On the Stability of Hierarchies in Games with Externalities

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Summary

We study the group stability of collective decision making when society is organized according to a non directed graph, and groups' payoff possibilities are given by a partition function. We focus on the stability properties of hierarchical organizations, formally described by minimally connected graphs (or trees). Building on previous works by Greenberg and Weber (1986, 1993) and by Demange (1994, 2001), we restrict the ability of raising objections to proposed payoff imputations to coalitions that are connected in the organization. We show that the stability properties of hierachical organizations, proved in Demange (1994, 2002), extend to partition function games with negative externalities. Under positive externalities, although not ensuring social stability, hierarchies are the "most stable" organizational forms for society.

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1 Introduction

A series of recent papers (Greenberg and Weber (1986, 1993), Demange (1994, 2001, 2002)) have studied the stability properties of hierachical organizations in cooperative decision problems. These papers are based on the common insight that the ability of coalitions to act independently of the rest of society (i.e., to raise an *objection*) may be related to the position of their members in the hierarchy. In Greenberg and Weber (1986, 1993), society is ordered on a line, and only coalitions that are "consecutive", in the sense that they form a connected interval on the line, are able to raise objections. This restriction of blocking power is there shown to be a sufficient condition for a nonempty core. Demange (1994, 2001, 2002) considers a larger class of organizations, defined by the set of all minimal connected graphs (trees). These structures have the property of inducing, for each *node* that we may consider as a the *root* of the tree, a hierachical order on the set of all nodes (that is, on the set of members of society). The concept of a "consecutive" coalition is here replaced by that of a "connected" coalition or, in Demange's terminology, of a "team".[1] Demange shows that a specific outcome, strictly related to the distribution of power in the hierachy, is objected by no team and is therefore a "stable" solution of the collective decision problem.

These papers suggest one important way in which the stability of a group can be affected by its internal organization; in particular, they show how the constraints imposed by any hierarchical structure on the ability of subgroups of members to coordinate on objections ensure the existence of at least one stable collective decision. The range of cooperative situation to which their result can be applied is however narrowed down by the assumption that the payoff possibilities of objecting coalitions are fully determined by the actions chosen by coalitional members. As witnessed by a large literature developed in the last two decades[2], in many important instances of cooperative decision making the payoff possibilities of coalitions may depend on the actions taken by non coalitional members. These are typically situations in which multiple groups can coexist and interact within the same society, examples ranging from oligopolistic markets, to international environmental agreements, to trade areas, and so on. In all these problems, the incentives to object to a given organization must be assessed

[1]It should be noted that "consecutive" coalitions and "teams" are special cases of what Kaneko and Wooders (1982) called "basic" coalitions in their pioneering investigation of coalitional stability when blocking is restricted to a susbet of all coalitions.

[2]For extensive surveys of this literature see Bloch (1997) and Yi (2001).

with respect to the new patterns of strategic interaction that characterize the configuration of memberships induced by the objection. For example, the incentives of managers to leave a firm may depend on how profitable it would be for them to compete against their firm in the common market, and on how the shape and size of the firm is affected by their departure.

In order to extend Demange's analysis to cooperative problems exhibiting such "externalities", we adopt a *partition function* as a primitive description of payoff possibilities of players, specifying the "worth" of a coalition as a function of the coalition structure in which it is embedded. [3] For these games, we define a *hierarchical payoff imputation,* coinciding with Demange (2002)'s hierachical outcome in games without externalities. We show that if the partition function exhibits negative externalities[4] and a superadditivity condition known as "full cohesiveness", this imputation is objected by no connected coalition in any hierarchy. In contrast, we show by means of an example that the hierarchical imputation may fail to satisfy this stability requirement in games with positive externalities. More importantly, these games may not admit any stable payoff imputations when society is organized according to the star graph, describing an extreme form of hierarchical organization with a central player directly "supervising" all the other members of society.

This latter result highlights the impossibility of hierachical structures to ensure social stability in situations providing agents with strong incentives to exploit the cooperative behavior of other members of society (that is, situations in which free riding is a relevant issue). We show, however, that hierarchies *do possess* desirable stability properties even in these cases. In fact, if no stable collective decision exists for any hierarchical organization, then the same is true for all organizational forms society may adopt. In this sense, hierarchies represent the "most stable" organizational forms under positive externalities.

The paper is organized as follows: Section 2 introduces the main concepts and notation. Section 3 presents the main results. Section 4 contains an discussion of our results and of the relation between the present framework and that adopted by Demange (2002). Section 5 concludes the paper.

[3]Partition functions were first proposed by Thrall and Lucas (1963) and then recently used in most works on coalition formation (see the quoted surveys by Bloch (1997) and Yi (2001)).

[4]Our results refer to the classification of partition functions into the classes of *positive* and *negative externalities,* based on the welfare effect of group formation on non group members. Negative externalities arise when non members are hurt by the formation of a group, while positive externalities arise when non members benefit from the group. Instances of strategic situations satisfying this classification are the formation of trade areas (negative externalities) and of environmental coalitions (positive externalities).

2 Preliminaries

2.1 Games in Partition Functions

We consider a set $N = \{1, 2, ..., n\}$ of agents, that we denote as a *society*, with generic member denoted by i. We let $\Pi(N)$ denote the set of all partitions π of the set N, that is, all collections $\{B_1, B_2, ..., B_m\}$ of subsets of N with empty pairwise intersection and whose union coincides with N. For each subset S of N, we let $\Pi(S)$ denote the set of all partitions of S, with generic element π_S.

Let $\pi \in \Pi(N)$ and $S \in \pi$; we call the pair (S, π) an embedded coalition, and the set E the set of all embedded coalitions. A partition function v is a map from the set E to the set of non negative real numbers, with the element $v(S, \pi)$ denoting the aggregate payoff generated by coalition S in partition π. For simplicity, we will write $v_S(\pi)$ for $v(S, \pi)$ and $v(\pi)$ for $\sum_{B\in\pi} v_B(\pi)$. The pair (N, v) constitutes a game in partition function.

Partition functions allow for welfare externalities across coalitions. Basic features of these externalities can be expressed in terms of changes in the welfare of coalitional members as a consequence of changes in the organization of non coalitional members. Yi (1997, 2000) has shown that the following classification of externalities covers many well known economic problems in which group formation is a relevant issue.

Definition 1 *The partition π is a concentration of π' if it is possible to originate π from π' by a finite sequence of moves of single players from smaller to bigger coalitions.*[5]

Definition 2 *The partition function v exhibits* **positive externalities** *if $v_S(\pi) \geq v_S(\pi')$ whenever $\pi \backslash S$ is a concentration of $\pi' \backslash S$.*

Definition 3 *The partition function v exhibits* **negative externalities** *if $v_S(\pi) \leq v_S(\pi')$ whenever $\pi' \backslash S$ is a concentration of $\pi \backslash S$.*

Note that the traditional notion of a characteristic function comes as a special type of partition function, simultaneously satisfying both positive and negative externalities.

Throughout the paper we will assume that v satisfies the following property.

[5] Note that the concentration relation does not induce a complete ordering on partitions (see Yi (2000)).

Assumption 1 *The function* v *is fully cohesive, that is, for all* $S \subset N$, $\pi_S \in \Pi(S)$ *and* $\pi_{N\backslash S} \in \Pi(N\backslash S)$ *:*

$$v_S(\pi) \geq \sum_{B \in \pi_S} v_B(\pi_S, \pi\backslash S).$$

A fully cohesive function v assigns more to the subset $S \subset N$ than to any of its partitions, for any partition of the set $N\backslash S$. Note that if v is fully cohesive, then the highest aggregate value is generated in the system by the whole society N. A payoff imputation for (N, v) describe the distribution of this efficient payoff across the members of society.

Definition 4 *An imputation for the game* (N, v) *is a vector* $u \in R^n_+$ *such that* $v(N) \geq \sum_{i \in N} u_i$*.*

2.2 Organizations

2.2.1 Connected graphs as internal organizations of groups

We define a graph g as a pair $(N(g), L(g))$, where $N(g)$ is a set of *vertices* (or *nodes*) and $L(g)$ is a set of bilateral links between vertices, with the notation $ij \in L(g)$ denoting the link between i and j in g. We say that the graph g is connected if for all pairs of vertices i and j there exists a connecting path $P(i, j)$ in g, that is a set of vertices $\{i_1, i_2, ..., i_k\}$ such that $i = i_1$, $j = i_k$, and $i_p i_{p+1} \in L(g)$ for all $p = 1, ..., k - 1$. The graph $h = (N(h), L(h))$ is a subgraph of g if $N(h) \subseteq N(g)$ and $L(h) \subseteq L(g)$. The subgraph h of g is a *component* of g if it is connected and if there exists no other connected subgraph h' of g that includes h.

A connected graph g can be viewed as a coalition of players $N(g)$, endowed with the organizational structure $L(g)$; by allowing a direct or indirect communication between each pair of players, the structure $L(g)$ allows the set of players $N(g)$ to coordinate and to act as a "coalition" in the sense of cooperative game theory. For this reason, we refer to a connected graph as an *organization.* Any set of co-existing organizations can be represented as the set $C(g)$ of components of some disconnected graph g. With each graph g, we therefore associate the partition $\pi(g)$ uniquely induced on $N(g)$ by the set $C(g)$:

$$\pi(g) = \{N(h) : h \in C(g)\}. \tag{1}$$

2.2.2 Blocking Power and Incentives in Organizations

In order to be socially stable, a collective decision must be accepted by all members of society, and by all coalitions that may effectively form and raise objections. In this section we describe the way in which the ability and the incentives to raise such objections are shaped by the organizational form adopted by society.

Following the quoted works of Greenberg and Weber (1986, 1993) and Demange (1994, 2001, 2002), we assume that "connectedness" in the organizational form is a necessary requisite for a coalition to have the capacity to raise an objection. Formally, a coalition $S \subset N(g)$ is *connected* in the graph $g = (N(g), L(g))$ if for all pairs of vertices i and j in S there exists a connecting path $P(i,j)$ in g that is all included in S. This approach can be motivated by noting that every coalitional decision is the result of a series of joint activities, including the assessments of alternative actions, the evaluation of their consequences, and their actual implementation. These activities require a certain degree of coordination and, therefore, of communication among coalitional members. In terms of the graph describing the organization, they require connectedness.

Having defined the set of coalitions whose approval is required for a collective decision to be stable, we need to determine the incentives faced by these coalition within any given organization g. In the absence of externalities, the comparison between the payoff imputed to a coalition S within the organization and the payoff possibilities of S when acting "outside" the organization does not require any information about the reaction of the remaining organizational members (the set $N \backslash S$) to S's defection. When externalities are present, however, these reactions become relevant in the determination of coalitional incentives. In particular, when payoffs are described by a partition function, the relevant information is the configuration of remaining members of the organization into groups after the objection.

We will assume that the members of a coalition S defecting from an organization described by the graph g expect players in the complement set $N \backslash S$ to maintain their links unaltered after S's objection. These "Nash" or "zero" conjectures lead to an expectation on the configuration of players outside S given by the partition $\pi(g \backslash S)$, where the graph

$$g \backslash S = \{ij : ij \in g \text{ and } \{i,j\} \cap S = \emptyset\} \tag{2}$$

is obtained by deleting all vertices in S from g. Therefore, the partition of the set N associated with the defection of S from g is given by:

$$\pi\left(S,g\right)=\left(S,\pi\left(g\backslash S\right)\right). \tag{3}$$

Coalition S assesses its payoff in case of defection from g by looking at its payoff in the partition $\pi\left(S,g\right)$, as this is determined by the prevailing partition function v.

Definition 5 *Coalition S blocks the imputation u in the organization g if $v_S\left(\pi\left(S,g\right)\right) > \sum\limits_{i\in S} u_i$.*

It is important to note that the specification of the organizational form g has here two distinct roles in determining the stability of a given payoff imputation for the society N: first, it identifies the set of connected coalitions, those allowed to raise objections; second, it shapes the incentives of these coalitions (and, indeed, of all coalitions) by determining the partition induced on the players which are not active in the objection.

2.2.3 Hierarchies

In preparation of the analysis of section 3, we present here a special class of organizations, given by the set of minimally connected graphs, that is, those graphs containing the minimal number of links needed to achieve connectedness. These graphs, also denoted as *trees*, contain no cycle and, therefore, allow one and only one connecting path for every pair of vertices.[6]

A crucial property of trees is that for each vertex r they induce an incomplete order $\succ_r$ on the set of vertices N, of which r (the *root* of g) is the top element. The order $\succ_{g,r}$ is defined as follows:

$$j \succ_{g,r} k \Longleftrightarrow k \in P(r,j).$$

We read $j \succ_{g,r} k$ as "j follows k in g with root r". The order $\succ_{g,r}$ can be interpreted as the *hierarchical* structure induced on N by the tree g with root r. In this structure, r is superior to all other vertices in N, in the sense that all vertices follow r and r does not follow any other vertex. The following sets are defined for all $i \in N$:

$$D_i \;=\; \left\{j \in N : ij \in g \text{ and } j \succ_{g,r} i\right\};$$

[6] Trivially, if a graph admits a cycle it is not minimally connected, since one link can be deleted from the cycle still preserving connectedness.

$$F_i = \{j \in N : j \succ_{g,r} i\} \cup \{i\};$$
$$T_g = \{j \in N : F(j) = \{j\}\}.$$

The set D_i is the set of direct followers (or "subordinates") of i in g; we denote by D_S the union of the sets D_i taken over all $i \in S$. The set F_i is the set of followers (either direct or indirect) of node i, together with i itself. Obviously, $F_r = N$. The set T_g is the set of terminal nodes of g, that is, the set of nodes with no subordinates. It is clear that the absence of cycles directly implies that each node can have only one superior in the hierarchy.

We will denote by g_i the subgraph obtained by restricting g to the set of vertices F_i. Trivially, every graph g_i is a tree, with root i..

In what follows, we will drop both indexes r and g from the notation of the hierarchical ordering, and conventionally assume that the root vertex of g is 1. The following lemma characterizes the graph $g \backslash S$ obtained by deleting a connected set of vertices S from a tree g. Such characterization is extensively used in the proofs of the main propositions contained in the next section.

Lemma 1 *Let g be a tree and $S \subset N$ be connected in g.*

(i) there exists a vertex $r \in S$ such that $S \subseteq F_r$;

(ii) the components of the graph $g \backslash S$ are minimally connected, and are given by the graph $g \backslash F_r$ (when $r \neq 1$) and by the graphs $(g_i)_{i \in D(S)}$.

Proof. (i) If $1 \in S$ the argument is immediate. Let $1 \notin S$, and let k and j be two vertices in S for which there exists no vertex $h \in S$ such that $k \in F_h$ and $j \in F_h$. Let also $P(j,k)$ be the unique connecting path between k and j. By connectedness of S we have $P(j,k) \subset S$. However, we also have $k \in F_1$ and $j \in F_1$. Therefore, if $j \notin F_k$ and $k \notin F_j$, there exists some path $P'(j,k) \neq P(j,k)$ including player 1. So it must be that either $j \in F_k$ or $k \in F_j$, which contradicts the assumption.

(ii) We first show that the graphs $g \backslash F_r$ is minimally connected when $r \neq 1$ and empty when $r = 1$.. To show that $g \backslash F_r$ is connected, note that for all $i \in N \backslash F_r$ the is a path $P(1,i)$ in g that does not go through any of the vertices in F_r (otherwise this path would go through r, violating the definition of $N \backslash F_r$). Such path is therefore present in $N \backslash F_r$, unless $N = F_r$, in which case the graph $g \backslash F_r$ is empty. Since $g \backslash F_r$ contains no additional link with respect to the minimally connected graph g, the graph $g \backslash F_r$ is also minimally connected. To show that the graph g_i is connected for all $i \in D_S$, note that every vertex in F_i is connected to i by a path which is included in F_i. Therefore, for each pair of vertices in F_i, there is a connecting path in g_i all contained in F_i. Since g is minimally connected, g_i admits no cycle.

We now need to show that these graphs are the components of $g \backslash S$.

Note first that since $F_i \subset F_r$ for all $i \in D_S$ we have $F_i \cap N \backslash F_r = \emptyset$ for all $i \in D_S$. Also, $F_j \cap F_k = \emptyset$ for j and k in D_S; to see this, note that if j and k are in D_S, then j and k cannot be ordered by $\succ$, otherwise, by connectedness of S, either j or k should belong to S. But in this case, then there exist two paths connecting h and 1, one passing through j and another passing through k, contradicting the assumption that g is a tree. We then prove that no link is present between members of any two of these sets of vertices. Suppose first that $jk \in L(g \backslash S)$ for $j \in N \backslash F_r$ and $k \in F_i$, for $i \in D_S$. Since $j \in N \backslash F_r$, the (unique) path $P(1, j)$ does not go through r, while $P(1, k)$ does. So, we can construct a path $P'(1, j)$ by considering the path $\{ij \cup P(1, k)\}$, contradiction the assumption that g contains no cycle. The fact that no link is present between vertices in F_j and in F_k in $g \backslash S$ follows again from the absence of cycles in g. ■

3 Results

This section contains our main results. We first define a vector of utilities, derived recursively along the tree structure of a generic hierarchy in a way at all similar as done for the hierarchical outcome in Demange (1994, 2002). We show that this vector does not always define an imputation for the society N, since it may impute negative amounts of utility to some player. However, we show that this is never the case in games with negative externalities, and that for such games this vector of utilities defines an imputation. Moreover, negative externalities ensure that this specific imputation is blocked by no connected coalition.

We then consider the class of games with positive externalities. We show that for games in this class there exist hierarchical organizations for which no imputation is immune from blocking by connected coalitions. However, hierarchical structures are still the most stable organizational forms, in the sense that if no hierarchy ensures the existence of a stable imputation, then no other organization does.

We choose to present our results in this section without attempting a discussion of their relation to the quoted literature. An extensive treatment of this relation is contained in section 4.

3.1 The Hierarchical Utility Vector

We define the following utility vector u^* recursively.

Definition 6 *Let g be a tree and v be a partition function. The* **hierarchical utility vector** *$u^*$for (v, g) is obtained recursively as follows:*

$$\begin{aligned} u_i^* &= v_i(\{i\}, N\backslash\{i\}) \text{ for all } i \in T_g; \\ u_i^* &= v_{F_i}(F_i, N\backslash F_i) - \sum_{h \in F_i \backslash \{i\}} u_h^* \text{ for all } i \in N\backslash T_g. \end{aligned}$$

The vector u^* imputes to each vertex i of g its marginal contribution to the graph g_i if i leaves the set of players $N\backslash(F_i\backslash\{i\})$ to join the set $F_i\backslash\{i\}$. Note that the vector u^* does not necessarily define an imputation for the game (N, v), even when the function v is fully cohesive, since some player may be imputed a negative amount of utility. This is shown in the following example.

Example 1 *Let $N = \{1, 2, 3\}$ and let g be such that $L(g) = \{12, 13\}$. The partition function satisfies:*

$$v_2(\{2, 13\} = v_3(\{3, 12\} > v_2(\{2, 1, 3\}).$$

The utility value u_1^* is given by

$$u_1^* = v(N) - v_2(\{2, 13\}) - v_3(\{3, 12\}).$$

Note that if $v_2(\{2, 13\}) > v_2(\{2, 1, 3\})$, u_1^* can be negative even if v is fully cohesive.

3.2 Games with Negative Externalities

We first show that the presence of negative elements in the vector u^* in example 1 was due to the property of positive externalities of the employed partition function v. Indeed, when v is fully cohesive and has negative externalities, all the elements of u^* are non negative.

Lemma 2 *Let v be fully cohesive and exhibit negative externalities. The hierarchical utility vector u^* is an imputation for (N, v).*

Proof. We need to show that $u_i^* \geq 0$ for all $i \in N$. The argument is trivial for $i \in T_g$. Let $i \in N\backslash T_g$, and consider the set of direct followers D_i of i and, for each $j \in D_i$, the set F_j.

Applying iteratively the definition of u^* on each set F_j we obtain:

$$u_i^* = v_{F_i}(\{F_i, N \backslash F_i\}) - \sum_{j \in D_i} v_{F_j}(\{F_j, N \backslash F_j\}). \tag{4}$$

Consider now the term $v_{F_j}(\{F_j, N \backslash F_j\})$ for each $j \in D_i$. The collection of coalitions $\left\{(F_h)_{h \in D_i}, N \backslash F_i, \{i\}\right\}$ forms a partition of N by lemma 1; also, the set $N \backslash F_j$ is a concentration of the sub-partition $\left\{(F_h)_{h \in D_i \backslash \{j\}}, \{i\}, N \backslash F_i\right\}$. Negative externalities of v imply therefore that for all $j \in D_i$:

$$v_{F_j}(\{F_j, N \backslash F_j\}) \leq v_{F_j}\left(\{(F_h)_{h \in D_i}, \{i\}, N \backslash F_i\}\right), \tag{5}$$

so that, summing up over the set D_i we obtain:

$$\sum_{j \in D_i} v_{F_j}(\{F_j, N \backslash F_j\}) \leq \sum_{j \in D_i} v_{F_j}\left(\{(F_h)_{h \in D_i}, \{i\}, N \backslash F_i\}\right). \tag{6}$$

By full cohesiveness of v, we also have

$$\sum_{j \in D_i} v_{F_j}\left(\{(F_h)_{h \in D_i}, \{i\}, N \backslash F_i\}\right) + v_i\left(\{(F_h)_{h \in D_i}, \{i\}, N \backslash F_i\}\right) \leq v_{F_i}(\{F_i, N \backslash F_i\}). \tag{7}$$

This fact, together with (4) and (6), implies:

$$v_i\left(\{(F_h)_{h \in D_i}, \{i\}, N \backslash F_i\}\right) \leq v_{F_i}(\{F_i, N \backslash F_i\}) - \sum_{j \in D_i} v_{F_j}(\{F_j, N \backslash F_j\}) = u_i^*. \tag{8}$$

This, together with the fact that $v_i\left(\{(F_h)_{h \in D_i}, N \backslash F_i), \{i\}\}\right) \geq 0$, implies the result. ■

Having proved that u^* defines an imputation for all games with negative externalities, we can assess whether it is also a stable outcome for a society organized according to the associated hierarchical structure. This is done in the next theorem.

Theorem 1 *Let g be a tree and v satisfy negative externalities. The hierarchical imputation u^* for (g, v) is blocked by no connected coalition in g.*

Proof. We prove the result by contradiction. Suppose that S is a connected coalition that improves upon the imputation u^*, meaning that

$$\sum_{i \in S} u_i^* < v_S\left(\pi\left(S, g\right)\right). \tag{9}$$

Using the definition of u^*, (9) becomes

$$v_{F_r}\left(\{N\backslash F_r, F_r\}\right) - \sum_{j\in D_S} v_{F_j}\left(\{N\backslash F_j, F_j\}\right) < v_S\left(\pi\left(S,g\right)\right), \tag{10}$$

where r denotes the root of S in g. We will show that (10) leads to a contradiction of assumption 1.

By Lemma 1, the partition $\pi\left(S,g\right)$ induced by the formation of S has the following form:

$$\pi\left(S,g\right) = \left(\{N\backslash F_r, S, (F_j)_{j\in D_S}\}\right). \tag{11}$$

Note now that for each $j \in D_S$, the set $N\backslash F_j$ is a concentration of the partition

$$\left\{N\backslash F_r, S, (F_k)_{k\in D_S\backslash\{j\}}\right\}.$$

Negative externalities imply that for all $j \in D_S$:

$$v_{F_j}(\{F_j, N\backslash F_j\}) \leq v_{F_j}\left(\{N\backslash F_r, S, (F_k)_{k\in D_S}\}\right). \tag{12}$$

Inequalities (10) and (12) imply

$$v_{F_r}\left(\{F_r, N\backslash F_r\}\right) - \sum_{j\in D_S} v_{F_j}\left(\{N\backslash F_r, S, (F_k)_{k\in D_S}\}\right) < v_S\left(\pi\left(S,g\right)\right). \tag{13}$$

Rearranging terms and using (11) we obtain the following inequality.

$$v_{F_r}\left(\{N\backslash F_r, F_r\}\right) < \sum_{j\in D_S} v_{F_j}\left(\{N\backslash F_r, S, (F_k)_{k\in D_S}\}\right) + v_S\left(\{N\backslash F_r, S, (F_k)_{k\in D_S}\}\right). \tag{14}$$

Since the collection of sets $(S, (F_k)_{k\in D_S})$ forms a partition of the set F_r (see lemma 1), it follows that condition (14) violates assumption 1, which concludes the proof. ■

The way in which negative externalities work in favor of stability of u^* can be intuitively illustrated by the simple case of a star graph, made of a central player maintaining all the links with $(n-1)$ peripheral players. First, each of these obtains at u^* exactly its outside option by leaving the star, which is the lowest possible payoff a single player can generate under negative externalities. Looking now at connected coalitions, note that each must contain the central player; therefore every objection by a connected coalition S must leave the non members isolated. Each of these non members will therefore get, after the objection, a weakly higher payoff than at u^*, implying that S cannot improve upon u^* by cohesiveness of v.

3.3 Games with Positive Externalities

Theorem 1 cannot be extended to games with positive externalities. As example 1 has shown, players at the bottom of the hierarchy possess very high outside option and, correspondingly high claims, that cannot be met by any distribution of the social surplus. In the extreme case of the star graph, discussed at the end of the previous section, the $(n-1)$ terminal players claim the highest possible payoff that a single player can get in the game (that is, the one he generates by facing the rest of the players united).

This "free riding" problem not only prevents u^* from being a feasible imputation in example 1, but also from being a stable collective decision in problems in which it does define an imputation for society. This is shown in the next proposition.

Proposition 1 *Let g be a star graph with set of vertices N. There exist functions v with positive externalities for which the hierarchical utility vector u^* for (g, v) defines an imputation for (N, v) but is blocked by some coalition connected in g.*

Proof. The proof is by a counter-example. Let $N = \{1, 2, 3, 4\}$. Conventionally, let 1 be the center of g^*. Let v be as follows:

$$\begin{aligned} v\,(N) &= 10+\varepsilon \\ v_i\,(\{i,j,k,l\}) &= 1 \\ v_i(\{i,jkl\}) &= 3 \\ v_i(\{i,jk,l\}) &= 2.5 \\ v_{ij}(\{ij,k,l\}) &= 5. \end{aligned}$$

Note that v exhibits positive externalities. In fact, $v_i(i, jkl) > v_i(i, jk, l)$ since (jkl) is a concentration of (jk, l). In this example the vector u^* is given by

$$\begin{aligned} u_1^* &= 10+\varepsilon-9 = 1+\varepsilon; \\ u_i^* &= 3,\ i = 2, 3, 4. \end{aligned}$$

Consider coalition $\{12\}$. It induces the partition $\{12, 3, 4\}$ with a payoff of $v_{12}(\{12, 3, 4\}) = 5$. In u^* players 1 and 2 collectively get $u_{12}^* = 4+\varepsilon$, which is less than 5 for ε small enough. ■

One question that naturally arises at this point is whether other imputations, different from u^* can be found that are immune from blocking by coalitions that are connected in the star graph g. The next proposition shows that this is not possible, and that the instability of the hierarchical vector u^* for the star organization implies the instability of all feasible imputations.

Proposition 2 *Let g be a star graph with set of vertices N. Let v satisfy positive externalities. If u^* is blocked by some connected coalition in g, then all imputation u are blocked by some connected coalition in g.*

Proof. Suppose u^* is blocked by the central player i, and let $u \neq u^*$ be an imputation for (N, v). If $u_j < u_j^*$ for some $j \neq i$, then j blocks u by leaving the star graph and getting u_j^*. If $u_j \geq u_j^*$ for all $j \neq i$, then, since $\sum_{h \in N} u_h^* = \sum_{h \in N} u_h$, player i still blocks u. Suppose now that some connected coalition S blocks u^*. If

$$\sum_{h \in S} u_h^* \geq \sum_{h \in S} u_h$$

then S blocks u as well; if

$$\sum_{h \in S} u_h^* < \sum_{h \in S} u_h$$

then for some player $j \notin S$ it must be that $u_j^* > u_j$ Since j must be a peripheral player, he blocks u by leaving the star graph and getting u_j^*. ■

Proposition 2 shows that under positive externalities the exist hierarchical organizations (the star) in which no stable collective decision can be achieved. Note that, however, in the example developed in proposition 1, the only non hierarchical organization (the complete graph) would suffer from the same (and possibly worse) instability problems. Indeed, all coalitions are connected in the complete graph, and, thanks to positive externalities, each would face a weakly higher payoff in leaving the complete star than by leaving the star.

The next proposition uses these arguments to show that although the adoption of a hierarchical organization does not ensure the existence of a stable collective choice, it nevertheless maximizes the likelihood of achieving it. Loosely speaking, under positive externalities hierarchies turn out to be the "most stable" organizational forms for society.

Proposition 3 *Suppose for no tree g there exists some imputation u which is stable against blocking by connected coalitions in g. Then no imputation u exists which is stable against blocking by connected coalitions in g', for all connected graph g'.*

Proof. Consider any connected graph g', and let g a minimally connected graph included in g', that is, for which $L(g) \subset L(g')$ (clearly, one such graph exists for all connected graphs g). By the statement of the proposition, we know that for all imputation u, there exists one coalition S which is connected in g that blocks u, that is, for which

$$v_S\left(\pi\left(S,g\right)\right) > \sum_{i\in S} u_i. \tag{15}$$

Consider now the partition $\pi\left(S,g'\right)$, in which S in embedded if it leaves the graph g'. Since $L(g) \subset L(g')$, then $L(g\backslash S) \subseteq L(g'\backslash S)$. It follows that each component of $g'\backslash S$ is either a component of $g\backslash S$ or can be obtained by merging two or more components of $g\backslash S$. Using the definition of $\pi\left(S,g'\right)$, we conclude that the partition $\pi\left(S,g'\right)$ is a concentration of the partition $\pi\left(S,g'\right)$. By positive externalities we obtain

$$v_S\left(\pi\left(S,g'\right)\right) \geq v_S\left(\pi\left(S,g'\right)\right),$$

meaning that coalition S can obtain a higher payoff by leaving g' than by leaving g. It follows that if S blocks u in the graph g (see condition (15)), it also blocks u in the graph g'.

It remains to be shown that no coalition S exists that is connected in g but not in g'. This immediately follows from the fact that $L(g\backslash S) \subseteq L(g'\backslash S)$, since all the paths connecting any two members in S in g are present in g'. ■

4 Discussion

The results of the previous section confirm the general insight provided by Demange's (1994, 2002) work on the stability properties of hierachical organizations. In particular, we have seen that hierarchies guarantee the existence of stable distributions of social welfare in the presence of negative externalities, while they maximize the likelihood of finding such distributions in the presence of positive externalities.

One final issue to address is whether our results can be obtained as corollaries of Demange's analysis or, more in general, how they relate to it. To allow for a discussion of the present results in Demange's framework, we will refer to and ad-hoc characteristic function, expressing the payoff possibilities of each coalition within a given hierarchy g, as these are determined in definition 5. This function is defined, for any pair (v,g), as follows:

$$V_g(S) \equiv v_S\left(\pi\left(S,g\right)\right), \; for \; all \; S \subseteq N. \tag{16}$$

It is clear that the imputation $u \in R^n_+$ is blocked by coalition S in the organization g under the partition function v (see definition 5) if and only if u is blocked by S in the game in characteristic function (N, V_g).

We first note that the hierarchical vector u^* defined in definition 6 for the tree g and the partition function v, coincides with the "hierarchical outcome" defined by Demange for the game (N, V_g) as follows:[7]

$$u_i^* = V_g(F_i) - \sum_{h \in D_i} V_g(h), \quad for\ all\ i \in N. \tag{17}$$

It is clear that if V_g is superadditive, then u^* defines an imputation for the game (N, V_g). More importantly, Demange's analysis can be invoked to conclude that u^* is not blocked by any connected coalition in g. These considerations, together with the results of section 3.3 in the present paper, directly imply that games with positive externalities fail to generate a superadditive V_g even if the originating partition function is fully cohesive. More interestingly, the next example shows that superadditivity may fail even for fully cohesive games with negative externalities (for which the hierachical imputation u^* has been shown in theorem 1 to satisfy the stability concept used in Demange).

Example 2 *Let* $N = \{1, 2, 3\}$ *, let* $L(g) = \{12, 13\}$ *and the (anonymous) function* v *be such that*

$$\begin{aligned} v_1(\{1,2,3\}) &\equiv V_g(\{1\}) > v_1(\{1,23\}) = v_2(\{2,13\}) = V_g(\{2\}); \\ v(N) &\equiv V_g(N) = v_1(\{1,23\}) + v_{\{23\}}(\{1,23\}) + \varepsilon, \end{aligned}$$

for $\varepsilon > 0$. *The partition function* v *so defined is fully cohesive and satisfy negative externalities. However, for* ε *small enough we obtain*

$$V_g(\{1\}) + V_g(\{2,3\}) \equiv v_1(\{1,2,3\}) + v_{\{23\}}(\{1,23\}) > v(N) \equiv V_g(N), \tag{18}$$

which violates superadditivity of V_g.

The reason why full cohesiveness of v does not imply superadditivity of V_g is made clear by condition (18) in example 2: while the first property refers to the sum of coalitional values in any given partition, the second may refer to coalitional values as they are determined by

[7] We are here simplifying Demange's framework (defined in terms of coalitional action spaces and preferences) by directly referring to a game in characteristic function.

v in different partitions. In the case of (18), these values refer to the partitions $\{1, 2, 3\}$ and $\{1, 23\}$.

Despite the failure of V_g to be superadditive, our stability results of theorem 1 can still be interpreted in terms of Demange's (2002) analysis. There, in the absence of superadditivity a stable partition of the players in sub-hierarchies is shown to be stable, and to inducing the superadditive cover of the grand coalition N. Let $\pi = \{S_1, S_2, ..., S_p\}$ denote such partition for a given function V_g. As already noted, the values imputed by V_g to each element of π may refer to the worth assigned by the originating function v to such elements in different partitions, and therefore may not describe a feasible outcome. It can be shown, however, that this is never the case if v has negative externalities and if π partitions g into trees (or sub-hierarchies).

Lemma 3 *Let g be a tree, and V_g be obtained from the pair (v, g), where v satisfies negative externalities. Let also $\pi = \{S_1, S_2, ..., S_p\}$ be the partition of N obtained by considering some partition of g in the sub-trees $(g_1, g_2, ..., g_p)$. Then*

$$\sum_{k=1}^{p} V_g(S_k) \leq \sum_{k=1}^{p} v_{S_k}(\pi).$$

Proof. By definition of V_g we have that for all $k = 1, 2, ..., p$:

$$V_g(S_k) = v_{S_k}(\{S_k, \pi(S_k, g)\})$$

where $\pi(S_k, g)$ is given by the set of components of the graph $g \backslash S_k$. Let

$$\pi(S_k, g) = \{T_1, T_2, ..., T_m\}.$$

Since S_j is a tree, for all $j = 1, 2, ..., p$, and since T_h is maximal for all $h = 1, 2, ..., m$, we conclude that for all $j = 1, 2, ..., p$ there is some $h \in \{1, 2, ..., m\}$ for which $S_j \subset T_h$. It follows that $\pi(S_k, g)$ is a concentration of $\pi \backslash S_k$. By negative externalities:

$$v_{S_k}(S_k, \pi(S_k, g)) \leq v_{S_k}(\pi).$$

Since this argument can be repeated for all $k = 1, 2, ..., p$, we obtain the result. ■

We therefore conclude that the partition of g into sub-hierarchies induced by the procedure described by Demange has the property of assigning to each sub-hierachy a feasible aggregate payoff in all games with negative externalities. Moreover, full cohesiveness of the originating partition function v implies that the aggregate payoff produced by the full hierarchy (defined on N) is greater than that produced by any such partition. As a consequence, the value produced by the full hierarchy coincides with that produced by the superadditive cover of N according to V_g. We can therefore apply Demange's result to the full hierachy to obtain the result of theorem 1. As lemma 3 makes clear, the same cannot be argued for games with positive externalities, consistently with the negative results of section 3.3.

5 Conclusions

We have studied the group stability of collective decisions when society is organized according to a non directed graph and groups' payoff possibilities are given by a partition function. We have focused on the stability properties of hierarchical organizations, formally described by minimally connected graphs (or trees). Our analysis has built on the work of Greenberg and Weber (1993) and Demange (1994, 2002), with which it shares the basic assumption that the organizational form determines the set of coalitions that can object to any collective decision (namely, the set of connected coalitions).

Our main result shows that a specific "hierarchical" imputation of payoffs is stable in all games with negative externalities, extending Demange's result, obtained for games in characteristic function, to this larger class of games. We then show that although games with positive externalities may not allow any stable imputation on some hierarchical organization, still hierarchies represent the "most stable" structure that society may adopt in the process of collective decision making.

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(liii) This paper was circulated at the International Conference on "Climate Policy – Do We Need a New Approach?", jointly organised by Fondazione Eni Enrico Mattei, Stanford University and Venice International University, Isola di San Servolo, Venice, September 6-8, 2001

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