Coalition Formation in Games without Synergies

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NOTA DI LAVORO 43.2004

MARCH 2004

CTN – Coalition Theory Network

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Summary

This paper establishes sufficient conditions for the existence of a stable coalition structure in the ”coalition unanimity” game of coalition formation, first defined by Hart and Kurz (1983) and more recently studied by Yi (1997, 2000). Our conditions are defined on the strategic form game used to derive the payoffs the game of coalition formation. We show that if no synergies are generated by the formation of coalitions, a stable coalition structure always exists provided that players are symmetric and either the game exhibits strategic complementarity or, if strategies are substitutes, the best reply functions are contractions. We illustrate the role of synergies in a Cournot oligopoly example with cost reducing R&D.

Keywords: Coalition formation, Synergies, Strong Nash equilibrium

JEL Classification: C7

We thank Francis Bloch for helpful comments and the audience at the XV Italian Meeting in Game Theory and Apllications in Urbino,9-12 July 2003.

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1 Introduction

This paper studies the existence of stable coalition structures in games of coalition formation. We follow the stream of literature on coalition formation that views cooperation as a two stage process: a first stage in which players form coalitions, and a second stage in which formed coalitions interact in some underlying "economic" strategic setting (see Bloch (1997) and Yi (2003) for extensive surveys of this approach). This process is formally described by a strategic form game of coalition formation, in which a given "rule" maps players' announcements of coalitions into a well defined coalition structure, which in turns determines the equilibrium strategies at the second stage when the "economic" game is played by coalitions. In this paper we focus on the "gamma" or "coalitional unanimity" rule, first considered in Hart and Kurz (1983) and also studied in Yi (2003) for partition function games, predicting that a coalition forms if and only if all of its members have announced it.

Our analysis is based on a primitive description of strategic possibilities of players and coalitions in the "economic" game by means of a strategic form game G. This game exhaustively describes the actions available to players, both as individuals and as coalitions, and the way in which any profile of actions induces a payoff allocation for players. More specifically, in any given partition, coalitional strategy sets are given by the Cartesian products of their members' strategy sets, and coalitional payoff functions are given by the sum of their members' payoff functions, as these are described by G. In this context, the formation of a coalition does not expand coalitional members strategic possibilities with respect to G, if not by allowing them to choose their strategies in a coordinated manner. In other words, each game $G(\pi)$ associated with a second stage in which the partition π has formed, contains no additional information to G other than the configuration of coalitions. This framework rules out the possibility of *coalitional synergies*, by this meaning any advantage in forming a coalition that is not related to the coordination of members' strategies (as, for example in R&D cooperation games).

The focus on the properties of the strategic form game G is the main difference between our approach and that of, for example, Yi (1977, 2003), in which conditions for the existence of stable coalition structures are derived in terms of the properties of the equilibrium payoffs of the game $G(\pi)$ as a function of the partition π. Indeed, although Yi (1997) refers to a symmetry assumption directly defined on a strategic form game to be played at the second stage of the coalition formation process, this assumption is solely used to obtain a simpler description of equilibrium payoffs, that end up depending only on the number of players in each coalition. If interpreted as a feature of all possible games to be played at the second stage (that is, for all possible partitions), this symmetry condition rules out the presence of synergies, and is hardly compatible with the kind of situations covered by Yi's analysis. To rule out such ambiguities, we therefore reformulate the symmetry assumption as a feature of the primitive game G, and explicitly derive all games $G(\pi)$ under the assumption of no synergies.

While it is well known that the existence of synergies can lead to instability even in games which are ex-ante symmetric (that is, symmetric within coalitions and not across coalitions, see Yi (2003) and section 4 of the present paper), what conditions would, in the absence of synergies, ensure the existence of a stable coalition structure is still an open question. We show that our symmetry assumption on G (which, together with the absence of synergies implies *ex-post* symmetry in each game $G(\pi)$), is sufficient for the existence of a stable coalition structure, provided that the effect of externalities satisfies two properties. First, the cross-effect of player's actions on other players' payoffs must be monotone, both across players and across strategy profiles (we will refer to the classes of positive and negative externalities). Second, payoff functions must either exhibit strategic complementarity (in the sense of Bulow et al. (1985)) or generate best replies which are contractions (in other words, strategic substitutability should not be too strong). Typical examples of games belonging to these classes are cartel formation in Cournot and Bertrand oligopolies, public good games, environmental games.

We can interpret our results directly in terms of the effect on the profitability of joint deviations in the coalition unanimity game. Consider the strategy profile inducing the grand coalition, and any joint deviation by coalition $S \subset N$. Under positive externalities, S will tend to lower the level of its members' strategies with respect to the efficient level. Strategic complementarity implies, however, that players in $N \backslash S$, now organized as singletons, will themselves lower their strategies, thereby hurting S through the effect of positive externalities. Hence, S's deviation are in general not profitable. Strategic substitutes have the opposite properties: if S drops out from N wishing to produce less under positive externalities (and more under negative), then the players in $N \backslash S$ react by producing more under positive (and less under negative), thereby benefiting coalition S. If this reaction is large enough to compensate the decrease on the payoff of the members of S caused, through the cross effect, by the decrease in their strategies, S's deviation is profitable. The assumption that best replies are contractions limits the magnitude of such reactions and, together with the symmetry and the no synergies assumptions, ensures the stability of the grand coalition.

The paper is organized as follows. Section 2 describes the setup, defines the game of coalition formation and discusses our main assumptions. In Section 3 the main results are presented. Section 4 illustrates the role of synergies through the use of a simple economic example.

2 The Setup

2.1 The Strategic Form Game G

Players' interaction is described by the game in strategic form $G = \left(N, (X_i, u_i)_{i \in N}\right)$ in which N is a finite set of n players, X_i is the set of strategies of player i and $u_i : X_N \rightarrow R_+$ is the payoff function of player i, for all $i \in N$, where $X_N = \prod\limits_{i=1}^{n} X_i$. We make two main assumptions on G.

Assumption 1 *(Symmetric Players): $X_i = X \subset R$ for all $i \in N$. Moreover, for all $x \in X_N$ and all pairwise permutations $p : N \rightarrow N$:*

$$u_{p(i)}\left(x_{p(1)}, ..., x_{p(n)}\right) = u_i\left(x_1, ..., x_n\right).$$

Assumption 2 *(Monotone Externalities): One of the following two cases must hold:*

1. *Positive externalities: $u_i(x)$ strictly increasing in $x_{N \setminus i}$ for all i and all $x \in X_N$;*
2. *Negative externalities: $u_i(x)$ strictly decreasing in $x_{N \setminus i}$ for all i and all $x \in X_N$.*

Assumption 1 requires that all players have the same strategy set, and that players payoff functions are symmetric, by this meaning that any pairwise switch of strategies between players induces a pairwise switch of payoffs. Assumption 2 requires that the cross effect on payoffs of a change of strategy have the same sign for all players and for all strategy profiles.

2.2 Coalition Formation in G

A coalition in the game G is defined as a subset of players $S \subset N$, while the set N itself is denoted as the "grand coalition". A configuration of coalitions is described by the notion of a *coalition structure*, that is, a partition of the set N.[1] One way of studying how coalitions emerge in the system is to consider a game of coalition formation in which each player $i \in N$ announces a coalition $S \ni i$ to which he would like to belong; for each profile $\sigma = (S_1, S_2, ..., S_n)$ of announcements, a partition $\pi(\sigma)$ of N is assumed to be induced on the system. This approach was first considered by Von Neumann and Morgenstern (1944), and

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[1] We remind here that a partition of N is a collection $\{B_1, B_2, ..., B_m\}$ of subsets of N with empty pairwise intersections and whose union coincides with N.

more recently studied by Hart and Kurz (1983) and by part of the literature on coalition formation. The rule according to which $\pi(\sigma)$ originates from σ is obviously a crucial issue for the prediction of which coalitions will emerge in equilibrium. Here we concentrate on the "gamma" rule, predicting that a coalition emerges if and only if all its members have declared it (from which the name of "unanimity rule" also used to describe this game, see Yi (2003)). Formally:

$$\pi(\sigma) = \{S_i(\sigma) : i \in N\}$$

where

$$S_i(\sigma) = \begin{cases} S_i \quad if \quad S_i = S_j \quad for\ all\ j \in S_i \\ \{i\} \quad otherwise \end{cases}.$$

The gamma rule is used to derive a payoff function v_i mapping from the set of all players' announcements Σ into the set of real numbers. The payoff functions v_i are obtained by associating with each partition $\pi = \{S_1, S_2, ..., S_m\}$ a game in strategic form

$$G(\pi) = (\{1, 2, ..., m\}, (X_{S_1}, X_{S_2}, ..., X_{S_m}), (U_{S_1}, U_{S_2}, ..., U_{S_m})),$$

in which X_{S_k} is the strategy set of coalition S_k and $U_{S_k} : \Pi_{k=1}^{m} X_{S_k} \rightarrow R_+$ is the payoff function of coalition S_k, for all $k = 1, 2, ..., m$. The game $G(\pi)$ describes the interaction of coalitions after π has formed as a result of players announcements in Γ. The unique Nash equilibrium of the game $G(\pi)$ gives the payoff of each coalition in π; within coalitions, a fix distribution rule yields the payoffs of individual members. (see Bloch (1996) and Yi (2003) for surveys).

In this paper, we used the game G to derive all games $G(\pi)$, one for each partition π, by simply assuming that $X_{S_k} = \prod_{i \in S_k} S_k$ and $U_{S_k} = \sum_{i \in S_k} u_i$, for every coalition $S_k \in \pi$. Note that each $G(\pi)$ preserves the original features of the game G, without endowing coalitions with any additional strategic possibility. Forming a coalition does not enlarge the set of strategy available to its members and does not modify the way payoffs within a coalition originate from the strategies chosen by players in N. Thus, here the only advantage for players to form coalitions is to coordinate their strategies in the game G in order to obtain a coalitional efficient outcome. This approach is appropriate for many well known games such as Cournot and Bertrand cartel formation and public good games, but rules out an important driving force of coalition formation, i.e. the exploitation of synergies, typically arising for instance in R&D alliances or mergers among firms yielding some sort of economies of scales.

We assume (see the discussion below) that each coalition maximizes its aggregate payoff at a profile in which each of its members play the same strategy. Formally, for $S \subseteq N$, if

$$x_S^* \in \arg\max_{x_S \in X_S} \sum_{i \in S_k} u_i(x_S, x_{N \setminus S})$$

then $x_i^* = x_j^*$, for all $i, j \in S$, and for all $x_{N \setminus S} \in X_{N \setminus S}$. This assumption direct induces the equal split imputation $u_{s_k} = \frac{U_{S_k}}{|S_k|}$ within each coalition at equilibrium. The game Γ is therefore defined by the triplet (N, Σ, v_i), with player $i \in N$ receiving payoff $v_i(\sigma) \equiv u_i(x(\pi(\sigma))$ if profile σ is played.

We point out that the assumption that $G(\pi)$ admits a unique Nash equilibrium for all π, commonly used in the literature to obtain a well defined payoff functions for the game Γ, does not appear to be very restrictive in the class of games covered by this paper (see section 3). In particular, the contraction condition we use in proposition 2 directly ensures the uniqueness of the Nash equilibrium of $G(\pi)$. Moreover, the property of increasing differences used in proposition 1 together with assumptions 1 and 2 implies that either the greatest or the least element of the set of Nash equilibria Pareto dominates all other elements of this set (which of the two depends on the sign of the externality), and represents therefore a natural selection. Note also, that under increasing differences and assumptions 1 and 2, efficient coalitional joint strategies always consist of identical strategies for each member (for a proof of this fact, see Currarini and Marini (2003)). In games without increasing differences, this assumed property of efficient joint strategies would be implied by concavity of individual players payoff functions in the game G, together with assumption 1.

We finally define a stable coalition structure for the game Γ as a partition induced by a Strong Nash Equilibrium strategy profile.

Definition 1 *The partition* π *is a stable coalition structure for the game* Γ *if* $\pi = \pi(\sigma^*)$ *for some* σ^* *with the following property: there exists no* $S \subseteq N$ *and* $\sigma_S \in \Sigma_S$ *such that*

$$\begin{aligned} v_i(\sigma_S, \sigma^*_{N \setminus S}) &\geqslant v_i(\sigma^*), \ \textit{for all } i \in S \\ &\quad \textit{and} \\ v_h(\sigma_S, \sigma^*_{N \setminus S}) &> v_h(\sigma^*), \ \textit{for some } h \in S. \end{aligned}$$

3 Results

In this section we study the existence of a stable coalition structure for the game Γ. We obtain two main results: we first show in proposition 1 that under our symmetry assumptions 1 and 2, all games G with strategic complements admit the grand coalition as a stable coalition structure for the associated game Γ. We then show in proposition 2 that the same result extends to games with strategic substitutes under a contraction assumption, which bounds the effect of strategic substitutability on the (negative) slope of reaction maps.

Instead of directly showing that the unique strategy profile σ^* yielding the grand coalition in the game Γ is not improved upon by any coalitional joint deviation, we proceed by proving that a property of the game G, shown by Yi (2003) to imply the stability of the grand coalition in the associated game Γ, is satisfied under our assumptions. This property is indicated by Yi (2003) as one of the main features of coalitional games with positive spillovers, although being formally independent. It requires that at the equilibrium profile of strategies associated with any *given* partition of the set of players, the members of smaller coalitions are better off than the members of larger coalitions.; in terms of the present notation, it is stated as follows:

Condition 1 *Let π be a partition of N, and let $S \in \pi$ and $T \in \pi$. If $|T| \geq |S|$ then $u_s(x(\pi)) \geq u_t(x(\pi))$.*

We proceed by first establishing a basic preparatory lemma, showing that in the present setting condition 1 can be reformulated in terms of the magnitude of the strategies played within T and S at $x(\pi)$. This result will allow us to work directly on these magnitude in the following lemmas and propositions. Some additional notation is required.

Notation 1 *Given a partition π of N, we consider $S \in \pi$ and $T \in \pi$, with $|T| \geq |S|$. We denote by $x_s \in X$ and by $x_t \in X$ the strategies chosen by each member of S and T at the equilibrium profile $x(\pi)$, respectively.*[2] *It will be useful to refer to a partition of the coalition T into the disjoint subsets T_1 and T_2 of T, such that $|T_1| = |S|$ (T_2 is, of course, the empty set if $|T| = |S|$). To keep notation simple, we will refer to players payoffs omitting from the argument of payoff functions all the strategies played by players in $N \backslash (T \cup S)$ at the equilibrium profile $x(\pi)$. More precisely, we will use the following notational convention:*

$$((x, y), z) \equiv \left((x)_{i \in T_1}, (y)_{i \in T_2}, (z)_{i \in S}, (x_j(\pi))_{j \in N \backslash (T \cup S)}\right)$$

where $(x)_{i \in T_1}$ denotes the joint strategy $x_{T_1} \in X_{T_1}$ in which $x_i = x$ for all $i \in T_1$, and the same notational convention applies to $(y)_{i \in T_2}$ and $(z)_{i \in S}$. It follows that the triplet $((x_t, x_t), x_s)$ identifies the equilibrium profile $x(\pi)$.

With these notational conventions in mind, we can establish the first lemma,

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[2] We remind here that we have assumed that at $x(\pi)$ all members of the same coalition play the same strategy.

Lemma 1 *Let Assumptions 1 and 2 hold. Then:*

i) Under Positive Externalities, $u_s(x(\pi)) \geq u_t(x(\pi))$ *if and only if* $x_s \leq x_t$*;*

ii) Under Negative Externalities, $u_s(x(\pi)) \geq u_t(x(\pi))$ *if and only if* $x_s \geq x_t$*.*

Proof. We first prove the result for the case of positive externalities, starting with the "only if" part. By assumption 1, all members of T get the same payoff at $x(\pi)$. By definition of $x(\pi)$, the profile in which all members of T play x_t maximizes the utility of each member of T, so that

$$u_t((x_t, x_t)\, x_s) \geq u_t((x_s, x_s), x_s). \tag{1}$$

Suppose now that $x_s > x_t$. By assumption 1 and 2.1 we have

$$u_t((x_s, x_s), x_s) = u_{t_i}((x_s, x_s), x_s) = u_s((x_s, x_s), x_s) > u_s((x_t, x_t), x_s). \tag{2}$$

To prove the "if" part, consider coalitions T_1, T_2 and S which, as defined at the beginning of this section, are such that $|T_1| = |S|$ and such that $\{T_1, T_2\}$ forms a partition of T. By definition of $x(\pi)$, the utility of each member of S is maximized by the strategy profile x_S. Using the definition of u_s and of x_s we write:

$$u_s((x_t, x_t), x_s) \geq u_s((x_t, x_t), x_t). \tag{3}$$

By assumption 2.1, if $x_s \leq x_t$ then

$$u_s((x_t, x_t), x_t) \geq u_s((x_s, x_t), x_t). \tag{4}$$

Finally, by assumption 1 and the fact that $|T_1| = |S|$, we obtain

$$u_s((x_s, x_t), x_t) = u_{t_1}((x_t, x_t), x_s) = u_t((x_t, x_t), x_s), \tag{5}$$

implying, together with (4) and (5), that

$$u_s(x(\pi)) = u_s((x_t, x_t), x_s) \geq u_t((x_t, x_t), x_s) = u_t(x(\pi)). \tag{6}$$

Consider now the case of negative externalities (assumption 2.2). Condition (1) holds independently of the sign of the externality. Suppose therefore that $x_s < x_t$. By negative externalities and symmetry we have

$$u_t((x_s, x_s), x_s) = u_s((x_s, x_s), x_s) > u_s((x_t, x_t), x_s). \tag{7}$$

The "if" part is proved considering again coalitions T_1, T_2 and S. Again, Condition (3) holds independently of the sign of the externality. By negative externalities, if $x_s \geq x_t$ then

$$u_s((x_t, x_t), x_t) \geq u_s((x_s, x_t), x_t). \tag{8}$$

As before, we use assumption 1 and the fact that $|T_1| = |S|$ to obtain

$$u_s((x_s, x_t), x_t) = u_t((x_t, x_t), x_s), \tag{9}$$

and, therefore, that

$$u_s(x(\pi)) = u_s(x_t, x_s) \geq u_t(x_t, x_s) = u_t(x(\pi)). \tag{10}$$

■

We are now ready to establish our first result: symmetric games with increasing differences satisfy condition 1. Increasing differences are defined as follows:

Definition 2 *The payoff function u_i exhibits increasing differences on X_N if for all S, $x_S \in X_S$, $x'_S \in X_S$, $x_{N \backslash S} \in X_{N \backslash S}$ and $x'_{N \backslash S} \in X_{N \backslash S}$ such that $x'_S > x_S$ and $x'_{N \backslash S} > x_{N \backslash S}$ we have*

$$u_i\left(x'_S, x'_{N \backslash S}\right) - u_i\left(x_S, x'_{N \backslash S}\right) \geq u_i\left(x'_S, x_{N \backslash S}\right) - u_i\left(x_S, x_{N \backslash S}\right).$$

Proposition 1 *Let assumptions 1-2 hold, and let u_i have increasing differences on X_N, for all $i \in N$. Let π, T and S be defined as in Notation 1. Then: i) Positive Externalities imply $x_s \leq x_t$; ii) Negative Externalities imply $x_s \geq x_t$.*

Proof. *i)* Suppose that, contrary to our statement, positive externalities hold and $x_s > x_t$. By increasing differences of u_i for all $i \in N$ (and using the fact that the sum of functions with increasing difference has itself increasing differences), we obtain:

$$u_s((x_s, x_t), x_s) - u_s((x_s, x_t), x_t) \geq u_s((x_t, x_t), x_s) - u_s((x_t, x_t), x_t). \tag{11}$$

By definition of x_s we also have:

$$u_s((x_t, x_t), x_s) - u_s((x_t, x_t), x_t) \geq 0. \tag{12}$$

Conditions (11) and (12) directly imply:

$$u_s((x_s, x_t), x_s) - u_s((x_s, x_t), x_t) \geq 0. \tag{13}$$

Referring again to the partition of T into the disjoint coalitions T_1 and T_2 as defined in Notation 1, an application of the symmetry assumption 1 yields:

$$\begin{aligned} u_s((x_s, x_t), x_s) &= u_{t_1}((x_s, x_t), x_s); \qquad (14) \\ u_s((x_s, x_t), x_t) &= u_{t_1}((x_t, x_t), x_s). \end{aligned}$$

Conditions (13) and (14) imply:

$$u_{t_1}((x_s, x_t), x_s) \geq u_{t_1}((x_t, x_t), x_s). \tag{15}$$

Positive externalities and the assumption that $x_s > x_t$ imply:

$$u_{t_2}((x_s, x_t), x_s) > u_{t_2}((x_t, x_t), x_s). \tag{16}$$

Summing up conditions (15) and (16), and using the definition of T_1 and T_2, we obtain:

$$u_t((x_s, x_t), x_s) > u_t((x_t, x_t), x_s), \tag{17}$$

which contradicts the assumption that x_t maximizes the utility of T given x_s.

The case *ii)* of negative externalities is proved along similar lines. Suppose that $x_s < x_t$. Conditions (13) and (14), which are independent of the sign of the externalities, hold, so that (15) follows. Negative externalities also imply that if $x_s < x_t$ then (16) follows. We therefore again obtain condition (17) and a contradiction. ■

Proposition 1 and a direct application of Lemma 1 and proposition 4.7 in Yi (2003) yields the following theorem, establishing the stability of the grand coalition.

Theorem 1 *Let assumptions 1-2 hold, and let u_i have increasing differences on X_N, for all $i \in N$. Then the grand coalition N is a stable coalition structure in the game of coalition formation Γ derived from the game in strategic form G.*

Proof. By proposition 1, positive externalities imply that for all π, at $x(\pi)$ larger coalitions choose larger strategies than smaller coalitions, while the opposite holds under negative externalities. By lemma 1, this implies condition 1. The result of proposition 4.7 in Yi (2003) shows that condition 1 directly implies the stability of the grand coalition in Γ. To provide a sketch of that proof, we note that any coalitional deviation from the strategy profile σ^* yielding the grand coalition induces a coalition structure in which all members outside the deviating coalitions appear as singleton. Since these players are weakly better off than any of the deviating members (by condition 1), and since all players were receiving the same payoff at σ^*, a strict improvement of the deviating coalition would contradict the efficiency of the outcome induced by the grand coalition. ■

The stability of the efficient coalition structure $\pi^* = \{N\}$ in this class of games can be intuitively explained as follows. In games with increasing differences, players strategies are strategic complements, and best replies are therefore positively sloped. Also, positive externalities imply that the deviation of a coalition $S \subset N$ is typically associated with a lower level of S's members' strategies with respect to the efficient profile $x(\pi^*)$, and with a higher level in games with negative externalities (see lemma 2 below). If strategies are the quantity of produced public good (positive externalities), S will try to free ride on non members by reducing its production; if strategies are emissions of pollutant (negative externalities), $\acute{S}$ will try to emit more and take advantage of non members' lower emissions. The extent to which these deviations will be profitable ultimately depend on the reaction of non members. In the case of positive externalities, S will benefit from an increase of non members' production levels; however, strategic complementarity implies that the decrease of S's production levels will be followed by a decrease of the produced levels of non members. Similarly, the increase of S's pollutant emissions will induce higher pollution levels by non members. Free riding is therefore little profitable in these games.

From the above discussion, it is clear that deviations can be profitable only if best reply functions are negatively sloped, that is, strategies must be substitutes in G. However, the above discussion suggests that some "degree" of substitutability may still be compatible with stability. Indeed, if S's decrease in the production of public good is followed by a moderate increase in the produced level of non members, S may still not find it profitable to deviate from the efficient profile induced by π^*. We will show that if the absolute value of the slope of the reaction maps is bounded above by 1, the stability result of theorem 1 extends to games with strategic substitutes.

Definition 3 *The function $f_s(x,y)$ denotes the best reply of coalition S (in terms of the choice of its representative member) to the choices (x,y) of the representative member of coalitions T_1 and T_2, respectively, given that all the coalitions in π other than S and T play according to the profile $x(\pi)$. Formally:*

$$f_s(x,y) = \arg\max_{z\in X} u_s\left((x)_{i\in T_1}, (y)_{i\in T_2}, (z)_{i\in S}\right)$$

We obtain in the same way the functions $f_{t_1}(y,z)$, where (y,z) are the choices of members in T_2 and S, respectively, and $f_{t_2}(x,z)$, where (x,z) are the choices of members in T_1 and S, respectively.

We start by a lemma characterizing the best reply of T_1 to the strategy profile $x(\pi)$.

Lemma 2 *Let assumptions 1 and 2 hold. Let π, T, S, T_1 and T_2 be defined as in Notation 1. Then i) Positive Externalities imply $f_{t_1}(x_t,x_s) \leq x_t$; ii) Negative Externalities imply $f_{t_1}(x_t,x_s) \geq x_t$.*

Proof. Consider first point i). By definition of x_t, for all $y \in X$ we write:

$$u_{t_1}((x_t, x_t), x_s) + u_{t_2}((x_t, x_t), x_s) = u_t(x_t, x_s) \geq u_t(y, x_t, x_s) = u_{t_1}((y, x_t), x_s) + u_{t_2}((y, x_t), x_s). \tag{18}$$

Suppose now that $f_{t_1}(x_t, x_s) > x_t$. By definition of the map f_{t_1}, we have:

$$u_{t_1}((f_{t_1}(x_t, x_s), x_t), x_s) \geq u_{t_1}((x_t, x_t), x_s). \tag{19}$$

Also, by Positive Externalities, we have:

$$u_{t_2}((f_{t_1}(x_t, x_t), x_s) > u_{t_2}((x_t, x_t), x_s). \tag{20}$$

Equations (19) and (20) contradicts equation (18).

The case of Negative Externalities is proved along similar lines. In particular, suppose that $f_{t_1}(x_t, x_s) < x_t$. Equation (20) is directly implied, while equation (19) does not depend on the sign of the externalities. This leads again to a contradiction of (18). ■

The bound on the slope of reaction maps is imposed by the following contraction assumption.

Assumption 3 *(contraction) Let π, S, T and T_1 be defined as in Notation 1. Let $y', y'', z', z'' \in X$. Then, for some number $c < 1$ we have:*

$$\left\| f_{t_1}\left(y'', z''\right) - f_{t_1}\left(y', z'\right) \right\| \leq c \left\| \left(y'', z''\right) - \left(y', z'\right) \right\| .$$

Proposition 2 *Let assumptions 1-3 hold. Let π, T, S, T_1 and T_2 be defined as in Notation 1. Then: i) Positive Externalities imply $x_s \leq x_t$; ii) Negative Externalities imply $x_s \geq x_t$.*

Proof. We first consider the case of Positive Externalities (case *i)*). Suppose that, contrary to our statement, $|S| \leq |T|$ and $x_s > x_t$. Assumption 1 (symmetry) directly implies

$$x_s - x_t = f_{t_1}(x_t, x_t) - x_t \tag{21}$$

where we have used the definition of the map f_{t_1} introduced before.

By Lemma 1 we know that Positive Externalities imply:

$$f_{t_1}(x_t, x_s) \leq x_t. \tag{22}$$

Equations (21) and (22) directly imply that:

$$x_s - x_t \leq f_{t_1}(x_t, x_t) - f_{t_1}(x_t, x_s) \tag{23}$$

where both sides of the inequality are non negative.

It is clear that (23) violates assumption 3 (contraction) with respect to the map f_{t_1} and to the change of the strategy played by members of S from x_t to x_s. ■

We again invoke Lemma 1 and Proposition 4.7 in Yi (2003) to conclude that proposition 2 directly implies the following theorem.

Theorem 2 *Let assumptions 1-3 hold. The grand coalition N is a stable coalition structure in the game of coalition formation Γ derived from the game in strategic form G.*

The obtained results can be summarized as follows: symmetry (in the form of assumptions 1 and 2) and the absence of synergies (here implied by the fact that coalitional payoffs are obtained as the sum of players payoffs in the original game G) are sufficient conditions for the grand coalition to be a stable coalition structure in the game Γ, provided that reactions maps are not "too decreasing".

4 An Illustration of the Role of Synergies Using a Cournot Game of Cartel Formation

Let us consider the usual symmetric Cournot oligopoly with linear inverse demand $P(X) = a - X$, where $X = \sum_{i \in N} x_i$ represents the total output, and with a symmetric linear cost for each firm $c(x_i) = cx_i$, with $a > c$ and $a > X$. We know that the payoff of each firm $i \in S \subset N$ when all remaining firms split up in singletons, is given by:

$$v_i\left(x\left(\pi\left(\sigma'\right)\right)\right) = \frac{(a-c)^2}{s(n-s+2)^2},$$

where $n \equiv |N|$, $s \equiv |S|$ and $\sigma' = \left(\{S\}_{i \in S}, \{N\}_{i \in N \backslash S}\right)$. The grand coalition, induced by the profile $\sigma^* = \left(\{N\}_{i \in N}\right)$, is a stable coalition structure in the Γ game of coalition formation, if

$$v_i\left(x\left(\pi\left(\sigma^*\right)\right)\right) = \frac{(a-c)^2}{4n} \geq v_i\left(x\left(\pi\left(\sigma'\right)\right)\right) = \frac{(a-c)^2}{s(n-s+2)^2}$$

Note that the condition above is usually verified for every $s \leq n$.

With $n = 3$, for instance, the grand coalition is a stable coalition structure in the Γ game because deviations by individual firms yield a Cournot equilibrium per-firm payoff of $v_i = \frac{(a-c)^2}{16}$, while two firms jointly deviating obtain each the payoff $v_i = \frac{(a-c)^2}{18}$. Both these outcomes are dominated by the per capita payoff $v_i = \frac{(a-c)^2}{12}$ obtained in the grand coalition.

The stability of the grand coalition arises here because the game respects assumptions 1-3 of our model: firms' payoff are ex-ante symmetric, externalities between firms are monotone (negative) and firms' best replies are contractions. Moreover, the game possesses no synergies in the sense introduced before: the payoff of a cartel of firms is just given by the *sum* of payoffs of the firms in the cartel.

It can now be shown that, even maintaining all assumptions of our theorem 2, the existence of synergies in the cartel formation game can make the grand coalition unstable. Let us introduce a simple form of synergy by assuming, as in Bloch (1995) and Yi (1997), that when firms coordinate their action and create a cartel they can also pool their research assets to develop a new technology in such a way to reduce the cost of each firm in proportion to the number of firms cooperating in the project. We use the following specification of costs: $c(x_i, s_i) = (c + 1 - s_i)\, x_i$, where s_i is the cardinality of the coalition containing firm i and where, by assumption, $a > c \geq n$. As shown by Yi (1997), at the unique Nash equilibrium associated with the partition π, the profit of each firm in a coalition of size s_i is given by:

$$v_i\left(x\left(\pi\right)\right) = \frac{\left(a - \left(n+1\right)\left(c + 1 - s_i\right) + \sum_{j=1}^{k} s_j\left(c + 1 - s_j\right)\right)^2}{(n+1)^2},$$

When $\pi = \pi\left(\sigma'\right)$, symmetry can be used to reduce the above expression to:

$$v_i\left(\pi\left(\sigma'\right)\right) = \frac{\left(a - \left(n - s_i + 1\right)\left(c + 1 - s_i\right) + \left(n - s_i\right)c\right)^2}{(n+1)^2}.$$

Although the grand coalition cartel enjoys a very high level of synergy, straightforward manipulations show that the deviation of a coalition S_i from the grand coalition in the game Γ is always profitable whenever:

$$s_i > -\frac{1}{2}n + c - \frac{1}{2}\sqrt{(n^2 - 4\left(nc - c^2\right) - 8(a - c - 1)}.$$

For example, for $n = 8$, a deviation by a group of six firms ($s_i = 6$) induces a per firm payoff of $v_i\left(\pi\left(\sigma'\right)\right) = \frac{(a-c+15)^2}{81}$ higher than the per firm payoff in the grand coalition $v_i\left(\pi\left(\sigma^*\right)\right) = \frac{(a-c+7)^2}{81}$. Note that in this example condition 1 in section 2 is violated since each firm playing as singleton obtains a payoff $\frac{(a-c)^2}{81}$ which is lower than $\frac{(a-c+15)^2}{81}$.

5 Concluding Remarks

In this paper we have established sufficient conditions for the existence of a stable coalition structure in the coalition unanimity game (or "gamma" game) of coalition formation, as defined by Hart and Kurz (1983). These conditions are directly defined on the strategic form game G used to derive the payoffs in the game of coalition formation. In particular, the absence of synergies is shown to imply the stability of full cooperation if players are symmetric, externalities are monotone and best replies are not "too decreasing". We think there are potentially interesting extensions of our paper, investigating the conditions on G for the existence of equilibrium in other games of coalition formation such as, for instance, Hart and Kurz's (1983) delta or "exclusive membership" game, and under alternative equilibrium concepts, such as Ray and Vohra's (1997) equilibrium binding agreements.

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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

(lxii) This paper was presented at the ENGIME Workshop on “Communication across Cultures in Multicultural Cities”, The Hague, November 7-8, 2002

(lxiii) This paper was presented at the ENGIME Workshop on “Social dynamics and conflicts in multicultural cities”, Milan, March 20-21, 2003

(lxiv) This paper was presented at the International Conference on “Theoretical Topics in Ecological Economics”, organised by the Abdus Salam International Centre for Theoretical Physics - ICTP, the Beijer International Institute of Ecological Economics, and Fondazione Eni Enrico Mattei – FEEM Trieste, February 10-21, 2003

(lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003

(lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003

(lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003

(lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003

(lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference “The Future of Climate Policy” , Cagliari, Italy, 27-28 March 2003

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