Networks with Group Counterproposals

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Keywords: Efficiency, Bargaining Protocol, Counterproposals, Network Formation, Transfers, Externalities, Groups, Coalitions

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Abstract

We study two n-player sequential network formation games with externalities. Link formation is *tied* to simultaneous transfer selection in a Nash demand like game in each period. Players in groups can counterpropose. We give necessary and sufficient conditions for efficiency in terms of cyclical monotonicity. The n-player group version always yields efficiency.

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1 Introduction

We study network formation. Our focus is on the role of sequential bargaining with group counterproposals in obtaining efficient and stable outcomes.

As illustration only, say production of a good has as a side effect, *externalities,* on agents (e.g. pollution). Anything has a "price". The producer is so good at networking and lobbying, with money transfers, that only she has connections with consumers, regulators, etc., and therefore options and all the bargaining power. Whatever she proposes is accepted, and she gets a monopolist payoff net of transfers within the status quo. Let other conditions be held constant. Years later, agents learn to network (e.g. using "Facebook"); so groups (environmental, etc.), that create externalities by destroying goods, can form and so counterpropose. The old monopolist catches up and can do the same. We evaluate if the changes produce a new *efficient* status quo, where net payoffs and not the amount of goods, etc., are maximized. We use the idea in Nash (1950) [9] that if outside options (net payoff prospects in other groups) change, bargaining power is modified and the effects on stable payoffs can be quantified.

For this purpose, we construct two games with *groups* that differ in size where members are players that "propose" a permanent bilateral network *link*. Groups consist either of all n players or those in the new *component* (sets of links that connect a set of players directly or indirectly) that forms if the link forms. A link forms if and only if transfers *match* identically in a Nash demand like game (Nash (1950) [10]) in each period where players in a group choose transfers simultaneously. Some transfers are interpreted as *unilateral rejections*. These can flow across components only in the *n-group* game. Links are proposed in an *order* similar to a game of bridge as in Aumann and Myerson (1988) [2]; however, our groups are not bilateral. Such order allows players to counter-propose in groups. Payoffs are obtained if the game ends. Instead, these are given by *any* payoff allocation rule *and* net of transfers (payoffs are therefore endogenous). Such rules are derived from *any* partition or value function (of the network structure) of a network game with and without links of communication respectively; so externalities among players in distinct components are possible.

We rule out *subgameperfect equilibria (SPE)* with histories where, say, every player in a group expects the other members to choose a unilateral rejection even if they can do better by coordinating and matching transfers. Second, we rule out SPE outcomes that even though better are not "rational" for the group. For the first type of coordination failure, we use *group* SPE, (*GSPE)*. This refinement selects group efficient SPE transfer profile's continuation values assuming future players do the same. For the second type, we use *Nash* GSPE, a GSPE where continuation values are the Nash Bargaining Solution which involves not just efficient but rational group coordination (See Nieva (2008b) [12] for implementation, etc).

Efficiency is characterized in terms of *cyclical monotonicity* of payoff allocation rules in the *component-group* game. Under this condition, the total payoff of the *new* component that results if a given link forms can be lower than the sum of the total payoffs of the *merged* components (which result if the given link is severed), provided the new component is not in the efficient network. The n-group game yields always efficiency (in networks without communication). Coexistence of efficiency and inefficiency can occur only under GSPE.

Efficiency results, as for transfers, link formation depends on the total continuation value of the new group in a new component relative to the sum of all members' outside options. The former is the total net payoff in the expected efficient network for the new group. The latter is the sum of total net payoffs of the groups in the merged components as no more links are expected to form.

Coexistence is eliminated as the Nash Bargaining Solution for a player is a monotonic <u>function</u> of her relative outside option. Total outside options of all players in a new component (if *another* link is proposed) may decrease relative to the sum of their outside options in the merged components. So the efficient network can fail to form. Say, if its net payoffs in a GSPE are better than outside options of all players in the new component but worse than outside options for some of these players in the merged components (See example).

Our paper belongs to the literature that studies the role of simultaneous payoff determination and link formation (bargaining) in non cooperative network formation games in solving the tension between stability and efficiency.[1]

Bloch and Jackson (2007) [4] study the effects of transfers in a simultaneous

[1] Non bargaining games ("with zero transfers") are surveyed in Jackson, M., (2005) [6] for the simultaneous case; a sequential case is studied in Aumman and Myerson (1988) [2].

game. Rich transfers account for externalities in general; however, efficient and inefficient equilibria coexist.

Currarini and Morelli (2000) [5] and Mutuswami and Winter (2002) [7] raise the importance of sequentiality and non group bargaining as *all* their SPE are efficient for a large class of value functions. The result is obtained as the efficient network is not "blocked" and so can block inefficient ones. In Currarini and Morelli (2000) [5], in principle, given that a previous proposer can ask all of the rest of the payoff of the efficient network, his demand is only constrained by the next proposer not reciprocating links of the connected efficient network. As the latter, in turn, can ask for all the remainder in the best resulting inefficient network, the earlier proposer's demand is constrained by the difference. These constrained demands (in the efficient network) can always block n decreasing outside options (as for total payoff monotonicity in players' size of components) as these can offer better prospects even though these are decreasing too. As outside options differ in Mutuswami and Winter (2002) [7], payoff predictions differ. In the latter case, results also hold if there are externalities and even without monotonicity as sorts of "transfers" with contingent cost contributions across components are possible (so as in Bloch and Jackson (2007) [4], the same results but in a sequential game) in variations of their game.

Instead, our players in groups counterpropose. As net payoffs in the efficient network may not satisfy more than n outside options unless we have n player groups, results follow. Nieva (2008a) [11] uses bilateral groups to answer open questions (e.g. conditions for coexistence) in Bloch and Jackson (2007) [4] if counterproposals are possible.

Slikker and van den Nouweland (2001) [13] find that cooperative refinements like Strong and Coalition Proof Nash Equilibrium (that involve counterproposals in a sense) in an n and 3-player simultaneous game respectively can yield inefficiency. As for the next idea and for the difference in notions of stability, our results are complementary and general as they focus in communication networks without externalities. Note that sequentiality is not an issue.

The criticism that results are sensitive to irrelevant details of the sequential bargaining protocol does not apply. A necessary condition for a GSPE and sufficient for a SPE is that net payoffs in the *final* network cannot be *blocked*. So our approach is both cooperative and noncooperative; nothing is irrelevant. Equilibrium transfers and net payoffs have to satisfy sets of inequalities associated to some cooperative solution (explicit in our bargaining protocols) defined by "the possibilities for coalition (groups) forming, promising, and threatening...., rather than whose turn it is to speak" (Aumann (1988) [1]).

The criticism applies neither to Currarini and Morelli (2000) [5] nor to Mutuswami and Winter (2002) [7] as their games resemble bargaining without groups and counterproposals, a degenerate case in our "family" of games. It applies "whenever players rather than coalitions propose coalitions".

In section 2, we give notation for networks, link payoff allocation rules to value or partition functions, transform the Aumann and Myerson (1988) [2] game into our general game, and define stability, groups and transfers' specifics. In section 3, we study efficiency (proofs are in Appendix). We conclude.

2 The Games

2.1 Preliminary Definitions

2.1.1 Notation for Networks

The set of players in a network relationship is $N = \{1, ..., n\}$. A *network* g is a set of unordered pairs of distinct players belonging to N. Each pair is represented by a link between the two players. So g is also the set of links of g. The number of links in g is $|g|$. The set of players with at least one link in network g is $N(g)$.

The link that joins players i and j is ij. The network with the maximum number of links is the *complete* network g^N. In the empty network $g^{\emptyset}$, there are no links, players are *isolated*. The set G of all possible networks on N is $\{g : g \subseteq g^N\}$. The network that results by adding link ij to network g is $g + ij$. An *ordered network* or (vector) $\overrightarrow{g}$ is a list of the $|g|$ links in g such that its e^{th} entry is the e^{th} link that has formed. The subvector that contains the first k links that have formed is $\overrightarrow{g}_K$, where $K = \{1, ...k\}$. It is a subvector of the partitioned vector $[\overrightarrow{g}_K, \overrightarrow{g}_{-K}] = \overrightarrow{g}$.

A *path* in a network $g \in G$ between players i and j is a sequence of players $i_1, ..., i_K$ with $i_k i_{k+1} \in g$ for all $k \in \{1, ..., K-1\}$, where $i_1 = i$ and $i_K = j \in g$. A *component* of a network g is is a non empty subset of the network $g' \subseteq g$ such that for all $i, j \in N(g')$, there exists a path between players i and j in g', and if $i \in N(g')$ and $ij \in g$, then $ij \in g'$. The set of components of g is $C(g)$.

2.1.2 Payoff Allocation Rules in Networks

We study *communication network and network games.* In the first case (skip wlg.), links are of communication and the primitive is a *cooperative game in partition function form* w with N as the player set defined as follows:

The set of all *coalitions* is $CL = \{S | S \subseteq N, S \neq \varnothing\}$. The set of *partitions* of N is PT. The set $\{S^1, ..., S^l\} \in PT$ if and only if $\bigcup_{k=1}^{l} S^k = N$, $\forall k \in \{1, .., l\}$, $S^k \neq \varnothing$ and $S^k \cap S^j = \emptyset$ if $k \neq j$ and $j \in \{1, .., l\}$.

Let ECL be the set of embedded coalitions, the set of coalitions with specifications as to how the other players are aligned. Formally: $ECL = \{(S, Q) | S \in Q \in PT\}$. For any finite set L, let $\mathbb{R}^L$ denote the set of real vectors indexed on the members of L. A game in partition function form is a vector $w \in \mathbb{R}^{ECL}$. For any such $w \in \mathbb{R}^{ECL}$ and any embedded coalition $(S, Q) \in ECL$, $w^N_{S,Q}$, the (S, Q) component of w^N, is interpreted as the *payoff* (transferable utility) which the coalition S would have to divide if they coordinate effectively among its members if all the players were aligned into the coalitions of partition Q.

A communication network game $\bar{v}$ assumes that effective coordination can occur if all players in a coalition can communicate directly or indirectly with all the other members, if $N(g) = N\left(g^N\right)$. So a coalition's value depends not only on the partition but on the network structure. We represent this latter dependence by $\bar{v}^g \in \mathbb{R}^{ECL}$ for all $g \in G$. A network game with communication is denoted by a list $\bar{v}$ where each entry corresponds to a unique $g \in G$.

In network games, there is a value function v defined on the set of networks.

A *payoff allocation rule* is an assignment of payoff for each player $i \in N$. In communication networks, it depends on the partition and the network structure. In particular, for player i, one has $\varphi_i^{\bar{v}^g}$. For network games, we have ρ_i^g (given v). Without loss of generality, we refer only to ρ^g and v.

We use two notions of efficiency. A network g is *efficient* relative to v if $v(g) \geq v(\ddot{g})$ for all $\ddot{g} \in G$. A network g is *constrained efficient* relative to v and ρ if there does not exist any $\ddot{g} \in G$ and a payoff allocation rule $\tilde{\rho}$ such that:

(a) $\tilde{\rho}_i^{\ddot{g}} \geq \tilde{\rho}_i^g$ for all i with strict inequality for some i and

(b) for all $g \in G$ and for all components $g' \in C(g)$, $\sum_{i \in N(g')} \rho_i^g = \sum_{i \in N(g')} \tilde{\rho}_i^g$.

The last notion is adequate if transfers flow only within components.

2.2 The Aumann-Myerson Game

In Aumann-Myerson (1988) [2] (A-M), pairs of players can accept or reject their permanent link proposed following a rule of *order* o as in the game bridge. This order o depends on the sequence of links that have formed and an initial exogenous order, a one to one function $o_\emptyset : [1,..,|g^N|] \to g^N$. Let ordered network $\overrightarrow{g}$ be given, where $|g| = |g^N| - \bar{r}$ and $\bar{r} \in [0,..,|g^N|]$. The number of links that have not formed yet is $\bar{r}$. Let $r \in [1,.,\bar{r}]$. If $r-1$ links in $g^N \backslash g$ have been rejected, link ij is the r^{th} to be proposed if the *current* order $o_{\overrightarrow{g}}(r) = ij$. The game ends if all $\bar{r}$ links have been rejected, or if $\bar{r} = 1$ and the $|g^N|^{th}$ link forms. Iteratively, if the r^{th} link has formed, the new current order $o_{(\overrightarrow{g},ij)} : [1,..,\bar{r}-1] \to g^N \backslash (g + ij)$ is such that if link $pq \neq ij$ is the m^{th} link in the previous order $o_{\overrightarrow{g}}$, then $pq = o_{(\overrightarrow{g},ij)}(m-r)$ if $m > r$; otherwise, $pq = o_{(\overrightarrow{g},ij)}(m + \bar{r} - r)$.

Suppose there are three players. The initial order $o_\emptyset$ is 12, 23, 13. If link 12 is rejected, 23 is proposed next. If 23 is accepted, 13 is proposed first. If then 13 is rejected 12 proposes next. If 12 is rejected the game ends, and so on.

Ordered network $\overrightarrow{g}$ is *terminal* and so is its last link $ij_{|g|}$ if these are the last to form at the end of the game. Then, each player receives its payoff according to the Myerson values (Myerson (1977) [8]), a payoff allocation rule, in network g. As there is perfect information, this game has subgameperfect equilibria (SPE) each associated to a unique *final network*.

2.3 The General Transfer Game

The only difference between our games and that in A-M is that the formation of a link depends on a group of players, that includes the two players that have such link, choosing transfers out of their payoffs in terminal networks.

2.3.1 Players' Actions, Histories and Networks

The initial history in the game Tr is $h^0 = \emptyset$. Let $\ell(h^0)$ be a set of links that includes the link to be *proposed* at h^0, $ij(h^0)$, where $ij(h^0) = o_\emptyset(r(h^0))$, and $r(h^0) = 1$; so $ij(h^0)$ is the first link in the A-M exogenous order $o_\emptyset$. In period

0, there are no links and so $g\left(h^0\right)=g^{\emptyset}$. Only if a player belongs to the *group* of *proposers,* her action set is non trivial; that is, only if $q\in P\left(h^0\right)=N\left(\ell\left(h^0\right)\right)$, then she chooses $t^q\in T_q\left(h^0\right)=\mathcal{L}\left(h^0\right)$, a vector of *transfers*.

We define iteratively *history* h^{k+1}, a sequence of transfers chosen:

For $k=0,..,\bar{k}$, where $\bar{k}$ is the maximum number of periods the game can have, we take as given: history $h^k=\left(t^{-1},t^0,..,t^{(k-1)}\right)$, where $t^{-1}=h^0$; the ordered network that has formed $\overrightarrow{g}\left(h^k\right)$; the action set for player q, $T_q\left(h^k\right)=\mathcal{L}\left(h^k\right)$; $\ell\left(h^k\right)$, the set of links that includes the link proposed at h^k, $ij\left(h^k\right)$, where $ij\left(h^k\right)=o_{\overrightarrow{g}(h^k)}\left(r\left(h^k\right)\right)$, i.e., $ij\left(h^k\right)$ is the $r\left(h^k\right)^{th}$ link in the current A-M order $o_{\overrightarrow{g}(h^k)}$, where $r\left(h^k\right)\in\left\{1,...,\bar{r}\left(h^k\right)\right\}$ and $\bar{r}\left(h^k\right)=\left|g^N\right|-\left|g\left(h^k\right)\right|$.

Proposers $q\in P\left(h^k\right)=N\left(\ell\left(h^k\right)\right)$ choose simultaneously transfers $t^q\in T_q\left(h^k\right)$; a profile of transfers is $t\in T\left(h^k\right)=\mathcal{L}\left(h^k\right)^{\left|P\left(h^k\right)\right|}$. A transfer by player q is a *unilateral rejection* if at least one of its entries is negative, if it is not that case that $t^q\left(h^k\right)\geq\mathbf{0}$. Link $ij\left(h^k\right)$ forms and transfers are binding if and only if for all pairs of proposers $q',q''\in P\left(h^k\right)$ transfers *match;* that is, these are identical, $t^{q'}=t^{q''}$, and there is no unilateral rejection.

If transfers match, the next history and ordered network are respectively $h^{k+1}=\left(h^k,t^k\right)$ and $\overrightarrow{g}\left(h^{k+1}\right)=\left(\overrightarrow{g}\left(h^k\right),ij\left(h^k\right)\right)$. If $g\left(h^k\right)+ij\left(h^k\right)=g^N$, a terminal history is reached. Otherwise, the action set $T\left(h^{k+1}\right)=\mathcal{L}\left(h^{k+1}\right)^{\left|P\left(h^{k+1}\right)\right|}$, where $P\left(h^{k+1}\right)=N\left(\ell\left(h^{k+1}\right)\right)$, $ij\left(h^{k+1}\right)\in\ell\left(h^{k+1}\right)$; so both players $i\left(h^{k+1}\right)$ and $j\left(h^{k+1}\right)$ are proposers of link $ij\left(h^{k+1}\right)$, where $ij\left(h^{k+1}\right)=o_{\overrightarrow{g}(h^{k+1})}\left(r\left(h^{k+1}\right)\right)$, $r\left(h^{k+1}\right)=1$, is the first link in the new A-M current order $o_{\overrightarrow{g}(h^{k+1})}$ proposed at h^{k+1}. If t^k is not a transfer match, $\overrightarrow{g}\left(h^{k+1}\right)=\overrightarrow{g}\left(h^k\right)$. In the latter case, if $r\left(h^k\right)=\bar{r}\left(h^k\right)$, a terminal history is reached, otherwise $T\left(h^{k+1}\right)=\mathcal{L}\left(h^{k+1}\right)^{\left|P\left(h^{k+1}\right)\right|}$, where $P\left(h^{k+1}\right)=N\left(\ell\left(h^{k+1}\right)\right)$, $ij\left(h^{k+1}\right)\in\ell\left(h^{k+1}\right)$, $ij\left(h^{k+1}\right)=o_{\overrightarrow{g}(h^{k+1})}\left(r\left(h^{k+1}\right)\right)$, $r\left(h^{k+1}\right)=r\left(h^k\right)+1$; i.e., $ij\left(h^{k+1}\right)$ is the $\left(r\left(h^k\right)+1\right)^{th}$ link in the current A-M order proposed at h^{k+1} as $o_{\overrightarrow{g}(h^{k+1})}=o_{\overrightarrow{g}(h^k)}$. A profile of transfers is $t\in T\left(h^{k+1}\right)=\mathcal{L}\left(h^{k+1}\right)^{\left|P\left(h^{k+1}\right)\right|}$.

Suppose h is a terminal history with terminal network $\overrightarrow{g}(h)$. So h_{-1} is the history in period $|h_{-1}|$ such that $|h_{-1}|+1$ is the total number of periods in the game if the game ends with $\overrightarrow{g}(h)$ after some action was played in h_{-1}. By definition h describes an entire sequence of actions from the start of the game on. We denote by $H^{\bar{k}}$ as the set of all such terminal histories that can be identified with the set of possible *outcomes* when the game is played.

2.3.2 Pure Strategies and Payoffs

A pure strategy for player i is a contingent plan on how to play at period k of the game for possible histories h^k. Let H^k denote the set of all period k-histories, and $T_{i,H^k}=\cup_{h^k\in H^k}T_{i,h^k}$.

A pure strategy for player i is a sequence of maps $\{s_i^k\}_{k=1}^{\bar{k}}$ such that s_i^k maps H^k to the set of player i's feasible actions T_{i,H^k} (i.e., $s_i^k(h^k)\in T_{i,h^k}$ if $h^k\in H^k$).

The set of pure strategies for player i in the game is denoted by S_i.

A sequence of actions for a profile for such strategies $s \in S$ is called the *path* of the strategy profile, where S is the set of all strategy profiles: In period zero, actions are $t^0 = s^0 \left(h^0\right)$. The actions in period 1 are $t^2 = s^2 \left(t^1\right)$ and so on. Since the terminal histories represent an entire sequence of play or path associated with a given strategy, one can represent each players' corresponding *overall's* payoff as a function $u_i : H^{\bar{k}} \to \mathbb{R}$. Abusing notation, we denote the payoff vector to profile $s \in S$ as $u(s) = u\left(h\right)$, where h is the path of s, as one can assign an outcome in $H^{\bar{k}}$ to each strategy $s \in S$. In all our games, payoffs outcomes are realized only at the end of period $|h_{-1}|$ for all terminal histories h; these are denoted by $\nu\left(h_{-1}, t\right)$ where $\left(h_{-1}, t\right) = h$. Hence, payoffs associated to h equal the period payoffs in h_{-1}, that is, $u\left(h\right) = \nu\left(h_{-1}, t\right)$. In that case, players receive their payoff according to the payoff allocation rule net of transfers.

2.3.3 Stability Concepts

Nash Equilibrium A pure-strategy *Nash equilibrium* is a strategy profile s such that no player i can do better with a different strategy, $u_i(s_i, s_{-I}) \geq u_i(s_i', s_{-I})$ for all $s_i' \in S_i$, where $I = \{i\}$.

Subgameperfect Equilibrium Since all players know the history h^k, one can view the game from period k on with history h^k as an extensive form game in its own and denote it by $Tr\left(h^k\right)$. To define payoff functions in this game, note that if the sequence of choices and actions or path leading to an outcome of the game in periods k through k' are t^k through $t^{k'}$, the terminal history is $h' = (h^k, t^k, .., t^{\left|h'_{-1}\right|})$ where $\left|h'_{-1}\right| = k'$. The payoffs for player i are $u_i(h')$.

Strategies in $Tr\left(h^k\right)$ are defined in a way where the only histories one needs to consider are those consistent with h^k. Precisely, any strategy profile s of the whole game induces a strategy profile $s|h^k$ on any $Tr\left(h^k\right)$. For each i, $s_i|h^k$ is the *restriction* of s_i to the histories consistent with h^k. One denotes the restriction profile set by $S|h^k$.

Let terminal histories h' be such that $h' = (h^k, t^k, .., t^{\left|h'_{-1}\right|})$ and the associated subset of $H^{\bar{k}}$ be denoted by $H^{\bar{k}}(h^k)$. As one can assign an outcome in $H^{\bar{k}}(h^k)$ to each restriction profile $s|h^k$ where $s \in S$, the overall payoff vector to the restriction $s|h^k$, will be denoted abusing notation by $u(s|h^k)$. Thus, one can speak of Nash equilibria of $Tr\left(h^k\right)$. A strategy profile s in Tr is a SPE if, for every h^k, the restriction $s|h^k$ to $Tr\left(h^k\right)$ is a Nash equilibrium of $Tr\left(h^k\right)$.

Refinements Say, we have our game Tr with two players and only one period. The Nash equilibria are identical as those in the Nash Demand game (Nash (1950) [10]) or that in Bloch and Jackson (2007) [4]; coordination failures are possible. In general, if there are at least two individual transfers that differ (maybe one or two of them are unilateral rejections) from the other ones at any history in our game, such transfer profile can be supported as a SPE even though the group that proposes can do better if it coordinates on a transfer match (if continuation values are better for all). Based on Bernheim and Ray (1989) [3], we assume efficient cooperative bargaining in order to eliminate such equilibria in a "similar" way pairwise Nash equilibria does in the simultaneous games in Bloch and Jackson (2007) [4]:

A *group SPE (GSPE)* is a SPE strategy profile s such that at every history h^k there does not exist a transfer match t'^k such that for all $i \in P\left(h^k\right)$, the individual GSPE *continuation value* $u_i(s|\left[h^k, t'^k\right]) > u_i(s|h^k)$. If the latter inequality is weak, then we have a *strong GSPE*. If in addition pairs, coordinate on the continuation value consistent with the Nash bargaining solution, then we have a *Nash GSPE* (in any solution, future pairs do the same). Existence, uniqueness, and implementation of Nash GSPE are studied in a companion paper Nieva (2008b) [12]. Note that all these refinements of SPE are *consistent*. This means that these are used in any future history, or, intuitively, credible.

2.4 Group and Transfer Specifics

Component-group Game: Let ij be the link proposed at history h. Given h, the group of proposers $P(h)$ coincides with the players in the *new* component g'^* if ij forms; $P(h) = N(\ell(h))$ (in comunication networks $P(h)$ is a coalition) is such that $ij \in \ell(h) = [g(h) + ij]' = g'^* \in C[g(h) + ij]$.

Each proposer $q \in P(h)$ at h chooses simultaneously an infinite dimensional vector of transfers $t^q(h)$. An entry in this vector is denoted by $t^q(h, h^+) \in \mathbb{R}^{n^2}$, where history $h^+ = h$ or *follows* h *after link* ij forms; i.e., its subvector $h^+_{|h|+1} = (h, t)$, where t is a transfer match; so $\overrightarrow{g}(h^+)_{|g(h)|+1} = (\overrightarrow{g}(h), ij)$.

For all $k \in \left\{1, .., n^2\right\}$ and for all $q \in P(h)$, the k^{th} entry in $t^q(h, h^+)$ is $t^q_{zz'(k)}(.)$, a transfer from $z(k) \in P(h)$ to $z'(k) \in N$ that player q proposes if network $\overrightarrow{g}(h^+)$ is terminal; so, for simplicity, there are no transfers contingent on transfers; hence, $t^q(h, h^+) = t^q(h, h')$ if $\overrightarrow{g}(h^+) = \overrightarrow{g}(h')$. Transfers are zero if $h^+ = h$, $t^q_{lp}(h, h) = 0$, and not defined in histories after link ij is rejected.

Self transfers are zero; $t^q_{lp}(.) = 0$ if $l = p$. Whenever $\overrightarrow{g}(h^+) = (\overrightarrow{g}(h), ij)$, if $p \notin P(h)$, then $t^q_{lp}(h, h^+) = 0$; transfers are only among members in $P(h)$ if link ij is terminal. There are no transfer across components $g'(h^+) \in C(g(h^+))$ and isolated players. Abusing notation, denote isolated players as a component $g'^{\emptyset}(h^+)$. We then require $t^q_{lp}(h, h^+) = 0$ if $l \in N(g'(h^+))$ and $p \notin N(g'(h^+))$.

Consider terminal history $h \in H^{\bar{k}}$ with terminal network $\overrightarrow{g}$. The subvector h_{K^e}, $e \leq |g|$, is the history in period k^e where the e^{th} link of $\overrightarrow{g}$ forms; h is then consistent with h_{K^e}. Let $t(h_{K^e})$ be the transfer match at h_{K^e}. Period payoffs are not discounted and these are zero unless $g = g^N$ and $t(h_{-1})$ is a transfer match, or $g \neq g^N$ and $t(h_{-1})$ is not a transfer match. In any case, $q \in N$ gets her payoff given by the allocation rule ρ^g_q in terminal network g plus transfers to her from proposers $m \in P(h_{K^e})$, $e \leq |g|$, minus her transfers to other players $p \in N$ agreed upon when she proposes. Let $\Theta = \{e | q \in P(h_{K^e})\}$; $\{h_{K^e}\}_{e \in \Theta}$ is the set of all histories where q proposes. The net payoff for q is

$\nu_q(h_{-1}, t) = \rho^g_q + \sum_e \sum_{m \in P(h_{K^e})} t^m_{mq}(h_{K^e}, h) - \sum_{e \in \Theta} \sum_p t^q_{qp}(h_{K^e}, h)$.

The n-group Game: Abusing notation, it is the component game where for all h, the n players are in the "new component" if $ij\,(h)$ forms.

3 Efficiency Analysis

First, we illustrate *why a necessary condition for a GSPE and sufficient for a SPE is that a transfer match and net payoffs in the final network have to satisfy sets of inequalities, or, equivalently, net payoffs cannot be blocked by a group in another network.*

Example: A three player network game where the order is $12, 23, 13$

1———————2   3

$\rho_1^{12} = \frac{1}{2}$ $\rho_2^{12} = \frac{1}{2}$ $\rho_3^{12} = 0$

2———————1———————3

$\rho_2^{213} = 0$ $\rho_1^{213} = 0$ $\rho_3^{213} = 0$

2 $\rho_2^{g^N} = .4$

↙ ↘

1 —— 3

$\rho_1^{g^N} = .4$ $\rho_3^{g^N} = .4$

Suppose that players 1 and 2 choose a transfer match that yield net payoffs of half each and form link 12 in period 0. If links 23 and 13 are rejected in that order, they indeed get this as then the game ends. Hence, the continuation values of players in group $\{1, 2, 3\}$ if unilaterally rejecting in period 2 (when they propose link 13) are $(.5, .5, 0)$.

Suppose GSPE (or strong GSPE) is used. If network 213 forms with any *given* transfer match, the complete network forms in any GSPE of the subgame at next period 3 as link 23 is accepted. If a player unilaterally rejects 23, players obtain any given associated triplet of net payoffs in terminal network 213; these *outside options* sum up to zero. As the complete network's total payoff is 1.2, the same group in the complete network can *block* outside options with better net payoffs (cooperative notions using inequality conditions); as then, there is no individual profitable deviation, there is always a Nash equilibrium and so a SPE in period 3 that gives any player at least the continuation value of her unilaterally rejecting (non cooperative notions). Note that total continuation values of any such given transfer match sum up to 1.2 in previous period 2.

If any network is blocked by the complete (ordered) network (in the sense above), terminal on the path of some strategy profile, that is, if all required inequalities[2] are satisfied, then the complete network is a SPE outcome as then, it is not blocked. In general, there can be efficient and inefficient SPE final networks with net payoffs that don't require satisfying such inequalities. More networks can be final if players in groups fail to coordinate by choosing unilateral

[2]Net payoffs for a deviator on such path in the expected complete network have to be at least as good as the one she expects in the resulting network after her deviation.

rejections. Note that, such failure is not allowed in any cooperative solution[3].

Hence, once we require GSPE, not being blocked becomes a necessary condition for a network to be final. Now, even if all the required inequalities are satisfied for a given network to be final (say, in a different scenario, network 213 offering net payoffs that are better than $(.5, .5.0)$ and net payoffs in the complete network, etc.), in general, transfer matches may coexist that don't satisfy the inequalities[4] and can not be eliminated in a GSPE; its continuation payoffs may be better for one member and worse for the other one relative to the ones of matches that do satisfy the inequalities (See Nieva (2008a) [11] for examples).

Next, with the same example, we illustrate the idea that *for all equilibria to be efficient a necessary condition is that a Nash GSPE like solution is used*; *moreover, such a solution is consistent with Aumann's quote in the introduction.*

Even if <u>*total*</u> continuation values in period 2 are better than total outside options, $1.2 > .5+.5+0$, link 13 may not form. Given any transfer match, there is a GSPE in next period 3 in which at least one of the three players looses relative to $(.5, .5, 0)$. Then, accepting link 13 is not even a SPE outcome in the subgame at period 2. For any loser, it is optimal to unilaterally reject. The only way to ensure that the three players get at least their outside options in period 2 is for the transfer match not to change them in next period 3. But its sum has to be equal to zero. So, in general, efficiency is not an equilibrium. However, under Nash GSPE, efficiency is restored as any division of 1.2 among the three players is a continuation value for an appropriate transfer match in period 2. Say, if transfer match implies the triplet $(.15, .15, -.3)$, the Nash Bargaining Solution (NBS) adds $\frac{(1.2-0)}{3} = .4$ to these outside options in period 3; so $(.55, .55, .1) > (.5, .5, 0)$. In contrast, the GSPE can yield $(.4, .4, .4) > (.15, .15, -.3)$, but then link 13 is rejected in period 2.

We think that GSPE is not reasonable in this set up as it does not respond by increasing the continuation value of a player with a higher outside option. Groups fail to coordinate in subtle threats. Note that implicit in Aumann's quote is the assumption that threats have to be the outcome of *cooperation,* rational, and not just efficient coordination of actions.

The illustration for the role of cyclical monotonicity (c.m) and the irrelevance of contingent transfers in obtaining efficiency follows. Loosely, if c.m. holds all players in a group on a path to an efficient ordered network gain by matching transfers. As a consequence, they merge components they belong to to begin with. So what matters for link formation are total *continuation* payoffs of groups or, equivalently, components, as contingent transfers are "renegotiated" (See, in contrast, the bilateral-group game in Nieva (2008a) [11]).

Let d and a be the total payoff for the complete network and the two link network respectively in the same example. Denote by c and b_c the total payoff for the linked players in a one link network and that of the isolated player respectively. Let b_i, b_j and b_l be the payoff for the individual players in the

[3] There are restrictions on which coalitions can block. But if one can block, threats are payoffs that sum up to its *total* payoff; blocking is efficient.

[4] This means that if such matches are chosen the given network will not be final.

empty network. The order is ij, jl, il.

Necessary and sufficient conditions for efficient Nash GSPE are:

I) $(d-a)+a>a$, so after a two link network, the complete one forms;

II) given I, $(d-(c+b_c))+(c+b_c)>(c+b_c)$, so after a one link network one with two links forms;

III) given II, $\frac{2}{3}(d-c-b_c)+c>b_i+b_j$, so group $\{i,j\}$ forms link ij (say, $i=1$, $j=2$, $l=3$) "if b_i and b_j are outside options".

Note that the first term in brackets in each inequality is the *Nash Surplus*, the amount beyond the total outside options that all proposers receive if a link forms. Also, in III, group $\{i,j\}$ receives $\frac{2}{3}(d-c-b_c)+c$ regardless of how c is divided according to i and j's transfer match. So if the three conditions hold, as before, there is a division of c that yields continuation payoffs that would be better than "outside options b_i, b_j", the bilateral NBS; so the first link ij forms expecting the complete network.

S*trong* c.m. holds as *all* ordered efficient networks satisfy I-III. Even if ijl (123) forms in period 1, the complete network forms. If link 12 is rejected, net payoffs are those in the complete network that forms if either link 23 is accepted in period 1 or rejected. Note that b_i and b_j are not outside options in period 0.

In general, strong c.m. is sufficient but not necessary. Consider a non symmetric payoff allocation rule. Even if the efficient network can still be reached after a deviation, the resulting inefficient final network may not block continuation values of not deviating.

The term *cyclical* is used as a new component that results by merging, say, two, may have a total payoff lower than the sum of payoffs in these two even if the former has more members. That is not true with size monotonicity in Currarini and Morelli (2000) [5]. Note that example exhibits size monotonicity.

The condition has more inequalities as the total payoff of a given component (and so outside options) may be influenced by externalities depending on the order and number of merged components by the time the players in the given component group propose again. Before formalizing, we define concepts.

Given network g, the *component value function* is $v'^g : C(g) \to \mathbb{R}$. The total payoff of a component is $v'(g')$, $g' \in C(g)$, and it is equal to the sum of its members' payoff allocations, $v'^g(g') = \sum_{i \in N(g')} \rho_i^g$. Let $\overrightarrow{g}'^{*}_{-X} = ij_{|g|-x} + \sum_{t=1,..,p\left(\overrightarrow{g}_{-(X+1)}\right)} \overrightarrow{g}'^{t}_{-(X+1)}$ be the new component $\overrightarrow{g}'^{*}_{-X} \in C\left(\overrightarrow{g}_{-X}\right)$ that results if the $(|g|-x)^{th}$ link of $\overrightarrow{g}$ forms and $p\left(\overrightarrow{g}_{-(X+1)}\right)$ components $\overrightarrow{g}'^{t}_{-(X+1)} \in C\left(\overrightarrow{g}_{-(X+1)}\right)$ merge. Abusing notation, denote a player i without links as a component $\overrightarrow{g}'^{\emptyset}$ of $\overrightarrow{g}$. Set $N\left(\overrightarrow{g}'^{\emptyset}\right) = i$. The total continuation value for players $N\left(\overrightarrow{g}'\right)$ in component $\overrightarrow{g}'$ is $F\left(\overrightarrow{g}'\right)$.

Condition: *Given order o, and payoff allocation rule ρ, the set of component value functions v'^g, $g \in G$, is strong (weak) cyclical monotonic if for each (at least one) efficient ordered network $\overrightarrow{\breve{g}}$:*

(a) *Set $\overrightarrow{g} = \overrightarrow{\breve{g}}$ and $F\left(\overrightarrow{g}'\right) = v'^g\left(\overrightarrow{g}'\right)$. Iteratively for $x = 1, ..., |g|-1$. For $t = 1, ., p\left(\overrightarrow{g}_{-X}\right)$, the Nash surplus for players in merged component $\overrightarrow{g}'^{t}_{-X}$ is*

$S\left(\overrightarrow{g}'^{t}_{-X}\right)=\frac{N\left(\overrightarrow{g}'^{t}_{-X}\right)}{N\left(\overrightarrow{g}'^{*}_{-(X-1)}\right)}\left[F\left(\overrightarrow{g}'^{*}_{-(X-1)}\right)-\sum_{t=1,..,p\left(\overrightarrow{g}_{-X}\right)}v'\left(\overrightarrow{g}'^{t}_{-X}\right)\right].$

We require $S\left(\overrightarrow{g}'^{t}_{-X}\right)>0$. *Set* $F\left(\overrightarrow{g}'^{t}_{-X}\right)=S\left(\overrightarrow{g}'^{t}_{-X}\right)+v\left(\overrightarrow{g}'^{t}_{-X}\right)$. *Otherwise,* $F\left(\overrightarrow{g}'_{-X}\right)=F\left(\overrightarrow{g}'_{-(X-1)}\right)$, *where* $\overrightarrow{g}'_{-X}\in C\left(\overrightarrow{g}_{-X}\right)$ *is not merged.*

(b) *If* $\overrightarrow{\breve{g}}$ *can still form, it is never a Nash GSPE to form a link* $ij\notin\breve{g}$.

(c) *Condition in (a) does not hold for any* $\overrightarrow{g}^{N}_{E}$, *where* $e>|\breve{g}|$ *and any* $\overrightarrow{g}^{N}$ *is such that its subvector* $\overrightarrow{g}^{N}_{|\breve{g}|}=\overrightarrow{\breve{g}}$ ■

Part (b) is necessary if the efficient network is not the complete one. Also, (b) is a tautology; a more precise condition requires ordered network specific variations of (a+c) that are almost a restatement. If $\overrightarrow{\breve{g}}=\overrightarrow{g}^{N}$ (b) and (c) are satisfied vacuously.

Suppose $\overrightarrow{\breve{g}}=\overrightarrow{g}^{N}$. Consider a symmetric n player cooperative game without externalities but with cooperation structures. Let $v(N_1\cup N_2\cup N_3)$ be the value of the coalition of n players. Let the three sets be disjoint and so a partition of N, $|N|=|N_1|+|N_2|+|N_3|$. Let N_1 and N_2 merge first on a path to $\overrightarrow{\breve{g}}$. Two conditions for this (incomplete) "order of finer partitions" are

$v(N)-v(N_1\cup N_2)-v(N_3)>0$, and

$v(N_1\cup N_2)+\frac{\sum_{k=1,2}|N_k|}{\sum_{k=1,.,3}|N_k|}\left[v(N)-v(N_1\cup N_2)-v(N_3)\right]>v(N_1)+v(N_2).$

These conditions may seem complex and most importantly not practical. But note that superadditivity in links, superadditivity of cooperative games and "monotonicity" as in Currarini and Morelli (2000) [5] and Mutuswami and Winter (2002) [7] imply our condition but not viceversa. So, this complexity seems to be the cost of generality.

Theorem 1: *Under strong c.m, all Nash GSPE are efficient and constrained efficient.*

Corollary 1: *If all Nash GSPE are efficient then weak c.m. holds.*

In the **n-group game** the analysis is very similar.

Theorem 2: *All Nash GSPE outcomes are efficient for all network games.*

4 Conclusion

We study two "cooperative and noncooperative" sequential network formation games with counterproposals of transfers tied to link formation. It seems to be that a necessary condition for solving the tension between stability and efficiency is that the efficient network can block. With counterproposals, the all player group is sufficient. The role of groups of heterogenous sizes with other factors, maybe overlooked, are important issues. Bilateral groups are studied in Nieva (2008a) [11]. Anyway, a Nash GSPE like solution concept is needed in general. Its appeal is being consistent with rational threat behavior of blocking coalitions (for its implementation, see Nieva (2008b) [12]).

5 Appendix

Proof Th. 1: Let $\breve{g}$ be efficient. Suppose for now that $\breve{g}$ is final *if* it forms. By contradiction, let some ordered network $\overrightarrow{\breve{g}}_{-1}$ be final. As for strong c.m., $\overrightarrow{\breve{g}}$ forms. The total continuation value for proposers at history $\breve{h}_{K^{|\breve{g}|-1}}$, where the $(|\breve{g}|-1)^{th}$ link of $\overrightarrow{\breve{g}}$, $o_{\overrightarrow{\breve{g}}_{-2}}(\breve{r})$, forms, is $\sum_{i\in P\left(\breve{h}_{K^{|\breve{g}|-1}}\right)} u_i\left(s^*|\left(\breve{h}_{K^{|\breve{g}|-1}},t\right)\right) = F\left(\overrightarrow{\breve{g}}'^{*}_{-1}\right)$; t is a transfer match, and $s^*|\left(\breve{h}_{K^{|\breve{g}|-1}},t\right)$ is a Nash GSPE in subgame $Tr\left(\left(\breve{h}_{K^{|\breve{g}|-1}},t\right)\right)$.

By induction for $x=2,...,|\breve{g}|-1$, suppose that if $\overrightarrow{\breve{g}}_{-(X-1)}$ forms, $\overrightarrow{\breve{g}}$ does too. Let some $\overrightarrow{\breve{g}}_{-X}$ be final. By strong c.m. (a+b), if link $o_{\overrightarrow{\breve{g}}_{-X}}(\breve{r})\in\overrightarrow{\breve{g}}$ is the last efficient link in the current order to be proposed (at $\breve{h}_{K^{|\breve{g}|-(x-1)}}$), without loss of generality, it is accepted as outside options can be improved upon,

$$\sum_{i\in P\left(\breve{h}_{K^{|\breve{g}|-(x-1)}}\right)} u_i\left(s^*|\left(\breve{h}_{K^{|\breve{g}|-(x-1)}},t\right)\right) = F\left(\overrightarrow{\breve{g}}'^{*}_{-(X-1)}\right) >$$
$$\sum_{t=1,..,p\left(\overrightarrow{\breve{g}}_{-X}\right)} v'\left(\overrightarrow{\breve{g}}'^{t}_{-X}\right) = \sum_{i\in P\left(\breve{h}_{K^{|\breve{g}|-(x-1)}}\right)} u_i\left(s^*|\left(\breve{h}_{K^{|\breve{g}|-(x-1)}},t^d\right)\right),$$

where $s^*|\left(\breve{h}_{K^{|\breve{g}|-(x-1)}},t^d\right)$ is a Nash GSPE and t^d contains unilateral rejections. Then at least this efficient link forms in the current order $o_{\overrightarrow{\breve{g}}_{-X}}$. In a possible scenario, using (a+b), an efficient $\bar{r}^{th}<\breve{r}$ preceding link forms if $\overrightarrow{\bar{g}}$ is instead the final ordered network, where $\bar{g}=\breve{g}$. Without loss of generality, $\sum_{i\in P\left(\breve{h}_{K^{|\breve{g}|-x}}\right)} u_i\left(s^*|\left(\breve{h}_{K^{|\breve{g}|-x}},t\right)\right) = F\left(\overrightarrow{\breve{g}}'^{*}_{-X}\right)$,[5] if $\overrightarrow{\bar{g}}$ is the final ordered network. Hence if $\overrightarrow{\breve{g}}_{-X}$ forms $\overrightarrow{\breve{g}}$ forms.

After using (c) with a "reverse" argument, if $\overrightarrow{\breve{g}}$ forms, it is final■

Proof Th. 2: Consider any g as a component with n players. Then, (a+c) in c.m. hold. We show (b). Suppose that no efficient link is left to be proposed in the current order: if a first inefficient one forms, its Nash GSPE continuation net payoffs have to improve on (1) *given* net payoffs obtained if all remaining links are rejected; second, the same is true if another inefficient link forms with respect to (2) continuation net payoffs if an inefficient link is expected to form in a Nash GSPE. As (a) holds, from Th. 1, there is a transfer match such that Nash GSPE continuation net payoffs are better than (2) or (1) if the last efficient link is rejected. Any inefficient link proposed earlier on is rejected as at least one player gains expecting the efficient network to form (regardless of the efficient link in the order that forms later on) as there is still an efficient link to be proposed. As this holds for any *given* payoffs, if an efficient link forms, another efficient one forms next■

[5] These are total net payoffs for the group $P\left(\breve{h}_{K^{|\breve{g}|-x}}\right)$ in the efficient network if players in components to be merged agree at $\breve{h}_{K^{|\breve{g}|-x}}$ on a transfer match.

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