful, unless more complex policy strategies, in which environmental policy interacts with other policy measures, are adopted. This is why in the environmental economics literature two main sets of instruments have been proposed to expand environmental coalitions, i.e. to increase the number of signatories of an environmental agreement. These instruments are "transfers" and "issue linkage".

3. Environmental Cooperation and Transfers

Let us consider transfers first. It is quite natural to propose transfers to compensate those countries which may lose by signing the environmental agreement. In other words, a re-distribution mechanism among signatories, from gainers to losers, may provide the basic requirement for a self-enforcing agreement to exist, i.e. the profitability of the agreement for all signatories. Therefore, if well-designed, transfers can guarantee that no country refuses to sign the agreement because it is not profitable. Formally, this implies $P_i(S)+T_i \geq P_i(\emptyset)$, for all $i \in S$, where T_i denotes the transfer given or received by country i and where a budget constraint requires T_i to be self-financed (compensated Pareto criterion) . Chander and Tulkens (1993, 1994) show that there exist transfers such that not only is each country better off with full cooperation than it is with no cooperation, but it is also better off with full cooperation than it is in any sub-coalition, provided the remaining countries behave non-cooperatively. This result is important because it implies that no country or

[8] In the asymmetric case, the rule which is chosen to divide the gains from cooperation among the countries in the coalition (usually called burden-sharing rule) plays a crucial role because it affects the likelihood that each country decides to sign the agreement. The burden-sharing rule is usually taken from cooperative game theory and Nash's and Shapley's one are the most used. By contrast, in the symmetric case different rules lead to the same outcome (equal shares).

group of countries has an incentive to exclude other countries from the environmental coalition, i.e. the grand coalition is optimal (but it may not be stable).

Transfers play a major role also with respect to the stability issue. Indeed it is not sufficient to guarantee the profitability of the environmental agreement. Incentives to free-ride must also be offset. The possibility of using self-financed transfers to stabilise environmental agreements is analysed in Carraro and Siniscalco (1993), Hoel (1994) which show that transfers may be successful only if associated with a certain degree of commitment. For example, when countries are symmetric, only if a group of countries is committed to cooperation, another group of uncommitted countries can be induced to sign the agreement by a system of transfers.[9] Suppose that *s* is the largest stable coalition when no transfer system is implemented. The joint additional benefit for countries belonging to *s* when an additional country j enters the coalition is $\Sigma_{i\in s}[P_i(s\cup j)) - P_i(s)] > 0$ (where it is assumed that the environmental benefit monotonically increases with the number of cooperators). The incentive for country j to free ride on the $s\cup j$ coalition is $Q_j(s) - P_j(s\cup j) > 0$, because the coalition $s\cup j$ is not stable. Hence, the coalition $s\cup j$ can be stabilised by a system of transfers if the joint benefits from cooperation are larger than the incentive to free-ride, i.e. (i) $\Sigma_{i\in s}[P_i(s\cup j) - P_i(s)] > Q_j(s) - P_j(s\cup j)$, and if: (ii) there exists a sharing rule such that $P_i(s\cup j) - P_i(s) \geq 0$ for all $i\in s$; (iii) countries belonging to the coalition *s* are committed to cooperation[10]. However, these conditions are difficult to be met for the case in which j is replaced by $S\backslash s$, i.e. in the case in which transfers are used to achieve the grand coalition.[11]

More importantly, the idea of commitment, albeit partial, i.e. confined to a group of countries, cannot be entirely consistent with the concept of self-enforcing agreement stressed in the previous sections.

If we accept the notion of weak self-enforcing agreement, proposed in Carraro-Siniscalco, 1993) where a sub-group of countries can commit themselves to cooperation, then three types of partial

[9] This condition is less stringent when countries are asymmetric. See Botteon and Carraro (1997a).

[10] See Carraro and Siniscalco (1993) where the result is shown for symmetric countries.

[11] When *j* is replaced by $S\backslash s$, conditions (i)-(iii) are met if the net benefit for the marginal country in *s* is large. This cannot be the case when all countries are identical (symmetric) because the net benefit of the marginal country

commitment (possible blue-prints for environmental cooperation) can be proposed (of course, other types of institutional mechanisms could be proposed as well):

- stable coalition commitment when only the j countries belonging to the stable coalition commit to cooperation;
- sequential commitment when the j countries are committed to cooperation and any new signatory, as soon as it enters the expanded coalition, must commit to cooperation as well;
- external commitment when a subset of non-cooperating countries commits to transfer welfare in order to induce the remaining non-signatories to cooperate, and to guarantee the stability of the resulting coalition.

Assuming these alternative commitment schemes, Carraro and Siniscalco (1993) analyse the formal conditions to expand coalitions. A general conclusion emerges from their analysis. Both the existence of stable coalitions, and the possibilities of expanding them, depend on the pattern of interdependence among countries. If there is leakage, i.e. a non-cooperating country expands its emissions when the coalition restricts them, thus offsetting the effort of the cooperating countries, then environmental benefits from cooperation are low, the incentive to free-ride is high, and conditions for transfers to be effective are unlikely to be met. If, on the contrary, there is no leakage, i.e. the free-riders simply enjoy the cleaner environment without paying for it, but do not offset the emission reduction by the cooperating countries, then environmental benefits are larger, free-riding is less profitable and transfers may achieve their goal to expand the coalition..

The stability issue has been often analysed within a theoretical framework in which all countries are identical (symmetric). However, there are a few attempts to analyse the existence of self-enforcing agreements and the role of transfers in the case of asymmetric or heterogeneous countries. This is done both in Barrett (1997a) and in Botteon and Carraro (1997a). These papers show that asymmetries may increase the effectiveness of transfers rather than reducing it. For example, a commitment may not be necessary (in this case an agreement with transfers would also be self-enforcing). Moreover, they address the issue of burden sharing by showing that the way in which gains are re-distributed affects both profitability, as previously stressed, and stability of the agreement, thus modifying the effectiveness of transfers and the role of commitment. In other

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is approximately zero (when the number of countries is large), but it is more likely when countries are asymmetric (see Botteon and Carraro, 1997a).

words, there are two types of transfers: those which make the agreement profitable to all countries and those which make it stable. There are therefore two objectives (profitability and stability) with a single instrument (transfers), a situation that economists immediately recognise as inefficient.

4. Issue Linkage

This is why a second approach to address the profitability and stability problems has been proposed. The basic idea is to design a negotiation mechanism in which countries do not negotiate only on the environmental issue, but also on another interrelated (economic) issue. For example, Barrett (1995) proposes to link environmental negotiations to negotiations on trade liberalisation, whereas Carraro and Siniscalco (1995, 1997), Katsoulacos (1997) propose to link them to negotiations on R&D cooperation.

Again we must distinguish the profitability from the stability problem. The idea of "issue linkage" was originally proposed by Folmer *et al.* (1993) and Cesar and De Zeeuw (1994) to solve the problem of asymmetries among countries. The intuition is that some countries gain on a given issue, whereas other countries gain on a second one. By "linking" the two issues it may be possible that the agreement in which the countries decide to cooperate on both issues is profitable to all of them. Formally, if $P_{i1}(s)$ is the payoff of country i when it joins coalition *s* on issue 1, and $P_{i2}(s)$ denotes country i's payoff when it join the same coalition on issue 2, we have that the idea of "issue linkage" solves the profitability problem if $P_{i1}(s) + P_{i2}(s) \geq P_{i1}(\emptyset) + P_{i2}(\emptyset)$ for all $i \in s$, where for some $i \in s$ we may have $P_{i1}(s) \leq P_{i1}(\emptyset)$ or $P_{i2}(s) \leq P_{i2}(\emptyset)$.[12]

The idea of "issue linkage" can also be used to achieve the stability goal. Suppose there is no profitability concern (either because countries are symmetric or because a transfer scheme is implemented to make the agreement profitable to all countries). Consider the case in which it is Pareto optimal to link the environment to another economic issue (see Carraro-Siniscalco, 1995 for a formal definition). Then, if stable, the linked agreement is also self-enforcing (no commitment is necessary).

[12] Here we assume the payoffs on the two issues to be additive. More generally, it should be $P_{iu}(s) \geq P_{iu}(\emptyset)$ for all $i \in s$, where $P_{iu}(.)$ denotes country i's payoff when the two issues are linked (see Carraro and Siniscalco, 1995).

Let us consider the stability of the linked agreement. Formally, there is no incentive to leave the linked coalition (i.e. the coalition is internally stable) if $P_{1i}(s) + P_{2i}(s) \geq Q_{1i}(s\backslash i) + Q_{2i}(s\backslash i)$ for all $i \in s$, where for some $i \in s$ we may have $P_{1i}(s) \leq Q_{1i}(s\backslash i)$ or $P_{2i}(s) \leq Q_{2i}(s\backslash i)$. In words, the mechanism can be explained through the following example.[13] Suppose the environmental negotiation is linked to the negotiation on R&D cooperation, which involves an excludable positive externality and increases the joint coalition welfare. In this way, the incentive to free-ride on the benefit of a cleaner environment (which is a public good fully appropriable by all countries) is offset by the incentive to appropriate the benefit stemming from the positive R&D externality (which is a club good fully appropriable only by the signatory countries). The latter incentive can stabilise the joint agreement, thus increasing its profitability because countries can reap both the R&D cooperation and the environmental benefit (this second benefit would be lost without the linkage).

However, this example points out to another problem. As said in Section 2, one assumption is implicit in the literature on self-enforcing environmental agreements, i.e. that the payoff function $P_i(s)$ is monotonically increasing with the coalition size, i.e. with the number of signatories when all countries are symmetric. In the context of issue linkage, this may not be true, as shown by Carraro and Siniscalco (1997) for the case in which environmental negotiations are linked to negotiations on R&D cooperation. The reason is that R&D cooperation provides a competitive advantage to signatories which can exploit a more efficient technology and therefore produce at lower unit costs. However, the competitive advantage tends to disappear when the number of signatories increases because an increasing number of countries share the same more efficient technology. On the other hand, there are diminishing returns of R&D cooperation. This implies that it may be optimal to exclude some countries from the joint R&D and environmental cooperation (the so-called exclusive membership stability of Yi and Shin, 1994).

To better understand the implications of a non-monotonic payoff function, let $L_i(s) = Q_i(s\backslash i) - P_i(s)$ be country i's stability function. When positive, it shows that country i has no incentive to defect from coalition s. In the symmetric case, the intersection between $L_i(s)$ and the horizontal axis, where the number of countries is shown, define the stable coalition which is formed by j* signatories (see Figure 1). However, j°, the <u>optimal</u> number of countries in the joint coalition (the

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[13] See Carraro and Siniscalco (1997) for a full presentation of the model.

maximand of the payoff function), may be lower than the number of countries belonging to the stable group of signatories of the joint agreement. As a consequence, three groups of countries may emerge (three roles): (a) those which cooperate (j°); (b) those which would like to cooperate but are excluded from the agreement and are therefore forced to non-cooperation (j*-j°); (c) and those which prefer not to cooperate (free-riders: n-j*). This case is depicted in Figure 1.

Notice that the above possibility is certainly not the only one. In Figure 2, we represent the case in which "issue linkage" can stabilise the grand coalition (the function Li(s) is above the horizontal axis for all $2 \leq j \leq n$). In this case, there are only two group of countries, those which sign the agreement and those which are excluded from the coalition. We can say that in this case the benefits from the agreement which is linked to the environmental one dominate the environmental benefits. Hence, no country wants to be excluded from the joint agreement. Viceversa, in Figure 3 the weight of the environmental benefits is much larger. As a consequence, j*, the number of countries which join the stable coalition is smaller than j°, the number of countries in the optimal coalition. Therefore there are again only two groups. The group of signatories and the free-riders.

The above results hold both when countries are symmetric (Carraro and Siniscalco, 1997) and when they are asymmetric (Botteon and Carraro, 1997b). In the asymmetric case a further problem arises. A given country i may prefer some countries, say j and h, as partners in the cooperating group, but these countries may want to sign the agreement with country k, rather than with i. And k may prefer i and h rather than j. In this case, an equilibrium may not exist, i.e. a stable international environmental agreement may not be signed (Botteon and Carraro, 1997b).

These latter insights lead to the conclusion that issue linkage may damage environmental protection rather than benefit it. This is the case whenever the incentives to exclude some countries from the linked agreement and the political economy problem that undermines the emergence of an equilibrium dominate the benefits of linking two synergetic (in terms of profitability and stability) issues.

5. A more general coalition structure

The results described in Sections 3 and 4 depend on a very specific definition of coalition stability, which is based on assumptions A1-A3. In this section, we propose to use a more general approach, in which group deviations are allowed for, i.e. a group of countries can jointly decide to defect, and in which coalitions interactions are accounted for, i.e. coalitions, rather than singletons only, can negotiate on the environmental agreement. In other words, we propose to relax assumptions A2 and A3.

This change of assumptions has important implications. Whereas in the previous sections only one coalition could emerge, the free-riding countries behaving as singletons, in this section we allow for the emergence of a complex coalition structure in which several coalitions may emerge at the equilibrium. The problem is to determine which equilibrium structure is most likely. Whether one in which one coalition is formed, or one in which k>1 coalitions, which interact among each others, characterise the equilibrium of the non-cooperative coalition game.

The implications for environmental negotiations are clear. In the latter case, there would not be one environmental agreement, but k agreements signed by k groups of countries. The multiplicity of coalitions may allow for region-specific agreements in which the characteristics of countries in the region are better reflected by the contents of the agreement.

Notice that several definitions have to be modified to take into account that countries and coalitions are now the actors of the game. For example, in a single coalition game, free-riders can behave solely as singletons and thereby the worth of the (unique) coalition is easily determined, and the stability of a coalition structure coincides with the stability of such a coalition. By contrast, in a multicoaltional game, the complement set behaviour is not fixed and the worth of a coalition is not defined uniquely. In particular, the worth of a coalition depends on the behaviour of the complement set and this is why considering the stability of a single coalition is meaningless in a multicoalition game. It is rather necessary to analyse the stability of all possible coalitions structures, in terms both of individual deviations and of group deviations. Unfortunately, the feasible coalition structures increase significantly as the number of players increases.

The concept of spillovers and the related definition of free-rider also have to be modified. We say that there are coalitional environmental spillovers (from one coalition to the others and to free-riders) if, when coalitions merge to form a larger coalition, the other coalitions and the singletons not affected by the change are better off. In words, the payoff of a player is larger the larger the size and the lower the number of the coalitions formed by the resulting complementary set. This implies that the complementary set defined by a singleton structure embodies the worst possible complement structure for a coalition, i.e. the minimax one[14]. In this sense the single coalition game is referred to as a benchmark for the multicoalition game, since it represents the minimum payoff any coalition can obtain in a multicoalition game.

The free-riding incentive, which naturally arises in a game with positive externalities, can be re-defined as follows. In any coalition structure, members of small coalitions have higher payoffs than members of big coalitions. The limit case is the one of singletons (i.e. coalitions formed by one player only) which receive the greatest net benefit from the other coalitions' abatement.[15]

Even if non singleton coalitions can form, the stability and the profitability condition are defined with respect to an individual viewpoint, consistently with the spirit of a non cooperative approach. Therefore, a coalition structure π is profitable if any coalition s in π is profitable. A coalition $s \in \pi$ is profitable if each cooperating player belonging to s gets a payoff larger than the one he would get in the singleton structure.

Let us now consider the stability condition. Consider a coalition belonging to any coalition structure: since it is always possible for any cooperating country to deviate to form a singleton, the internal stability condition is again a necessary condition. In the single coalition case, this condition was coupled with the external stability one. Indeed, in the single coaltion case, these two conditions are sufficient to define the equilibrium coalition structure, since countries have only two possible strategic choices: joining a coalition (i.e. signing the agreement) or behaving as a lone free-rider (singleton). By contrast, in the multicoalition game, the first stage is no more a binary choice game, since if a country chooses to cooperate, he has also to choose which coalition to join. This is why a further condition on the entire coalition structure, the intracoalition stability, has to be added.

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[14] Furthermore in a game with positive spillovers the minimax and the maximin strategies coincide.

[15] Yi (1997) shows that the partition function of a multicoalition game with positive externalities usually satisfies these two properties.

Furthermore, since in the multicoalitional game the complementary set of a coalition does not necessarily behave as a singleton set, in the stability condition we need to account for the behaviour of the complementary set. Here we use a sort of Nash assumption. Players in a given coalition *s* assume that the coalition structure formed by players not in *s* remains constant. We can therefore say that a coalition structure π is stable if each coalition $s \in \pi$ is:

- internally stable, i.e. no cooperating player would be better off by leaving the coalition to form a singleton;
- external stable, i.e. no singleton $i \in \pi$ would be better off by joining any coalition $s \in \pi$.
- intracoalition stable, i.e. no player belonging to $s \in \pi$ would be better off by leaving *s* to join any coalition $s' \in \pi$.

Unfortunately, game theory is far from having achieved a well-defined non-cooperative theory of coalition formation under the above general assumptions and definitions. There are several stability concepts that can be used and which unfortunately provide different equilibrium coalition structures. Among them, let us recall the concept of equilibrium binding agreements proposed by Ray and Vohra (1996), the concepts of α-stability and β-stability proposed in Hart and Kurz (1983), the sequential stability concept of Bloch (1994), the open-membership stability proposed by Yi and Shin (1994) and the farsighted stability concept used in Chew (1994), Mariotti (1997).

Despite the large number of equilibrium concepts, the results that can be derived from applying these theoretical refinements to a simple model of climate change negotiations (Cf. Carraro and Moriconi, 1997) are quite interesting and share some common features:

- the equilibrium coalition structure is not formed by a single coalition. In general, many coalitions form at the equilibrium;
- the grand coalition, in which all countries sign the same environmental agreement, is unlikely to be an equilibrium;
- coalitions of different sizes may emerge at the equilibrium (even when countries are symmetric).

The specific results on the size of the coalitions depend on the model structure and in particular on the slope of countries' reaction functions, i.e. on the presence of carbon leakage. If there is no leakage and countries are symmetric, and if we stick to assumption A1, then the equilibrium is characterised by many small coalitions, each one satisfying the properties of internal and external stability. Using the example of environmental negotiations proposed by Carraro and Siniscalco (1992), the coalition s* which is part of the general coalition structure is formed by three countries. Hence, if countries are equal to *n*, the equilibrium coalition structure is formed by i(n/3) coalitions, where i(n/3) denotes the integer part of n/3, and by n-i(n/3) singletons.

Different results may be obtained by changing the rules of the game and the related equilibrium concept. If countries choose whether or not to form a coalition in a sequential order, then Bloch (1994) shows that the equilibrium coalition structure is defined by the Fibonacci decomposition of *n*.[16] For example, if 15 countries negotiate, the coalition structure is defined by two coalitions, one of 9 and one of 6 countries. If countries are farsighted in the sense of Chew (1994) and Mariotti (1997), then even the grand coalition may be the equilibrium coalition structure.

These results are not enough to identify the characteristics of the likely outcome of the present international negotiations on climate change. In one case coalitions structures are very dispersed, with many small stable coalitions, whereas in other cases equilibrium coalition structures are quite concentrated. However, in general there is more than one coalition at the equilibrium. Therefore, the effort to achieve a single environmental agreement at the world level seem not to be consistent with countries' incentives to sign the agreement. If countries are free to choose the number and features of agreements, then the negotiation process is likely to lead to several agreements. As a consequence, if the negotiating agenda focuses on a single agreement, will it reduces the probability of stabilising climate change (recall that cooperating countries in a single coalition structure are worse off than cooperating countries in a multiple coalition structures)? Should countries and international institutions realise that an agreement on climate change control can be easier to achieve if many regional agreements, which account for the specific characteristics of countries in the region, is proposed?

Notice that these questions and doubts implicitly contains an extension of previous theoretical results, derived for the case of symmetric countries, to the case of asymmetric countries. Unfortunately, there is no theoretical analysis that can support this type of extension, which can

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16 Let us recall the definition of Fibonacci numbers, $f_o = 1$, $f_1 = 2$ and $f_j = f_{j-1} + f_{j-2}$. Next consider, for any integer n, the following partition. In the first step, select the largest Fibonacci number f^1 smaller than n. Then, at any step k, select the largest Fibonacci number f^k smaller than n - Σf^i where f^i are the Fibonacci numbers determined in the previous steps. This finite procedure yields a unique result called Fibonacci decomposition of n.

therefore be accepted only as very preliminary. However, results contained in Barrett (1997a), Botteon-Carraro (1997a) for the case in which a single coalition is assumed at the equilibrium, suggest that theoretical results derived for the case of symmetric countries are largely confirmed when countries' asymmetries are introduced into the model. More work on this issue would nonetheless be very important.

The consequence of the results proposed in this section, albeit preliminary and restricted to the case of symmetric countries, is that the structure of international environmental agreements is a crucial dimension of the negotiating process. If all countries negotiate on a single agreement the incentives to sign are lower than those which characterise a multiple agreement negotiating process. At the equilibrium, the environmental benefit (quality) would also be lower. Should a change of strategy be proposed at the institutional level or will it emerge endogenously?

6. Conclusions and Further Research Directions

Even if the literature on international environmental negotiations and cooperation is likely to develop further in the next year and to provide new results on the existence and features of self-enforcing agreements, there are a few conclusions that can be drawn. First, the attempt to achieve an agreement signed by all countries is likely to be unsuccessful if the negotiation is restricted to emissions only. Second, even when the negotiations is broadened to include transfers and/or it is linked to negotiations on other international issues, the outcome may not be the grand coalition, because of lack of commitment (in the case of transfers) or because of the conflict between optimality and stability of the coalition (in the case of issue linkage). Third, when more than one coalition is allowed for, the equilibrium coalition structure which endogenously emerges from the negotiation process is characterised by several coalitions. This implies that regional agreements on climate change may be a likely outcome of the negotiation process.

There are several directions of further research that deserve additional efforts. The strategic dimension of environmental negotiations, both at the international and domestic levels (voters may be asked to ratify and environmental agreement) opens interesting political economy problems

(Currarini and Tulkens, 1997; Carraro and Siniscalco, 1998). The lack of a supra-national authority calls for an analysis of new international institutions (Compte and Jehiel, 1997 propose an international arbitrator). The possibility to expand coalitions by linking environmental and trade negotiations requires further theoretical and empirical analyses. A dynamic framework may be more appropriate to deal with environmental issues in which the stock of pollutants, rather than the flow (emissions) is the crucial variable to monitor (see Maler, 1990; Van der Ploeg-De Zeeuw, 1992). Finally, the analysis of the impact of transfers and issue linkage on the size of stable coalitions should be extended to the theoretical approach described in Section 5, where multiple coalitions are allowed for.

More empirical work is also necessary. The existing empirical literature is large, but it assumes the exogenous formation of environmental coalitions, and assesses the effects of countries' decisions to sign the agreement on the main economic and environmental variables. However, an empirical analysis of the incentives to sign the agreement and of the negotiation process that leads to the endogenous formation of the coalition is still missing. Moreover, the empirical analysis would help understanding whether the theoretical results, usually derived in the case of symmetric countries, still hold when the negotiations take place between countries of different sizes, natural resource endowments, development stages, etc.

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FIGURE 1. EQUILIBRIUM GROUPS OF COUNTRIES WITH LINKED NEGOTIATIONS

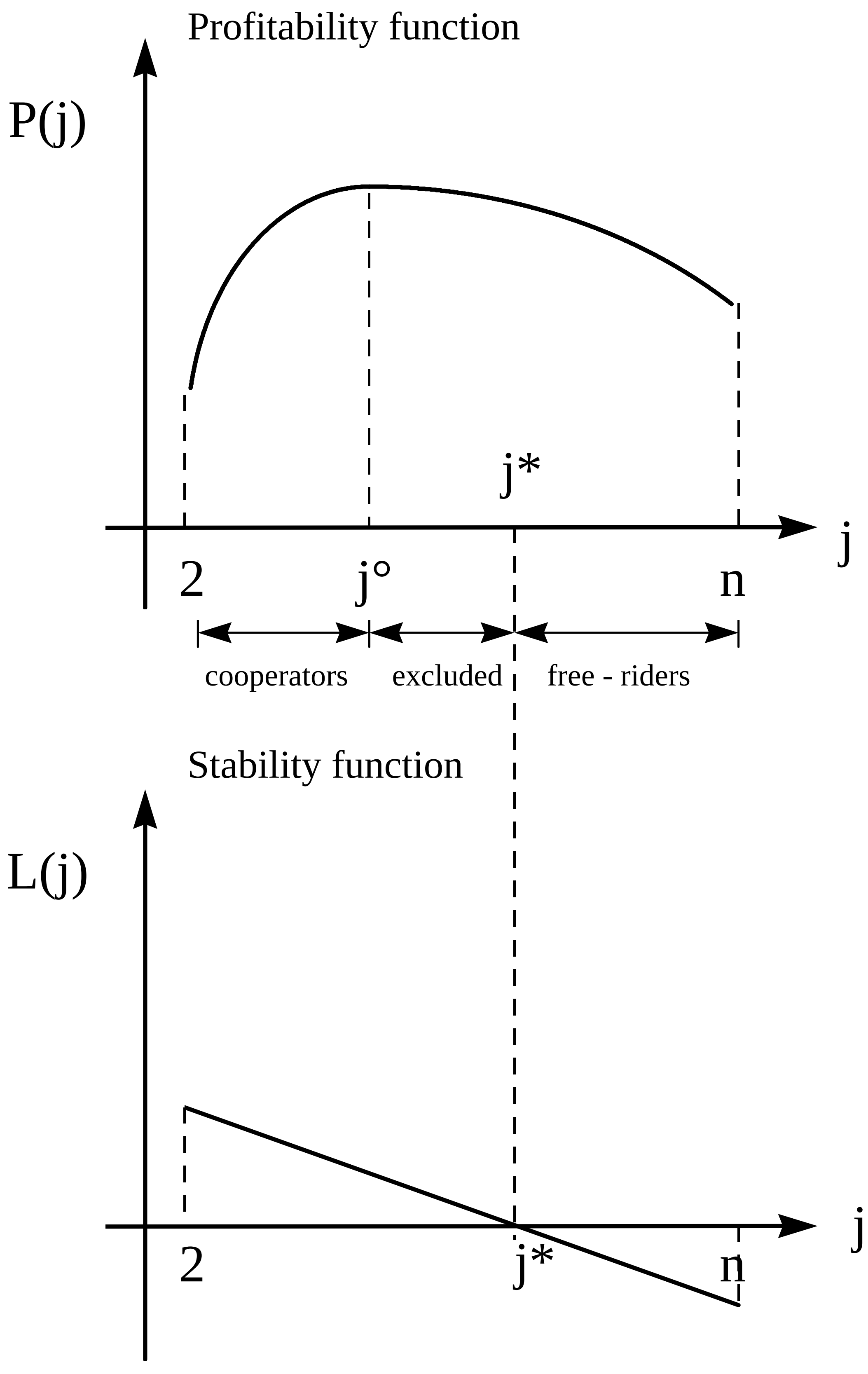

FIGURE 2. EQUILIBRIUM GROUPS OF COUNTRIES WITH LINKED NEGOTIATIONS (R&D cooperation benefits dominate))

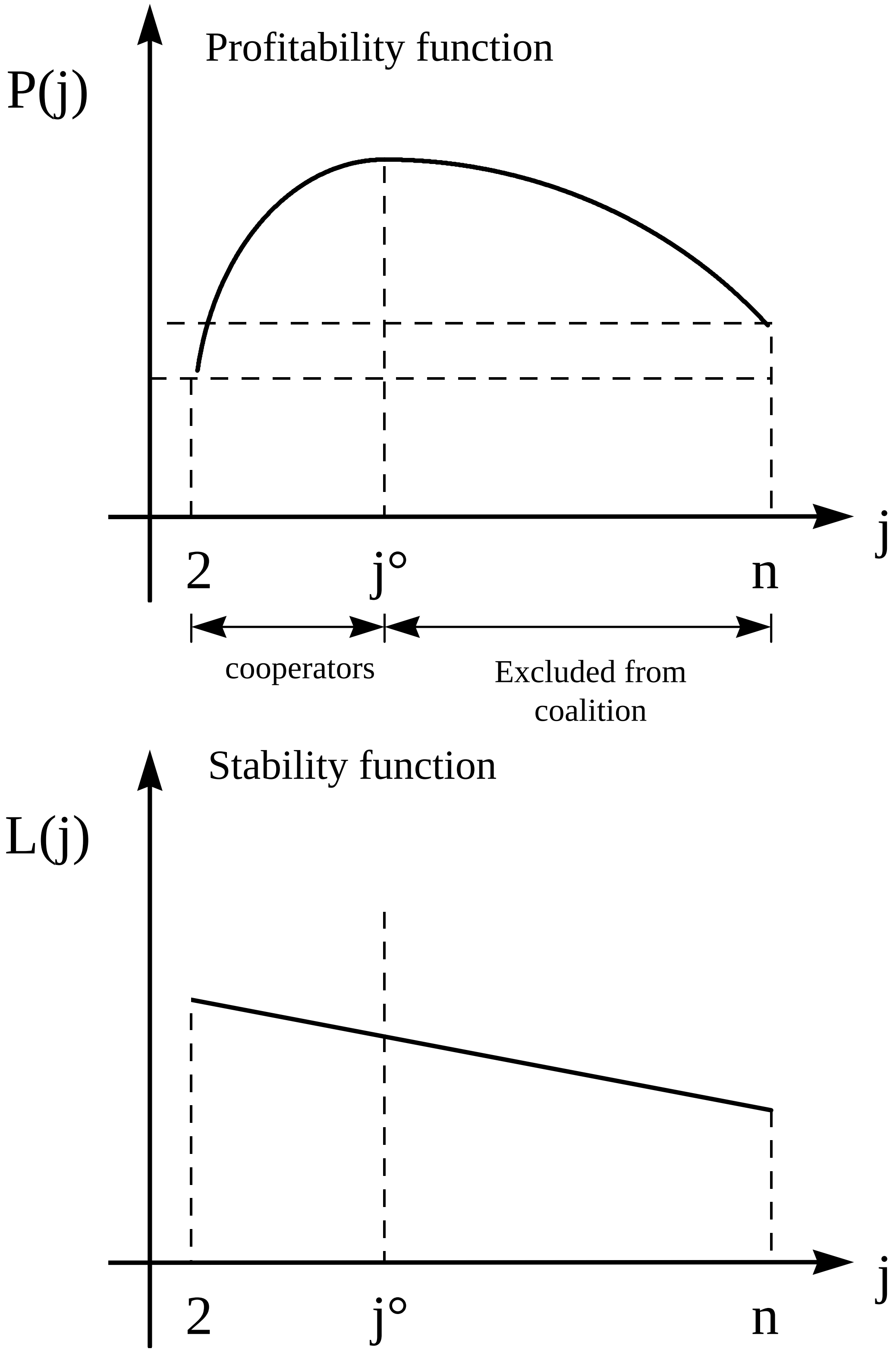

FIGURE 3. EQUILIBRIUM GROUPS OF COUNTRIES WITH LINKED NEGOTIATIONS (Environmental cooperation benefits dominate)