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Summary

We propose a framework to analyze coalition formation with heterogeneous agents. Existing literature defines stability conditions that do not ensure that, once an agent decides to sign an agreement, the enlarged coalition is feasible. Defining the concepts of *refraction* and *exchanging*, we set up conditions of existence and enlargement of a coalition with heterogeneous agents. We use the concept of exchanging agents to give necessary conditions for internal stability and show that refraction is a sufficient condition for the failure of an enlargement of the coalition. With heterogeneous agents we can get a situation where a group of members of an unstable coalition does not deviate, neither within the coalition nor within the extended coalition. Hence, the possibilities of agreement are richer than in the standard analysis with homogeneous agents. Examples of industrial economics are used for illustration, and an application to climate change negotiations is discussed in more detail.

Keywords: Heterogeneity, Coalition, Exchanging, Refraction, Global Externalities

JEL Classification: C72, D74, Q28

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1. Introduction

Agents negotiate in a great number of economic situations on issues of common interest. This leads to the formation of coalitions, which often interact with other coalitions. Several reasons explain the formation of these coalitions: economies of scale, reduced competition ... However, if these incentives were not compensated, they would push towards total cooperation (the grand coalition). In reality, on the contrary, opposite forces reduce cooperation. The fundamental question is not only if cooperation can emerge, but also which structure of cooperation can emerge (a structure describing the arrangement of all agents in various coalitions). Hence, the objective of this paper is to study cooperation focusing on the coalition structure (there is no reason a priori to focus only on the grand coalition, since interactions may create alternative structures). The difficulties found in the development of the World Trade Organization (WTO) can be seen as an example where more regional structures have had greater success: Europe (European Union), North America (NAFTA) or Asia (ASEAN).

We are interested in situations where externalities between coalitions exist. Coalitions are not, as in standard cooperative game theory, autonomous and autarkical entities. The coalitions of the structure are interdependent and interact, i.e. the welfare of each player depends not only on what occurs inside his coalition but also on the whole structure.

Building on the previous example, the formation of the European Union changed not only the welfare of its Member States, but also that of third countries, since all these countries are finally integrated in the same network. The phenomenon is well-known in international trade theory. Since Viner (1950) we know that trade unions increase trade inside the union while they reduce trade with third parties. Hence, trade unions produce a negative externality to third countries, which see the volume of their exchanges decrease.

Of course, the externality can also be positive, as in the case of oligopolies¹. The creation of a non-excluding cartel reduces the competing environment in the market (e.g. OPEC members are not the largest beneficiaries of the restrictions and quotas they impose on themselves).

We start this article from the observation that, given heterogeneity, even if an agent who is external to the coalition benefits from joining it, the extension of the coalition is not

necessarily feasible. The only possibility to avoid this is to assume an irreversible commitment by those wishing to obtain a broad coalition. This assumption, made by Carraro and Siniscalco (1993) while analyzing transfrontier pollution problems for homogeneous countries with the possibility of transfers, contradicts the concept of cartel, where countries maintain the right to end cooperation. Moreover, with heterogeneous agents, individual welfare in the coalition is not a monotonous function; it depends also on the type of agents considered. Thus, the link between the welfare of a member of the cooperating coalition and the deviation of this member requires a non-trivial analysis, contrary to the traditional framework where agents are homogeneous.

Our framework differs from coalition formation approaches based on the Nash equilibrium where a player who changes coalition assumes that, neither its former partners nor its future partners react to an individual movement (e.g. Aspremont *et al.*, 1983; Donsimoni *et al.*, 1986 or Aspremont and Gabszewicz, 1986). In this literature (see Greenberg (1994)), a player does not care neither about the fate of the members of his original coalition nor about the fate of those of the coalition he joins. Greenberg (1994) proposed the concept of *individually stable equilibrium*, which deviates considerably from the Nash equilibrium. Greenberg's concept is defined as a partition of all players (in our case, a coalition and a set of singletons) where no-one can change coalition in a way which is advantageous for him individually and for all the members of the coalition he joins. The refinement proposed in this paper implies an equilibrium concept close to Greenberg's, with the sole difference that we only require that no player shall be able to make a movement which is individually advantageous for him and which, at the same time, safeguards the feasibility of the coalition he joins.

We give conditions under which a decrease in individual welfare of a former member of the coalition after the enlargement is a sufficient signal of instability of the extended coalition (i.e. for the failure of the enlargement). In addition, the heterogeneity context studied enables to distinguish two types of problems: (i) formation difficulties, i.e. the existence of free-rider behaviors (incentives for agents not to join the coalition), and (ii) deviation of existing coalitions. We show that the difficulties encountered during the process of formation of a coalition can induce the instability of the coalition and influence its possibilities of enlargement.

The paper is organized as follows. Section (2) presents the analysis framework, specifying the concept of stable coalition in the presence of heterogeneous agents. Section (3) introduces the concept of an exchanging agent, while section (4) studies the role of the members whose benefit decreases with the size of the coalition, which enables us to define the concept of refraction. We analyze in section (5), using the concepts of exchanging and refraction, the possibilities of formation of a coalition in the case of a global pollution problem (climate change); by studying the incentive to become a member of such a coalition. Section (6) concludes and proposes some future extensions.

2. The framework

Let $N = \{1, \dots, n\}$ be all the agents, presumed heterogeneous, bargaining amongst themselves to coordinate their behavior. The negotiation game has two stages. The first stage is an adhesion game where each agent decides to take part, or not, in an agreement. The negotiations are concluded either by an agreement, or by a failure. If an agreement is reached, the j signatory agents ($2 \leq j \leq n$) form a coalition. From then on each member of the coalition delegates his decision power to the coalition, which maximizes the joint benefit of the coalition. On the other hand, outsiders maximize their individual benefit. If no coalition is formed, each agent plays in a non-cooperative manner. Once the decision of the first stage is taken, agents determine their behavior in the second stage taking into account the previously formed coalitional structure. Following Carraro and Siniscalco (1993), the resolution of such a game can be done defining a "meta-game" in which agents choose to cooperate (or not) by anticipating the results of the second stage. Hence, we need additional specifications.

Let $C_p = \{1, \dots, p\}$ be the subset of p agents forming a cooperating coalition ($C_p \subset N$) and $F_q = \{p+1, \dots, n\}$ the complementary in N . The latter set designs a fringe of $q = n-p$ agents opposed to the cooperating coalition. The partition $[C_p, F_q]$ defines a coalitional structure. We suppose that for any structure of coalitions $[C_p, F_q]$, a system of benefits exists that defines, in a unique manner, a benefit $\pi_i(C_p)$ for each agent $i \in N$. This system of benefits identifies without ambiguity a model by the character (homogeneous or heterogeneous) of its agents.

Definition 1.

A model is said homogeneous if for any $p < n$, a pair $(\pi^F(p), \pi^C(p))$ exists such that the following properties are simultaneously checked for any coalition structure:

$$\forall i \in F_q \quad \pi_i(F_q) \equiv \pi^F(p) \quad (P1)$$

$$\forall i \in C_p \quad \pi_i(C_p) \equiv \pi^C(p) \quad (P2)$$

A model with homogeneous agents supposes that benefits are equal in the cooperating coalition and on the fringe. Moreover, the level of these benefits depends only on the size p of the coalition and not on its composition. Under these circumstances, a necessary and sufficient condition to obtain a stable coalition is to integrate the largest possible number of homogeneous agents, analyzing only the interest for the members on the fringe to join the cooperating coalition.

We call any agent ($i \in C_p$) who obtains a higher benefit in the structure of coalition $[C_p - \{i\}, F_q \cup \{i\}]$ than in $[C_p, F_q]$ a deviating member of the coalition. Internal and external stability of a coalition is analyzed considering only individual movements from the coalition towards the fringe, or from the fringe towards the coalition. The set of all deviating members is noted:

$$D(C_p) = \left\{ i \in C_p, \pi_i(C_p) < \pi_i(C_p - \{i\}) \right\}$$

We define the stability of the coalition C_p based on the sets $D(C_p)$ and $D(C_p \cup \{j\})$, where j indicates an agent on the fringe.

Definition 2.

The cooperating coalition is stable if C_p is both (i) internally stable (i.e. $D(C_p) = \emptyset$) and (ii) externally stable (i.e. for any actor $j \in F_q$: $D(C_p \cup \{j\}) = \emptyset$).

Definition (2) describes an open membership game, i.e. each player is free to join and to leave the coalition without the consensus of the other members of the coalition (D'Aspremont et al., 1983; Carraro and Siniscalco, 1993; Yi and Shin, 1994). The negotiation process can be thought as if each player announces a message, and all the players who announce the same

message form a coalition. Thus, this membership rule implies that a coalition accepts any new player who wants to join it.

Definition (2(i)) is the traditional definition of internal stability. However, it defines external stability of a coalition by the internal instability of any coalition enlarged by one agent. More precisely, two cases are considered:

- (i) the entry in the coalition is not advantageous for any agent of the fringe. This is the case analyzed for homogeneous agents by Aspremont *et al.* (1983) and developed by Carraro and Siniscalco (1993) and Barrett (1994, 1997) to study international environmental cooperation.
- (ii) the entry in the coalition is advantageous for an agent on the fringe, but involves the defection of an agent belonging initially to the coalition. Instability implies the failure of any negotiation to extend the initial coalition.

The analysis of external stability of a coalition with heterogeneous agents is more complex², since we need to take into account the characteristics of q sets $D(C_p \cup \{j\})$ ($j = p+1, \dots, n$). We have to compare: (i) the benefit that any player $j \in F_q$ obtains in $[C_p, F_q]$ with the benefit he obtains in $[C_p \cup \{j\}, F_q - \{j\}]$ and, (ii) the benefit that any player $i \in C_p$ gets in $[C_p \cup \{j\}, F_q - \{j\}]$ compared to $[(C_p - \{i\}) \cup \{j\}, (F_q - \{j\}) \cup \{i\}]$. Let us note that if a coalition is stable with Aspremont *et al.*'s (1983) concept, it is also stable using definition (2), whilst the reciprocal is not true. Thus, our concept implies a weakening of traditional concepts.

3. Exchanging and internal stability

The possible existence of multiple equilibria in the preceding game, which would imply several stable coalitions, may complicate coalition formation analysis. Botteon and Carraro (1997, 1998) and Barrett (1997) confirm this possibility in their simulation studies on coalition formation about international environmental issues. This multiplicity can take two forms: (i) several stable cooperating coalitions of different sizes, or (ii) several stable cooperating coalitions of the same size.

Existence of several stable coalitions of the same size implies interchangeability of certain members of a stable coalition with certain members on the fringe. To change from one stable coalition to another one of the same size, we just have to permute members of the coalition and members on the fringe. However, a member of a coalition is not necessarily interested in changing his place with a member on the fringe. To discuss this issue in more detail, we define the following set (for any coalition C_p of size p and for any agent j pertaining to the fringe F_q):

$$S_j(C_p) = \left\{ i \in C_p, \pi_i(C_p) < \pi_i[(C_p \cup \{j\}) - \{i\}] \right\}.$$

This set contains all the agents of the cooperating coalition who would prefer to exchange their place with the agent j on the fringe. We call them “exchanging” agents with j . This exchanging phenomenon implies an incentive for agent i not to become a candidate to the formation for the coalition of size p when C_{p-1} has already been formed. This also implies difficulties for the formation of the coalition of size p in a former phase.

To illustrate this concept, let us consider the following game Γ . This game has four players (subscripted $i = 1, 2, 3, 4$) and is represented by the pay-off matrix shown in Table 1, where α, β et δ are real numbers.

Table 1. Game Γ

Structure	Welfare			
	π_1	π_2	π_3	π_4
$\{1\}, \{2\}, \{3\}, \{4\}$	0	0	0	0
$[\{1,2\}, 3, 4]$	1	α	2	1
$[\{1,3\}, 2, 4]$	1	β	4	2
$[\{1,4\}, 2, 3]$	1	β	1	1
$[\{2,4\}, 1, 3]$	0.5	1	1	1
$[\{2,3\}, 1, 4]$	δ	1	3	3
$[\{1,2,3\}, 4]$	1.5	2	3	4

We can, for example, characterize the set $S_3(\{1,2\})$:

$$\begin{array}{ll}
S_j(\{1,2\}) = \{1\} & \text{if } \alpha > \beta \text{ and } \delta > 1 \\
\{1,2\} & \text{if } \alpha < \beta \text{ and } \delta > 1 \\
\{2\} & \text{if } \alpha < \beta \text{ and } \delta < 1 \\
\emptyset & \text{if } \alpha > \beta \text{ and } \delta < 1.
\end{array}$$

The exchanging concept formalizes the idea that a member of the coalition could plan to exchange his place with an unspecified agent on the fringe, and that this incentive constitutes a sign of deviation. However, it is not sure that this incentive for exchanging would automatically imply an incentive to deviate. If we assume $0 < \alpha < \beta$ and $\delta > 1$ in game Γ , $S_3(\{1,2\}) = \{1,2\} \neq \emptyset$ and $S_3(\{1,2\}) \cap D(\{1,2\}) = \emptyset$.

The issue raised here is the connection between the incentive to exchange and the incentive to deviate, i.e., the impact of non-vacuity of $S_j(C_p)$ on the internal stability of C_p .

Whereas a potential deviator compares his benefit inside the coalition to his benefit outside (without any further modification of the structure $[C_p, F_q]$), the exchanger compares his benefit inside and outside by keeping the size p of the coalition unchanged. If we consider a coalition formed by several non-related agents in Donsimoni's (1985) heterogeneous model, non-effective members of the coalition will never be exchangers, while this coalition is internally unstable³.

Let us define:

$$O_j(C_p) = \left\{ i \in C_p, \pi_i(C_p - \{i\}) < \pi_i((C_p - \{i\}) \cup \{j\}) \right\}.$$

This set contains the members who, while deviating, would prefer to see the agent j joining the coalition. Thus, $O_j(C_p)$ highlights a positive externality of concentration, shown by the preference for a coalition of size p rather than of size $p-1$. Taking into account these precisions, proposition 1 shows the connections between exchanging and deviating:

Proposition 1.

For any agent $j \in F_q$, we have the following properties:

$$O_j(C_p) \cap D(C_p) \subset S_j(C_p) \quad (\text{i})$$

$$S_j(C_p) \setminus (S_j(C_p) \cap O_j(C_p)) \subset D(C_p) \quad (\text{ii})$$

Proof. Directly from the notation in (i) and (ii).

To understand the relevance of this proposition, we have to compare it to Stigler's (1950) argument on intrinsic instability of collusions, given the higher benefits obtained by agents which are not involved in the process. Let us suppose that an agent i of the fringe joins C_{p-1} and denote the new coalition of size p as $C_p = C_{p-1} \cup \{i\}$. For agent $i \in C_p$ and for one agent $j \in F_q$, we now consider the properties:

$$\pi_i(C_p) < \pi_j(C_p) \quad (\text{P3})$$

$$\pi_i(C_p) < \pi_i[(C_p \cup \{j\}) - \{i\}] \quad (\text{P4})$$

Property (P3) means that agent j has a lower benefit in the coalition than in the fringe. This property can be seen as a first interpretation of Stigler's remark. It constitutes the main cause of collusion failure when a great number of identical agents exist in the economy, so that an agent of the coalition can get the benefit obtained on the fringe. But, if there are a limited number of agents, a marginal variation in the size of the coalition (or of the fringe) is likely to modify significantly the outcome of the game. This is why we propose to reason keeping the size of the coalition invariant; to analyze Stigler's conjecture in a context where the number of players is not excessive.

Property (P4) simply states that agent i is an exchanger with agent j on the fringe. In a homogeneous model, the sets C_p and $S_j(C_p)$ coincide for any actor j on the fringe if and only if property (P3) is satisfied by all players in the game.

Proposition (1) can be seen as the condition validating Stigler's argument, since we characterize situations where the difficulties observed during the coalition formation predetermine its instability. Assertion (i) characterizes cases where the deviation of a member of the coalition is not related to the exchanging phenomena. Thus, if there is a member i who is deviating from C_p and who is not an exchanger with a member j on the fringe, then i is not

part of $O_j(C_p)$. Assertion (ii) gives a sufficient condition of instability of a coalition that had problems in its formation process ($S_j(C_p) \setminus (S_j(C_p) \cap O_j(C_p)) \neq \emptyset$). Under this condition, the exchangers with one or more agents of the fringe will be potential deviators. They are thus an intrinsic cause of internal instability of the coalition. We can now formulate the following corollary, which provides another interpretation of assertion (ii):

Corollary 1.

If a cooperating coalition C_p is internally stable, then: $\forall j \in E_q \ S_j(C_p) \subseteq O_j(C_p)$.

Proof.

If C_p is internally stable, $D(C_p) = \emptyset$.

Thus, according to (ii), we have: $S_j(C_p) \setminus (S_j(C_p) \cap O_j(C_p)) = \emptyset$.

Hence: $\{i, i \in S_j, i \in S_j(C_p) \cap O_j(C_p)\} = \emptyset$, which implies: $S_j(C_p) \subseteq O_j(C_p)$. ■

Corollary (1) gives a necessary condition of internal stability of a coalition that had formation problems, in the sense of a lack of candidates. A coalition including exchanging agents with an external agent j is internally stable only if these agents belong to the set $O_j(C_p)$. Hence, the set $O_j(C_p)$ is at the heart of the discussion on the deviating signals likely to be produced by exchanging agents⁴.

Let us characterize (in game Γ) the set $O_3(\{1,2\})$:

$$\begin{array}{ll}
 O_3(\{1,2\}) = \{1\} & \text{if } \beta < 0 \text{ and } \delta > 0 \\
 \{1,2\} & \text{if } \beta > 0 \text{ and } \delta > 0 \\
 \{2\} & \text{if } \beta > 0 \text{ and } \delta < 0 \\
 \emptyset & \text{if } \beta < 0 \text{ and } \delta < 0.
 \end{array}$$

If $\beta > 0$ and $\delta < 0$, set $O_3(\{1,2\})$ does not contain agent 1: the cooperation of agent 3 with agent 2 generates a negative externality on agent 1 remained on the fringe. On the other hand, in this case we have $O_4(\{1,2\}) = \{1,2\}$. In other words, when agent 1 leaves coalition $\{1,2\}$, he

prefers that coalition $\{2,3\}$ is not formed, but he finds the formation of coalition $\{2,4\}$ advantageous.

In homogeneous models, the characterization of this set $O_j(C_p)$ is trivial. With (P1) and (P2), we have for any coalition C_p :

$$[\forall j \in F_q \ O_j(C_p) = C_p] \Leftrightarrow [\pi^F(p-1) < \pi^F(p)].$$

Either $O_j(C_p)$ is empty, or it includes all the members of the coalition. In particular, if the welfare of the fringe is an increasing function of the size p of the coalition, we have systematically $O_j(C_p) = C_p$ for any coalition and any member j of the coalition. In addition, if property (P3) is checked (and all the agents of the coalition are exchangers), assertion (i) tells us that if $O_j(C_p) \equiv \emptyset$ then the coalition is internally unstable. Hence, in the case of homogeneous agents for whom benefits are higher on the fringe than in the coalition, and where an internally stable coalition exists, an increase in the size of the coalition is always beneficial to agents who have remained independent. That is the result obtained by Barrett (1994) in his analysis of global pollution problems.

4. Refraction and external stability

Let us consider henceforth the possibilities of enlargement of a coalition to new members. With heterogeneous agents, the entry of a new member in the cooperating coalition does not necessarily increase the benefit of all the former members. However, those who see their benefit decrease will not necessarily deviate within an extended coalition. In practice, the effect of this entry on the benefits of the members of the coalition can vary in a more or less significant way, according to the characteristics of its members and the newcomers.

We call a ‘refractory member’ to the entrance of $j \in F_q$ in the coalition, any agent $i \in C_p$ who gets a higher benefit in $[C_p, F_q]$ than in $[C_p \cup \{j\}, F_q - \{j\}]$. We note $R_j(C_p)$ the set of refractory members to the entrance⁵ of $j \in F_q$:

$$R_j(C_p) = \left\{ i \in C_p, \pi_i(C_p \cup \{j\}) < \pi_i(C_p) \right\}.$$

This set of refractory members was not taken into account in the definition of external stability (see definition (2)). The distinction between stability of the extended coalition and refraction is based on the assumption that the former members do not have the right to choose the future components of the coalition. Thus, our approach to the enlargement of the cooperating coalition neglects the idea of optimality in the choice of allies, since players do not choose their partners explicitly. The counterpart is that their decision to cooperate does not imply any commitment: the players may leave the coalition in any moment in time. Refraction blocks the extension of the coalition if it goes together with an effective incentive for deviation.

Proposition (2) shows how the characterization of the exchangers set makes it possible to establish direct connections between refraction and deviation in the extended coalition.

Proposition 2

For any agent $j \in E_q$, we have:

$$S_j(C_p) \cap R_j(C_p) \subset D(C_p \cup \{j\}) \quad (\text{iii})$$

$$[C_p \setminus S_j(C_p)] \cap D(C_p \cup \{j\}) \subset R_j(C_p). \quad (\text{iv})$$

Proof. *Directly from the writing of conditions (iii) and (iv).*

To have a refractory agent i blocking the enlargement of the coalition to an agent j , he needs only to be an exchanger with j (assertion (iii)). The refractory agent can threaten the coalition by announcing his deviation after the enlargement, and this threat is credible since it is the best action he can take. Assertion (iv) gives a sufficient condition to ensure that a deviating agent of the extended coalition is a refractory member to the entry of an agent j on the fringe. For this, it suffices that the agent is not an exchanger with j . Thus, the relation between refractory and external agents allows us to deduce external stability of a coalition.

Corollary 2.

If $\forall j \in E_q \ S_j(C_p) \cap R_j(C_p) \neq \emptyset$, then coalition C_p is externally stable.

Corollary (2) is a sufficient condition for external stability of a coalition, based on the existence of members that are both not candidates to its formation and refractory to its

enlargement. In other words, a coalition that is extended to an agent j on the fringe, in spite of the refraction of certain members, is a coalition whose members are happy to belong to it (in the sense that they are not willing to exchange their place with j).

Let us come back to game Γ . If $\alpha > 2$, $\beta < 2$ and $\delta < 1.5$, the coalition $\{1,2\}$ is externally unstable. Indeed, it can integrate agent 3 ($D(\{1,2,3\}) = \emptyset$) even though agent 2 is refractory to its enlargement. Corollary (2) tells us that this extension is possible in spite of the refraction of agent 2 because this agent is not an exchanger with agent 3 on the fringe⁶. One can also show that the reciprocal corollary is not true. To see that, set $2 < \beta < \alpha$ and $\delta < 1$. In this case, coalition $\{1,2\}$ cannot be enlarged by the integration of agent 3, although $S_3(\{1,2\}) \cap R_3(\{1,2\}) = \emptyset$ since $S_3(\{1,2\}) = \emptyset$.

Thus, our analysis of external stability in the presence of heterogeneous agents explicitly poses the problem of refraction compared to external stability. In terms of the general theory of coalition formation, the concept of individually stable equilibrium of Greenberg (1977) is closely related to the criterion of refraction as long as the set of achievable benefit vectors for the coalition is restricted to⁷ $[\pi_i(C_p)_{i \in C_p}]$. However, this criterion reduces the independence of the agents belonging to the cooperating coalition. Indeed, this approach gives the members an exogenous right of veto, in addition to their basic right to choose their individual action (i.e. destabilization of the coalition by deviation). That is in contradiction with the concept of coalition itself. Thus, we neglect this possibility⁸.

With homogeneous agents, if one member of the coalition is refractory to new membership, all the members are. Moreover, if property (P3) is satisfied, the refraction is enough to block the extension of the coalition ($R_j(C_p) \subset D(C_p \cup \{j\})$), since $\pi^C(p) < \pi^F(p)$. External stability of the coalition results from the incentive of the members on the fringe to join it. This last point explains why the concepts of refraction and deviation have not appeared in the literature as independent factors of analysis of external stability.

Proposition (1) and (2) enable us to characterize the cases for which stable coalitions can be established in spite of non-refraction of its members to its extension. The answer to this question highlights the role of $O_j(C_p)$ ($j \in F_q$). We can write the following corollary:

Corollary 3.

If C_p is stable and for $j \in F_q$, $R_j(C_p) = \emptyset$, then $O_j(C_p) = C_p$.

That is, if for any agent j of the fringe, $O_j(C_p) = C_p$ and $R_j(C_p) \neq \emptyset$, coalition C_p is necessarily unstable. In other words, given the negative external effects of concentration on outsiders, refraction is an indicator of the inexistence of stable coalitions.

5. Coalition formation

We will now illustrate the concepts introduced by adapting them to the climate change problem. Climate change is a typical example of a global environmental problem, since emissions in one country have an impact on the future climate of all countries. In other words, emission abatement is a global public good. Indeed, although each country benefits from emission abatements of other countries, no country is interested in individually committing itself to reduce its emissions, since the emissions of each country contribute for a negligible amount to aggregate emissions. This property of non-exclusion from the benefits implies that fighting climate change requires international coordination of environmental policies. Thus, international agreements must be signed to carry out significant emission reductions. Given this non-exclusion of the benefits we find the characteristics of the prisoner's dilemma (PD): individual interest privileges non-cooperation while joint interest privileges cooperation.

From the point of view of climate change the PD emphasizes that, given free-rider behavior (or deviation), cooperation is not achievable. If one stuck to this basic representation, no emission abatement policy would be undertaken. This is known in natural resource economics as 'the tragedy of the commons' (Hardin, 1968; Dasgupta and Heal, 1979). However, some initiatives already exist (Finus, 2003) and on climate change the Kyoto Protocol (1997), although not yet in force, seems to inaugurate the era of large-scale cooperation. Thus, in its static version the PD does not capture certain specificities of the climate change problem. In particular, it does not allow agents to communicate. Such an assumption is not relevant in the case of climate change, since countries encourage communication, through negotiations.

However, as soon as negotiations start, the rules of the game are modified. Since countries seek to coordinate their action, we have to use a coordination game to explain cooperation (coordination taking the form of a stable coalition). According to Carraro and Siniscalco (1993) the best game to analyze this situation is not the PD but the “chicken” game.

To analyze the set of exchangers within the climate change framework, building on Carraro and Siniscalco (1993), we focus on the adhesion strategies of two countries belonging initially to the fringe. We then stress the problem of the multiplicity of non-cooperative equilibria, by showing that this can be the outcome for a given size of the coalition (i.e. there are several stable coalitions of the same size). We study this game under the assumption of possible dissymmetry between the benefits of the two countries.

Let us consider that a coalition is formed and that two countries i and j on the fringe must decide to join, or not, this coalition. Strategies $s_i = 1$ and $s_i = 0$ (respectively $s_j = 1$ and $s_j = 0$) are adhesion and non-adhesion strategies to C_{p-1} . Table 2 represents the game in the standard form.

Table 2. The climate change game

		player j	
		$s_j = 1$	$s_j = 0$
player i	$s_i = 1$	$\pi_i(C_{p-1} \cup \{i, j\}), \pi_j(C_{p-1} \cup \{i, j\})$	$\pi_i(C_{p-1} \cup \{i\}), \pi_j(C_{p-1} \cup \{i\})$
	$s_i = 0$	$\pi_i(C_{p-1} \cup \{j\}), \pi_j(C_{p-1} \cup \{j\})$	$\pi_i(C_{p-1}), \pi_j(C_{p-1})$

Take the case where $C_{p-1} \cup \{i\}$ and $C_{p-1} \cup \{j\}$ are internally stable coalitions of size p . If i (respectively j) adhere to $C_{p-1} \cup \{j\}$ (respectively $C_{p-1} \cup \{i\}$), then country j (respectively i) has an incentive to deviate. Thus, coalitions $C_{p-1} \cup \{i\}$ and $C_{p-1} \cup \{j\}$ are also externally stable and check consequently the following properties:

$$\pi_i(C_{p-1} \cup \{i\}) > \pi_i(C_{p-1}), \quad \pi_j(C_{p-1} \cup \{j\}) > \pi_j(C_{p-1}) \quad (\text{P5})$$

$$\pi_i(C_{p-1} \cup \{j\}) > \pi_i(C_{p-1} \cup \{i, j\}), \quad \pi_j(C_{p-1} \cup \{i\}) > \pi_j(C_{p-1} \cup \{i, j\}). \quad (\text{P6})$$

Hence, if properties (P5) and (P6) hold, the game has two Nash equilibria, i.e. (0,1) and (1,0). In a framework with homogeneous countries, these two equilibria are Pareto-optimal. Moreover, under the assumption of welfare growth with p ($\pi_j(C_{p-1} \cup \{i\}) > \pi_j(C_{p-1})$ and $\pi_i(C_{p-1} \cup \{j\}) > \pi_i(C_{p-1})$), they dominate the outcome (0,0), which proves to be the worst solution for both countries. As Carraro and Siniscalco (1993) underline, this is a “chicken” game. Multiple equilibria, and their Pareto character, threaten the constitution of coalition C_p (i.e. the outcome can be (0,0) since each country has an incentive not to cooperate given the cooperation of the other). This explains the formation difficulties of a stable coalition of size p .

With heterogeneous countries, the Pareto-optimality of the Nash equilibria is not systematic. One of the equilibria can Pareto-dominate the other. The condition of existence of such a situation is given in the following proposition.

Proposition 3.

One of the equilibria ((0,1) or (1,0)) Pareto-dominates the other if and only if:

$$(i,j) \in S_j(C_{p-1} \cup \{i\}) \cdot \{ C_{p-1} \cup \{j\} \setminus S_i(C_{p-1} \cup \{j\}) \} \quad (P7)$$

or:

$$(i,j) \in S_i(C_{p-1} \cup \{j\}) \cdot \{ C_{p-1} \cup \{i\} \setminus S_j(C_{p-1} \cup \{i\}) \}. \quad (P8)$$

If none of these relations holds, there are no dominance relationships between these Nash equilibria. There is no dominance relationship since i and j are reciprocally exchangers or reciprocally non-exchangers, when they belong to the coalition of size p , i.e.:

$$[i \in S_j(C_{p-1} \cup \{i\}) \text{ and } j \in S_i(C_{p-1} \cup \{j\})] \text{ or } [i \notin S_j(C_{p-1} \cup \{i\}) \text{ and } j \notin S_i(C_{p-1} \cup \{j\})].$$

In these two situations, we have a conflict between countries i and j : a reciprocal incentive to remain outside the coalition of size p or, on the contrary, to take part in its formation. Both countries (i and j) are not candidates to the formation of the coalition, preferring to see the other joining the coalition. This behavior is the consequence of higher benefits for non-participants than for participants, which promotes free-riding. In other words, when countries i and j have to decide whether to join (or not) the coalition, both prefer to leave the initiative to the other.

In models with homogeneous countries, it is generally more advantageous to stay outside rather than inside a coalition of size p . Anticipation of higher welfare on the fringe encourages countries not to be candidates in the formation of such a coalition. If $\pi^F(p) > \pi^C(p)$, any permutation between a member of the coalition and one on the fringe (keeping the size of the coalition), is profitable for the leaving party and unprofitable for the replacing party. Thus, properties (P3) and (P4) are checked by all players. Hence, all coalitions of size p are faced, in their formation process, with the problem of multiple Pareto efficient Nash equilibria highlighted in Table 2.

In short, the absence of dominance relationships is explained by symmetry in the incentives to exchange of both candidates to the coalition formation. With homogeneous countries this identity of incentives is immediately checked, inducing a systematic difficulty for the formation of the coalition. Heterogeneity can solve this problem, by allowing dissymmetry of the exchanging incentives. In this case, one of the Nash equilibria of the game will dominate the other and thus be selected.

In addition, one can check that a sufficient condition for $(0,0)$ being Pareto dominated by $(1,1)$, i.e. that $(0,0)$ is the collectively worst solution, is that $i \in O_j(C_{p-1})$ and $j \in O_i(C_{p-1})$. These two properties, together with that of coalition stability, enable us to write the following inequalities which ensure that $(1,1)$ Pareto-dominates $(0,0)$:

$$\pi_i(C_{p-1}) < \pi_i(C_{p-1} \cup \{i\}) < \pi_i(C_{p-1} \cup \{i,j\}) \quad \text{and} \quad \pi_j(C_{p-1}) < \pi_j(C_{p-1} \cup \{j\}) < \pi_j(C_{p-1} \cup \{i,j\}).$$

With homogeneous countries, if one assumes that welfare in the coalition grows with its size (as Carraro and Siniscalco (1993)), which implies systematic absence of refraction, both Nash equilibria only Pareto-dominate the worst solution, i.e. $(0,0)$. The game is then a “chicken” game. With heterogeneous countries, the two Nash equilibria Pareto-dominate the solution $(0,0)$ only if (necessary and sufficient condition) $i \in O_j(C_{p-1})$ and $j \in O_i(C_{p-1})$. However, they can also Pareto-dominate solution $(1,1)$, so that the game becomes a “battle-of-the-sexes”. It is easy to show that $(1,1)$ is Pareto-dominated by the equilibria if and only if i and j are both refractory, or, more precisely, $i \in R_j(C_{p-1} \cup \{i\})$ and $j \in R_i(C_{p-1} \cup \{j\})$. In short, if the

enlargement of the coalition has positive effects on the countries of the coalition and on those on the fringe, the preceding coordination game is of the type “battle-of-the-sexes”.

6. Conclusion

Three fundamental points come out from our analysis. First, we have shown that the existence of heterogeneous agents imposes an individualized analysis of their incentives to join the fringe. We have highlighted that the stability of a cooperating coalition cannot be analyzed studying only the ex-post possibilities of deviation of its members, since their propensity to exchange is also relevant. The definition of the exchanging agents’ set constitutes a reasonable interpretation of Stigler’s (1950) argument on the destabilization of a given coalition. In addition, our approach implies reconsidering the traditional concept of external stability. With exchanging agents, refraction can be seen as a sufficient condition for the failure of an enlargement. Hence, problems associated with the formation of a coalition can have direct impacts not only on its internal stability but also on the future options of enlargement.

Second, we have highlighted the need of a game to make the stable coalition endogenous. Contrary to the traditional approach, a game adapted to the new definition of external stability suggests sequential decision-making of the players, since, with each extension, the former members are requested to state their intentions (to deviate or not). It is not excluded that a simultaneous cooperative game can have these properties. The question is how complicated incorporating this into the analysis will be. This constitutes a possible extension of this work.

Third, our paper offers some conclusions on the issue of the extension of a coalition by means of monetary transfers between its members. Under the assumption of sovereign agents, a non-deviating refractory agent cannot be opposed to the extension of the coalition. If this agent is deviating, the instability of the coalition is inevitable (except supposing the possibility of monetary transfers on behalf of the non-deviating members). With homogeneous agents, this stabilization by transfers is always impossible since all the members of an unstable coalition are systematically deviating and therefore cannot finance the transfers. The presence of heterogeneous agents shows the possibility for different results in this direction, since in an unstable coalition there may be a group of agents who do not deviating either within the coalition or within the extended coalition. The proposed game Γ

shows the existence of a type of agent who does not deviate, whatever the size of the coalition. Without ex-ante transfers, the different payoffs inside the coalition can imply that certain agents, particularly favored, are never encouraged to leave it, whereas others (losers) are at the origin of its instability. These are the members for whom non-deviating agents need to grant ex-post transfers in order to obtain a stable coalition.

Notes

¹ In oligopoly games, firms form coalitions to reduce competition. They can either increase their prices or decrease the quantities produced. However, in the second case, the reaction of outsiders is more aggressive. In a price game, outsiders will also increase their prices, to the advantage of the members of the coalition (Davidson and Deneckere, 1984). In a quantity game, outsiders will increase their output, decreasing the market share of the cartel (Salant *et al.*, 1983).

² Basing his analysis on a price-leadership model for oligopolistic competition, Donsimoni (1985) proposed a first approach of heterogeneity by stressing the differentiation of production costs in industry. However, Donsimoni defines an externally stable coalition as a coalition including the largest possible number of firms of each type. In other words, a coalition is externally unstable as long as the integration of an additional firm does not cause the deviation of a firm with the same production costs. This restrictive definition has no particular interest for our case, since the profit of all the members of the coalition varies in the same direction as that of a new member, and this whatever its type.

³ Let $C_1 < \dots < C_m$ denote the per-unit costs of all producers in the industry (assuming there are m type of producers). A connected segment is defined as a sequence $C_r, C_{r+1}, \dots, C_{r+s}$ with $1 < r < m$ and $0 < s < m-r$. It is possible to show (although Donsimoni (1985) did not carry out the calculations explicitly), that a member of the coalition is never an exchanger with a more powerful firm of the fringe, whereas he is systematically an exchanger with a less effective external firm.

⁴ The set $O_j(C_p)$ can be empty in an economic sector where the formation of a coalition implies weakening competitors (e.g. when a cartel has the effect of increasing competition due to the changes in the efficiency of firms). If the formation of a coalition implies technology-sharing which tends to reduce costs, the intensification of competition resulting from cooperation could prove disastrous for firms which have remained independent. In the sequential analysis of coalition formation proposed by Bloch (1995), the non-cooperative equilibrium generates a reduction in profits for the firms that did not join the R&D coalition (this property holds for quantity as well as for price competition).

⁵ In game Γ , if $\alpha > 2$, agent 2 is the only refractory to the entry of agent 3 in the coalition $\{1, 2\}$. On the other hand, if $\alpha < 2$, the set $R_3(\{1, 2\})$ is empty.

⁶ Which is the case, since $S_3(\{1, 2\}) = \{1\}$ for $1 < \delta < 1.5$ and $S_3(\{1, 2\}) = \emptyset$ if $\delta < 1$, and hence $2 \notin S_3(\{1, 2\})$.

⁷ Dréze and Greenberg (1980) proposed an alternative to the concept of *individually stable equilibrium*, defining a *contractual individually stable equilibrium*. For this type of equilibrium, we impose that no player can change coalition and benefit both the coalition which he leaves and that which he joins. To satisfy the properties of this concept of equilibrium, using refraction as the criterion of external stability is not the only modification to be made to our approach. The condition for internal stability $D(C_p) = \emptyset$ is too strong, since it is enough to require of a coalition, to ensure internal stability, (i) emptiness of $D(C_p)$ or (ii) that for any element i of $D(C_p)$, there is a member j of the coalition C_p such that $\pi_j(C_p - \{i\}) < \pi_j(C_p)$.

⁸ In the model of leadership in price with cost differentiation of Donsimoni (1985), one can easily check that refraction is never observed. Indeed, whatever the type of a new member to the coalition, the profit of the former members increases. Thus, in this model heterogeneity does not allow a clear dissociation of the two phenomena: refraction and the deviation in the extended coalition.

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- (lix) This paper was presented at the ENGIME Workshop on “Mapping Diversity”, Leuven, May 16-17, 2002
- (lx) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002
- (lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003
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