Fondazione Eni Enrico Mattei

Stable Organizations with Externalities

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NOTA DI LAVORO 51.2002

JULY 2002

Coalition Theory Network

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Summary

We study the stability properties of organizations in partition function games, describing cooperative situations with externalities. An organization is defined as a group of agents, together with a set of bilateral relations, formally, a connected graph. Because of the presence of externalities, the profitability of coalitional threats to an organization depend on the reaction of non coalitional members. This reaction is likely to depend on the links that non coalitional members maintain in the organization. We show that this directly implies that minimally connected organizations emerge under positive externalities, while the fully connected organization emerges under negative. This result is shown to hold independently of the adopted payoff imputation rule. Sharper predictions are possible for the specific case of the egalitarian rule. Here, if only coalitions that are connected in the organization can effectively object to it, the star organization prevails under positive externalities, and the wheel, a non fully connected organization, prevails under negative.

Keywords: Organizations, graphs, networks, cooperation, coalitions, externalities

JEL: C72, D20

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This paper has been produced within the research activities of the Coalition Theory Network, managed by the Center of Operation Research and Economics, Louvain-La-Neuve, the Fondazione Eni Enrico Mattei, Milan, the GREQAM, Université de la Méditerannée, Marseille and the CODE, University of Barcelona. It has been presented at the Seventh Meeting of the Coalition Theory Network organised by FEEM in Venice, Italy, January 11-12, 2002.
The author thanks Matt Jackson, David Perez Castrillo, Francis Bloch, Massimo Morelli, Marco Marini, Sanjeev Goyal and the participants to the above workshop. The usual disclaimer applies.

1 Introduction

In various economic problems, agents face incentives to form groups and coalitions. The classical game theoretic analysis of cooperation has mainly addressed the problem of how to split the efficiency gains among coalitional members, proposing solutions based on various fairness or stability considerations. More recently, new models of coalition formation have focused on the prediction of the equilibrium configuration of groups, formally summarized by a *coalition structure* (a partition of the set of players into disjoint coalitions).[1] These models have proved useful in the analysis of economic problems in which the formation of multiple coalitions is observed, and in which the payoff possibilities of a coalition depend on the configuration of other groups in the system. Among the various contribution to this field of research[2], a series of results by Yi (1997, 2000) have related the properties of equilibrium coalition structures to the *sign* of such external effects. Yi shows that the two classes of *positive* and *negative* externalities[3] provide a useful organizing principle in studying economic problems in which coalitions are a relevant feature.

Coalition structures do not contain information on how coalitional members achieve the necessary degree of coordination in order to act as a group. As first suggested in the seminal paper by Myerson (1977), a richer representation of the cooperative framework would be provided by a *graph* (or, in Myerson's terminology, *cooperation structure),* specifying all bilateral connections between players in the system. By considering the equivalence classes of the connectivity relation[4] (given by the components of the graph), a partition of the set of

[1]Although the possibility of multiple coalitions was already implicit in the analysis of stable sets by von Neumann and Morgenstern (1944) and of bargaining set by Aumann and Maschler (1964), and explicit in the work by Aumann and Dreze (1974), the focus of these work was not the analysis of which groups endogenously form in the system.

[2]See Hart and Kurz (1983), Bloch (1996), Ray and Vohra (1997, 1999), Yi (1997). For two extensive surveys of this approach, see Bloch (1997) and Yi (2000).

[3]The sign of the externalities refers to the welfare effect exerted on non coalitional members by the formation of a coalition. Positive externalities attain to cases in which this effect is positive (as in public good games or Cournot oligopolies), while negative extenalities attain to negative welfare effects (as in trade areas). Some authors use the term "splillovers" to distinguish betwenn the gains from cooperation, occurring within a coalition, from the welfare effect across coalitions (see Bloch (1996) and Konishi, Weber and Le Breton (1997)).

[4]Two players are connected in a graph if there exists a path in the graph of which these players are endpoints (see section 2 for formal definitions).

players is obtained, that can be interpreted as the coalition structure induced by the graph.[5] The additional information provided by the architecture of each component can be viewed as a description of the internal *organization* of coalitions, possibly describing the pattern of bilateral communication and negotiations (as in Myerson (1977) and Aumann and Myerson (1988)), of information processing (as in Bolton and Dewatripont (1994)) or of decision making (as in Demange (2001)).

This paper studies the endogenous formation of cooperation structures in the presence of externalities across groups. We adopt a partition function as primitive, specifying the worth of a coalition as a function of the coalition structure to which it belongs. Differently from Myerson (1977) and all the following literature on network formation[6], we therefore allow the value produced by each component of a graph to depend on the partition induced by the set of components; we, however, do not allow this value to depend on the architecture of components, taking, in this sense, a step back with respect to Jackson and Wolinsky (1996). For a discussion of these differences, we refer to the final part of this introduction.

We focus on connected *graphs,* henceforth *organizations,* identifying coalitions with specific internal structures in terms of bilateral relation between members. In the same spirit of Yi's (1999) work on coalition structure, we wish to study the structural characteristics of organizations under positive and negative externalities. While Yi's analysis looked at the external configuration of groups (coalition structures), ours focuses on groups' internal organization. Our results show that structural features of an organization, such as its degree of connectedness, of hierarchy and, in some cases, its entire architecture, can be related to the *sign* of the externality faced by its members. In particular, we show that positive externalities favor the formation of cohesive and hierarchical organizations, while negative externalities favor dispersed and horizontal ones.

Our approach is coalitional in spirit. We define stability of an organization taking as primitive the threat of members to separate from the organization and take independent action. The strategic possibilities of coalitions are therefore weaker than in the *strong stability* concept used in Jackson and van den Nouweland (2001) (and, equivalently, in the strong Nash equilibrium concept used in Dutta et al. (1998) and Dutta and Mutuswami (1997)), in that we "force" all members of an objecting coalition to sever all links with the other players

[5]Underlying this approach is the idea that a coalition arises when all members are pairwise connected.

[6]See, however, the paper by Mutuswami and Winter (2000) on the design of incentives in networks with, possibly, externalities.across components.

in the organization. This approach is, however, equivalent to that of Jackson and van den Nouweland (2001) under the component wise egalitarian imputation rule, to which part of our results refer.[7]

Our analysis builds on a basic observation, underlying the equilibrium analysis of coalition structures with externalities. As a result of the externalities, the incentives of coalitional members to defect from a coalition and take independent action depend on the consequences of their defection on the configuration of the "residual" players, that is, those coalitional members which are not active in the defection. If these remain compact, defectors will face high incentives under positive externalities (as, for instance, free riders in public goods problems) and low incentives under negative externalities (as, for instance, countries leaving a trade area). If, in contrast, the residual players split up into singletons, defectors will face low incentives under positive externalities, and high incentives under negative.

The attempt to specify reasonable reactions of residual players has motivated a variety of approaches to the analysis of stable coalition structures, building these reactions in the model by means of behavioral assumptions[8]. In this respect, one important element of the present analysis is that the additional information provided by organizations on the structure of cooperation can be used to formulate clear-cut predictions on such reactions. In fact, these are likely to depend on the links maintained by residual players in the organization. This is certainly an appropriate assumption if links are to express long term relationships, such as trust or institutional relations; in this case, maintaining (or re-establishing) such links after the organization is disrupted should be easier for players who were linked in the organization. An interpretation of defections as deviations in a strategic form game of link formation, as in Dutta and Mutuswami (1997), would predict that these links remain unchanged after the defection. In this case, by determining well defined "reactions" of non coalitional members, each organization would provide well defined incentives to any objecting coalition. More importantly, these incentives would depend in a clear-cut way on the sign of the external effects: *positive externalities* will reward objections that leave the residual part of the group

[7]The component wise egualitarian rule has been shown by Jackson and van den Nouweland (2001) to play a crucial role for the existence of strong Nash equilibria.

[8]The Δ and Γ games of coalition formation by Hart and Kurz (1983) , or, equivalently, the membership rules employed in Yi (1997), are examples of such behavioural assumptions. Other approaches have "endogenized" the reaction of residual players, either by considering a sequential structure (Bloch (1996), Ray and Vohra (1999)), or by imposing consistency requirements (Ray and Vohra (1997) and, more recently, Xue et al. (2002)).

connected, and penalize objections that disintegrate the group, while opposite arguments apply to the case of *negative externalities*.

As an illustration, consider a *star* organization, with one central players maintaining all the links. The profitability of individual objections crucially depends on the player's position in the organization, according to the sign of the externality. If this sign is positive, the objection is less profitable if raised by a central player than by a peripheral player, for in the first case the rest of the players react by disintegrating the group, neutralizing the incentives to free-ride. The opposite is true under positive externalities, where leaving the organization from a peripheral position would make the departing player face a compact group after the objection.

The theoretical problem we address is whether it is possible to associate with each sign of the externalities a class of organizations, providing "minimal" incentives to all coalitions who have the "ability" to object. This ability may be unrelated to the organizational structure, as in the case of the strong stability concept of Jackson and van den Nouweland (2001), or may be determined by the links maintained by players, as in Greenberg and Weber (1986, 1993) and Demange (2001). We will consider both cases, assuming, in the second case, that only coalitions that are connected in an organization may object to it.[9]

We obtain the following results.

First, the class of minimally connected organizations minimizes the incentives to object of all possible coalitions under positive externalities, while the same is true for the complete organization (i.e., the maximally connected one) under negative externalities. This holds independently of the adopted imputation rule, and implies that if all coalitions have the ability to object, then minimally (resp., maximally) connected stable organizations always exist under positive (resp., negative) externalities, provided the set of stable organization is nonempty; moreover, partition functions can be found for which organizations belonging to these two classes are the unique stable ones.

Second, the restriction of the objecting power to connected coalitions allows for sharper predictions of stable egalitarian organizations.[10] Under positive externalities, minimal incentives to object are provided by the *star* organization, confirming (and qualifying) the previous

[9]This approach, taken in the papers by Greenberg and Weber (1986, 1993) and by Demange (2001), is appropriate for cases in which links express relations that are not alterable (or, at least, established) at the time objections are raised. We think, for instance, of relations based on trust or on insitutional arrangements.

[10]We here mean organizations adopting an egualitarian imputation rule.

prediction of minimal connections. Under negative externalities, a non complete organization - the *wheel* - turns out to possess equivalent stability properties to the complete one. The emergence of a non maximally connected architecture under negative externalities can be best understood by noting that adding links to a given organization has, in this case, two opposite effects on stability. First, a more connected structure decreases the incentives to object of each coalition, by inducing a more concentrated partition on residual players. This effect was at the basis of the prediction of the complete organization when all coalitions may raise objections. Second, additional links enlarge the set of connected coalitions (here, the only ones able to object). The resulting trade off has the wheel organization as an equilibrium point.

Related Literature

Our analysis contributes to two distinct by closely related literatures, whose object is the study of the formation of coalition structures and of networks.

With respect to the first stream of literature, we already pointed out how the consideration of an internal organization of coalitions (and, more generally, of cooperation structures) provides new and useful insights for the analysis of the equilibrium configuration of groups, mainly by allowing for a well defined and natural prediction of how residual players react to coalitional deviations. In the same spirit of the work by Demange (2001) on characteristic function games, this direction of research may allow for new results on the existence of stable coalition structures in games with externalities.

With respect to the recent and growing literature on network formation, the present analysis is a first step towards a characterization of equilibrium networks in the presence of externalities across *components*. This is a new element in the theory, traditionally based on primitives that do not allow for a treatment of such external effects.[11] Our contribution is, however, not directly comparable with the recent developments in the literature on network formation, for two main limitations present in our analysis. First, our approach neglects all efficiency issues related to the architecture of connected graphs, a limitation common to all the literature prior to Jackson and Wolinsky (1996). This limitation may be interpreted as a

[11] Myerson's (1977) approach relied on a characteristic function game. Although Jackson and Wolisky's formulation in, in principle, not incomplatible with externalities, their assumption of component additivity, maintained in all following papers, rules out this possibility. This assumption is maintained in all the following literature (see, for instance, Dutta and Mutuswami (1997) and Currarini and Morelli (2000), with the sole exeption of Mutuswami and Winter (2000).

restriction of the cooperative problems covered by our analysis, ruling out important features of network formation such as costs in establishing and maintaining links or congestion in connections; alternatively, we may view the present approach as a way of isolating the effect of different signs of the externality on the organizational structure of groups, that would, in a more general framework, be endogenously determined also by efficiency considerations.

The second limitation implicit in our approach is related to the employed stability concept, ruling out the possibility of players to alter the existing organizational structure in order to induce more favorable payoff imputations, except for the specific case of the component wise egalitarian imputation rule, treated in Section 3.2 and 3.3. On such incentives to alter maintained links without separating from the group, build most recent works on network formation, including Aumann and Myerson (1988), Qin (1996), Dutta et al. (1998), Jackson and Wolinsky (1996), Dutta and Mutuswami (1997) and Currarini and Morelli (2000). For general imputation rules, our results should be therefore interpreted as an assessment of the stability properties of alternative connected network structures imposed on (or adopted by) existing groups, and not alterable by the group's members, in the same spirit as Greenberg and Weber (1993) and Demange (2001).

The rest of the paper is organized as follows. Section 2 introduces graph theoretic concepts and definitions, and presents the employed concepts of stability. Section 3 contains our main results. Section 4 concludes the paper and discusses directions for further research.

2 Concepts and Notation

This section introduces the main tools of analysis of the paper. We first define a graph, describing the set of all bilateral relationships established by agents in the system. We then discuss how a graph identifies equivalence classes of players that can be interpreted as groups, each characterized by a specific internal organization. We then describe how value is produced in the system as a function of the groups that are formed, and how this value in imputed to individual agents. Finally, we define the stability concepts that will be used in the analysis of section 4.

2.1 Graphs

We consider a set of players $N = \{1, 2, ..i, .., n\}$. Players can communicate by means of bilateral relations, or "links"; we denote a link between i and j by ij. A simple non directed *graph* $g = (N(g), L(g))$ describes the set of links between pairs of players in the set $N(g)$ (vertex set). When possible, we will use the notation $ij \in g = (N(g), L(g))$ meaning that $\{ij\} \in N(g)$ and $ij \in L(g)$. We denote by G^S the set of all possible graphs with vertex set S, for all $S \subseteq N$. When the set of vertices is left unspecified, it is understood to be N. Given the graph $g = (N(g), L(g))$, we also denote by $L_S(g)$ the set of those links in L that have at least one endpoint in the set of vertices S:

$$L_S(g) = \{ij \in L : \{i, j\} \cap S \neq \emptyset\}.$$

We say that the graph $g' = (N(g'), L(g'))$ is a *subgraph* of $g = (N(g), L(g))$ if $N(g') \subseteq N(g)$ and $L(g') \subseteq L(g)$; we use the notation $g' \subseteq g$ for the specific case in which g' is a subgraph of g and $N(g') = N(g)$. Particular subgraphs of $g \in G^N$ are the graph $g \backslash S = (N \backslash S, L \backslash L_S(g))$ obtained by deleting the set of vertices S from g, and the graph $(g - S) = (N, L \backslash L_g(S))$ obtained by deleting all links incident to players in S. Note that $g \backslash S$ has $(n-s)$ vertices, while $(g - S)$ has n vertices.

We say that two graphs g and g' are homeomorphic if we can obtain g from g' by relabelling the vertices of g and accordingly changing its links. We will refer to an "architecture" as to an homeomorphism class of graphs.

2.2 Connectedness and Organizations

In this paper we are primarily interested in how graphs identify the set of organizations that emerge in the system. In order to do it, we need to introduce the concept of connectedness. The set of vertices $W = \{i_1, i_2, ..., i_m\}$ such that $i_k i_{k+1} \in g$ for all $k = 1, 2, ..., m-1$ is called a *walk* and is said to connect vertices i_1 and i_m in g. If $i_k \neq j_{k+1}$ for all $k \in \{1, 2, ..., m-1\}$, then W is a *path* if $i_1 \neq j_m$, and W is a cycle if $i_1 = j_m$.

The graph g is *connected* if for each pair of vertices in $N(g)$ there is a connecting path. For short, we refer to the connected graph g as an *organization*, made of a group of agents $N(g)$ and of an organizational structure given by the set $L(g)$. We say that the subset of vertices $S \subset N(g)$ is connected in g if for each pair of vertices in S there is a connecting path in g. We denote by $\mathbf{S}^c(g)$ the set of subsets of vertices of g that are connected in g.

A *component* h of the graph g is a maximal connected subgraph of g.[12] We denote by $C(g)$ the set of components of g. The components of g are the equivalence classes of the connectedness relation induced by g on N. We can therefore use the set $C(g)$ to associate with each graph g a unique partition $\pi(g)$ of the set of players $N(g)$:

$$\pi(g) = \{S \subseteq N(g) : S = N(h) \text{ and } h \in C(g)\}.$$

Note that the graph g induces a unique collection of organizations. Also, for each possible coalitions structure π on N there exist many graphs g such that $\pi(g) = \pi$, and that all connected graphs g yield $\pi(g) = \{N\}$. All connected graphs are therefore representative of situations in which the grand coalition forms, although each of them specifies a different organizational structure. Three specific connected architectures will be studied.

Definition 1 *The star architecture has one central vertex c, linked to all other $n-1$ vertices, and no other link.*

Definition 2 *The wheel architecture has n links and a unique cycle going through all vertices.*

Definition 3 *The complete architecture has all links between all pairs all vertices*

We will denote by g^s, g^w and g^N graphs with the star, wheel and complete architectures, respectively.

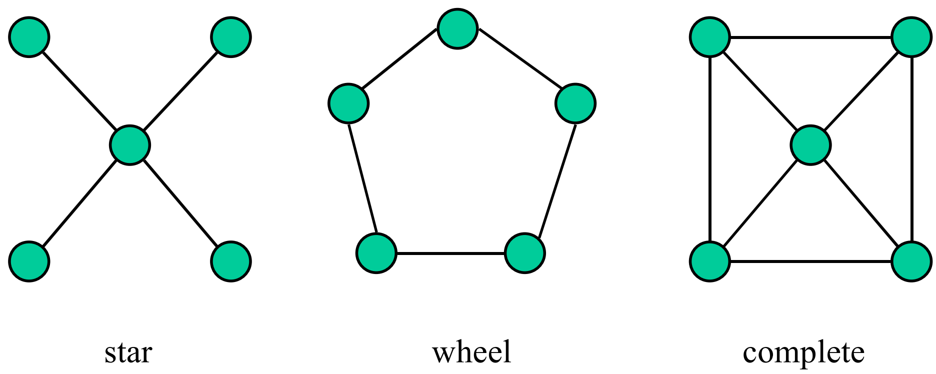

Figure 1: Architectures

The following definition refer to the consequences of the deletion of subsets of vertices from a graph, and will extensively used in the stability analysis of sections 3 and 4.

[12]A connected subgraph h is maximal if no other connected subgraph h' exists that contains h.

Definition 4 *The set of vertices S is a vertex-cut for graph g if $g\backslash S$ has more components than g. If $S = \{i\}$ is a vertex cut we say that i is a cut-vertex.*

2.3 Values

The aggregate welfare produced in the system depends on the pattern of communication established by agents. We assume that aggregate welfare only depends on the coalition structure $\pi(g)$ and not by the whole architecture of the graph g. Values are given by a *partition function* v mapping each coalition structure $\pi = \{B_1, B_2, ..., B_m\}$ for N into a vector $v(\pi) = (v_{B_1}(\pi), v_{B_2}(\pi), ..., v_{B_m}(\pi))$, where $v_{B_k}(\pi)$ denotes the aggregate payoff of coalition B_k if π emerges, for all $k = 1, 2, .., m$. Behind the use of a partition function lies the implicit assumption that it is possible to determine the payoff produced by each group within each possible coalition structure. One way to justify this assumption is to interpret the values of $v(\pi)$ as the equilibrium payoff of some normal form game played by the elements of π if π forms[13]. We denote by V the set of all partition functions.

Since the payoff of a coalition may depend on the whole coalition structure to which that coalition belongs, partition functions allow for the presence of externalities. Externalities are present when $\pi \neq \pi'$ implies that $v_S(\pi) \neq v_S(\pi')$ for some $S \in \pi$. The following definitions classify externalities in two classes.

Definition 5 *The partition π is a concentration of π' if it is possible to originate π from π' by successively moving single players from smaller to bigger coalitions. We say that π is a strict concentration of π' if π is a concentration of π' and $\pi \neq \pi'$.*[14]

Definition 6 *The partition function v exhibits* **positive externalities** *if $v_S(\pi) \geq v_S(\pi')$ whenever $\pi\backslash S$ is a concentration of $\pi'\backslash S$, with strict inequality if $\pi\backslash S$ is a strict concentration of $\pi'\backslash S$.*

Definition 7 *The partition function v exhibits* **negative externalities** *if $v_S(\pi) \leq v_S(\pi')$ whenever $\pi'\backslash S$ is a concentration of $\pi\backslash S$, with strict inequality if $\pi\backslash S$ is a strict concentration of $\pi'\backslash S$.*

[13] This interpretation was first suggested by Ichiischi (1980), and then extensively adopted in the coalition formation literature.

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

We denote by V^{+} and V^{-} the sets of all partition functions exhibiting positive and negative externalities, respectively.

2.4 Imputations

To complete our presentation of the model, we introduce an imputation rule Y, mapping pairs (g, v) into vectors in R^n. An imputation rule ex-ante specifies how the aggregate value produced by a graph is distributed among players.

Throughout the paper we will only consider rules that satisfy the following two properties.

Definition 8 *The imputation rule Y is component balanced (CB) if $\forall g, \forall v, \forall S \in \pi(g)$:*

$$\sum_{i \in S} Y_i(g, v) = v_S(\pi(g)).$$

Component balance, first defined in Jackson and Wolinsky (1996), imposes that no value be transferred across components, so that the aggregate payoff imputed to each organization is determined by the partition function v only.

The second property we assume is anonymity (AN), basically requiring that the names of the players do not matter for their payoff imputation, which depends only on their position in the architecture (we refer to Jackson and Wolinsky (1996) for a formal definition).

The simplest anonymous and component balanced imputation rule is obtained by equally sharing the value of each component among its vertices.

Definition 9 *The Component Wise Egalitarian Imputation Rule (CWE) Y^{ce} shares the value of each component equally among its vertices. Formally, for all $i \in h$ and all $h \in C(g)$:*

$$Y_i^{ce}(g, v) = \frac{v_{N(h)}(\pi(g))}{|N(h)|}.$$

2.5 Stability Concepts

In order to be a predictable outcome, an organization should have the property of not providing its members with incentives to rearrange their own links. This approach has lead to the concepts of *pairwise stable* graphs in Jackson and Wolinsky (1996), where only pairs and individual players can raise objections, and of *strongly stable* graphs in Dutta and Mutuswuami

(1997) and Jackson and van den Nouweland (2001), where any coalition can form and object to a graph.[15]

A common feature of these concepts is that in case of objection by a coalition S to a graph g, players in $N \backslash S$ maintain all their current links unchanged and do not attempt to form new ones. This assumption is indeed consistent with an interpretation of coalitional objections to graph g as coordinated deviations from some strategy profile for N inducing g in a normal form game of link formation. Strongly Stable graphs can be therefore viewed as Strong Nash Equilibria or the link formation game. In this paper we maintain this approach, and study alternative stability concepts, that differ with respect to the strategic possibilities available to objecting coalitions.[16] We define these concept for general (that is, connected as well as disconnected) graphs, although our analysis will focus on organizations, defined as connected graphs.

If all coalitions can form and revise their links in any desired way, the strong stability concept of Jackson and van den Nouweland obtains.

Definition 10 *The graph g' is* **obtainable** *from the graph g by coalition S if*

1. $ij \in g'$ *and* $ij \notin g \Rightarrow \{i, j\} \subseteq S$;

2. $ij \in g$ *and* $ij \notin g' \Rightarrow \{i, j\} \cap S \neq \emptyset$.

Definition 11 *The graph g is* **strongly stable** *with respect to (Y, v) if there exists no $S \subseteq N$ and no graph g' such that:*

1. *g' is obtainable from the graph g by coalition S;*

2. *$Y_i(g', v) > Y_i(g, v)$ for all $i \in S$.*

If objecting coalitions face the simpler binary choice of whether to stay within a group or to leave it (a natural assumption in the coalition formation literature), a weaker stability concept results.

[15] Although Dutta and Mutuswami (1997), differently from Jackson and van den Nouweland (2001) study network formation as a game in normal form, their concepts of strong stability concepts are essentially equivalent.

[16] The issue of how players outside an objecting coalition react to the objection becomes crucial when extenalities are allowed (see section 3).

Definition 12 *The graph g' is* **stand alone obtainable** *from the graph g by coalition S if $g' = g \backslash S \cup g''$ for some $g'' = (S, L)$.*

Definition 13 *The graph g is* **stand-alone stable** *with respect to (Y, v) if there exists no $S \subset N$ and graph g' such that:*

1. *g' is stand-alone obtainable from the graph g by S;*
2. *$Y_i(g', v) > Y_i(g, v)$ for all $i \in S$.*

Note that in both concepts defined above, the possibility of players to get organized in coalitions, exchange opinions about the status quo payoff imputation and look for attainable improvements is not affected by their links in the graph. However, if links describe the information flows between agents within a group, any two players that are not directly linked within an organization may be unable to take coordinated actions, unless some intermediate players connect them and agree to deliver the necessary information. If links are taken as given at the time of the objection, the formation of disconnected coalitions should be ruled out.[17]

Definition 14 *The graph g is* **c-stable** *with respect to (Y, v) if there exists no $S \subseteq N$ such that S is connected in g and no graph g' obtainable by S from g such that:*

$$Y_i(g', v) > Y_i(g, v) \ \forall i \in S.$$

3 Results

This section studies stable organizations. We first present a set of results on stand alone stability, that do not rely on any specific assumption on the imputation rule other than component balance and anonymity. We then study the structure of strongly stable and c-stable organizations for the specific case of the Component Wise Egalitarian Rule.

[17]This approach is consisten with an interpretation of links in terms of long term relationships, such as trust or insitutional relations. Compare this approach with the analysis of Greenberg and Weber (1993) and Demange (2001).

3.1 Stand Alone Stable Organizations

Under stand alone stability, coalitional objections have a simple structure, with objectors seceding from the organization, and the rest of the players (hereafter denoted "residual") maintaining their current links. It follows that if two organizations are ordered by inclusion, the same inclusion order will hold (weakly) on the graphs induced by coalitional objections on residual players. This is illustrated by Figure 2 for a 5 vertex graph g and a graph g', obtained by adding the link 45 to g. Objections raised by any coalition S including either vertices 4 or 5 (or both) induce the same graph on $N\backslash S$ from both organizations; formally, $g'\backslash S = g\backslash S$. Objections raised by any coalition S' that does not include 4 nor 5 leads to a more connected structure if raised against g' than if raised against g; formally, $g'\backslash S \subset g\backslash S$ (see Figure 2). If externalities are positive, such objections will be more profitable when raised against the organizational g' than if raised against g. If externalities are negative, the opposite will hold.

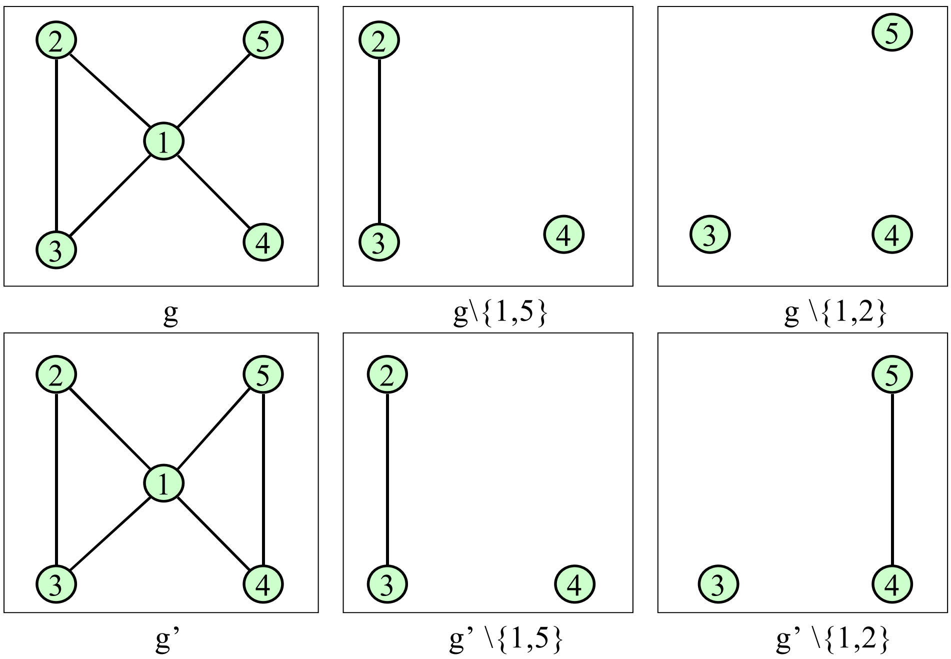

Figure 2: Effects of coalitional objections on two graphs ordered by inclusion.

In the next propositions this argument is used to show that minimal incentives to object are provided by minimally connected organizations under positive externalities, and by the complete organization under negative externalities.

Proposition 1 *Let $v \in V^+$. Let g be a stand alone stable organization w.r.t. (Y, v). There exists an imputation rule Y' such that all organizations g' such that $g' \subset g$ are stand alone stable w.r.t. (Y', v). If $Y = Y^{ce}$ then $Y' = Y^{ce}$.*

Proposition 2 *Let $v \in V^-$. Let g be a stand alone stable organization w.r.t. (Y, v). There exists an imputation rule Y' such that all organizations g' such that $g \subset g'$ are stand alone stable w.r.t. (Y', v). If $Y = Y^{ce}$ then $Y' = Y^{ce}$.*

The above results imply the following facts:

1) for each minimally connected organization g there exists a function $v_g \in V^+$ for which g is stable with respect to v_g but no organization including g is;

2) there exists a function $v \in V^-$ for which the complete organization is stable with respect to v and such that all non complete organizations are not.

These result abstract from all efficiency issues related to the organizational structure[18]. Accounting for such issues would provide agents with additional, and possibly opposite, incentive to delete and sever links. These additional incentive may well lead to different organizations from those predicted here. Nevertheless, our results highlight a clear-cut effect of the sign of the externality faced by coalitional members on the structure of the adopted organization. In particular, positive externalities favor the stability of groups with a low degree of cohesion, while negative favor the formation of more intense relationships and more cohesive groups.

3.2 Egalitarian Strongly Stable Organizations

The results of propositions 1 and 2 do not in general extend to the strong stability concept, as the following example shows.

Example 1 *Let $g \subset g'$ be as in Figure 2. Consider the graphs that player 1 can obtain from graphs g and g' by deleting his links with players 2 and 3. If $Y_1(v, g\backslash\{2,3\}) > Y_1(v, g'\backslash\{2,3\})$, player 1 has more incentives to raise this particular objection to the graph g than g', although $g \subset g'$. Note that since player 1 is central with respect to 4 and 5 in the three-vertex star graph $g\backslash\{2,3\}$, while he is symmetric to these players in $Y_1(g'\backslash\{2,3\})$, the assumption that*

[18] Such issues are considered by Jackson and Wolinsky (1996), and by almost all the following literature.

$Y_1(g\backslash\{2,3\}) > Y_1(g'\backslash\{2,3\})$ *is not unreasonable (it is indeed consistent with the axiom of the Myerson rule). The argument follows by noting that if* $Y_1(v, g'\backslash\{2,3\}) = Y_1(v, g') \geq Y_1(v, g)$*, then* g *is not strongly stable even if* g' *is.*

The failure of proposition 1 in example 1 is related to the role of the imputation rule Y. Given Y, player 1 has an incentive to separate from players 2 and 3, forcing players 4 and 5 to remain connected with him and to end up worse off. This opportunity arises as a consequence of the additional links from g to g', invalidating proposition 1. A crucial property of Y in this example is that player 1 is imputed a higher payoff than 2 and 3 after the objection to g. If Y assigned an equal payoff to these three players before and after player 1's objection, the incentives of these three players would be aligned, replicating the incentives of coalition $\{1, 4, 5\}$ in the case of stand alone stability. This fact is formally established in the following lemma, showing that strong stability and stand alone stability are equivalent concepts under the CWE rule (proof in the appendix).

Lemma 1 *The organization* g *is strongly stable (c-stable) w.r.t.* (Y^{ce}, v) *if and only if there exists no coalition* S *(connected coalition* S *in* g*) and graph* g' *such that* g' *is stand alone obtainable from* g *by* S *and, for all* $i \in S$*,*

$$Y_i^{ce}(g\backslash S \cup g', v) > Y_i^{ce}(g, v).$$

Remark 1 *The results of propositions 1 and 2 extend to the strong stability concept when the adopted imputation rule is the CWE.*

The next propositions shows, however, that the extreme symmetry introduced by the adoption of the CWE rule leads to the result that the internal organization of a group is immaterial for its strong stability under positive externalities.

Proposition 3 *Let* $v \in V^+$*. For any pair of organizations* g *and* g'*,* g *is Strongly Stable w.r.t.* (Y^{ce}, v) *if and only if* g' *is Strongly Stable w.r.t.* (Y^{ce}, v)*.*

We can rephrase the above result by saying that under the CWE rule, the internal organization of a group cannot be determined on the sole basis of the effect of positive externalities on the profitability of objections. Note that this also applies to graphs which are ordered by inclusion, such as g and g' in Figure 2. Here, although coalition $N\backslash\{4,5\}$ has more incentives to deviate against g' than against g, still we can find a 3 player coalition that would face equivalently high incentives when deviating from g (in this case, such coalition may be $\{2, 3, 4\}$). Since all 3 players coalition get the same payoff in both graphs, it follows that if g is strongly stable, so is g', despite the fact that the latter provides more incentives to object to some of the possible coalitions.

We finally remark how, by Step 2 in the proof of proposition 3 (showing that for all possible coalitional sizes, there is at least one coalition that would, by objecting, leave the group compact), the conditions for the strong stability of any arbitrary organization are the same as those required for the grandcoalition to be a strong Nash equilibrium of the Δ game by Hart and Kurz (1983).

3.3 Egalitarian C-stable Organizations

The indeterminacy result of proposition 3 was driven by the extreme symmetry induced by the adoption of an egalitarian imputation rule, jointly with the assumption of unconstrained coalition formation intrinsic in the strong stability concept. This section shows that once this symmetry is broken by limiting the objecting power to connected coalitions, the indeterminacy disappears[19] and two specific architectures - the *star* under positive externalities and the *wheel* under negative - minimize the incentives to object of all admissable coalitions.

3.3.1 The Star Organization

We remind the definition of the star architecture.

Definition 15 *The star architecture has one central vertex c, linked to all other* $n-1$ *vertices, and no other link.*

We first discuss the structural properties of the star architecture, on which our results are based. Note first that the set of coalitions that are connected in a star architecture only contains either single vertices or subsets of vertices that include the central vertex. Thus, all non trivial coalitional objections to a star organization induce non coalitional members to split up and remain singletons. This reaction is the least profitable for objectors under positive externalities, and the most profitable under negative. Objection by individual members, in

[19]Technically, the property proved in Step 2 of proposition 3 does not hold if only connected coalitions are considered. In the star graph, for instance, there is no connected set of two or more vertices that, if removed, leave all the other vertices connected.

contrast, induce, if raised by peripheral players, a connected graph on the other players - the most profitable situation under positive externalities. In this case, however, a simple graph theoretic fact, stating that every graph has at least two non cut vertices (see the footnote to the proof of proposition 1), implies that such deviations cannot be more profitable than those raised by a non cut vertex to any arbitrary organization. These arguments are used to develop the following propositions, whose detailed proofs are given in the appendix.

Proposition 4 *Let $v \in V^{+}$. If the star organization is not c-stable w.r.t. (Y^{ce}, v) then no c-stable organization w.r.t. (Y^{ce}, v) exists. Moreover, for all other organizations g there exists a value function $v_g \in V^{+}$ such that although the star organization is c-stable w.r.t. (Y^{ce}, v_g), g is not.*

We obtain the following corollary.

Corollary 1 *The organization g is the unique c-stable organization w.r.t. (Y^{ce}, v) for at least one $v \in V^{+}$ if and only if g has the star architecture.*

Since the star graph is minimally connected, the result of proposition 4 refines the prediction obtained in proposition 1 for the case of stand alone stability. Unlike all other minimally connected organizations, the star has the property that each (connected) coalitional deviation leads to the disintegration of the group, thus minimizing the incentives of objectors to free ride on the beneficial effects of positive externalities. The next proposition establishes that, under negative externalities, the star organization has opposite properties, providing connected coalitions with maximal incentive to object.

Proposition 5 *Let $v \in V^{-}$. If the star organization is c-stable w.r.t. (Y^{ce}, v) then all organizations are c-stable w.r.t. (Y^{ce}, v). Moreover, for all other organization g, there exists a function $v_g \in V^{-}$ such that although the g is c-stable w.r.t. (Y^{ce}, v_g), the star organization is not.*

3.3.2 The Wheel Organization

We remind the definition of the wheel architecture.

Definition 16 *The wheel architecture has n links and there is a unique cycle going through all vertices.*

We first show, in the next lemma, that the wheel and the complete architectures share equivalent c-stability properties, independently of the sign of the externalities.

Lemma 2 *Let v be an arbitrary partition function. The graph g^N is c-stable w.r.t. (Y^{ce}, v) if and only if the graph g^w is c-stable w.r.t. (Y^{ce}, v).*

As for the case of the star, the set of connected coalitions in the wheel architecture possesses special properties: each coalition S connected in g^w induces a connected subgraph $g^w \backslash S$. Therefore, the coalition structure $\pi(g^w \backslash S)$ is a concentration of every other coalition structures on the set $N \backslash S_k$. Negative externalities directly imply that all (connected) coalitional objection to g^w are (weakly) less profitable than they would be, if raised against any other organization (with the sole exception of the complete one). These arguments lead to the next propositions (see appendix for a detailed proof.).

Proposition 6 *Let $v \in V^-$. If the wheel organization is not c-stable w.r.t. (Y^{ce}, v) then no c-stable organization w.r.t. (Y^{ce}, v) exists. Moreover, if g is not complete and has not the wheel architecture, there exists a function $v^g \in V^-$ such that although the wheel organization is c-stable w.r.t. (Y^{ce}, v^g) , g is not.*

We obtain the following corollary.

Corollary 2 *The organization g is the unique c-stable organization w.r.t. (Y^{ce}, v) for at least one $v \in V^-$ if and only if g has either the complete or the wheel architecture.*

Unlike the case of positive externalities, here the restriction to connected coalitions does not act as a refinement of the result obtained proposition 6 for stand alone stability (selecting the complete graph). The emergence of the wheel architecture can be explained in terms of the effect of additional links on the c-stability properties of an organization. As in proposition 6, the increased connectedness of non coalitional members decreases the profitability of each objection. However, additional links have also the effect of enlarging the set of coalitions that are connected in the organization, and thereby capable to object. These two opposite effects generate a trade-off, whose equilibrium point is the wheel organization, sharing the same property as the complete one (and no other) of inducing a connected reaction of non coalitional members to each objection by a connected coalition.

The next proposition shows how these same properties of the wheel and complete organizations provide, in the opposite case of negative externalities, connected coalitions with maximal incentive to object.

Proposition 7 *Let $v \in V^{+}$. If the wheel organization is c-stable w.r.t. (Y^{ce}, v) then every organization is c-stable w.r.t. (Y^{ce}, v). Moreover, if g is not complete and has not the wheel architecture, there exists a function $v^{g} \in V^{+}$ such that although g is c-stable w.r.t. (Y^{ce}, v^{g}), the wheel organization is not.*

We finally remark that both the star and the wheel architectures have been shown to play an important role in other contexts of network formation (see, for instance, Bala and Goyal (2000)). These architectures possess opposite hierarchical characteristics. The star graph is a vertical and centralized structure, with one agent processing all the information within the organization. The wheel and complete graphs are, in contrast, two egalitarian and horizontal organizations, representing the minimally and the maximally connected *regular* organizations.

4 Concluding Remarks

This paper explores the possibility that the presence of welfare externalities across groups can be among the determinants of their internal organization. Referring to the classes of "positive" and "negative" externalities, we look at the organizations that minimize the incentives of their members to raise objections under either sign of the external effect. We find that, abstracting from the well known efficiency issues related to the choice of an organization, positive externalities favor the adoption of dispersed organizations, characterized by few connections between their members, while negative externalities favor the formation of more cohesive structures. We also show that if connectedness is needed in order to object to a group, then two specific organizations - the star and the wheel - prevail under positive and negative externalities, respectively. These structures have opposite hierarchical natures, with a "principal" in charge of all information flows in the first, and all agents placed in symmetric positions in the second. These sharp predictions are obtained for the specific case of an egalitarian imputation rule, bearing no consequence on the payoff distribution within the group.

We wish to end by discussing possible extensions and directions for future research. The idea that external effects may affect characteristics that are internal to groups is quite suggestive and new. An investigation of the properties of the class of imputation rules that guarantee stability under either type of externalities seems like an interesting development of the present paper's analysis. Our analysis has suggested that the bargaining power of each player is affected by her position in the group, to the extent that this determines the consequences of her objection on the connectedness of the group. We may therefore argue that the bargaining power of players that "connect" the group should be lower under positive externalities, since the defection of such players would disintegrate the group, neutralizing the incentives to free ride. However, such players have the "merit" of allowing the group to exist, and would be imputed, in the absence of externalities, a higher payoff by rules such as the Myerson's value. A different but strictly related open problem is that of existence of stable organizations. This problems has been addressed in games without externalities in the quoted paper by Greenberg and Weber (1986) and Demange (2001), and is object of current research for games with externalities.

APPENDIX

Proposition 1. *Let $v \in V^+$. Let g be a stand alone stable organization w.r.t. (Y, v). There exists an imputation rule Y' such that all organizations g' such that $g' \subset g$ are stand alone stable w.r.t. (Y', v). If $Y = Y^{ce}$ then $Y' = Y^{ce}$.*

Proof. Suppose that g is stand alone stable w.r.t. (Y, v). Let $g \subseteq g'$ and let Y' be such that

$$Y'_i\left(g', v\right) = Y_i\left(g, v\right) \;\; \forall i \in N. \tag{1}$$

Since g is stand alone stable w.r.t. (Y, v), for all $S \subset N$ and all graphs $g_S \in G^S$ we have:

$$\sum_{h \in C(g_S)} v_{N(h)}\left(\pi\left(g\right)\right) \leq \sum_{i \in S} Y_i\left(g, v\right) = \sum_{i \in S} Y_i\left(g', v\right). \tag{2}$$

Consider now the graph $g \backslash S \in G^{N \backslash S}$. Since $g' \subset g$ we also have $g' \backslash S \subseteq g \backslash S$. Therefore, positive externalities of v imply:

$$\sum_{j=1}^{p} v_{N(h_j)}\left(\pi\left(g'\right)\right) \leq \sum_{j=1}^{p} v_{N(h_j)}\left(\pi\left(g\right)\right). \tag{3}$$

Equations (2) and (3) imply that S cannot object to g' given (Y', v). ■

Proposition 2. *Let $v \in V^-$. Let g be a stand alone stable organization w.r.t. (Y, v). There exists an imputation rule Y' such that all organizations g' such that $g \subset g'$ are stand alone stable w.r.t. (Y', v). If $Y = Y^{ce}$ then $Y' = Y^{ce}$.*

Proof. The proof is identical to the proof of Proposition 1, noting that for all S if $g \subset g'$ then $g \backslash S \subset g' \backslash S$. ■

Lemma 1. *The organization g is strongly stable (c-stable) w.r.t. (Y^{ce}, v) iff there exists no coalition S (connected coalition S in g) and graph $g' \subset g^S$ such that for all $i \in S$*

$$Y_i^{ce}(g \backslash S \cup g', v) > Y_i^{ce}(g, v).$$

Proof. The "only if" part is trivial. We prove the "if" part for the strong stability concept. We first show that if a connected graph g is not strongly stable, then there is an objection that disconnects the objecting coalition from the graph g. Since g is not strongly stable w.r.t. (Y^{ce}, v), there exists a coalition S and a graph g' such that g' is obtainable from g by S and such that all players in S are better off at g' than at g according to (Y^{ce}, v). Letting the collection of components $\{h_1, ..., h_m\}$ denote those elements of $C(g')$ containing members of S, we have that for all $j = 1, 2, ..., m$,

$$\frac{v_{N(h_i)}\left(\pi\left(g'\right)\right)}{n\left(h_i\right)} > \frac{v\left(\pi\left(g\right)\right)}{n} = \frac{v\left(\{N\}\right)}{n}. \tag{4}$$

To show that this implies that coalition $T = \cup_{j=1}^{m} N(h_j)$, with $S \subset T$, also improves upon the graph g, note that if g' is obtainable by S from g, then it is obtainable from g by any coalition T such that $S \subset T$, by replicating the links severed and added by players in S from g to g' and leaving the links involving players in $T \backslash S$ at g unchanged in g'.

We finally prove the "if" part for the c-stability concept. If g is not c-stable, then consider coalition S, graph g' and components $\{h_1, ..., h_m\}$ as above, with condition (4). We note that since S was connected, then there exists a walk going through at least one vertex in each of the components in $\{h_1, ..., h_m\}$. But since components are themselves connected graphs, then the coalition $T = \cup_{j=1}^{m} N(h_j)$ is connected, which concludes the final part of the proof. ■

Proposition 3. *Let $v \in V^+$. For any pair of organizations g and g', g is Strongly Stable w.r.t. (Y^{ce}, v) if and only if g' is Strongly Stable w.r.t. (Y^{ce}, v).*

Proof. We proceed in 3 steps.

Step 1. By connectedness of g and g', $Y_i^{ce}(g,v) = Y_i^{ce}(g',v) = \frac{v(\{N\})}{n}$ for all $i \in N$. If g is strongly stable w.r.t. (Y^{ce}, v), then by lemma 1 we can write:

$$v_S\left(\{S, \pi\left(g \backslash S\right)\}\right) \leq s\frac{v\left(\{N\}\right)}{n} \quad \forall S \subset N. \tag{5}$$

Suppose that g' is connected and is not strongly stable w.r.t. (Y^{ce}, v). In this case there exists some T such that

$$v_T\left(T, \pi\left(g' \backslash T\right)\right) > t\frac{v\left(\{N\}\right)}{n}. \tag{6}$$

To show that (5) contradicts (6) we need to prove a fact on connectedness of graphs in Step 2.

Step 2. *If g is connected, then for all $k = 1, 2, ..., n$ we can find a set of vertices S of size k such that $g \backslash S$ is connected.*

We proceed by induction on k. For $k = 1$, let i be the endpoint of a maximal path in g (there must always exists such a path since g is connected). Since it is an endpoint, then all the vertices adjacent to i must belong to that path, which is still connected in $g \backslash i$. It follows that the graph $g \backslash i$ is connected as long as g was connected. Suppose now that the hypothesis is true for $k = m$. Then there exists a set S of size m such that $g \backslash S$ is connected. We now apply again the result of the first part of the proof to say that there exists some $i \in N \backslash S$ which is not a cut vertex for $g \backslash S$. Consider then the coalition $S \cup i$. This coalition is of size $m + 1$, and, by the fact that $(g \backslash S) \backslash i$ is connected, we conclude that $g \backslash (S \cup i)$ is connected, which proves the result.

Step 3. We use step 2 to conclude that there exists some coalition T of size t such that $g \backslash T$ is connected. By positive externalities, this implies

$$v_T\left(T, \pi\left(g \backslash T\right)\right) \geq v_T\left(T, \pi\left(g' \backslash T\right)\right). \tag{7}$$

Inequalities (5) and (7), together with the properties of the imputation rule Y^{ce}, contradict condition (6). ■

Proposition 4. *Let $v \in V^+$. If the star organization is not c-stable w.r.t. (Y^{ce}, v) then no c-stable organization w.r.t. (Y^{ce}, v) exists. Moreover, for all other organizations g there exists a value function $v_g \in V^+$ such that although the star organization is c-stable w.r.t. (Y^{ce}, v_g), g is not.*

Proof. We first show in step 1 that if there exists a connected graph g which is c-stable w.r.t. (Y^{ce}, v), then g^s is also c-stable w.r.t. (Y^{ce}, v). Steps 2 and 3 prove the second part of the proposition.

Step 1. Let g be a connected c-stable graph w.r.t. (Y^{ce}, v). For all $i \in N$:

$$Y_i^{ce}(g) \geq Y_i^{ce}(g - i). \tag{8}$$

Since there must exist at least two vertices in g which are not cut-vertices for g,[20] then (8) and the assumption that g is connected imply that for all $i \in N$:

$$Y_i^{ce}(g) \geq v_i(\{i, N \backslash i\}). \tag{9}$$

We conclude that individual deviations by $i \neq c$ cannot be profitable in g^s. By positive externalities, this also implies that individual deviations by c from g^s, inducing the empty graph on the set of vertices $N \backslash \{c\}$, cannot be profitable.

Consider now coalition S of size $s \geq 2$, and assume it is connected in g. Since g is c-stable we have

$$\sum_{i \in S} Y_i^{ce}(g) = s \frac{v(N)}{n} \geq v_S(\pi(g - S)). \tag{10}$$

For any connected coalition S' of equal size s in g^s (we know there must be at least one and it must include c), the partition $\pi(g \backslash S)$ is a concentration of $\pi(g^s \backslash S') = \emptyset^{N \backslash S'}$, so that, using (10) and positive externalities, we obtain:

$$s \frac{v(N)}{n} \geq v_S\left(\pi\left(g^s \backslash S'\right)\right). \tag{11}$$

To prove that c-stability of g implies c-stability of g^s, it suffices to show that for each connected coalition in g^s there exists a connected coalition in g of equal size. Since g is connected there must be a non cut vertex i in g such that $g \backslash i$ is a connected graph of size $n-1$ (see footnote 12). By the same argument, there must be some non cut-vertex j in $g \backslash i$, so that $g \backslash (i \cup j)$ is a connected graph of size $n-2$. And so on until size 1. So, connectedness of g implies that for each size $k = 1, 2, ..., n$, there exists a coalition S_k of size k that is connected in g.

[20] This can be easily proved as follows. Let i be the endpoint of a maximal path in g (there must always exists such a path since g is connected). Since it is an endpoint, then all the vertices adjacent to i must belong to that path, which is still connected in $g \backslash i$. It follows that the if g is connected.then graph $g \backslash i$ is connected too.

Step 2. Let $g \neq g^s$. Let v^g be such that g^s is c-stable w.r.t. (Y^{ce}, v^g) and satisfy the constraint

$$v_T^g(\pi(g^s - T)) = t\frac{v(N)}{n} \tag{12}$$

for some set of vertices T of size $t \geq 2$ which is connected in g^s. Suppose first that we can always choose T such that $g \backslash T \neq \emptyset$ (this fact is proved in step 3). Note also that $g^s \backslash T = \emptyset$ for some labelling of the set of vertices N. Positive externalities and the fact that $\pi(g \backslash T)$ is a concentration of $\pi(g^s \backslash T) = \emptyset$ imply:

$$v_T^g(\pi(g - T)) > v_T^g(\pi(g^s - T)) = t\frac{v^g(N)}{n}, \tag{13}$$

which shows that g is not c-stable with respect to (Y^{ce}, v^g).

Step 3. *For every connected graph $g \neq g^s$ there exists some connected coalition T of size bigger than one such that $g \backslash T \neq \emptyset$.*

If $g \neq g^s$ and g is connected then there exist two vertices i, j both with two incident links, that is there exist h, k and l, m such that $\{ih, ik, jl, jm\} \subset g$. Now suppose that $ij \notin g$. Since g is connected, there exists a walk going from j to either h or k or both, and this walk does not go through i. Therefore, deleting either ik or ih, respectively, leaves this walk connected, which proves the result for coalition T being either $\{i, k\}$ or $\{ih\}$, respectively. Suppose now that $ij \in g$. In this case, we can distinguish between two cases: either $j \in \{h, k\}$ or $j \notin \{h, k\}$. In the first case, suppose $j = h$: then, if $jk \in g$ we obtain a cycle with vertices i, j, k, so that the result would proved for coalition $\{ik\}$. If $jk \notin g$, then there must be some l such that $jl \in g$. In this case, the result is proved for coalition $\{ik\}$, since $jl \in g \backslash \{ik\}$. ■

Proposition 5. *Let $v \in V^-$. If the star organization is c-stable w.r.t. (Y^{ce}, v) then all organizations are c-stable w.r.t. (Y^{ce}, v). Moreover, for all other organization g, there exists a function $v_g \in V^-$ such that although the g is c-stable w.r.t. (Y^{ce}, v_g), the star organization is not.*

Proof. We prove the two parts of the proposition in separate steps.

Step 1. Let $\bar{\pi}$ denote the singletons coalition structure. If g^s is c-stable, then

$$Y_c^{ce}(g^s - c) = v_c(\bar{\pi}) \leq \frac{v(\{N\})}{n}. \tag{14}$$

By negative externalities, for all g and $i \in N$:

$$v_c(\bar{\pi}) \geq v_i(\pi(g - i)). \tag{15}$$

It follows that no player can profitably deviate from g.

Turning to coalitional deviations, note that for all $k = 1, 2, ..., n-1$ we can find a connected set of vertices S_k of size k such that $g^s \backslash S_k = \emptyset^{N \backslash S_k}$; if g^s is c-stable w.r.t. (Y^{ce}, v), then for each such coalition S_k of size k and for all partitions π_S of S_k :

$$k \frac{v(\{N\})}{n} \geq \sum_{T \in \pi_{S_k}} v_T \left(\pi_{S_k}, \bar{\pi}_{N \backslash S_k} \right), \tag{16}$$

Note finally that, by negative externalities, if S_k has size k then, for all π_S and $\pi_{N \backslash S}$,

$$\sum_{T \in \pi_{S_k}} v_T \left(\pi_{S_k}, \bar{\pi}_{N \backslash S_k} \right) \geq \sum_{T \in \pi_S} v_T \left(\pi_S, \pi_{N \backslash S} \right), \tag{17}$$

so that S_k cannot improve upon graph g for all $k = 1, 2, ..., n-1$.

Step 2. Let $g \neq g^s$. By step 3 in proposition 4, there exists a connected coalition T such that $g \backslash T \neq \emptyset$. Let $v^g \in V^-$ be such that for all set of vertices T connected in g:

$$v_T^g (\pi (g - T)) = t \frac{v^g (\{N\})}{n}. \tag{18}$$

Consider g^s and let its central player c belong to T. By negative externalities:

$$t \frac{v^g (\{N\})}{n} = v_T^g (\pi (g - T)) < v_T^g (\pi (g^s - T)), \tag{19}$$

which proves that g^s is not c-stable w.r.t. (Y^{ce}, v^g). ■

Lemma 2. *Let $v \in V$. The graph g^N is c-stable w.r.t. (Y^{ce}, v) if and only if the graph g^w is c-stable w.r.t. (Y^{ce}, v).*

Proof. Suppose g^N is c-stable w.r.t. (Y^{ce}, v). Note that for all $S \subset N$ the set of vertices S is connected in g^N. Also, for all $S \subset N$ the graph $g^N \backslash S$ is connected. Therefore, if g^N is c-stable w.r.t. (Y^{ce}, v) we have for all $S \subset N$:

$$v_S (\{N \backslash S, S\}) \leq s \frac{v(\{N\})}{n}. \tag{20}$$

Note now that is S is a set of connected vertices in g^w then the graph $g^N \backslash S$ is connected. This implies that inequality (20) applies to such sets and g^w is c-stable.

Suppose now that g^w is c-stable w.r.t. (Y^{ce}, v). Then for all set S of connected vertices in g^w inequality (20) holds. Note also that for all $k = 1, 2, ..., n-1$ there is a set of vertices S_k of size k which is connected in g^w.. This implies that the complete graph g^N is c-stable w.r.t. (Y^{ce}, v). ■

Proposition 6. *Let $v \in V^-$. If the wheel organization is not c-stable w.r.t.* (Y^{ce}, v) *then no c-stable organization w.r.t.* (Y^{ce}, v) *exists. Moreover, if g is not complete and has not the wheel architecture, there exists a function $v^g \in V^-$ such that although the wheel organization is c-stable w.r.t.* (Y^{ce}, v^g) *, g is not.*

Proof. We prove the first part of the proposition in step 1, and the second in steps 2 and 3.

Step 1. We proceed by showing that if there exists a c-stable organization g w.r.t. (Y^{ce}, v), then there exists a wheel organization which is also c-stable w.r.t. (Y^{ce}, v).

If g is connected, then for all $k = 1, 2, ..., n$ there exists a connected coalition S_k in g of size k.[21] Since g is stable w.r.t. (Y^{ce}, v) then for all $k = 1, 2, ..., n$, and any of the associated sets S_k connected in g, we have:

$$v_{S_k}\left(\pi\left(g - S_k\right)\right) \leq k\frac{v\left(\{N\}\right)}{n}. \tag{21}$$

Consider now a wheel organization g^w. For all sets of vertices T_k connected in g^w the graph $g^w \backslash T_k$ is connected. By negative externalities this implies that if T_k is of size k, then

$$v_{T_k}\left(\pi\left(g^w - T_k\right)\right) \leq v_{S_k}\left(\pi\left(g - S_k\right)\right). \tag{22}$$

Inequalities (21) and (22) imply that g^w is c-stable.

Step 2. Consider now a non complete organization $g \neq g^w$, and suppose that g^w is stable w.r.t. (Y^{ce}, v^g) for some $v^g \in V^-$. Suppose first that we can find a set of vertices S which is connected in g and such that $g \backslash S$ is not connected. In this case, we construct v^g in order to satisfy the additional constraint:

$$v_S^g\left(\pi\left(g^w - S\right)\right) = s\frac{v^g\left(\{N\}\right)}{n}. \tag{23}$$

By negative externalities:

$$v_S^g\left(\pi\left(g - S\right)\right) > v_S^g\left(\pi\left(g^w - S\right)\right) = s\frac{v^g\left(\{N\}\right)}{n}, \tag{24}$$

[21] This can be easily shown by proving that for all $k = 1, 2, ..., n$ there exists a set of vertices S_k such that $g \backslash S_k$ is connceted. Since deleting links cannot increase the number of components of a graph, the set $N \backslash S_k$ is connected in g. We proceed by induction on k. For $k = 1$, note that since g is connected and it has a vertex i which is not a cut vertex for g, then $g \backslash i$ is connceted. The induction hypothesis is thus satisfied by $S = N \backslash i$. Suppose now the induction hypothesis holds for $k = m$ and consider the set S_m such that $g \backslash S_m$ is connceted. Since the graph $g \backslash S_m$ has a non-cut vertex j, the induction hypothesis holds for $S_m \cup j$ of size $m + 1$.

which implies that S can object to g and that g is not c-stable. We therefore just need to show that such a set S can be found. We do this in step 3.

Step 3. *For every connected but non complete graph $g \neq g^w$ there is a set of vertices S which is connected in g and such that $g \backslash S$ is not connected.*

If $g^w \nsubseteq g$, then in g there is no common cycle on which all vertices lie. By an application of the Expansion Lemma in graph theory (see for instance, Theorem 4.2.4 in West (2001), there must exist a cut vertex in g. Since single vertices are by definition connected, the result follows.

Consider then a connected but non complete graph g such that $g^w \subset g$. Let $ij \notin g$, and let P_1 and P_2 denote the two paths connecting i and j in g^w. Note that both P_1 and P_2 are connected in g, $P_1 \cap P_2 = \{i, j\}$ and that $P_1 \cup P_2 = N$.

If the set of vertices $N \backslash \{i, j\}$ is connected in g, then this set can be used to prove the result noting that $g \backslash (N \backslash \{i, j\}) = \emptyset$.

If $N \backslash \{i, j\}$ is disconnected in g, then the assumption that $g^w \subset g$ implies that there exist k, l in either P_1 or P_2 such that $kl \in g \backslash g^w$. Suppose, w.l.g., that $\{k, l\} \subset P_1$, and let, again w.l.g., k be closer[22] to i than l in P_1. Consider now the path P that coincides with P_1 between i and k and then include the link kl and coincides again with P_1 after l until j. [23] Note that $P \subset P_1$ and that $P \backslash P_1$ is nonempty, since the vertices k and l are not consecutive in P_1, so that there exist some vertex $m \in P_1$ which comes after k and before l in P_1 and that is not in P. This implies that the set of vertices P separates the sets of vertices $P_1 \backslash P$ from the set $N \backslash N P_1$, proving the result. ∎

Proposition 7. *Let $v \in V^+$. If the wheel organization is c-stable w.r.t. (Y^{ce}, v) then every organization is c-stable w.r.t. (Y^{ce}, v)..Moreover, if g is not complete and has not the wheel architecture, there exists a function $v^g \in V^+$ such that although g is c-stable w.r.t. (Y^{ce}, v^g), the wheel organization is not.*

Proof. We proceed in two separate steps, proving the first and second parts of the proposition, respectively.

Step 1. The argument is easier for the complete organization g^N, and by lemma 1 it applies to the wheel graph too. We first note that for all sets of vertices S, $g^N \backslash S$ is connected; also, all sets of vertices are connected in g^N. Therefore, if g^N is c-stable w.r.t. (Y^{ce}, v), then

[22] Distance in a graph is defined as the shortest path between two vertices.

[23] Note that it may be the case that $i = k$. In this case, however, we know that $l \neq j$.

for all $S \subset N$:

$$v_S\left(\{N \backslash S, S\}\right) \leq s\frac{v\left(\{N\}\right)}{n}. \tag{25}$$

Let now g be an arbitrary organization. Let also T be a connected set of vertices in g. By positive externalities and (25) we have:

$$v_T\left(\pi\left(g-T\right)\right) \leq v_T\left(\{N \backslash T, T\}\right) \leq t\frac{v\left(\{N\}\right)}{n}. \tag{26}$$

This implies that T cannot improve upon g, and proves the result for g^N.

Step 2. Let g be a non complete organization such that $g \neq g^w$. We construct the function $v^g \in V^+$ to satisfy all c-stability constraints for g and in addition:

$$v_T^g\left(\pi\left(g-T\right)\right) = t\frac{v^g\left(\{N\}\right)}{n}, \tag{27}$$

where T is a connected coalition in g such that $g \backslash T$ is not connected (see step 3.in proposition 6). By positive externalities we have

$$v_T^g\left(\pi\left(g-T\right)\right) < v_T^g\left(\pi\left(g^w-T\right)\right) \tag{28}$$

where g^w is constructed in such a way that T is connected in g^w (note that for each set of vertices T there exists some labelling of the set N under which T connected in g^w). Inequalities (27) and (28) imply that g^w is not c-stable. ■

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(xlii) This paper was presented at the International Workshop on "Climate Change and Mediterranean Coastal Systems: Regional Scenarios and Vulnerability Assessment" organised by the Fondazione Eni Enrico Mattei in co-operation with the Istituto Veneto di Scienze, Lettere ed Arti, Venice, December 9-10, 1999.
(xliii)This paper was presented at the International Workshop on "Voluntary Approaches, Competition and Competitiveness" organised by the Fondazione Eni Enrico Mattei within the research activities of the CAVA Network, Milan, May 25-26,2000.
(xliv) This paper was presented at the International Workshop on "Green National Accounting in Europe: Comparison of Methods and Experiences" organised by the Fondazione Eni Enrico Mattei within the Concerted Action of Environmental Valuation in Europe (EVE), Milan, March 4-7, 2000
(xlv) This paper was presented at the International Workshop on "New Ports and Urban and Regional Development. The Dynamics of Sustainability" organised by the Fondazione Eni Enrico Mattei, Venice, May 5-6, 2000.
(xlvi) This paper was presented at the Sixth Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Louvain-la-Neuve, Belgium, January 26-27, 2001
(xlvii) This paper was presented at the RICAMARE Workshop "Socioeconomic Assessments of Climate Change in the Mediterranean: Impact, Adaptation and Mitigation Co-benefits", organised by the Fondazione Eni Enrico Mattei, Milan, February 9-10, 2001
(xlviii) This paper was presented at the International Workshop "Trade and the Environment in the Perspective of the EU Enlargement ", organised by the Fondazione Eni Enrico Mattei, Milan, May 17-18, 2001
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(l) This paper was presented at the Workshop "Growth, Environmental Policies and Sustainability" organised by the Fondazione Eni Enrico Mattei, Venice, June 1, 2001
(li) This paper was presented at the Fourth Toulouse Conference on Environment and Resource Economics on "Property Rights, Institutions and Management of Environmental and Natural Resources", organised by Fondazione Eni Enrico Mattei, IDEI and INRA and sponsored by MATE, Toulouse, May 3-4, 2001
(lii) This paper was presented at the International Conference on "Economic Valuation of Environmental Goods", organised by Fondazione Eni Enrico Mattei in cooperation with CORILA, Venice, May 11, 2001
(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
(liv) This paper was presented at the Seventh Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Venice, Italy, January 11-12, 2002
(lv) This paper was presented at the First Workshop of the Concerted Action on Tradable Emission Permits (CATEP) organised by the Fondazione Eni Enrico Mattei, Venice, Italy, December 3-4, 2001
(lvi) This paper was presented at the ESF EURESCO Conference on Environmental Policy in a Global Economy "The International Dimension of Environmental Policy", organised with the collaboration of the Fondazione Eni Enrico Mattei , Acquafredda di Maratea, October 6-11, 2001.

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