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Summary

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Keywords: Coalitional Bargaining, Nash Program, Simultaneous Payoff, Demands, Uncertainty
JEL Classification: C71, C72, C78

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The Coalitional Nash Bargaining Solution with Simultaneous Payoff Demands

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Abstract

We consider a standard coalitional bargaining game where once a coalition forms it exits as in Okada (2011), however, instead of alternating offers, we have simultaneous payoff demands. We focus in the producer game he studies. Each player is chosen with equal probability. If that is the case, she can choose any coalition she belongs to. However, a coalition can form if an only if payoff demands are feasible as in the Nash (1953) demand game. After smoothing the game (as in Van Damme (1991)), when the noise vanishes, when the discount factor is close to 1, and as in Okada´s (2011), the coalitional Nash bargaining solution is the unique stationary subgameperfect equilibrium.

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1. Introduction

In Okada (2011) and Compte and Jehiel (2010) the coalitional Nash bargaining solution[1], a cooperative solution for situations where coalitions can form, is found to be the unique stationary equilibrium outcome as the discount factor goes to 1 in variations of a standard Rubinstein´s (1982) alternating offers bargaining game extended to allow for coalition formation. In

[1]This maximizes the product of players utility levels within points in the core of a cooperative game.

this paper, we show that in the producer game as in Okada (2011), the coalitional bargaining solution (after adding uncertainty) is the unique stationary subgameperfect H-essential equilibrium (an extension of Van Damme´s (1991) static H-essential equilibrium) of a coalitional bargaining game that differs from the Rubinstein version in that simultaneous payoff demands are considered. Hence, this paper belongs to the Nash Program (1953), the literature that looks for noncooperative games that have as equilibrium outcomes ad-hoc cooperative solutions.

In our game, in each period, players are chosen with equal probability from the set of active players. If chosen, this player, to be called as the *initiator,* can choose a coalition she belongs to. Once she chooses a coalition a simultaneous Nash demand game (Nash (1953)) is played with the members of that coalition. This coalition forms if an only if payoff demands are feasible given the value the coalition generates. If a coalition forms its members are deleted from the set of active players and consumption, in terms of transferable utility, is realized. If the coalition does not form one period elapses and the game repeats itself with the same set of active players. The number of periods is infinite and perpetual disagreement yields a payoff of zero. There are no externalities and the underlying cooperative game is superadditive. Players discount future payoffs.

As an equilibriun notion, we use a refinement of subgameperfect equilibrium (SPE). As it is well known, repeated Nash demand like games have a plethora of Nash and SPE equilibria (See Stahl (1990) for the two player case). So we use a refinement, the Nash group stationary subgameperfect equilibrium (Nash GSSPE), of stationary subgame perfect equilibrium (SSPE) consistent with the Nash Bargaining solution (NBS) related to Nieva´s (2002, 2005, 2008, 2014) Nash GSPE for games with finite horizon. In a Nash GSSPE, the expected discounted payoffs each time a coalition plays the Nash demand game are the NBS of a bargaining problem where the total surplus is the value of this coalition and disagreement payoffs are expected Nash GSSPE payoffs if payoff demands are not feasible.

In section 3, we proof existence of Nash GSSPE using the Kakutani´s fixed point theorem and characterize the grand coalition Nash GSSPE in general. In contrast with Okada (2011), the grand coalition Nash GSSPE exists if and only if the percapita value of the grand coalition is in the Core *regardless* of the value of the discount factor. Next, we use these results to prove in section 4 that the Nash GSSPE coincides with the coalitional bargaining solution in the producer game when the discount factor is close to 1 as in Okada (2011). We follow the structure of the latter paper as close as possible. Finally, in the appendix, we give an outline of the straightforward extension to the n-player case of Van Damme's (1991) smoothing technique (inspired in Nash (1953)) for the two player Nash demand game. We also show simultaneously how this extension is used in our game. It is not hard to see then that the Nash GSSPE is the unique SSPE when the discount factor is close to 1 and the noise vanishes (or, equivalently, the unique SSPE H-essential equilibrium).[2]

2. Preliminaries

Let (N, v) be an n-person game in coalitional form where utility is transferable. The set of players is $N = \{1, 2, ..., n\}$. A nonempty subset S of N is a *coalition* of players. The set of all coalitions of N is $C(N)$. The characteristic function of this game is v, a real valued function defined on $C(N)$ is normalized, that is, $v(\{i\}) = 0$ for all $i \in N$. We also assume it is superadditive, that is, $v(S \cup T) \geq v(S) + v(T)$ for any two disjoint coalitions S and T. Finally, it is essential, $v(N) > 0$. For each coalition S, $v(S)$ is the total utility that members in S can distribute among themselves in any way they agree to.

A payoff allocation for coalition S is a vector $x^S = \left(x_i^S\right)_{i \in S}$ of real numbers where x_i^S is the payoff for player $i \in S$. A payoff allocation x^S is *feasible* if $\sum_{i \in S} x_i^S \leq v(S)$. Let X^S denote the set of all feasible payoff allocations for S and let X_+^S denote the set of all non-negative elements in X^S. If T is a finite set, $\Delta(T)$ denotes the set of all probability distributions on T.

As a non-cooperative bargaining procedure for a game (N, v), we consider the random proposer model as in Okada (2007) but with a twist. Negotiations can take an infinite number of bargaining rounds $t = (1, 2, ...)$. Let N^t be the set of all *active* players who have not formed a coalition yet at the beginning of period t. In the initial round $N^1 = N$. At the beginning of period t,

[2] We have been aware of the work of Abreu and Pierce (2013) that use the smooth Nash demand in an infinitely repeated game in an stochastic framework to single out as the noise vanishes the unique equilibrium (stationary) that turns out to be the variable threats Nash bargaining solution for a two player game. Besides the obvious differences, we want to point out that Nieva (2005) was the first paper to suggest the use of the smooth game after the simultaneous approach had been neglected as for the discouraging results in Stahl (1990).

a player $i \in N^t$ is selected with equal probability; we will call this player the *initiator*. This initiator i can choose a coalition S with $i \in S \subset N^t$. Once she has chosen S a Nash demand game (Nash 1953) is played among the s players in S as follows: All players in S state simultaneously their nonnegative payoff demands x_i^S for each player $i \in S$. If the payoff demand profile x^S is feasible then they agree, the coalition S forms and consumption takes place. Negotiations continue in the next period where the set of active players is $N^{t+1} = N^t - S$. If the payoff demand profile is not feasible then negotiations continue in the next period where $N^{t+1} = N^t$. The game ends when every player in N joins some coalition.

When a coalition S forms after payoff demand profile x^S is agreed upon in period t, the payoff of each player $i \in S$ is $\delta^{t-1} x_i^S$ where δ $(0 \leq \delta < 1)$ is the discount factor for future payoffs. When bargaining does not stop, all players who fail to join any coalition obtain zero payoffs.

The game is denoted by $\Gamma(N, \delta)$, where n is the initial set of active players and δ is the discount factor. This is a multistage game with observed actions, chance moves and with an infinite horizon.

We consider behavior strategies in $\Gamma(N, \delta)$. A history h_i^t in period t is a sequence of all past actions including the selection of the initiators. A strategy for player i, σ_i, maps histories where she moves to actions or in some cases randomized actions: If player i is an initiator in period t, $\sigma_i(h_i^t)$ is a probability distribution over all possible coalitions with $i \in S \subset N^t$. If a coalition $S \subset N^t$ is chosen in period t, $\sigma_i(h_i^t)$ is a payoff demand x_i^S with $i \in S$. Given a strategy profile $\sigma = (\sigma_1, ..., \sigma_n)$, the expected discounted payoff for player i in $\Gamma(N, \delta)$ is defined in the usual way. For each coalition $S \in C(N)$, a subgame of $\Gamma(N, \delta)$ after a coalition S has formed is denoted by $\Gamma(N - S, \delta)$, where recall $N - S$ is the set of active players. A strategy σ_i induces a strategy, a *restriction* $\sigma_i | \Gamma(N - S, \delta)$, in each subgame $\Gamma(N - S, \delta)$. In each period t, it will be useful to denote the subgame after a coalition S has been chosen by some initiator by $\Gamma(N^t, S, \delta)$.

A strategy σ_i for player i in $\Gamma(N, \delta)$ is called stationary if player i´s action depends only on payoff relevant history. In this model, a payoff relevant history consists of the set N^t of active players when the initiator has been selected; it also consists of the coalition S that has been chosen and the initiator who chose it when a player plays the Nash demand game in subgame $\Gamma(N^t, S, \delta)$.

It is known that repeated Nash Demand games have many subgame perfect equilibria (SPE) outcomes (See Stahl (1991)); take the divide dollar game; any division of the dollar, including $(0,0)$, is a possible SPE equilibrium outcome. It is not hard to see that these repeated games have also infinitely many stationary subgameperfect equilibria (SSPE). Hence, as an equilibrium notion for $\Gamma(N,\delta)$ we use a refinement of stationary subgame perfect equilibrium consistent with the Nash bargaining solution as in Nieva (2002, 2005, 2008, 2014). In the appendix, we explain that introducing uncertainty as in Van Damme (1991) is equivalent to our refinement of SSPE. Formally, we have:

Definition 1. *A strategy profile $\sigma = (\sigma_1, ..., \sigma_n)$ of $\Gamma(N,\delta)$ is a stationary subgame perfect equilibrium if σ is a subgame perfect equilibrium of $\Gamma(N,\delta)$ and every strategy σ_1 is stationary for each $i \in N$.*

For a stationary subgame perfect equilibrium of $\Gamma(N,\delta)$ σ, let v_i^S denote the expected payoff for player i in subgame $\Gamma(S,\delta)$.

Definition 2. *A strategy profile σ of $\Gamma(N,\delta)$ is a Nash group stationary subgame perfect equilibrium (Nash GSSPE) if σ is a stationary subgame perfect equilibrium of $\Gamma(N,\delta)$ and the expected discounted payoffs associated to the restriction σ to subgame $\Gamma(N^t, S, \delta)$ for each $S \subset N^t$ and each N^t is the solution to a Nash bargaining problem (whenever it is well defined) where the total transferable utility is $v(S)$ and disagreement payoffs are discounted payoffs if demands are not feasible that is $\delta v_i^{N^t}$ for each $i \in S$.*

Recall, as utilities are transferable, the Nash GSSPE discounted payoff for player i in subgame $\Gamma(N^t, S, \delta)$ is then equal to $\frac{v(S)-\sum_{j\in S}\delta v_j^{N^t}}{s} + \delta v_i^{N^t}$ for each $i \in S$, that is, it is equal to the *percapita Nash surplus* plus the disagreement payoff for player i.

It is clear that if $v(S) > \sum_{j\in S}\delta v_j^{N^t}$ the Nash GSSPE profile $\sigma(N^t, S, \delta)$ could consist of each player in S demanding payoff demand $x_i^S = \frac{v(S)-\sum_{j\in S}\delta v_j^{N^t}}{s} + \delta v_i^{N^t}$. Note also that Definition 2 implies that if the Nash bargaining solution is not well defined, say, if $v(S) \leq \sum_{j\in S}\delta v_j^{N^t}$, any SSPE restriction σ to subgame $\Gamma(N^t, S, \delta)$ can be chosen. In particular, if $v(S) < \sum_{j\in S}\delta v_j^{N^t}$, a Nash GSSPE predicts at $\Gamma(N^t, S, \delta)$ disagreement; the Nash GSSPE profile $\sigma(N^t, S, \delta)$ could consist of all players in S demanding unfeasible payoff demands.

The next two lemmas are key for our analysis. For a Nash GSSPE σ of $\Gamma(N,\delta)$, let $q_i^S \in \Delta(\{T | i \in T \subset S\})$, denote the random choice by initiator

i of coalitions T (of S) in $\Gamma(S,\delta)$ and recall v_i^S is the expected payoff for player i in subgame $\Gamma(S,\delta)$ (in a Nash GSSPE). We refer to a collection $(v^S, q^S)_{S\in C(N)}$, where $v^S = (v_i^S)_{i\in S}$ and $q^S = (q_i^S)_{i\in S}$, as the configuration of σ.

Lemma 3. *In every Nash GSSPE $\sigma = (\sigma_1, ..., \sigma_n)$ of $\Gamma(N,\delta)$, some coalition with more than one member forms with positive probability in the initial round and each member j receives more than δv_j^N.*

Proof. *For each $i \in N$, let v_i be player i´s expected payoff for σ in $\Gamma(N,\delta)$ in a Nash GSSPE. Because of super-additivity, any average over discounted payoffs of players that may be obtained in each coalition structure that occur with nonnegative probability is less than or equal than $v(N)$; this implies $\sum_{j\in N} v_j \leq v(N)$. Because the game is zero normalized, we have $v_i \geq 0$ for all $i \in N$. It follows that each initiator i can choose the grand coalition N and obtain strictly more than δv_i by the definition of the Nash bargaining solution. Hence, the claim follows as then the Nash surplus in the coalition that she ends up choosing optimally, say S, is positive, that is, $v(S) - \sum_{j\in S}\delta v_j > 0$; so, S has more than one member and all members get strictly more than δv_j^N for each $j \in S$.* ■

Let us now characterize the configuration of a Nash GSSPE.

Lemma 4. *A collection $(v^S, q^S)_{S\in C(N)}$, where $v^S = (v_i^S)_{i\in S}$ and $q^S = (q_i^S)_{i\in S}$, is the configuration of a Nash GSSPE in $\Gamma(N,\delta)$) if and only if the following conditions hold for every $S \in C(N)$ and every $i \in S$:*

(i) $q_i^S\ (S) > 0$ implies $\hat{S}$ is a solution of.

$$\max_{i\in T\subset S} \frac{v(T) - \sum_{j\in T}\delta v_j^S}{t} + \delta v_i^S \qquad (1)$$

(ii) $v_i^S \in R_+$ satisfies

$$\begin{aligned} v_i^S &= \frac{1}{s}\max_{i\in T\subset S}\left(\frac{v(T) - \sum_{j\in T}\delta v_j^S}{t} + \delta v_i^S\right) + \\ &\frac{1}{s}\sum_{j\in S, j\neq i}\left(\begin{array}{c} \sum_{j\in T\subset S, i\in T} q_j^S(T)\left(\frac{v(T)-\sum_{k\in T}\delta v_k^S}{t} + \delta v_i^S\right) + \\ \sum_{j\in T\subset S, i\notin T} q_j^S(T)\delta v_i^{S-T} \end{array}\right) \end{aligned} \qquad (2)$$

Proof. *First we proof necessity. Given the configuration of the Nash GSSPE, it is clear that if initiator i chooses optimally to randomize between coalitions the expected value that she gets in each coalition that is assigned positive probability has to be the maximum of Equation* (1) *, otherwise she would gain by assigning zero probability to a coalition that is not a maximizer and increasing the probability to a coalition that is a solution to* (1)*; hence, 1 follows. Part 2 is just the recursive definition of expected payoffs v_i^S. For sufficiency, we can use the single-period deviation property that local optimality of a strategy implies global optimality in an infinite-length multistage game with observed actions.* ■

3. Existence and Grand Coalition Nash GSSPE

First we prove existence of Nash GSSPE in the general case. We also characterize an equilibrium where only the Grand Coalition forms regardless of the initiator. These results will help us with the producer game later on.

Proposition 5. *There exists a Nash GSSPE of the bargaining model* $\Gamma(N,\delta)$
Proof. *The only difference with the proof in proposition 3.1 in Okada (2011) is that in our case the initiator chooses the coalition that maximizes equation 1 and not Okada´s equation 1. By Lemma 4, it suffices to prove that there exists a collection $(v^S,q^S)_{S\in C(N)}$ of players' expected payoff $v^S=(v_i^S)_{i\in S}$ and their random choices $q^S=(q_i^S)_{i\in S}$ of coalitions in all subgames $\Gamma(S,\delta)$ such that (i) and (ii) hold for every coalition $S\in C(N)$ and every $i\in S$. We prove this claim by induction regarding the cardinality s of coalition S. When $s=1$, where $S=\{i\}$, the claim trivially holds by setting $v_i^{\{i\}}=0$ and $q_i^{\{i\}}(\{i\})=1$. For any $2\leq s\leq n$, suppose that the claim holds for all $t=1,...,s-1$. Let $S\in C(N)$ be any coalition with s members. For all proper subsets T of S, let $v^T=(v_j^T)_{j\in T}$ be the expected payoffs for members in T and let $q^T=(q_j^T)_{j\in T}$ be their random choices of coalitions in the subgame $\Gamma(T,\delta)$ such that* (1) *and* (2) *in Lemma 4 hold. By the inductive assumption v^T and q^T exist. Let $\Delta_i^S\in\Delta(\{T|i\in T\subset S\})$, that is, it is the set of probability distributions over the subsets of S player i belongs to. We define a multi-valued mapping F from a compact and convex set $X_+^S\times\prod_{i\in S}\Delta_i^S$ to itself as follows. For $(x,q)\in X_+^S\times\prod_{i\in S}\Delta_i^S$, $F(x,q)$ is the set of all $(y,r)\in X_+^S\times\prod_{i\in S}\Delta_i^S$, that satisfy the following for all $i\in S$:*

(i) $r_i \in \Delta(\{\hat{S} | i \in \hat{S} \subset S$ *and* $\hat{S}$ *is a solution of* $\max_{i\in T\subset S}\left(\frac{v(T)-\sum_{j\in T}\delta x_j}{t}+\delta x_i\right)\})$.
(ii) $y_i \in R_+$ *satisfies*

$$\begin{aligned} y_i &= \frac{1}{s}\max_{i\in T\subset S}\left(\frac{v\left(T\right)-\sum_{k\in T}\delta x_k}{t}+\delta x_i\right)+ \\ &\quad \frac{1}{s}\sum_{j\in S, j\neq i}\left(\begin{array}{c}\sum_{j\in T\subset S, i\in T} q_j^S(T)\left(\frac{v(T)-\sum_{k\in T}\delta x_k}{t}+\delta x_i\right)+ \\ \sum_{j\in T\subset S, i\notin T} q_j^S(T)\delta v_i^{S-T}\end{array}\right) \end{aligned} \tag{3}$$

It is not hard to see that $F\left(x,q\right)$ *is a non-empty convex set in* $X_+^S \times \prod_{i\in S}\Delta_i^S$. *We can show that* F *is upper-hemicontinuous and compact valued using the maximum theorem. As then the assumptions for the Kakutani's fixed point theorem are satisfied, there exists a fixed point* (x^*,q^*) *of* F *with* $(x^*,q^*)\in F\left(x^*,q^*\right)$. *Set* $v_i^S = x_i^*$ *and* $q_i^S = q_i^*$ *for all* $i\in S$ *and the proposition follows.* ■

We next study the conditions under which the grand coalition N is formed independent of the initiator that is selected by random.

Definition 6. *A behavior strategy* σ *for* $\Gamma(N,\delta)$ *is called a grand coalition Nash GSSPE if it is a Nash GSSPE of* $\Gamma(N,\delta)$ *and the grand coalition forms, independent of the proposer.*

Theorem 7. *The grand-coalition Nash GSSPE of* $\Gamma(N,\delta)$ *is characterized as follows: The expected payoff* v_i *is given by* $v_i = \frac{v(N)}{n}$. *The grand-coalition Nash GSSPE exists if and only if its expected payoff vector* $(\frac{v(N)}{n},...,\frac{v(N)}{n})$ *is in the core of* (N,v), *that is,* $s\frac{v(N)}{n}\geq v\left(S\right)$, *for all* $S\subset N$.
Proof. *From equation 2, we obtain*

$$v_i = \frac{v\left(N\right)-\sum_{j\in N}\delta v_j}{n}+\delta v_i \tag{4}$$

After summing up over all i, *we obtain* $\sum_{j\in N} v_j = v\left(N\right)$ *and so* $\sum_{j\in N}\delta v_j = \delta v\left(N\right)$. *Using this in equation 3, we obtain* $v_i = \frac{v(N)}{n}$. *Next, since* N *forms in equilibrium, from equation 1 we have that*

$$\frac{v\left(N\right)-\sum_{j\in N}\delta v_j}{n}+\delta v_i \geq \frac{v\left(S\right)-\sum_{j\in T}\delta v_j}{s}+\delta v_i \tag{5}$$

for all $S \subset N$. After substituting $v_i = \frac{v(N)}{n}$ and cancelling out the necessity of the second claim follows. For sufficiency, suppose the expected payoff vector is in the core, then equation 4 holds. By Lemma 4 the claim follows. ■

Note that this results differs from that of the standard Rubinstein coalitional bargaining model (See Okada (2011)) where instead this is a limiting result. In other words, in the Rubinstein paradigm the expected payoff vector of the grand coalition $(\frac{v(N)}{n}, ..., \frac{v(N)}{n})$ does not need to be in the core if the discount factor δ is not close to 1.

4. The Producer Economy and the Coalitional Bargaining Solution

Uniqueness of Nash GSSPE in the general case for the coalitional bargaining game we study is an open question (as it is in the alternating offers coalitional bargaining model). So the coalitional bargaining solution for cooperative situations in general may not be an appropriate solution concept. However, it has been singled out as the unique non cooperative prediction in the alternating offers coalitional bargaining framework by Okada (2011) in a particular situation when the discount factor is close to 1; hence it is appropriate in this case. So we focus in the same situation and show that we obtain the same limiting results but with a simultaneous approach. We follow this paper´s structure as close as possible to emphasize the great similarity. The idea is that Nash GSSPE that are different than the grand coalition Nash GSSPE occur but for one degenerate case in circumstances under which the Grand Coalition Nash GSSPE can not form. In the degenerate case, in which both types of Nash GSSPE can occur, expected payoffs are the same; in any case, expected payoffs are those in the Coalitional Bargaining solution. That is the basic intuition in the central Theorem 11.

Consider a production economy ξ with an employer (player 1) and $n-1$ identical workers i $(= 2, ..., n)$, as in Shapley and Shubik (1967). A coalition of the employer and $s-1$ $(s \geq 1)$ workers yields the benefit $f(s)$, which is monotonically increasing in s with $f(1) = 0$. The benefit of any other coalition is zero. The core of the economy is nonempty since the allocation with the employer exploiting the total benefit $f(n)$ is in the core. To analyze the outcome of wage bargaining between the employer and workers, we apply our coalitional bargaining game with random initiators and simultaneous payoff demands. The grand-coalition Nash GSSPE will be called the full-employment equilibrium, and any other Nash GSSPE a partial-employment equilibrium. Let v_i be the expected payoff for player $i(=1,...,n)$ in a Nash GSSPE.

We start by showing that in a Nash GSSPE all workers have identical expected payoffs because of competition among them.

Lemma 8. *For all workers i and j, $v_i = v_j$ in every Nash GSSPE.*
Proof. *By contradiction. Denote the percapita Nash Surplus generated by coalition T by $\frac{W(T)}{t}$, where $W(T) = v(T) - \sum_{j\in T} \delta v_j$. Note that the coalitions that maximize the percapita Nash surplus over **all** coalitions that include the producer solve equation 1 for the producer. Denote the set of such coalitions by C_1. By Lemma 3, any coalition chosen with positive probability (with more than one member) in Nash GSSPE includes the producer as expected payoffs have to be positive. Hence, for each $S \in C_1$ and for each $i \in S$, we have $S \in C_i$.*

Consider first the case where player i' is not included in each $S \in C_1$. This implies that $\frac{W(S_{i'})}{s_{i'}} < \frac{W(S_1)}{s_1}$, where $S_i \in C_i$; that is, the coalitions that i' assigns positive probability in equilibrium have a lower percapita Nash product than those in C_1. Hence, the producer would reject such a coalition as he always can get $\frac{W(S_1)}{s_1} + \delta v_1$ and so $v_{i'} = 0$. A contradiction in view of lemma 3.

Consider the final case where for each $i \in N$ there exists $S \in C_1$ such that $i \in S$. This means that each player i gets $\frac{W(S_1)}{s_1} + \delta v_i$ for each $S_1 \in C_1$ when a coalition that she belongs to and that belongs to C_i is accepted in equilibrium. Let q_i^j be the probability that player i receives an offer when player $j(\neq i)$ is a coalition chooser, an initiator. Using equation 2, we have

$$v_i = \frac{1}{n}\left(\frac{W(S_1)}{s_1} + \delta v_i\right) + \frac{1}{n}\sum_{j\neq i} q_i^j \left(\frac{W(S_1)}{s_1} + \delta v_i\right),$$

for each $i \in N$, for some $S_1 \in C_1$. After rearranging, we find an expression for v_i,

$$v_i = \frac{W(S_1)}{s_1} \frac{1 + \sum_{j\neq i} q_i^j}{n - \delta\left(1 + \sum_{j\neq i} q_i^j\right)}. \tag{6}$$

With no loss of generality, we assume that $v_i > v_j$ for two different workers i, j. We want to show that $\sum_{k\neq j} q_j^k \geq \sum_{k\neq i} q_i^k$, and hence, in view of (5), $v_j \geq v_i$, thereby obtaining a contradiction.

We next show: (i) $q_j^k \geq q_i^k$ for any $k \neq i, j$, and (ii) $q_j^i \geq q_i^j$. Claim (i) follows from the fact that $i \in S$ implies $j \in S$ for any $S \in C_k$ because

$\delta v_i > \delta v_j$. To prove (ii), it suffices to show that $q_j^i < 1$ implies $q_i^j = 0$, that is, if there exists some $S_i \in C_i$ with $j \notin S_i$, then any $S_j \in C_j$ does not include i. Suppose not. Then, there exists some $S_i \in C_i$ with $j \notin S_i$ and some $S_j \in C_j$ with $i \in S_j$. Because $S_i \in C_i$ and $i \in S_j$, we have $\frac{W(S_i)}{s_i} \geq \frac{W(S_j)}{s_j} > \frac{W(S_j)}{s_j} + \frac{\delta v_j}{s_i} - \frac{\delta v_i}{s_i}$. By contrast, since $S_j \in C_j$, we have $\frac{W(S_j)}{s_j} \geq \frac{W((S_i-\{i\})\cup\{j\})}{s_i} = \frac{W(S_i)}{s_i} + \frac{\delta v_i}{s_i} - \frac{\delta v_j}{s_i}$. A contradiction. ■

Now we study all possible equilibria in the producer game and its expected payoffs. The full-employment equilibrium is characterized by Theorem 7. Next, we characterize a partial-employment equilibrium. Only the following two types of such equilibria exist, except for a degenerate class of the economy ξ. For $2 \leq s < n$, a Nash GSSPE is called an s-equilibrium if only coalitions with s members form with positive probability. For $2 \leq s < t \leq n$, a Nash GSSPE is called an (s,t)-equilibrium if only coalitions with s and t members form with positive probability. The basic idea here is that if such Nash GSSPE occur then the allocation $\left(\frac{f(n)}{n}, \frac{f(n)}{n}, ..., \frac{f(n)}{n}\right)$ is not in the core,

Proposition 9. *For $2 \leq s < n$, an s-equilibrium of the production economy ξ is characterized as follows.*

(i) The employer and each worker receive the expected payoffs

$$v_1 = f(s) - (n-1)\,v_2 \tag{7}$$

$$v_2 = \frac{f(s)\,(1 - s + \delta\,(s-1))}{n\delta\,(s-1) - s\,(n-1)} \tag{8}$$

respectively. Every worker receives an offer with probability $\frac{n(s-2)+1}{n(n-1)}$.

(ii) An s-equilibrium exists for any δ close to 1 if and only if $f(s) > f(t)$ for all $t < s$ and $f(s) = f(t)$ for all $t > s$. As δ goes to 1, the equilibrium allocation converges to a unique core allocation of the economy ξ for which the employer exploits the total payoff $f(n)$.

Proof. *(i) As only S coalitions are chosen with positive probability, it follows from Lemma 4 that*

$$v_1 = \frac{f(s) - \sum_{j\in S} \delta v_j}{s} + \delta v_1$$

and

$$f(s) = v1 + (n-1)v2. \tag{9}$$

After using Lemma 8, the unique solution of this system of equations is (6) *and* (7). *Let* q *be the probability that every worker receives an offer. Again, from Lemma 4, we have*

$$v_2 = \frac{1}{n}\left(\frac{f(s) - \sum_{j\in S}\delta v_j}{s} + \delta v_2\right) + q\left(\frac{f(s) - \sum_{j\in S}\delta v_j}{s} + \delta v_2\right)$$

After using Lemma 8 and then solving for q *, we have*

$$q = \frac{sv_2}{f(S) - \delta(v_1 - v_2)} - \frac{1}{n}$$

Use Equation (8) *to substitute for* $v_1 - v_2$*, then Equation (7) to substitute for* v_2 *and after some tedious algebra (try getting in the numerator of the first expression in the right hand side* $sf(s)(s-1)(\delta-1)$ *and then cancelling out* $sf(s)(\delta-1)$*) last part of* (i) *follows.*

(ii) *By Lemma 4, an* s*-equilibrium exists if and only if the percapita Nash product of* S ,$\frac{W(S)}{s} \geq \frac{W(T)}{t}$ *for all* $t \neq s$*. By definition of the Nash product and lemma 8, we have equivalently for all* $t \neq s$,

$$\frac{f(s) - (s-1)\delta v_2 - \delta v_1}{s} \geq \frac{f(t) - (t-1)\delta v_2 - \delta v_1}{t} \tag{10}$$

In view of (6) *and* (7), v_2 *converges to zero and* v_1 *to* $f(s)$ *as* δ *goes to* 1. *Noting this, we can show that the above inequality holds for any* δ *close to 1 if and only if* $f(s) \geq f(t)$ *for all* $t \neq s$*. Since* f *is a monotonically increasing function, we get that* $f(s) = f(n)$*. Next we show that* $f(s) > f(t)$ *for all* $t < s$*. From equation* (9) *get the expression* $tf(s) - sf(t) \geq \delta v_2(s-t) + (t-s)\delta v_1$*. Set* $f(s) = f(t)$ *and cancel out* $(s-t)$*. By equation* (8), *set* $v_1 = f(s) - (n-1)v_2$*. Next, use equation* (7) *and cancel out* $f(s)$*. Multiply by* $n\delta(s-1) - s(n-1) < 1$ *and after some algebra, we obtain* $1 \leq \delta$*, a contradiction.*

By (6) *and* (7), *we have that in the limit* $v_1 = f(n)$ *and* $v_2 = 0$*. When* $f(s) = f(t)$ *for all* $t \geq s$*, the core of the production economy* ξ *consists of a unique allocation* $(f(n), 0, ..., 0)$*. This proves the second part.* ■

Proposition 10. *For* $2 \leq s < t \leq n$*, an* (s,t)*-equilibrium of the production economy* ξ *is characterized as follows.*

(i) *The employer receives the expected payoff*

$$v_1 = \frac{f(s) - (s-1)\delta v_2}{s(1-\delta) + \delta}, \tag{11}$$

where, v_2, the expected payoff of the worker is

$$v_2 = \frac{f(t) - f(s)}{t - s} + \frac{(1-\delta)(sf(t) - tf(s))}{\delta(t-s)} \tag{12}$$

(ii) Assume that $t < n$. If an (s,t)-equilibrium exists for any δ close to 1, then $f(k) = f(n)$ for all $s \leq k \leq n$. Moreover, v_1 and v_2 converge to $f(n)$ and 0, respectively, as δ goes to 1.

(iii) Assume that $t = n$. As δ goes to 1, v_1 and v_2 converge to $v_1^* = \frac{(n-1)f(s)-(s-1)f(n)}{(n-s)}$ and $v_2^* = \frac{f(t)-f(s)}{(t-s)}$ respectively. The probability of full employment converges to 1 when $f(s) < f(n)$. If an (s,n)-equilibrium exists as δ goes to 1 then $\frac{f(n)}{n} \leq \frac{f(s)}{s}$. The expected payoff vector $(v_1^*, v_2^*, ..., v_2^*)$ is in the core of the production economy ξ, and the employer receives the minimum payoff v_1^* in the core.

Proof. *(i) By Lemma 4(i), if an (s,t)-equilibrium exists then the percapita Nash surplus of S ,$\frac{W(S)}{s} \geq \frac{W(K)}{k}$ for all $k \neq s$ and that of T , $\frac{W(T)}{t} \geq \frac{W(K)}{k}$ for all $k \neq t$. This implies, after using the definition of the Nash surplus and lemma 8, that*

$$\frac{f(s) - (s-1)\delta v_2 - \delta v_1}{s} \geq \frac{f(k) - (k-1)\delta v_2 - \delta v_1}{k} \tag{13}$$

for all $k \neq s$

$$\frac{f(t) - (t-1)\delta v_2 - \delta v_1}{t} \geq \frac{f(k) - (k-1)\delta v_2 - \delta v_1}{k} \tag{14}$$

for all $k \neq t$. By (12) and (13), we have

$$\frac{f(s) - (s-1)\delta v_2 - \delta v_1}{s} = \frac{f(t) - (t-1)\delta v_2 - \delta v_1}{t}. \tag{15}$$

Equation (14) implies that equation (2) in lemma 4(ii) becomes (as each player is paid the same after an equilibrium coalition forms regardless if it is S or T).

$$v_1 = \frac{f(s) - \sum_{j \in S} \delta v_j}{s} + \delta v_1 \tag{16}$$

First, we solve for v_1 in (15) and get equation (10). Next, we use (10) in (14) to solve for v_2 after tedious algebra manipulations.

(ii) This part follows almost identically the proof of proposition 4.2 (ii) in Okada (2011). Let p_s be the probability that an s-member coalition forms. Then,

$$v_1 + (n-1)v_2 = p_s f(s) + (1-p_s)f(t) \tag{17}$$

From (10) and (11), we can see that v_1 and v_2 converge to

$$v_1^* = \frac{(t-1)\,f\,(s) - (s-1)\,f\,(t)}{(t-s)}, \quad v_2^* = \frac{f\,(t) - f\,(s)}{(t-s)}, \tag{18}$$

respectively, as δ goes to 1. Let p_s^* be any accumulation point of $\{p_s\}$. Taking the limit in equation (14), we obtain $v_1^* + (n-1)v_2^* = p_s^* f(s) + (1-p_s^*)f(t)$. Substituting (17) into this equation, we obtain:

$$\left(p_s^* + \frac{n-t}{t-s}\right) f(s) = (p_s^* + \frac{n-t}{t-s})f(t). \tag{19}$$

Because $t < n$, $p_s^* + \frac{n-t}{t-s} > 0$ must hold. Thus, $f(s) = f(t)$. Then, $v_1^* = f(s)$ and $v_2^* = 0$ from (15). Finally, $f(s) = f(n)$ is obtained by letting δ go to 1 in (12) with $k = n$.

(iii) Setting $t = n$ in (17) yields $v_1^* = \frac{(n-1)f(s)-(s-1)f(n)}{(t-s)}$, $v_2^* = \frac{f(n)-f(s)}{(n-s)}$. Because $t = n$, (18) implies that $p_s^* f(s) = p_s^* f(n)$ for any limit point p_s^* of $\{p_s\}$. If $f(s) < f(n)$, then $p_s^* = 0$. Hence, the sequence $\{p_s\}$ converges to 0 as δ goes to 1. Therefore, regardless of whether $f(s) < f(n)$ or $f(s) = f(n)$ holds, we obtain: $v_1^* + (n-1)v_2^* = f(n)$. Because $f(s) \leq f(n)$, we have $v_1 + (n-1)v_2 \leq f(n)$ from (16). Substituting (10) and (11) into this inequality, a very tedious calculation yields $\frac{f(n)}{n} \leq \frac{f(s)}{s}$, in contrast to Okada (2011), for all $\delta < 1$. To show that $(v_1^*, v_2^*, ..., v_2^*)$ is in the core of the production economy ξ, first note that equations (10) and (13) with $t = n$ yield after a lot of rearranging

$$(k\,(1-\delta) + \delta)\,f(n) - (1-\delta)\,nf(k) - \delta f(k) \geq \delta v_2\,(n-k) \tag{20}$$

When δ goes to 1 this equation becomes

$$f(n) - f(k) \geq (n-k)\,\frac{f\,(n) - f\,(s)}{(n-s)} \tag{21}$$

, which is identical to equation (41) in the working paper version of Okada (2011), Okada (2007). Next, following Okada (2007), literally, equation (17) implies

$$v_1^* + (k-1)v_2^* = \frac{(n-k)\,f\,(s) - (s-k)\,f\,(n)}{(n-s)} \tag{22}$$

and (20) *and* (21) *imply that* $v_1^* + (k-1)v_2^* \geq f(k)$. *This together with* $v_1^*+(n-1)v_2^* = f(n)$ *show that* $(v_1^*, v_2^*, ..., v_2^*)$ *is in the core of the production economy* ξ. *Any core allocation* $(v_1, v_2, ..., v_2)$ *in which workers receive the same payoffs* v_2 *satisfies* $v_1 + (n-1)v_2 = f(n)$ *and* $v_1 + (s-1)v_2 \geq f(s)$. *These conditions imply* $v_1 \geq v_1^*$. *From* $v_1^* + (s-1)v_2^* = f(s)$ *it follows by contradiction that the employer receives the minimum payoff* v_1^* *in the core.*
■

We have the analogous to theorem 4.1 in Okada (2011) that is the central theorem in our paper.

Theorem 11. *The asymptotic values of the Nash GSSPE payoffs* v_1^* *and* v_2^* *for* δ *close to 1 are uniquely characterized as follows.*

(*i*) *If the allocation* $\left(\frac{f(n)}{n}, \frac{f(n)}{n}, ..., \frac{f(n)}{n}\right)$ *is in the core, then* $v_1^* = \frac{f(n)}{n}$ *and* $v_2^* = \frac{f(n)}{n}$.

(*ii*) *Otherwise, the workers receive wage* $v_2^* = \frac{f(n)-f(s)}{n-s}$ *, where* s *is the solution of* $\min_{1\leq k\leq n-1} \frac{f(n)-f(k)}{n-k}$. *The employer receives the smallest payoff in the core.*

(*iii*) *The asymptotic Nash GSSPE allocation* $(v_1^*, v_2^*, ..., v_2^*)$ *maximizes the generalized Nash product* $x_1x_2...x_n$ *within the core, that is, it is the Coalitional Bargaining Solution.*

Proof. *First, we argue that if there are other Nash GSSPE with more than two different sizes of coalitions, these have the same asymptotic values of players' expected payoffs as an* (s,t)*-equilibrium when the discount factor goes to 1. Equation* (16) *becomes with, say, 3 possible coalition sizes,* $s < t < t' < n$,

$$v_1 + (n-1)v_2 = p_s f(s) + p_t f(t) + (1 - p_s - p_t)\, f(t') \tag{23}$$

. *As* f *is monotonic, it follows from* (22) *that* $v_1 + (n-1)v_2 \geq p_s f(s) + (1-p_s) f(t)$. *After substituting* (17), *we imply* $f(s) \geq f(t)$. *Thus, from monotonicity of* f, $f(s) = f(t)$. *Then the proof proceeds as in the proof of Proposition* 10(*ii*) *but with* (22) *modified as*

$$v_1 + (n-1)v_2 = (p_s + p_t)\, f(s) + (1 - p_s - p_t)\, f(t') \tag{24}$$

. *It follows that* $f(t') = f(s)$ *and* $f(s) = f(n)$. *The same argument can be used if* $s < t < t' = n$ *to conclude that* $f(s) = f(t)$. *Next the proof in Proposition* 10(*iii*) *can be applied to* (23) *with* $t' = n$. *Second, from Propositions*

9 and 10 and Theorem 7 uniqueness follows when δ is close to 1. Part (i) follows from Theorem 7. In part (ii) the claims that workers receive $v_2^* = \frac{f(n)-f(s)}{n-s}$ and the employer receives the smallest payoff in the core follow from Propositions (9) *and* (10)*. That s is the solution of $\min_{1\leq k\leq n-1} \frac{f(n)-f(k)}{n-k}$ follows from* (20) *as for $k \neq s$ it is an strict inequality and if $k = s$ then it holds with equality. Finally, it is not hard to see that (iii) holds.* ■

5. Conclusion

We considered the standard coalitional bargaining game with alternating offers without renegotiation and externalities, however with simultaneous payoffs demands. In the producer game as in Okada (2011), we get identical results if we use the Nash GSSPE (a refinement of SSPE consistent with the Nash Bargaining solution) as a solution concept when the discount factor goes to 1 or if we look at the SSPE if we smooth the game as in Van Damme (1991) and the noise vanishes and the discount factor goes to 1. Hence a simultaneous approach also predicts the Coalitional Bargaining solution. A reasonable conjecture is that our results should extend to the situation where only one coalition can form as in Compte and Jehiel (2010). More importantly, our framework should also lead to predictions in models with renegotiation and externalities where extensions of the Coalitional Bargaining Solution may be possible to be defined based on our noncooperative approach. We leave that for future research.

A. Appendix: The n-player Smooth Nash Demand Game

We give an outline on how to extend the result to any n that the Nash bargaining solution is the unique H-essential equilibrium as in Van Damme´s (1991) result for $n = 2$ after smoothing this game and letting the noise vanish. We also show simultaneously how to fit this result into our model and the equivalence between the Nash GSSPE and the SSPE of the perturbed game when the noise vanishes and hence the uniqueness of this SSPE when the discount factor goes to 1.

Let S be the set of active players and suppose that coalition $T \subset S$ has been chosen, that is, we are in subgame $\Gamma(S, T, \delta)$. Following Van Damme (1991), we propose to smooth the Nash demand for players in T and then look at the SSPE when the amount of smoothing approaches zero. Consider the function $h\left(x^T\right)$ that gives the probability that payoff demand profile x^T

is feasible. More precisely, we restrict attention to perturbations in the class $H = \cup_{\epsilon>0} H^{\epsilon}$, where H^{ϵ} is the set of functions that satisfy

$h : \mathbb{R}^t_+ \to (0,1]$, h continuous, $h\left(x^T\right) = 1$ for $x^T \in X^T_+$, and

$$\max\left\{h\left(x^T\right), h\left(x^T\right)\prod_{i\in T} x_i\right\} < \epsilon \text{ if } \varrho\left(x^T, X^T_+\right) > \epsilon,$$

where $\varrho\left(x^T, X^T_+\right)$ is the Euclidean distance from x^T to X^T_+. The latter means that h decreases to zero sufficiently fast when x^T moves away from X^T_+. The smooth Nash demand game in subgame $\Gamma(S,T,\delta)$ is then $\Psi^{S,T}(h) = \left(T, (\mathbb{R}_+)_{i\in T}, \left(R^h_i\right)_{i\in T}\right)$ when uncertainty is described by h and where the continuous payoff function is $R^h_i\left(x^T\right) = x^T h\left(x^T\right) + \left(1 - h\left(x^T\right)\right)\delta v^S_i$.

In this set up, a (Nash) equilibrium $x^T$of $\Psi^{S,T}$ is an *H-essential equilibrium* if associated with every sequence $\{h^{\epsilon}\}_{\epsilon\downarrow 0}$ with $h^{\epsilon} \in H^{\epsilon}$ there is a sequence $\left\{x^{T,\epsilon}\right\}_{\epsilon\downarrow 0}$ such that $x^{T,\epsilon}$is an equilibrium of $\Psi^{S,T}(h^{\epsilon})$ and such that $x^{T,\epsilon}$ converges to x^T as ϵ approaches zero.

Van Damme (1991) shows, following Nash (1953), that the NBS is an H-essential equilibrium of the two player case in the two player standard smooth Nash demand game (Theorem 7.5.4). However, there is no assurance it is the unique H-essential equilibrium. Hence he gives an example of a "reasonable" function for which this is the case (Theorem 7.5.5). The proof for the n-player case is a straightforward extension following his same steps using the consistency property of the NBS. It follows that $\left(\frac{v(T)-\sum_{j\in T}\delta v^S_j}{t} + \delta v^S_i\right)_{i\in T}$ is the unique H-essential equilibrium of $\Psi^{S,T}$ and so Lemma 4 holds if we replace Nash GSSPE by SSPE and the smoothing technique (assuming independent perturbations) has been introduced and the noise vanishes in $\Psi^{S,T}$ for each $T \subset S$ and for each $S \subset C(N)$. The uniqueness of the SSPE when the noise vanishes in the producer game follows from the uniqueness of the Nash GSSPE when δ goes to 1.

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