A Non-cooperative Foundation of Core-Stability in Positive Externality NTU-Coalition Games

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Summary

We identify the core as an appealing stability concept of cooperative game theory, but argue that the non-cooperative approach has conceptual advantages in the context of economic problems with externalities. Therefore, we derive a non-cooperative foundation of core-stability for positive externality NTU-games. First, in the spirit of Hart/Kurz (1983), we develop a game that we call H-game and show that strong Nash equilibria coalition structures in this game are identical to α- and β-core stable coalition structures. Second, as a by-product of the definition of the H-game, we develop an extension called an I-game. Finally, we compare equilibria in the H- and I-game with those in the Δ- and Γ-game of Hart and Kurz (1983).

Keywords: Core-stability, non-cooperative game theory, positive externality games

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1. Introduction

Since the book by von Neumann and Morgenstern (1944), there has been an increasing interest in economics to study coalition formation. A coalition is a group of agents that coordinate their economic strategies in order to raise the welfare of its members. Examples include firms that coordinate their output or prices in oligopolistic markets (cartels), jointly invest in research assets (R&D agreements) or completely merge (joint ventures). Countries coordinate their tariffs (trade agreements and customs unions) or their environmental policy (international environmental agreements). The various contributions in the literature can be grouped into two approaches - cooperative and non-cooperative game theory - where most scholars take sides.[1] In this paper, we briefly review both approaches in the remaining part of the Introduction, stressing not only differences but also similarities. We identify the core as an appealing stability concept of cooperative game theory, but argue that the non-cooperative approach has conceptual advantages in the context of economic problems with externalities. Therefore, we present in subsequent sections a non-cooperative foundation of core-stability for positive externality games. Throughout, we restrict ourselves to non-transferable utility games (NTU-games).

The classical distinction between both approaches is that binding agreements between agents are possible in cooperative but not in non-cooperative game theory. However, as will become apparent below, this classification misses the point. On the one hand, also most concepts of cooperative game theory assume (at least implicitly) some punishment if players deviate from some agreement. On the other hand, also non-cooperative game theory assumes implicitly some form of commitment to cooperation within coalitions. Following Bloch (1997), a more appropriate distinction relates the two approaches to the tools and the foci of the analysis.

The analysis in cooperative game theory is based on the characteristic (also called coalitional) function v(.) that assigns a worth, $v(I^C)$, to a group of players (coalition) I^C. In an NTU-setting, this worth is a vector and assigns each member of I^C his individual payoff. The worth is a vector of payoffs that can be secured irrespective of players' behavior outside a coalition. What irrespective means depends on the specific definition of the characteristic function. Widely used definitions are the α- and β-characteristic functions. If we let I be the set of

[1] For an excellent overview of the two approaches with applications in the field of economics see Bloch (1997). A very good overview of non-cooperative coalition theory with applications is provided by Yi (1997 and 1999).

players, S the set of economic strategies and Π the set of payoffs, then $v^{\alpha}(I^C)$ are the highest payoffs that a group of players I^C can secure regardless of the strategies of external players. That is, $v_i^{\alpha}(I^C) = \pi_i(s^{I^C*}, s^{I\setminus I^C*})$ where $(s^{I^C*}, s^{I\setminus I^C*})$ is determined by $\min_{s^{I\setminus I^C}} \max_{s^{I^C}} \sum_{j\in I^C} \pi_j(s^{I^C}, s^{I\setminus I^C})$. $v^{\beta}(I^C)$ are the highest payoffs of I^C that external players $I\setminus I^C$ cannot prevent. That is, $v_i^{\beta}(I^C) = \pi_i(s^{I^C*}, s^{I\setminus I^C*})$ where $(s^{I^C*}, s^{I\setminus I^C*})$ is determined by $\max_{s^{I^C}} \min_{s^{I\setminus I^C}} \sum_{j\in I^C} \pi_j(s^{I^C}, s^{I\setminus I^C})$. This implies that if a player or group of players deviate from some agreement, the remaining players will punish the deviators by playing either their minimax or maximin strategy.

A payoff vector $\pi^*(s^*)$ resulting from some strategy vector s^* is said to belong to the α-(β-) core if no group of players can improve the payoff of at least one player through a deviation without reducing the payoff of another member of the group: There is no $I^C \subset I$ such that $v_i^{\alpha}(I^C)\,(\,v_i^{\beta}(I^C)) \geq \pi_i^*(s^*)\ \forall i \in I^C \wedge \exists\, j \in I^C : v_j^{\alpha}(I^C)\,(\,v_j^{\beta}(I^C)) > \pi_j^*(s^*)$.[2]

Thus the core is the set of weakly undominated payoff vectors – an appealing feature for a stability concept - explaining its widespread application in game theory.

From the examples it is evident that the focus of the analysis is on stable allocations of payoffs rather than on the actual coalition formation process itself. The strategic variables are economic and not coalition strategies. From the perspective of a coalition, all other players are a residual and act as a benchmark for deviations with punishment. Thus, in games with externalities, spillovers between coalitions are insufficiently captured. This explains why cooperative game theory has predominantly focused on stability of the efficient grand coalition.

In contrast, the analysis of non-cooperative game theory is based on the valuation function w(.) that assigns a vector of individual payoffs $w(C) = (w_1(C_j, C), ..., w_N(C_k, C))$ to each possible coalition structure $C \in X$. A coalition structure $C=(C_1, ..., C_M)$ is a partition of I, i.e., $C_j \cap C_k = \varnothing\ \forall\ j \neq k$, $\bigcup C_i = I$, $w(C) \in W(X)$ where W(X) is the set of payoff vectors. The first argument in $w_i(C_i, C)$ refers to the coalition to which player i belongs, the second to the particular coalition structure. The payoffs are typically derived from the assumption that players cooperate within their coalition but compete across coalitions. That is, coalition

[2] For consistency we use the weak dominance relation for deviations throughout the paper in the definitions of the core, strong Nash equilibrium, α.- and β-core stable coalition structures and Pareto-optimal coalition structures. That is, a group of players I^C deviates with a resulting change of its payoff vectors from x to y, if $y_i \geq x_i\ \forall i \in I^C$ and $\exists\, j \in I^C : y_j > x_j$. All results would be unaffected if we assumed a strict dominance relation as for instance in Bloch (1997).

members act as one player and choose their economic strategies in order to maximize the aggregate payoff to their coalition taking strategies of outsiders as given. Formally, let $w_i(C_i, C) = \pi_{i \in C_i}(s^*)$ where for a fixed coalition structure C=(C_1, ..., C_M), s^* satisfies

$$\forall C_i \in C : \sum_{i \in C_i} \pi_i(s^{C_i *}, s^{I \setminus C_i *}) \geq \sum_{i \in C_i} \pi_i(s^{C_i}, s^{I \setminus C_i *}) \quad \forall s^{C_i} \in S^{C_i}$$

where S^{C_i} is the set of possible strategies of coalition C_i. Thus, the valuation of player i, $w_i(C_i, C)$, is derived as a Nash equilibrium between coalitions in economic strategies. In order to study coalition formation three more steps have to be taken.

First, the set of membership (coalition) strategies Σ has to be specified where a particular strategy of player i is denoted by $\sigma_i \in \Sigma_i$. For instance, in the exclusive membership Δ- and Γ-game of Hart and Kurz (1983) each player announces a list of players with whom he would like to form a coalition. Hence, for each $i \in I$, the set of strategies of i is $\Sigma_i = \{C_i \subset I \mid i \in C_i\}$. Second, an output function $\psi(\sigma)$ that maps membership strategies into coalition structures has to be specified. For instance, in the Δ-game ψ^{Δ}: $C_i = \{i\} \cup \{j \mid \sigma_i = \sigma_j\}$ and in the Γ-game ψ^{Γ}: $C_i = \sigma_i$ if and only if $\sigma_i = \sigma_j \ \forall j \in \sigma_i$, otherwise $C_i = \{i\}$. That is, in the Γ-game the coalition only forms if and only if all members on a list make exactly this proposal. In contrast, in the Δ-game it suffices if a subgroup of players on the list makes the same proposal. Then the coalition is formed by this subgroup. Hence, a higher degree of unanimity is required in the Γ- than in the Δ-game to form a coalition. In both games membership is exclusive since players can only join a coalition with the consent of its members. In the Δ-game a deviation by a player or group of players (change of announcement) implies that the remaining players stick together whereas in the Γ-game the coalition of the deviators will break apart. Third, stability has to be defined. Typical concepts are Nash equilibrium (NE), considering only single player deviations, or Strong Nash equilibrium (SNE), considering also multiple player deviations. Formally, let $\tilde{X}^{I^C}(\sigma)$ be the set of coalition structures that a subgroup of countries I^C can induce if the remaining countries $j \in I \setminus I^C$ play $\sigma^{I \setminus I^C}$. Then σ^*, inducing coalition structure C^*, is called a SNE if no subgroup I^C can induce a coalition structure $\tilde{C} \in \tilde{X}^{I^C}(\sigma^*)$, which weakly dominates C^*. That is, $C^*(\sigma^*)$ is a SNE if there is no $I^C \subset I$ and a coalition structure $\tilde{C} \in \tilde{X}^{I^C}(\sigma^*)$ such that $w_i(\tilde{C}_i, \tilde{C}) \geq w_i(C_i, C^*) \ \forall i \in I^C \wedge \exists j \in I^C: w_j(\tilde{C}_j, \tilde{C}) > w_j(C_j, C^*)$. For a NE, $I^C = \{i\}$.

From the examples it is evident that the focus of the analysis is on the coalition formation process itself and economic strategies follow from Nash equilibrium behavior between

coalitions. Spillovers between coalitions are explicitly accounted for. Hence, non-cooperative game theory is useful for studying the incentive to cooperate in the presence of multiple coalitions and to rationalize inefficient outcomes particular in the context of externalities. Moreover, there is a clear conceptual distinction between the rules of coalition formation (strategies and output function) summarized under the definition of a coalition game and stability that follows from the definition of the equilibrium concept. This has at least two advantages. First, the reaction after a deviation follows from the rules of coalition formation and can thus be better related to the rational behavior of players. Second, a study of the effect of the coalition formation rules on equilibrium coalition structures allows drawing policy conclusions about the optimal institutional design of agreements. For instance, Bloch (1997) and Yi (1997) compare various membership rules for different economic problems that can be structured according to positive and negative externality games. In positive externality games the merger of coalitions benefits outsiders whereas this harms outsiders in negative externality games.[3] Roughly speaking, in positive externality games it turns out that exclusive membership sustains more stable coalition structures than open membership and under exclusive membership a high degree of unanimity is conducive to cooperation. In negative externality games this conclusion is more or less reversed.

In what follows we derive a definition of α- and β-core stable coalition structures for positive externality games in the context of the valuation function approach in section 2. In section 3, we present a non-cooperative foundation of α- and β-core stable coalition structures by defining a coalition game, called an exclusive membership H-game, and show that strong Nash equilibria coalition structures are identical to α- and β-core stable coalition structures. As a by-product of the definition of the H-game, we develop an extension in section 4 called an exclusive membership I-game. Finally, in section 5 we compare equilibria in H- and I-game with those in the Δ- and Γ-game of Hart and Kurz (1983) and point to some topics for future research.

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[3] Typical examples of positive externality games are output cartels (international environmental agreements) where firms (countries) not involved in a merger of single firms (countries) or a group of firms (group of countries) benefit from lower output (lower emissions) via higher prices (lower environmental damages). Firms competing in an oligopoly but jointly reducing production costs through cooperating on R&D exhibit a positive (negative) externality on outside firms if spillovers are high (low) as long as the positive spillover effect is larger (lower) than the negative competition effect. See Bloch (1997) and Yi (1997) for details.

2. A Definition of α- and β-Core Stable Coalition Structures for Positive Externality Games Based on the Valuation Function

In order to capture core-stability in a non-cooperative setting, we recall that the valuation of players depends on the coalition to which they belong and on the coalitions that other players form. Thus, following Bloch (1997), core-stability can be defined as follows:

Definition 1: α- and β-Core Stable Coalition Structures

A coalition structure C is α-core stable if there does not exist a group of players I^C *and a partition* C^{I^C} $(\cup C_i^{I^C} = I^C)$ *such that for all partitions* C^{I/I^C} *formed by external players* $w_i(C_i^{I^C},(C^{I^C},C^{I/I^C})) \geq w_i(C_i,C)$ $\forall i \in I^C$ *and* $\exists\, j \in I^C : w_j(C_j^{I^C},(C^{I^C},C^{I/I^C})) > w_j(C_j,C)$.

A coalition structure C is β-core stable if there does not exist a group of players I^C *such that for all partitions* C^{I/I^C} *of external players there exists a partition* C^{I^C} *of* I^C *such that* $w_i(C_i^{I^C},(C^{I^C},C^{I/I^C})) \geq w_i(C_i,C)$ $\forall i \in I^C$ *and* $\exists\, j \in I^C : w_j(C_j^{I^C},(C^{I^C},C^{I/I^C})) > w_j(C_j,C)$.

It is evident that α-core-stability corresponds to a minimax and β-core-stability to a maximin strategy in terms of coalitions. Hence, what punishment means after a deviation depends on the kind of externality between coalitions. We concentrate on positive externality games with the following property (Bloch 1997 and Yi 1997).

Assumption 1: Positive Externality Games

Let a coalition structure with M coalitions be denoted by $C=(C_1, ..., C_M)$*, a coalition structure with M-1 coalitions by* $C' =(C_1, ..., C_{M-1})$ *where* C' *is derived by merging two coalitions in C, and let* C_k *be a coalition not involved in the merger, then* $w_k(C_k, C) < w_k(C_k, C')$.

For Assumption 1 it is evident that the harshest punishment after a deviation of players I^C is if all other players $I \backslash I^C$ break up into singletons. That is, all coalitions to which the deviators belonged break up into singletons but also all other coalitions. Moreover, in the present context there is no difference between maximin and minimax. Hence, in terms of coalition structures, we can state the following lemma (without proof).

Lemma 1: α-β-Core Stable Coalition Structures in Positive Externality Games

A coalition structure C is α- and β-core stable if and only if there does not exist a group of players I^C *and a partition* C^{I^C} $(\cup C_i^{I^C} = I^C)$ *such that* $w_i(C_i^{I^C},(C^{I^C},1,...,1)) \geq w_i(C_i,C)$ $\forall i \in I^C$ *and* $\exists\, i \in I^C : w_i(C_i^{I^C},(C^{I^C},1,...,1)) > w_i(C_i,C)$ *under Assumption 1.*

From section 1 we know that coalition structures are derived from membership strategies and that stable coalition structures follow from the application of an equilibrium concept. Hence, two more steps are necessary for a complete non-cooperative foundation of core-stability. First, we have to construct a coalition game that implies that deviations lead to a resolution of all players not involved in a deviation. We call this an exclusive membership H-game because of its close similarity to Hart and Kurz´s exclusive membership Δ- and Γ-game. Second, Lemma 1 suggests that we have to apply an equilibrium concept that defines stability in terms of multiple deviations. We show that a strong Nash equilibrium (SNE) does this job. Taken together, we show that the set of SNE coalition structures in the H-game, $X^{SNE}(H)$, is equal to the set of α-β-core stable coalition structures, $X^{\alpha,\beta}$, in positive externality games.

3. Exclusive Membership H-game

The H-game is constructed in a similar fashion as the Δ- and Γ-game. That is, each player announces a message. However, different from the Δ- and Γ-game, the message is not a list of coalition members but a list that comprises the complete coalition structure. In addition, the outcome function, relating strategies to coalition structures, requires not only one but two steps. More specifically:

Definition 2: Exclusive Membership H-game

Let the strategy set of country i be given by $\Sigma_i = \{C^i \in X / i \in C_1^i\}$ *with* X *the set of coalition structures. A particular strategy* $\sigma_i = C^i = (C_1^i; C_2^i, ..., C_{M_i}^i)$ *of player i is composed of a list of players with whom he wants to form a coalition,* C_1^i*, and his preferred residual coalition structure,* $C_2^i, ..., C_{M_i}^i$*. Then the resulting coalition structure C is derived from output function* ψ^H *in two steps.*

First, a preliminary coalition structure $\tilde{C} = (\tilde{C}_1, ..., \tilde{C}_{\tilde{M}})$ *is determined:* $C_1^i \in \tilde{C}$ *if and only if* $C_1^i = C_1^j \ \forall j \in C_1^i$*, otherwise* $\{i\} \in \tilde{C}$**.**

Second, the final coalition structure $C = (C_1, C_2, ..., C_M)$ *follows from:* $\tilde{C}_j \in C \Leftrightarrow C^j = \tilde{C}$ $\forall j \in \tilde{C}_j$ *otherwise* $\tilde{C}_j$ *splits up into singletons in C.*

There are four things to be noted about Definition 2. First, step 1 in the output function ψ^H requires the same degree of unanimity to form a coalition as in the Γ-game. Step 2 is an additional requirement implying that also the formation of external coalitions must have been announced correctly. However, this announcement must only match with respect to the preliminary coalition structure $\tilde{C}$ (and not with respect to C which eventually forms) and may

thus be interpreted as unanimity of the Δ-type with respect to external coalitions. This suggests that in terms of external coalitions a stronger assumption of unanimity may be imposed. We turn to this issue in section 4 where we construct an exclusive membership I-game. Second, the preliminary coalition structure in step 1 comprises non-trivial coalitions, "voluntary" singletons that have proposed a singleton coalition and "involuntary" singletons whose proposals did not match. The assumption of step 2 can be relaxed without affecting results by requiring that only non-trivial coalitions and voluntary singletons (but not involuntary singletons) must be announced correctly by the members of a coalition C_i so that C_i forms. However, we discard this possibility for simplicity. Third, the two-step procedure determines for each set of messages a unique coalition structure. Fourth, each coalition structure can be generated if all players announce exactly this coalition structure. The last remark gives rise to the following lemma that demonstrates that the implicit punishments in the H-game and of α-β-core-stability are the same.

Lemma 2: Implicit Punishment in the H-Game

Suppose all players announce $\sigma_i = C^i = C$*, then a deviation by a group of players* I^C *(implying that they change their announcements) leads to a resolution of* $I \backslash I^C$ *if the deviation leads to a different coalition structure* $\tilde{C}$.

Proof: Consider two cases. Case 1: Suppose at least one player of I^C belongs to a non-trivial coalition C_i. Then C_i is not an element of $\tilde{C}$ anymore and all non-trivial coalitions to which players $I \backslash I^C$ belonged break up into singletons since C_i is not part of their message. Case 2: All players of I^C are singletons. a) A deviation does not lead in $\tilde{C}$ to a merger of singletons but only to at least one involuntary singleton. Hence, $\tilde{C}$ and also C do not change. (For instance, suppose four players announce $C^i=((1, 2), (3), (4))$ and hence $\tilde{C}=C=((1, 2), (3), (4))$. If player 4 deviates and proposes $C^4=((1, 2), (3, 4))$, then this has no affect on $\tilde{C}$ and also not on C.) b) A deviation leads in $\tilde{C}$ to a merger of singletons and possibly involuntary singletons. Then all players $I \backslash I^C$ break up into singletons since the "new coalition" is not part of their message. (For instance, suppose 5 players that all announce $C^i=((1, 2), (3), (4), (5))$ and hence $\tilde{C}=C=((1, 2), (3), (4), (5))$. If players 3 and 4 deviate and announce $C^3=C^4=((1, 2), (3, 4), (5))$, and player 5 $C^5=((1, 2), (3, 4, 5))$, then $\tilde{C}=((1, 2), (3, 4), (5))$ and $C=((1), (2), (3, 4), (5))$.) **(Q.E.D.)**

Using Lemma 2, we now can state our central result.

Proposition 1: Equivalence of Strong Nash Equilibrium Coalition Structures in the H-Game and α-β-Core Stable Coalition Structures

Let $X^{\alpha,\beta}$ be the set of α-β-core stable coalition structures and $X^{SNE}(H)$ the set of strong Nash equilibrium coalition structures in the H-game, then a) $X^{\alpha,\beta} \subset X^{SNE}(H)$ and b) $X^{SNE}(H) \subset X^{\alpha,\beta}$.

Proof: a) $C \in X^{\alpha,\beta} \Rightarrow C \in X^{SNE}(H)$: First, $C \in X^{\alpha,\beta}$ implies by Lemma 1 that a deviation by a group of players I^C leading to coalition structure $C' = (C^{I^C}, 1, ..., 1)$ is not beneficial where C^{I^C} is a partition of players I^C. Second, in the H-game, C forms if all players announce exactly C. Then, a deviation either does not change the coalition structure at all (Lemma 2: case 2a) or does lead to the complete resolution of all coalitions of players belonging to $I \backslash I^C$ (Lemma 2: case 1 and 2b). b) $C \notin X^{\alpha,\beta} \Rightarrow C \notin X^{SNE}(H)$: First, $C \notin X^{\alpha,\beta}$ implies that there is a group of players $I^C \subset I$ and a partition C^{I^C} of I^C such that $w_i(C') \geq w_i(C) \; \forall \, i \in I^C$ and $\exists \, i \in I^C : w_i(C') > w_i(C)$ holds where $C' = (C^{I^C}, 1, ..., 1)$. Second, players I^C can also induce coalition structure C' in the H-game by proposing C^{I^C} for themselves and for $I \backslash I^C$ those coalition structures that will form in $\tilde{C}'$. Then in step 1 of the output function, $\tilde{C}' = (\tilde{C}^{I^C}, \tilde{C}^{I/I^C})$ where $\tilde{C}^{I/I^C}$ is the partition of players $I \backslash I^C$ and $\tilde{C}^{I^C} = C^{I^C}$. $\tilde{C}^{I/I^C}$ comprises players that have no deviating players in their coalition and which are in the same coalition in $\tilde{C}'$ than in $\tilde{C}$ and players belonging to coalitions of deviators who are now singletons. In step 2 of the output function ($\tilde{C}' \rightarrow C'$), $\tilde{C}^{I^C}$ ($= C^{I^C}$) remains the same in C' than in $\tilde{C}'$ and all other coalitions break apart since they did not announce $\tilde{C}^{I^C}$ correctly. Hence, $C' = (C^{I^C}, 1, ..., 1)$. (**Q.E.D.**)

In order to characterize equilibrium coalition structures in the H-game and in the I-game (see section 4), we need two more definitions.

Definition 3: Pareto-optimal Coalition Structures

A coalition structure C is Pareto-optimal if there is no other coalition structure C' where at least one player is better off and no player is worse off, i.e., there is no C' such that $w_i(C_i', C') \geq w_i(C_i, C) \; \forall i \in I \wedge \exists j \in I: \; w_j(C_j', C') > w_j(C_j, C)$.

Definition 4: Individual Rational Coalition Structures

A coalition structure C is called individual rational if each player receives at least his payoff in the singleton coalition structure, i.e., $\forall i \in I: \; w_i(C_i, C) \geq w_i(\{i\}, 1, ..., 1)$.

Definition 3 is the classical definition of Pareto-optima applied to coalition structures in the context of valuations as proposed by Finus/Rundshagen (2003). Definition 4 uses the singleton coalition structure as a benchmark for individual rationality. Given the assumption of the valuation function (see Introduction), the singleton coalition structure represents the classical Nash equilibrium in terms of economic strategies. With these definitions we can now state the following.

Proposition 2: Nash Equilibrium and Strong Nash Equilibrium Coalition Structures in the H-Game

Let the set of individually rational coalition structures be denoted by X^{IR}*, the set of Pareto-optimal coalition structures by* X^{PO}*, the set of Nash (strong Nash) equilibrium coalition structures by* $X^{NE}(H)$ *(*$X^{SNE}(H)$*) in the H-game, then a)* $X^{NE}(H) = X^{IR}$*, b)* $X^{SNE}(H) \subset X^{IR} \cap X^{PO}$*.*

Proof: a) Consider coalition structure C and suppose that all players announce exactly C. i) Suppose a singleton in C changes its announcement. Then this player remains a (involuntary) singleton in $\tilde{C}'$. Since $\tilde{C}' = \tilde{C}$, this will trigger no reaction by others and hence this deviation cannot be profitable because $C' = C$. ii) Suppose a player belonging to a non-trivial coalition in C changes his announcement. Then, his coalition breaks apart in $\tilde{C}'$ and that of all other players in C'. Hence, a deviation is not profitable since $w_i(C_i, C) \geq w_i(\{i\}, C')$, $C' = (1, ..., 1)$, holds by individual rationality. b) $X^{SNE}(H) \subset X^{IR}$ follows from the fact that $X^{SNE}(H) \subset X^{NE}$ and $X^{NE}(H) = X^{IR}$ as stated above. $X^{SNE}(H) \subset X^{PO}$ immediately follows from the definition of strong Nash equilibrium (see Introduction) and Definition 3 of Pareto-optimal coalition structures. (**Q.E.D.**)

It may be worthwhile pointing out that not every Pareto-optimal coalition structure is individual rational. For instance, the grand coalition is always a Pareto-optimal coalition structure but may not be individually rational for some players in the case of heterogeneous payoff functions. A strong Nash equilibrium coalition structure must be a Pareto-optimal coalition structure (otherwise all players would have an incentive to jointly deviate to some other coalition structure), but the opposite is not true since a subgroup of players may have an incentive to move to another coalition structure, though other players will be negatively affected by such a move.

4. Exclusive Membership I-game

As pointed out in the discussion of the H-game, it is possible to invoke an even stronger degree of unanimity for coalitions to form. Thus, the description of strategies is the same as in the H-game and only the output function changes that requires only one step.

Definition 5: Exclusive Membership I-game

Let the strategy set of player i be given by $\Sigma_i = \{C^i \in X / i \in C_1^i\}$ *with* X *the set of coalition structures. A particular strategy* $\sigma_i = C^i = (C_1^i; C_2^i, ..., C_{M_i}^i)$ *of player i is composed of a list of countries with whom he wants to form a coalition,* C_1^i*, and his preferred residual coalition structure,* $C_2^i, ..., C_{M_i}^i$*. Then the resulting coalition structure C is derived from output function* $\psi^I : C = C^i$ *if and only if* $\sigma_i = \sigma_j \ \forall i \in I$*, otherwise* $C = (1, ..., 1)$*.*

A coalition structure only forms if all players have announced exactly this coalition structure. That is, not only the internal list of all members of coalition C_i (list of members in C_i) must match but also the external list of players outside of coalition C_i (list of partitions of players outside C_i). In other words, not only the degree of unanimity with respect to the internal list must be of the Γ-type but also with respect to the external list. For these stronger assumptions it is easy to derive the following result.

Proposition 3: Nash Equilibrium and Strong Nash Equilibrium Coalition Structures in the I-Game

Let the set of Nash (strong Nash) equilibrium coalition structures in the I-game be denoted by $X^{NE}(I)$ *(*$X^{SNE}(I)$*), then a)* $X^{NE}(I) = X^{IR}$*, b)* $X^{SNE}(I) = X^{IR} \cap X^{PO}$*.*

Proof: a) Any deviation leads to the singleton coalition structure that is not profitable if a coalition structure is individually rational. b) Any deviation by a subgroup of players $I^C \subsetneq I$ leads to the singleton coalition structure, which is not beneficial if the coalition structure is individually rational, and a deviation by all players I is not profitable if a coalition structure is Pareto-optimal. (**Q.E.D.**)

5. Comparison of Equilibrium Coalition Structures and Final Remarks

In this section we briefly relate the exclusive membership H- and I-game to the Δ- and Γ-game of Hart and Kurz (1983). In contrast to these authors, who showed $X^{SNE}(\Delta) \cup X^{SNE}(\Gamma) \subset X^{ß} \subset X^{\alpha}$, we can add now three more aspects to a comparison of

equilibrium coalition structures. First, we can be more specific in characterizing relations between equilibrium sets due to the assumption of positive externalities (Assumption 1). That is, $X^{\beta} = X^{\alpha} = X^{\alpha,\beta}$ from Lemma 1 and - as will be shown below - $X^{SNE}(\Delta) \subset X^{SNE}(\Gamma)$. Second, a comparison can be related to the rules of the coalition game since we have established $X^{SNE}(H) = X^{\alpha,\beta}$ in Proposition 1. Third, we can add a new comparison since we defined the I-game in Definition 5 and derived equilibrium coalition structures in Proposition 3. Fourth, we cannot only compare equilibrium coalition structures in terms of strong Nash equilibrium but also in terms of Nash equilibrium since we conceptually detangled stability from the rules of coalition formation. Taken together, we can state the following.

Proposition 4: Comparison Equilibrium Coalition Structures in the Exclusive Membership Δ-, Γ-, H- and I-Game

In positive externality games as defined in Assumption 1:

a) $X^{NE}(\Delta) \subset X^{NE}(\Gamma) \subset X^{NE}(H) = X^{NE}(I)$ *and*

b) $X^{SNE}(\Delta) \subset X^{SNE}(\Gamma) \subset X^{SNE}(H) \subset X^{SNE}(I)$.

Proof: To show the first two relations in a) and b) let $C^{\Delta'} = (C^{I^C}, C^{I/I^C}(\Delta))$, $C^{\Gamma'} = (C^{I^C}, C^{I/I^C}(\Gamma))$ and $C^{H'} = (C^{I^C}, C^{I/I^C}(H))$ be the resulting coalition structure if a player $I^C = \{i\}$ or group of players $I^C \subset I$ change their strategies where C^{I^C} is the partition of players I^C and C^{I/I^C} the partition of all other players. From the rules in these games it follows that $C^{I/I^C}(\Gamma)$ can be derived by merging coalitions in $C^{I/I^C}(H)$ and that $C^{I/I^C}(\Delta)$ can be derived from merging coalitions in $C^{I/I^C}(\Gamma)$. Hence from Assumption 1, $w_i(C^{I^C}, C^{\Delta'}) \geq w_i(C^{I^C}, C^{\Gamma'}) \geq w_i(C^{I^C}, C^{H'})$ $\forall$ $i \in I^C$. Thus, if a deviation is not profitable in the Δ-game, it will also not be profitable in the Γ-game and if a deviation is not profitable in the Γ-game, it will not be beneficial in the H-game. The last relation in a) and b) follows directly from Proposition 2 and 3. (**Q.E.D.**)

Proposition 4 clearly shows that the higher the degree of unanimity required to form coalitions, the easier it is to sustain stable coalition structures. Of course from an economic perspective it would be interesting to know what "more stability" means in welfare terms and for the level of economic strategies. This, however, requires being more specific about the underlying economic strategies of a model (see the example in the Introduction) and is therefore beyond the scope of this paper. We intend to take this issue up in future research.

We would like to finish with three remarks about future research. First, it seems obvious to construct a coalition game that captures the notion of α- and β-stability in the context of negative externality games. Second, we observe that in positive externality games the reaction of external players after a deviation of a group of players implied by the H-game (and α- and β-core stability) has a close resemblance to Chander/Tulkens´ γ-core in the context of the characteristic function approach. Chander/Tulkens (1997) assume that after a deviation of a group of players, the remaining players split up into singletons, playing a Nash equilibrium in terms of economic strategies. However, their definition of the characteristic function assumes transferable utility and they consider only that deviating players form one coalition.[4] Nevertheless, it would be interesting to relate the γ-core to strong Nash equilibrium coalition structures in our H-game if the underlying assumptions are matched. Third, it would be interesting to relate the cooperative game theoretical concept of the core to a non-cooperative coalition game if transfers between agents are possible. No doubt, this will be a difficult issue and requires deriving transfers between agents endogenously as Ray/Vohra (1999) proposed.

[4] This seems to be a restriction since in their global emission game superadditivity may fail to hold.

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