EFFICIENCY AND STABILITY IN A STRATEGIC MODEL OF HEDONIC COALITIONS

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Efficiency and Stability in a Strategic Model of Hedonic Coalitions

Antoni Rubí-Barceló*

Abstract

This paper analyzes the partitioning of a society into coalitions in a setting where heterogeneous players produce private and club goods. Their preferences are hedonic and are represented by a utility function with two arguments, namely their consumptions of these two goods. The focus is on the compatibility of overall societal welfare with individual incentives to move the coalition or accept new coalition mates under alternative utility specifications and agents' productivities.

Keywords: hedonic game, coalition, individual stability, efficiency

JEL Codes: C71, A14, D20

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1 Introduction

In many social, economic, and political problems individuals organize themselves in coalitions. Examples include social clubs, communities, firms, teams, or faculties. In many of these cases, players' preferences over alternative organizations are hedonic,[1] players' utility depends only on the composition of their own coalition. This paper examines the stability and efficiency of hedonic coalitions, when each player belongs to one and only one coalition, through a model of an economy where coalitions are formed for production and consumption purposes.

Each player, endowed with a productivity that can be either high or low, contributes to the production of both private and local public goods. Then, each agent consumes the local public good (or club good) produced by the coalition to which she belongs, and the amount of private goods that results from equally splitting the aggregate production of the coalition among all its members. As a leading interpretation of this model, one can think on coalitions as faculties (or firms). What is feasible to produce for a faculty depends on the aggregate productivity of its professors (workers). Once a faculty is constituted, professors can determine the aggregate production of both club and private goods. One can think on prestige of the faculty as an illustrating example of a club good; whereas the salary can be thought as the individual's share of the aggregate private output (in this model all members of a coalition will earn the same salary).

Players' hedonic preferences are represented by an utility function which is strictly increasing in both club and private goods consumptions. The objective of the paper is to study the partitions that will emerge from the strategic interaction among self-interested agents and compare them with respect to the efficient ones. This comparison is developed under three alternative utility specifications that differ in the elasticity of substitution between the two arguments. This comparative analysis illustrates how the conflict between efficiency and stability depends on the utility specification and, in particular, on the role of the externalities generated by the club good.[2]

[1] This terminology follows Drèze and Greenberg (1980).

[2] This conflict between efficiency and stability has been largely analyzed by the literature on network

In the present paper, only individual movements are allowed, *i.e* at most one individual considers changing her coalition at a time. Such stability tests make sense if players are small relative to the size of coalitions, or if the cost of coordinating movements to form new coalitions is high. The motivational examples cited above, *e.g.* employees considering changing firms or professors considering changing universities fulfill these features. Following these examples, it is also reasonable to assume that any individual considering changing her coalition needs the acceptance of the new group. For these reasons, *Individual Stability* is used here.[3] A coalition partition is individually stable if it is immune to individual movements which benefit the moving player and do not hurt any member of the coalition she joins.[4]

Since the seminal work Drèze and Greenberg (1980), the stability of coalition partitions where players have hedonic preferences has been analyzed in a large number of papers. For example, Guesnerie and Oddou (1981), Greenberg and Weber (1986) and Demange (1994) present models with local public goods and Greenberg and Weber (1993) or Banerjee et al. (2001) introduce some sort of political interaction in the stability analysis. Other references in the formation of hedonic coalitions literature are Cechlárová and Romero-Medina (2001), Bogomolnaia and Jackson (2002), Burani and Zwicker (2003), Diamantoudi and Xue (2003), Dimitrov et al. (2004), and Dimitrov and Sung (2004). Most of these papers focus on restrictions on preferences that lead to stable coalition partitions and focus on core stability and Nash stability[5].

The two papers most closely related to the present one are Milchtaich and Winter (2002) and Watts (2007) because they both analyze a situation with heterogeneous agents. Unlike the present work, they both fix the number of groups. However, the main differences relate to the structure of preferences and

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formation. See Jackson (2003) for a complete review.

[3]This concept is based on the notion of *individually stable equilibrium* from a transferable utility game model by Drèze and Greenberg (1980), but it was modified by Bogomolnaia and Jackson (2002) to apply to the purely hedonic setting, where no allocation of goods needs to be considered.

[4]Alternatively, one may consider other equilibrium notions. For example, one could assume that an individual could only change coalition when that move is beneficial to himself, to all the members of the coalition which she joins, and also to all members of the coalition which she leaves. That meaning is embodied in the notion of *contractual individual stability* introduced by Bogomolnaia and Jackson (2002) and based on the notion of *individually stable contractual equilibrium* adapted form Drèze and Greenberg (1980). Although this is a reasonable notion in some real examples, this paper will focus on cases in which the deviation does not require consent of the members of the deviator's original coalition.

[5] Bogomolnaia and Jackson (2002) is a notable exception because they use individual and contractual stability.

the stability concept. In Milchtaich and Winter (2002) agents want to join the group that has agents who are the most similar to themselves and Watts (2007) considers two payoffs functions: the first one is increasing in the average quality of the agents in the group (as the private good consumption part in the present paper) and the second one depends on the relative status of the player within his group. Nash equilibrium is used in Milchtaich and Winter (2002) whereas Watts (2002) uses a concept similar to IS.

Haeringer (2000) and Bogomolnaia et al. (2007) also introduce heterogeneity across agents. In these cases, agents differ on their location and the analysis focus on the stability under unanimous consent, free mobility and core.

Section 2 presents some basic notation and formally defines the coalition formation game. In this part of the paper, the utility function and the stability concept are formally introduced. Section 3 presents the results, Section 4 discuss them and Section 5 concludes.

2 Model

Consider a set of players $N = \{1,...,n\}$ who carry out activities as coalitions. A *coalition* is a subset $S_k \subset N$. A *coalition partition* is a set $\Pi = \{S_k\}_{k=1}^{K}$ that partitions N. *I.e.* $S_k \subset N$ are disjoint and $\bigcup_{k=1}^{K} S_k = N$. The size of S_k is denoted by s_k. Let N_i denote the set of all possible coalitions containing player i. Given Π and i, let $S_\Pi(i)$ denote the coalition $S_k \in \Pi$ such that $i \in S_k$.

This model considers a purely hedonic setting, so individuals' preferences over possible coalition partitions are entirely determined by the coalition they belong to. Player i's preferences are represented by an order $\succeq_i$ (a complete, reflexive and transitive binary relation) over the set N_i. Let $\succ_i$ denote the associated asymmetric binary relation. A coalition formation game $(N, \succ)$ is a set of players and a profile of binary relations. Players' preferences are represented by the utility function $\tilde{u}_i : N_i \to \mathrm{R}$. Thus, player i's utility is given by $\tilde{u}_i(S_\Pi(i))$. A coalition partition Π is *efficient* if for any partition $\Pi' \neq \Pi$, $\sum_{i=1}^{n} \tilde{u}_i(S_\Pi(i)) \geq \sum_{i=1}^{n} \tilde{u}_i(S_{\Pi'}(i))$.

A coalition structure Π is *individually stable* (IS) if there do not exist a player $i \in N$ and a coalition $S_k \in \Pi \cup \{\varnothing\}$ such that

$$\tilde{u}_i(S_k \cup \{i\}) > \tilde{u}_i(S_\Pi(i)) \text{ and } \tilde{u}_j(S_k \cup \{i\}) \geq \tilde{u}_j(S_k) \text{ for all } j \in S_k .$$

Each individual i has associated an inherent value v_i. A coalition S_k can produce $\eta_{S_k} \equiv \sum_{i \in S_k} v_i$ units of output. So, each player i brings v_i units of production to her coalition; thus, v_i can be interpreted as agent i's productivity. There are two types of players: high and low productivity players, whose values are normalized to 1 and $\rho < 1$, respectively.[6] The profile of players' values v is exogenously given at the beginning of the game and common knowledge.

The aggregate production of a coalition enters each member's utility function through two different channels. On the one hand, the total output of the coalition is equally split among all members of the coalition. This can be interpreted as a dividend or salary. As such, output can be seen as a *private good*. On the other hand, the total production of a coalition is interpreted as *prestige* for its members and, as such, it can be also seen as a *club good*, *i.e.* a non-rival good which is excludable for the non-members of the coalition. In consequence, agents' utility function is $u_i(\eta_{S_k}, s_k)$.[7] This paper analyzes the conflict between efficiency and stability in three different models that differ on the elasticity of substitution between private and club goods consumptions: (Case 1) Private and club goods consumptions are perfect substitutes, (Case 2) elasticity of substitution equals 1 and (Case 3) private and club goods consumptions are perfect complements.[8] Next, these three cases are analyzed in turn. All proofs are relegated to the appendix.

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[6] Notice that ρ is allowed to take negative values. In such a case, a low productivity player is interpreted to damage aggregate production.

[7] This function is redefined to express utility as a function of the productivity and the size of the coalition. For this reason, I use $u_i(\cdot)$ instead of $\tilde{u}_i(\cdot)$.

[8] These three alternatives can be seen as three particular cases of the following CES utility function:

$$u_i(\eta_{S_k}, s_k) = (\alpha(\frac{\eta_{S_k}}{s_k})^\gamma + (1-\alpha)\eta_{S_k}^\gamma)^{\frac{1}{\gamma}}$$

where $i \in S_k$, $\alpha \in (0,1)$ and $\gamma \leq 1$. The first part of the function represents the utility from the *private good* consumption, whereas the second one represents the utility from the *club good* consumption. Elasticity of substitution between these two consumptions is $\varepsilon = 1/(1-\gamma)$. Case 1 is obtained when $\varepsilon \to \infty$; in this case the utility function converges to a linear function. When $\varepsilon = 1$ the utility function becomes a Cobb-Douglas, as in Case 2. Finally, for $\varepsilon \to 0$, the utility function converges to a Leontief function, so private and club goods are perfect complements.

3 Results

3.1 Case 1

Consider that private and club goods consumptions are perfect substitutes, so that the utility function can be written as:

$$u_i(\eta_{S_k}, s_k) = \alpha \frac{\eta_{S_k}}{s_k} + (1-\alpha)\eta_{S_k} = \eta_{S_k}(1-\alpha(1-\frac{1}{s_k}))$$

First, efficient partitions are characterized. Let Π_g denote the partition where a unique (grand) coalition contains all players.

Proposition 1 (Case 1) When $\rho \geq 0$, Π_g is the unique efficient partition. When $\rho < 0$, an efficient partition is constituted by a unique multi-player coalition S_e containing all high productivity players. Partitions with isolated low-productivity agents are efficient whenever $\eta_{S_e} \leq -\rho(s_e - 2)$. Partitions with low productivity agents in S_e are efficient whenever $\eta_{S_e} \geq -\rho(s_e - 2)$.

Next, equilibrium partitions are characterized and $\hat{\eta}_{S_h}$ is specified in the appendix.

Proposition 2 (Case 1) A partition Π is IS if the following conditions hold:

(i) All high-productivity players are members of the same coalition S_h such that $\eta_{S_h} \geq \frac{s_h}{\alpha + s_h(1-\alpha)}$.

(ii) When $\rho < 0$, players not included in S_h are isolated.

(iii) When $\rho > 0$, only one coalition S_l can coexist with S_h if $\eta_{S_h} \geq \hat{\eta}_{S_h}$; otherwise, no other coalition will coexist with S_h. When $\rho = 0$, any distribution of those lows not included in S_h is IS.

3.2 Case 2

When elasticity of substitution between private and club good consumptions is constant and equal to 1 the utility function is a Cobb-Douglas function:

$$u_i(\eta_{S_k}, s_k) = (\frac{\eta_{S_k}}{s_k})^{\alpha} \eta_{S_k}^{1-\alpha} = \eta_{S_k} (\frac{1}{s_k})^{\alpha}$$

Efficient partitions are similar to the previous case:

Proposition 3 (Case 2) When $\rho \geq 0$, Π_g is the unique efficient partition. When $\rho < 0$, an efficient partition is constituted by a unique multi-player coalition S_e containing all high productivity players. Partitions with isolated low-productivity agents are efficient whenever $\eta_{S_e} \leq \frac{\rho(1-(s_e+1)^{1-\alpha})}{(s_e+1)^{1-\alpha} - s_e^{1-\alpha}}$. Partitions with low productivity agents in S_e are efficient whenever $\eta_{S_e} \geq \frac{\rho((s_e-1)^{1-\alpha}-1)}{(s_e-1)^{1-\alpha} - s_e^{1-\alpha}}$.

Thus, in cases 1 and 2 efficiency involves to group all players with non-negative productivity into the same coalition. On the other hand, when $\rho < 0$ efficiency requires a balance between the negative and positive externalities generated by lows and highs, respectively, on their coalition mates. This balance will determine how low productivity players must be distributed in the efficient partition according to the productivity bounds specified in the statement of the Propositions 1 and 3.
IS partitions are characterized below ($\tilde{\eta}_{S_h}$ is specified in the Appendix):

Proposition 4 (Case 2) A partition Π is IS if the following conditions hold:

(i) All high-productivity players are members of the same coalition S_h such that $\eta_{S_h} \geq s_h^{\alpha}$.

(ii) When $\rho < 0$, players not included in S_h are isolated.

(iii) When $\rho > 0$, only one coalition S_l can coexist with S_h if $\eta_{S_h} \geq \tilde{\eta}_{S_h}$; otherwise, no other coalition will coexist with S_h. When $\rho = 0$, any distribution of those lows not included in S_h is IS.

In cases 1 and 2, high productivity players attract each other and consequently, they will concentrate into the same coalition S_h. Stability of Π also requires that

any member of S_h should prefer to stay in this coalition rather than alone. This involves the productivity lower bound specified by condition (i) in Propositions 2 and 4. Finally, conditions (ii) and (iii) of both Propositions focus on low productivity players not included in S_h. When $\rho < 0$, negative externalities created by low productivity players to their coalition mates trivially explain part (ii). If $\rho > 0$ low productivity players not included in S_h will take advantage of the positive productivity of others and constitute a multi-agent coalition S_l that may remain separated from S_h only if the latter coalition is sufficiently productive so that members of S_h neither want to move to S_l nor accept members of S_l. These two last requirements involve the productivity lower bound of condition (iii) in Propositions 2 and 4.

3.3 Case 3

Now it is assumed that private and club goods are perfect complements, so the utility function can be written as:

$$u_i(\eta_{S_k}, s_k) = \min\{\alpha \frac{\eta_{S_k}}{s_k}, (1-\alpha)\eta_{S_k}\}$$

In this case, efficiency results change significantly. Let a coalition S_i be of type 1 if $\eta_{S_i} \geq 0$ and $\alpha/s_i \leq 1-\alpha$. A coalition S_i is of type 2 when $\eta_{S_i} < 0$ and $\alpha/s_i \geq 1-\alpha$. Notice that in these two types of coalitions, the first piece of the utility function is binding for all their members, so that players' utility only depends on private good consumption. All the remaining coalitions are of type 3, where members' utility is entirely determined by their club good consumption.

Proposition 5 (Case 3) When $\rho \geq 0$, Π_g is efficient; moreover, a partition with only type-1 coalitions is also efficient. When $\rho < 0$, any partition with only type-1 or 2 coalitions is efficient; moreover, an efficient partition can include at most one type-3 coalition S_j with $\eta_{S_j} \in [0, -\rho)$ and $s_j \in (\frac{\alpha}{1-\alpha} - 1, \frac{\alpha}{1-\alpha}]$ as long as the remaining coalitions (if any) are of type 2.

Notice that any partition where all players' utility is determined by their private good consumption, *i.e.* all coalitions are of type 1 or 2, is efficient.

Let $\breve{\eta}_{S_h}$ and $\overline{\eta}_{S_h}$ be specified in the appendix.

Proposition 6 (Case 3) A partition Π is IS if the following conditions hold:

(i) All high-productivity agents are in a unique coalition S_h such that $\eta_{S_h} \geq \breve{\eta}_{S_h}$.

(ii) When $\rho < 0$, agents not included in S_h constitute coalitions with less than $\alpha/(1-\alpha)$ members (type-2 coalitions).

(iii) When $\rho \geq 0$, $K \geq 1$ coalitions may coexist with S_h as long as each of them is of type 1, *i.e.* each coalition does not contain less than $\alpha/(1-\alpha)$ members[9], and $\eta_{S_h} \geq \overline{\eta}_{S_h}$.

Proposition 6 shows that, unlike efficient partitions, the characterization of IS partitions does not vary significantly with respect to cases 1 and 2. The main difference with respect to the previous cases refers to the size bounds of those coalitions without high productivity players specified in parts (ii) and (iii). The reason is that now players' utility can be entirely determined by their private good consumption. In this case there will not exist public good externalities; so (1) low productivity agents can share a coalition with other lows when $\rho < 0$ and (2) more than one coalition of low productivity agents can coexist with S_h when $\rho > 0$.

4 Discussion

The combination of the efficiency and stability results in cases 1 and 2 indicates that, from an efficiency perspective, S_h will tend to contain either too few low productivity players when $\rho \geq 0$ or too many when $\rho < 0$. This illustrates how the strategic interaction among self-interested players may generate inefficiencies.

When $\rho \geq 0$, the comparison is straightforward: low productivity agents can be disseminated across two different coalitions in an IS partition whereas efficiency requires to group all agents into an unique coalition. The inefficiency of the IS

[9] When $K = 1$ this lower bound does not apply.

partition is induced by the effects of the club good consumption, which are not fully internalized by self-interested agents. For example, notice that societal welfare increases when an agent moves to a bigger coalition because more agents will take advantage of the club good production of the deviator. However, these positive external effects are not considered by the involved agents who only care about their own consumption levels. In consequence, it is plausible that they have no individual incentives to accept this modification of the original partition, leading to the commented inefficiency.

In order to interpret the role of the parameters of the model (α and ρ) on the conflict between efficiency and stability a deeper analysis is developed here. The dissemination of low productivity agents in the IS partition can be sustained because members of S_h (1) block the entrance of new members and (2) do not want to move to S_l. First, the acceptance of a new low productivity agent in S_h will increase η_{S_h} but it will also decrease the private good consumption of any former member of the coalition. So, members of S_h can block the entrance of low productivity players when (i) ρ is sufficiently low (so that the increase of η_{S_h} is small enough and the decrease of the private good consumption is sufficiently big) or/and (ii) α is sufficiently high (so that the weight of the loss of private good consumption is sufficiently high). Second, an agent moving from S_h to S_l would benefit from a high coalition size s_l,[10] but her private good consumption would decrease. Thus, stability requires that (i) s_l and ρ are sufficiently low (so that η_{S_l} is small enough) or/and (ii) α is high enough (so that the weight of the loss of private good consumption is high enough). The sign of all these effects is reflected on $\hat{\eta}_{S_h}$ and $\tilde{\eta}_{S_h}$ in the appendix.

On the other hand, when $\rho < 0$ all high productivity players concentrate into the same coalition both in the efficient and the stable partitions, whereas all low productivity agents not included in this coalition are isolated. Thus, discrepancies between efficiency and stability, if any, arise in the aggregate productivity of the multi-agent coalition (or equivalently, in the number of low productivity members of this coalition). Propositions 1 and 3 specify the minimum productivity of the multi-

[10] In fact, this agent will move only if $s_l + 1 > s_h$.

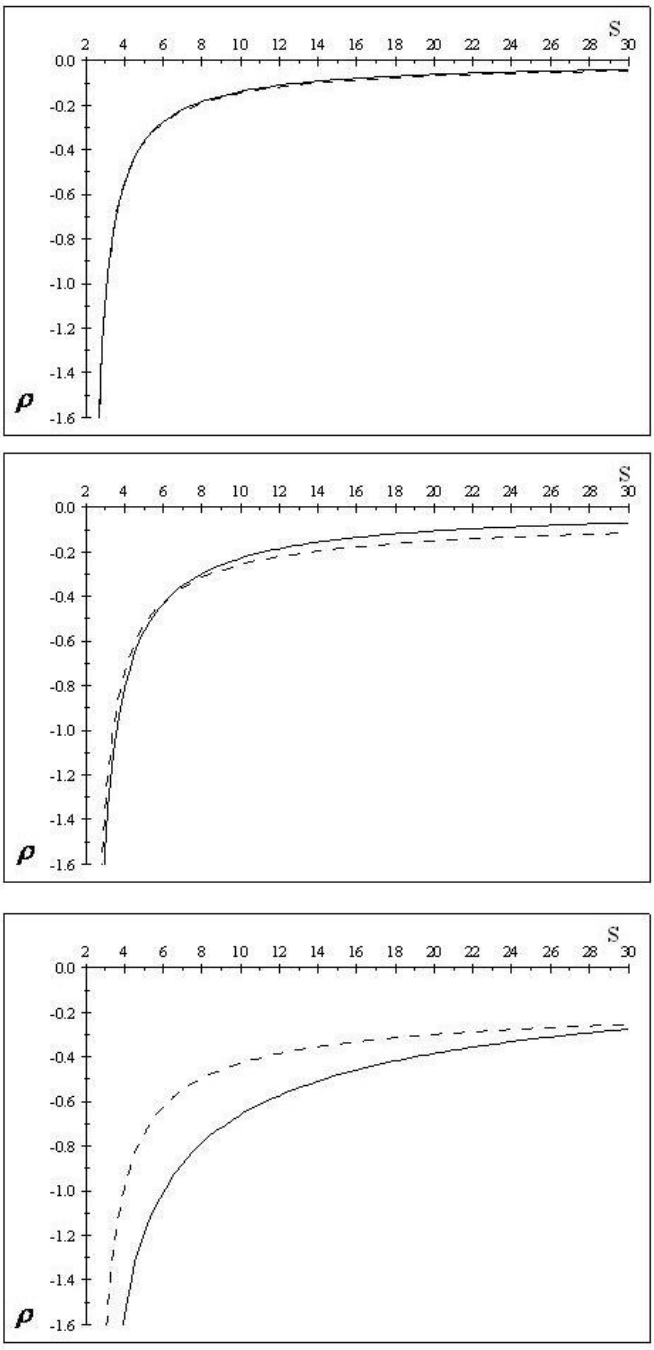
agent coalition from an efficiency viewpoint whereas part (i) of Propositions 2 and 4 detail the minimum productivity of S_h in an IS partition. By comparing these lower bounds, it can be seen that, except when $\rho > \bar{\rho}$,[11] the multi-agent coalition in the IS partition can be less productive than the efficient one, *i.e.* the number of low productivity agents in S_h can exceed the efficient level, except when the damage generated by low productivity agents is sufficiently low. The intuition behind this result is that low productivity agents generate negative effects to their coalition mates that are only partially considered by each coalition member (a particular agent does not consider the negative effects on her coalition mates) so that any particular high productivity member will decide to stay in this multi-agent coalition even though the whole society will benefit from separating highs and lows. To illustrate this point Figure 1 plots, for three particular values of α, how $\bar{\rho}$ evolves with the multi-agent coalition size, s.

[11] where

$$\bar{\rho} = \begin{cases} -\dfrac{s}{(s-2)(\alpha + s(1-\alpha))}, & \text{in case } 1; \\ -\dfrac{s^{\alpha}(s^{1-\alpha} - (s-1)^{1-\alpha})}{(s-1)^{1-\alpha} - 1}, & \text{in case } 2. \end{cases}$$

and s is the size of the multi-agent coalition.

Figure 1: $\overline{\rho}$ for cases 1 (solid line) and 2 (dashed line) when α = 0.1, 0.5, and 0.9, respectively.



For any pair (ρ, s) below the threshold represented by the curves, there exist IS partitions with an inefficiently high number of low productivity agents in the multi-agent coalition S_h. As Figure 1 shows, enlarging the multi-agent coalition widens the range of values of ρ that allow for this inefficiency. Notice also that increasing

the relative weight of private good consumption (α) narrows this range because it limits the weight of the external effects generated by the club good. Finally, note also that cases 1 and 2 present a very similar pattern.

The same results can be seen from another perspective, as the next corollary highlights.

Corollary 1 The efficient partition is IS if and only if:

• when $\rho > 0$, the number of low productivity agents in the society $L < \overline{L}$ where

$$\overline{L} = \begin{cases} \frac{n}{1-\rho}\left(1-\frac{1}{\alpha+n(1-\alpha)}\right), & in\ case\ 1; \\ \frac{n}{1-\rho}\left(1-n^{\alpha-1}\right), & in\ case\ 2. \end{cases}$$

• When $\rho < 0$, $\rho > \overline{\rho}$.

This result suggests that, in a hypothetical situation where players endogenously choose their productivity by investing in education, lowering the number of low productivity agents or increasing their productivity would allow to sustain the efficient partition as IS. A social policy reducing the costs of education would do both. A formal analysis of this argument is beyond the scope of this model and it is left for future research.

When public and private goods consumptions are perfect complements (case 3), the comparison between efficient and IS partitions shows that: (i) when $\rho < 0$ the IS partition will be efficient except when $s_h \leq \alpha/(1-\alpha)$, and (ii) when $\rho \geq 0$ the IS partition will be efficient except when S_h does not include all players and $s_h \leq \alpha/(1-\alpha)$.[12] Thus, efficiency of the IS partition requires a sufficiently high s_h. In that case, the private good consumption part of the utility function would be binding for members of S_h, so the commented distortion generated by club goods would not come into play. Consequently, the discrepancy between efficiency and stability

[12] In the appendix it is shown that a partition where S_h coexists with other coalitions can be sustained as IS only when $s_h \in [\frac{\alpha}{1-\alpha}-1, \frac{\alpha}{1-\alpha}]$ and $\eta_{S_h} \geq \max\{\frac{\alpha\rho}{(s_h+1)(1-\alpha)-\alpha}, \frac{\alpha(\rho s_l+1)}{(1-\alpha)(s_l+1)}\}$.

would vanish. In this respect, notice that a lower α, *i.e.* a lower weight of the private good consumption in players' utility, widens the intersection set between efficient and IS partitions. So, a lower α will reduce the conflict between efficiency and stability because when α decreases it is easier that private good consumption is binding and, consequently, club good consumption does not influence players' decisions.

5 Conclusion

The analysis presented here focus on the stability and efficiency of social partitions, when self-interested agents can change their coalition. The study is designed to illustrate which partitions are likely to be formed, and how this depends on the structure of preferences. Moreover, it examines the relationship between the set of efficient partitions and those which are stable to show how the intersection of these two sets is affected by preferences. To this end, the paper analyzes three utility functions that differ in the elasticity of substitution between the two arguments, namely club and private goods consumptions.

Results show the discrepancy between efficient and stable partitions in cases 1 and 2 where the elasticity of substitution between private and club goods tends to infinity and equals one, respectively. The reason why individual incentives might not lead to overall efficiency is that of externalities. In this model, they can be positive or negative depending on the sign of ρ; so the inefficiency can take two different forms, as explained in the previous section. These externalities are generated by the club good consumption, so that the tension between efficiency and stability is attenuated when the weight of public good consumption in players' utility is low (α high) or when public good consumption does not affect players' utility, as it may happen in case 3 where club and private goods consumptions are perfect complements.

The relationship between stability and efficiency of coalition structures is shown to be context dependent. It depends on the sign, size and influence of externalities.

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Appendix

Proof of Propositions 1 and 3. First, note that the hedonic nature of the game implies that modifying a partition will not modify the utility of players whose coalitions are not affected by this change.

Consider that $\rho \geq 0$. Suppose by contradiction that an efficient partition Π includes two coalitions S_1 and S_2. The aggregate marginal utility for merging S_1 and S_2 is:

Case 1

$$\Delta\omega = (1-\alpha)[\sum_{i=1,2} s_i \sum_{i=1,2} \eta_{S_i} - \sum_{i=1,2} s_i \eta_{S_i}]$$

Case 2

$$\Delta\omega = (\sum_{i=1,2} s_i)^{1-\alpha} \sum_{i=1,2} \eta_{S_i} - \sum_{i=1,2} (s_i^{1-\alpha} \eta_{S_i})]$$

Since $s_i > 0$ for any $i = 1,2$ and $\eta_{S_i} > 0$ for some $i = 1,2$,[13] then $\Delta\omega > 0$ in both cases contradicting efficiency of Π.

Consider that $\rho < 0$. The previous result implies that an efficient partition cannot include two coalitions with positive aggregate productivity. Moreover, the following lemma applies:

Lemma 1 An efficient partition cannot contain two multi-agent coalitions.

Proof Let H_{S_i} (L_{S_i}) be the number of high (low) productivity players in coalition S_i. First, I claim that an efficient partition cannot include a multi-agent coalition S_i with $\eta_{S_i} < 0$. If that was the case, the aggregate marginal utility for isolating all low productivity agents of S_i will be:

Case 1

$$\Delta\omega = (1-\alpha)(H_{S_i}^2 + \rho L_{S_i} - s_i \eta_{S_i}) \geq (1-\alpha)(\eta_{S_i}(1-s_i)) > 0$$

Case 2

$$\Delta\omega = H_{S_i}^{2-\alpha} + L_{S_i}\rho - s_i^{1-\alpha}\eta_{S_i} > \eta_{S_i}(1-s_i^{1-\alpha}) > 0$$

This contradicts efficiency.

Second, assume that an efficient partition contains two multi-agent coalitions S_1 and S_2 with $\eta_{S_i} = 0$ for any $i = 1,2$. This involves that each of S_1 and S_2 contains at least one high and one low. The aggregate marginal utility for isolating all lows and forming a coalition containing all highs is:

Case 1

$$\Delta\omega = (1-\alpha)((\sum_{i=1,2} H_{S_i})^2 + \rho \sum_{i=1,2} L_{S_i}) > 0$$

Case 2

$$\Delta\omega = H_{S_i}^{2-\alpha} + L_{S_i}\rho = H_{S_i}(H_{S_i}^{1-\alpha} - 1) > 0$$

which contradicts efficiency of that partition.

Finally, assume by contradiction that an efficient partition contains two multi-agent coalitions. The aggregate marginal utility for merging these two coalitions is:

Case 1

$$\Delta\omega = (1-\alpha)[\sum_{i=1,2} s_i \sum_{i=1,2} \eta_{S_i} - \sum_{i=1,2} s_i \eta_{S_i}] = s_1\eta_{S_2} + s_2\eta_{S_1}$$

Case 2

$$\Delta\omega = (\sum_{i=1,2} s_i)^{1-\alpha} \sum_{i=1,2} \eta_{S_i} - \sum_{i=1,2} (s_i^{1-\alpha}\eta_{S_i})]$$

Since the unique remaining possibility involves that $\eta_{S_i} > 0$ for at least one $i = 1,2$, both marginal aggregate utilities are positive, contradicting efficiency and concluding the proof ■

Therefore, all high productivity agents must concentrate into a unique coalition S_e such that $\eta_{S_e} \geq 0$. The aggregate marginal utility for isolating a low productivity agent (if any) from S_e is:

Case 1

[13] At least, there is one high productivity agent.

$$\Delta\omega = -\eta_{S_e} - \rho(s_e - 2)$$

Therefore, $\Delta\omega \leq 0$ if and only if $\eta_{S_e} \geq -\rho(s_e - 2)$.

Case 2

$$\Delta\omega = (\eta_{S_e} - \rho)(s_e - 1)^{1-\alpha} + \rho - \eta_{S_e} s_e^{1-\alpha}$$

In this case, $\Delta\omega \leq 0$ if and only if $\eta_{S_e} \geq \dfrac{\rho((s_e - 1)^{1-\alpha} - 1)}{(s_e - 1)^{1-\alpha} - s_e^{1-\alpha}}$.

Similarly, the aggregate marginal utility for adding an isolated low productivity player (if any) to S_e is:

Case 1

$$\Delta\omega = \eta_{S_e} + \rho(s_e - 2)$$

Therefore, $\Delta\omega \leq 0$ if and only if $\eta_{S_e} \leq -\rho(s_e - 2)$.

Case 2

$$\Delta\omega = (\eta_{S_e} + \rho)(s_e + 1)^{1-\alpha} - \rho - \eta_{S_e} s_e^{1-\alpha}$$

In this case, $\Delta\omega \leq 0$ if and only if $\eta_{S_e} \leq \dfrac{\rho(1 - (s_e + 1)^{1-\alpha})}{(s_e + 1)^{1-\alpha} - s_e^{1-\alpha}}$ ■

Proof of Propositions 2 and 4.

(i) By contradiction, suppose that an *IS* partition contains two (or more) coalitions S_i and S_j with high productivity members i and j, respectively. In all three cases, it is easy to see that the marginal utility of a coalition that accepts a high productivity new member cannot be negative, so:

$$u_i(\eta_{S_i} + 1, s_i + 1) \geq u_i(\eta_{S_i}, s_i)$$

and

$$u_j(\eta_{S_j} + 1, s_j + 1) \geq u_j(\eta_{S_j}, s_j).$$

In consequence, Individual Stability of Π requires that i and j do not have incentives to move to S_j or S_i, respectively. Thus, the following two conditions

must hold:

$$u_i(\eta_{S_i}, s_i) > u_i(\eta_{S_j} + 1, s_j + 1) \quad \text{(a1)}$$

and

$$u_j(\eta_{S_j}, s_j) > u_j(\eta_{S_i} + 1, s_i + 1). \quad \text{(a2)}$$

Since all players of a coalition obtain exactly the same utility, it can be concluded that:

$$u_j(\eta_{S_j}, s_j) > u_j(\eta_{S_i} + 1, s_i + 1) \geq u_i(\eta_{S_i}, s_i) > u_i(\eta_{S_j} + 1, s_j + 1) \geq u_j(\eta_{S_j}, s_j)$$

So, a contradiction is reached implying that (a1) and (a2) cannot hold simultaneously. Either i or j will have incentives to deviate. Therefore, all high productivity agents must concentrate in the same coalition, say S_h.

To avoid that high productivity agents in S_h will have incentives to isolate the following condition must hold

$$u_i(\eta_{S_h}, s_h) \geq u_i(1,1), \text{where} v_i = 1. \quad \text{(1)}$$

This inequality implies the following conditions for cases 1 and 2:

- $\eta_{S_h} \geq \dfrac{s_h}{\alpha + s_h(1-\alpha)}$
- $\eta_{S_h} \geq s_h^{\alpha}$

(ii) Condition (ii) in cases 1 and 2 is trivial.

(iii) When $\rho = 0$, the result is trivial. Consider $\rho > 0$. First, it is claimed that two coalitions S_i and S_j without highs cannot coexist in an *IS* partition. The marginal utility of the members of S_i for accepting a new low productivity member would be positive because the private good consumption would not be affected and club good consumption increases since $\rho > 0$. On the other hand, the marginal utility for the deviator $j \in S_j$ is positive whenever $\rho(s_i + 1) > \rho s_j$. For any pair of coalitions this condition will hold. Thus, in this case low productivity agents not included in S_h

must concentrate into a unique coalition, say S_l.

To conclude the proof we must finally show under which conditions can S_h and S_l coexist in equilibrium. Notice that members of S_l will always accept a high-productivity agent from S_h. On the other hand, members of S_h can either accept or reject the entrance of members of S_l. Let us analyze these two cases in turn:

- Members of S_h accept the entrance of members of S_l, *i.e.*

$$u_i(\eta_{S_h}, s_h) \leq u_i(\eta_{S_h} + \rho, s_h + 1) \tag{a3}$$

where $i \in S_h$.

Now it is claimed that if (a3) holds then stability of a partition including coalitions S_h and S_l will be violated. In consequence, (a3) cannot hold in equilibrium. By contradiction, consider that (a3) holds. If members of S_l had strict incentives to move to S_h then the partition would not be *IS*. Otherwise, the following would hold:

$$u_j(\eta_{S_h} + \rho, s_h + 1) \leq u_j(\eta_{S_l}, s_l) \tag{a4}$$

where $j \in S_l$.

Using (a3) and (a4) and given that $1 - \alpha > 0$, it can be concluded that:

$$u_i(\eta_{S_h}, s_h) \leq u_j(\eta_{S_l}, s_l) < u_j(\eta_{S_l} + 1, s_l + 1)$$

In words, high-productivity members of S_h would have incentives to move to S_l. Since members of S_l always accept high-productivity members, the partition constituted by S_h and S_l can be sustained as *IS* only if (a3) does not hold. In other words, this partition can be *IS* only if the following condition holds:

$$u_i(\eta_{S_h}, s_h) > u_i(\eta_{S_h} + \rho, s_h + 1) \tag{a5}$$

- Members of S_h do not accept the entrance of members of S_l. In this case, the unique possibility of deviation is that members of S_h move to S_l. This will not happen when the following condition holds:

$$u_i(\eta_{S_h}, s_h) > u_i(\eta_{S_l}+1, s_l+1) \qquad \text{(a6)}$$

Consequently, only if conditions (a5) and (a6) hold S_h and S_l can coexist in an *IS* partition.

These two requirements (a5 and a6) can only be satisfied if the following conditions hold:

$$- \ \eta_{S_h} > \hat{\eta}_{S_h} = \max\left\{\begin{array}{l} s_h\rho(1+(s_h+1)\dfrac{1-\alpha}{\alpha}), \\ (\rho s_l+1)(\dfrac{\alpha}{s_l+1}+1-\alpha)(\dfrac{\alpha}{s_h}+1-\alpha)^{-1} \end{array}\right\}$$

$$- \ \eta_{S_h} > \tilde{\eta}_{S_h} = \max\left\{\begin{array}{l} \rho((1+\dfrac{1}{s_h})^{\alpha}-1)^{-1}, \\ (\rho s_l+1)(\dfrac{s_h}{s_l+1})^{\alpha} \end{array}\right\} \ \blacksquare$$

Proof of Proposition 5. First consider that $\rho \geq 0$. Notice that by merging two (or more) coalitions the relative value of the first piece of the utility function becomes smaller with respect to the second one. Consequently, by merging two coalitions the binding piece of the utility of the involved agents can move from the second to the first one but not conversely. Next, it is proved that merging two coalitions always improves efficiency, except when all coalitions are of type 1 in which case the aggregate utility does not change. Therefore, Π_g and any partition with only type-1 coalitions are efficient.

Let us analyze the alternative cases in turn. If two type-3 coalitions merge, the second piece of the utility function is binding for all their members, and the resulting coalition is also type-3 then aggregate utility will increase.[14] On the other hand, merging two coalitions S_1 and S_2 such that $\alpha/s_i \geq 1-\alpha$ for some $i=1,2$ into a unique coalition S_t such that $\alpha/s_t \leq 1-\alpha$ also improves efficiency because the aggregate marginal utility would be:

$$\Delta\omega > s_1(\alpha\frac{\eta_{S_t}}{s_t}-\alpha\frac{\eta_{S_1}}{s_1})+s_2(\alpha\frac{\eta_{S_t}}{s_t}-\alpha\frac{\eta_{S_2}}{s_2})=0$$

[14]Except the non-generic case where $\rho=0$ and there is not any high type player in any of the two

Finally, if the first part of the utility function is binding for both coalitions' members, *i.e.* both are of type 1, the merged coalition will still be type 1 and aggregate utility will not change.

Consider that $\rho < 0$. The same argument used before can be applied here to demonstrate that type-1 and 2 coalitions can coexist in an efficient partition. The following two lemmas analyze the remaining possibilities.

Lemma 2 A type-3 coalition S_t with $\eta_{S_t} < 0$ cannot be part of an efficient partition.

Proof. Isolating a low productivity agent from S_t generates the aggregate marginal utility:

$$\Delta\omega = (s_t - 1)(A - (1-\alpha)\eta_{S_t}) + (B - (1-\alpha)\eta_{S_t})$$

where

- $(A,B) = \left\{ \begin{array}{ll} (\alpha\dfrac{\eta_{S_t} - \rho}{s_t - 1}, \alpha\rho), & if\ 1-\alpha \in (\dfrac{\alpha}{s_t}, \dfrac{\alpha}{s_t - 1}]; \\ ((1-\alpha)(\eta_{S_t} - \rho), \alpha\rho), & if\ 1-\alpha \in (\dfrac{\alpha}{s_t - 1}, \alpha]; \\ ((1-\alpha)(\eta_{S_t} - \rho), (1-\alpha)\rho), & if\ 1-\alpha > \alpha. \end{array} \right\}$ if $\eta_{S_t} \leq \rho$ and

- $(A,B) = \left\{ \begin{array}{ll} ((1-\alpha)(\eta_{S_t} - \rho), \alpha\rho), & if\ 1-\alpha \in (\dfrac{\alpha}{s_t}, \dfrac{\alpha}{s_t - 1}]; \\ (\alpha\dfrac{\eta_{S_t} - \rho}{s_t - 1}, \alpha\rho), & if\ 1-\alpha \in (\dfrac{\alpha}{s_t - 1}, \alpha]; \\ (\alpha\dfrac{\eta_{S_t} - \rho}{s_t - 1}, (1-\alpha)\rho), & if\ 1-\alpha > \alpha. \end{array} \right\}$ if $\eta_{S_t} \in (\rho, 0)$

After some algebra it is easy to show that $\Delta\omega > 0$ in all these cases ■

Lemma 3 Consider that S_j is a type-3 coalition. An efficient partition cannot include a pair of coalitions S_i and S_j when:

(i) S_i is a type-1 or type-3 coalition or

coalitions. This case cannot hold for any pair of coalitions because there is some high type player.

(ii) S_i is a type-2 coalition unless $\eta_{S_j} \in [0,-\rho)$ and $1-\alpha \in (\frac{\alpha}{s_j+1}, \frac{\alpha}{s_j}]$.

Proof. By the previous lemma $\eta_{S_j} \geq 0$. Since S_j is a type-3 coalition, $\alpha/s_j \geq 1-\alpha$.

First, consider that S_i is a type-1 coalition. Then, the aggregate marginal utility for merging S_i and S_j into a unique coalition S_t is:

$$\Delta\omega = s_i(\alpha\frac{\eta_{S_t}}{s_t} - \alpha\frac{\eta_{S_i}}{s_i}) + s_j(\alpha\frac{\eta_{S_t}}{s_t} - (1-\alpha)\eta_{S_j}) > 0 \qquad (*)$$

Second, consider that S_i is a type-3 coalition. By the previous lemma it must be that $\eta_{S_i} \geq 0$ and $\alpha/s_i \geq 1-\alpha$. As showed at the beginning of this proof, merging S_i and S_j improves efficiency.

Third, consider that S_i is a type-2 coalition. Aggregate marginal utility for merging S_i and S_j into a unique coalition S_t is given by (*) if $\eta_{S_t} \geq 0$ and $\alpha/s_t \leq 1-\alpha$ or $\eta_{S_t} < 0$ and $\alpha/s_t \geq 1-\alpha$. If $\eta_{S_t} \geq 0$ and $\alpha/s_t > 1-\alpha$ then aggregate marginal utility for merging S_i and S_j into a unique coalition S_t is:

$$\Delta\omega = s_i((1-\alpha)\eta_{S_t} - \alpha\frac{\eta_{S_i}}{s_i}) + s_j((1-\alpha)\eta_{S_t} - (1-\alpha)\eta_{S_j}) > 0$$

Finally, consider that $\eta_{S_t} \leq 0$ and $\alpha/s_t < 1-\alpha$. Isolating a low productivity agent from S_i does not affect aggregate utility. This isolated low productivity agent constitutes a type-2 coalition himself since $\alpha/s_i \geq 1-\alpha$ involves $\alpha \geq 1-\alpha$. Thus, merging this type-2 coalition and S_j will improve efficiency as soon as $\eta_{S_j} + \rho \geq 0$ or $\eta_{S_j} + \rho < 0$ and $\alpha/(s_j+1) \geq 1-\alpha$, as previously shown. Thus, efficiency of the original partition with S_i and S_j requires that $\eta_{S_j} < -\rho$ and $\alpha/(s_j+1) < 1-\alpha$. Adding the requirement from the previous lemma we have that $\eta_{S_j} \in [0,-\rho)$ and $s_j \in (\frac{\alpha}{1-\alpha}-1, \frac{\alpha}{1-\alpha}]$ ■ ■

Proof of Proposition 6

(i) Part (i) of the proof of Propositions 2 and 4 also applies here. Inequality (1) implies:

$$\eta_{S_h} \geq \breve{\eta}_{S_h} = \begin{cases} 1, & if\ s_h \leq \alpha/(1-\alpha); \\ s_h \min\{(1-\alpha)/\alpha, 1\}, & if\ s_h > \alpha/(1-\alpha). \end{cases}$$

(ii) Consider $\rho < 0$. When $s_i \geq \alpha/(1-\alpha)$ and S_i does not contain any high productivity member, notice that the second piece of the utility is binding, thus the marginal utility of an agent $i \in S_i$ for isolating is:

$$\Delta u_i = \begin{cases} \alpha\rho(1 - s_i \dfrac{1-\alpha}{\alpha}), & if\ \alpha \geq 1-\alpha; \\ (1-\alpha)\rho(1-s_i), & if\ \alpha < 1-\alpha. \end{cases}$$

which is positive in both cases. When $s_i < \alpha/(1-\alpha)$, the marginal utility of this deviation is zero. Moreover, if $s_j < \alpha/(1-\alpha)$ for any S_j without high productivity members, no low productivity agent j will have strict incentives to move to another coalition $S_i \neq S_j$ without highs because j's marginal utility is:

$$\Delta u_j = \begin{cases} 0, & if\ \alpha \geq (1-\alpha)(s_i+1); \\ \alpha\rho((s_i+1)\dfrac{1-\alpha}{\alpha} - 1) < 0, & if\ \alpha < (1-\alpha)(s_i+1). \end{cases}$$

Finally, members of S_h do not have incentives to accept low productivity new members. Thus, in this case, a partition constituted by S_h and coalitions with less than $\alpha/(1-\alpha)$ members is *IS*.

(iii) Let consider that $\rho \geq 0$. Now, it is claimed that apart from S_h, $K > 1$ coalitions can coexist as long as each of them contains more than $\alpha/(1-\alpha)$ members. To prove this claim by contradiction, assume that there are (at least) two coalitions S_i

and S_j such that $s_i \leq s_j$ and $s_i \leq \alpha/(1-\alpha)$. In such a case, a member of S_i, say i, can profitably deviate by moving to S_j because:

$$\Delta u_i = \begin{cases} (1-\alpha)\rho(s_j+1-s_i) > 0, & if\ s_j+1 \leq \alpha/(1-\alpha); \\ \alpha\rho(1-\frac{1-\alpha}{\alpha}s_i) > 0, & if\ s_j+1 > \alpha/(1-\alpha). \end{cases}$$

And members of S_j cannot be worse off by accepting i as a new member because (1) the utility obtained from the private good consumption by the members of a coalition without highs cannot decrease and (2) the utility from the club good consumption can only increase when $\rho \geq 0$. Therefore, coalitions without highs must have more than $\alpha/(1-\alpha)$ members.

To conclude the proof we must finally show under which conditions can S_h coexist with coalitions without highs in equilibrium. Let S_l denote the smallest of these coalitions without highs. At this point, the last part of point (iii) of the proof of Propositions (2) and (4) also applies. In consequence, only if conditions (a5) and (a6) hold S_h and S_l can coexist in an *IS* partition.

These two requirements (a5 and a6) can only be satisfied if $s_h \geq \frac{\alpha}{1-\alpha} - 1$ and $\eta_{S_h} > \overline{\eta}_{S_h}$, where $\overline{\eta}_{S_h}$ is specified below:

$$\overline{\eta}_{S_h} = \begin{cases} \frac{s_h}{s_l+1}(\rho s_l + 1) & , if\ s_h > \alpha/(1-\alpha); \\ \max\left\{ \begin{array}{l} \alpha\rho((s_h+1)(1-\alpha)-\alpha)^{-1}, \\ \frac{\alpha(\rho s_l+1)}{(1-\alpha)(s_l+1)} \end{array} \right\} & , otherwise. \end{cases}$$

Since $\frac{\partial \overline{\eta}_{S_h}}{\partial s_l} < 0$, if these inequalities hold for the smallest coalition without highs, they will also hold for the rest ■

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