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AN EQUIVALENCE THEOREM
FOR A BARGAINING SET

by

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AN EQUIVALENCE THEOREM FOR A BARGAINING SET*

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I. Introduction.

A weakness of the Core as a solution concept in economics and game theory is that it depends on the notion that when a coalition objects to a proposed allocation, i.e., engages on an improving move, it neglects to take into account the repercussions triggered by the move. See Greenberg (1986) for a recent discussion of this point and its connection to the ideas underlying the von Neumann-Morgenstern stable set solution.

Aumann and Maschler (1964) proposed a solution concept, the Bargaining Set, which addresses the above issue. Their idea is that for an objection based on a coalition to be effective it must be justified by the absence of a counterobjection, defined as an improving proposal by another coalition which leaves any common member of the two coalitions as well off as they are with the objection. That is, objections which admit counterobjections are frivolous and, therefore, disregarded. This is, of course, an imprecise description of the idea and, in fact, there is not a unique definition of the Bargaining Set. From the original Aumann-Maschler concept several variants have evolved and proved useful. See Maschler, 1976; Owen, 1982 and Shubik, 1983.

The Bargaining Set is larger than the Core: blocking is harder. Nonetheless in the mid-seventies Shapley and Shubik (see Shubik, 1985, Ch. 12, and Shapley-Shubik, 1985) and then Geanakoplos, 1978, showed that for transferrable utility, differentiable economies the equivalence principle holds: if the economy is large the Bargaining Set shrinks to the set of Walrasian allocations. Shapley and Shubik considered sequences of increasingly large economies while Geanakoplos studied directly the limit situation relying on techniques from non-standard analysis.

In this paper we first propose a simplification of the Bargaining Set. We then establish the equivalence theorem under a generality analogous to Aumann (1964). One advantage of our definition is that it does not depend on distinguished individual players and it is thus well defined in the continuum case. Our proof is not in essence more complex than Aumann's although it is different and it includes an existence argument. The key idea is a characterization of justified objections as those objections that, in a precise sense, can be price supported.

It is possible that the proposed redefinition of the Bargaining Set be of more general

interest. To assess this what is required is to see which forms the Bargaining Set takes in general games or in economic environments where the equivalence theorem does not hold, e.g. where the Core is large or where it is empty. Clearly, this is an interesting line of research which, for the moment, we have not pursued. But see Section VI for some additional comments.

II. Definitions and a Theorem.

There are ℓ commodities. Our set of agents is $I = [0, 1]$. Lebesgue measure on I is denoted λ . With P the space of continuous and strictly monotone preferences on R_+^ℓ our economy is a (measurable) map $t \mapsto (\succeq_t, \omega(t))$ into $P \times R_{++}^\ell$ such that $\int \omega < \infty$. This economy remains fixed for the rest of the paper.

An allocation is a $x : I \rightarrow R_+^\ell$ such that $\int x \leq \int \omega$. The allocation x is *Walrasian* if there is a $p \in R^\ell$ such that, for a.e. $t \in I$, $p \cdot x(t) \leq p \cdot \omega(t)$ and $p \cdot v > p \cdot \omega(t)$ whenever $v \succ_t x(t)$.

DEFINITION. The pair (S, y) , where $S \subset I$ and $y : S \rightarrow R_+^\ell$, is an objection to (or against) the allocation x if:

- a) $\int_S y \leq \int_S \omega$
- b) $y(t) \succeq_t x(t)$ for a.e. $t \in S$ and $\lambda\{t \in S : y(t) \succ_t x(t)\} > 0$.

DEFINITION. Let (S, y) be an objection to the allocation x . The pair (T, z) , where $T \subset I$ and $z : T \rightarrow R_+^\ell$ is a counterobjection to (S, y) if:

- a) $\int_T z \leq \int_T \omega$,
- b) $\lambda(T) > 0$, and
- c) (i) $z(t) \succ_t y(t)$ for a.e. $t \in T \cap S$,
(ii) $z(t) \succ_t x(t)$ for a.e. $t \in T \setminus S$.

DEFINITION. An objection (S, y) is said to be justified if there is no counterobjection to it. The Bargaining Set is the set of allocations against which there is no justified objection.

A Walrasian allocation necessarily belongs to the Bargaining Set since there can be no objection, justified or not, against it (just apply the standard argument showing that

Walrasian allocations belong to the Core). The aim of this paper is to show that the converse is also true.

THEOREM. *If there is no justified objection against the allocation x then x is Walrasian. Hence, an allocation x belongs to the Bargaining Set if and only if it is Walrasian.*

Observe that even the weaker result: "if there is no justified objection against x then x is Pareto optimal" requires a non-trivial proof.

A topic for further research is the asymptotic version of the above theorem. Note that our Bargaining Set is well defined for finite economies and that it can well be larger than the Core (see example in Section VI). The validity of the Theorem if preferences are unordered has recently been analyzed by Grodal, 1986. See also Vind (1986) for a discussion of related concepts of Bargaining Set.

REMARK 1: Because of strict monotonicity of preferences the definition of counterobjection can be weakened to just requiring strict preference for a positive measure subset of the counterobjecting coalition. For the Theorem we cannot do with less than this. In particular, strict preference cannot simply be replaced by weak preference (as it will be clear from careful consideration of the example in Remark 6).

REMARK 2: If the presence of weak preference in the definition of objection is thought unattractive the Theorem will still obtain with strict preference if the Aumann-Maschler concept of the "leader" of the objection is reintroduced à la manner of Geanakoplos (1978). Let $\delta > 0$ be an arbitrarily small number. Suppose now that given an allocation x we define a δ -objection to be a triple (K, S, y) such that $K \subset S$, $\lambda(K) \leq \delta$, and (S, y) is an objection with $y(t) \succ_t x(t)$ for a.e. $t \in S$. A counterobjection to (K, S, y) is a counterobjection (T, z) to (S, y) such that $T \cap K = \emptyset$. A δ -objection is justified if there is no counterobjection to it.

Let there be a justified objection (S, y) against x . For any $\delta > 0$ we can select a group $K \subset \{t \in S : y(t) \succ_t x(t)\}$, $\lambda(K) < \delta$, and transfer some of their goods to the members of $S \setminus K$. The result is a δ -objection (K, S, y') which satisfies $y'(t) \succ_t y(t)$ for a.e. $t \in S \setminus K$. But this implies that any counterobjection to (K, S, y') is also necessarily a counterobjection to (S, y) . Since the latter is justified it follows that (K, S, y') is also. Therefore the Theorem

yields: "given any $\delta > 0$, if there is no justified δ -objection against the allocation x then x is Walrasian."

III. Walrasian Objections.

The central idea for the proof of the Theorem is the consideration of a special class of objections generated by means of prices.

DEFINITION. The objection (S, y) to the allocation x is Walrasian if there is a price system $p \neq 0$ such that, for a.e. t ,:

- (i) $p \cdot v \geq p \cdot \omega(t)$ for $v \succsim_t y(t), t \in S$
- (ii) $p \cdot v \geq p \cdot \omega(t)$ for $v \succsim_t x(t), t \in I \setminus S$.

The Theorem is then obtained by combining the following two Propositions:

PROPOSITION 1. Any Walrasian objection (S, y) to an allocation x is justified.

PROPOSITION 2. If x is not a Walrasian allocation then there is a Walrasian objection against it.

The next Proposition, the converse of Proposition 1, shows that the concept of Walrasian objection is more than a technical tool.

PROPOSITION 3. If (S, y) is a justified objection to an allocation x then it is also a Walrasian objection.

REMARK 3: Proposition 3 makes clear that typically there will be a few justified objections against an objectionable allocation. Indeed justified objections have to be Walrasian and, while those exist (Proposition 2), they are obtained by solving a supply and demand problem that typically will have a finite number of solutions. Note the contrast with Core theory. It is well known that under the conditions of Proposition 2 if an allocation is not Walrasian then it can be improved upon in a great variety of manners.

REMARK 4: The fact that justified objections must be Walrasian also helps to understand why we cannot strengthen the concept of objection by requiring strict preference for a.e. $t \in S$. Suppose we are in a type economy and we consider an allocation x satisfying the equal treatment property. Then the Walrasian objection (S, y) , with objecting price vector p , will

itself satisfy the equal treatment property in the following sense: if t, t' are of the same type and $t \in S$, $t' \notin S$ then $y(t) \sim_t x(t)$. This is easy to verify. Note first that $p \cdot y(t) = p \cdot \omega(t)$ because y must be a Walrasian allocation for S (which implies also $p \gg 0$). Suppose now that $y(t) \succ_t x(t)$. Then $y(t) \succ_{t'} x(t')$ and so $p \cdot y(t) > p \cdot \omega(t') = p \cdot \omega(t)$ which is impossible. Hence $y(t) \sim_t x(t)$. We must conclude therefore that if a coalition with a justified objection includes only part of some type of agents (and this may be unavoidable; see next two remarks) then it is not possible for these agents to strictly improve at the objection.

REMARK 5: Given an allocation x and a price vector p any agent t having a Walrasian demand at p strictly preferred (resp. dispreferred) to $x(t)$ will be part (resp. remain outside) of any group attempting a Walrasian objection sustainable by p . The only freedom left corresponds to the marginal consumers t who are indifferent between getting $x(t)$ or their Walrasian demands at p .

REMARK 6: It may be instructive to discuss an Edgeworth Box example. In Figure 1 there are two equal-mass types and we are considering the non-Walrasian, equal treatment allocation x . The curves BD and AC represent the relevant regions of the offer curves of the two types. Recalling the content of the previous remark it is easy to convince oneself that the price vectors p capable of sustaining a Walrasian objection can only have one of the following three forms:

- (i) p lies strictly between p_1 and p_2 and is an overall Walrasian equilibrium price (i.e., the curves BD and AC cross at the allocation corresponding to p). Then the objecting coalition is the coalition of the whole.
- (ii) $p = p_1$ and the marginal type, type 2, is on the long side, i.e. B is to the left of A . Then the objecting coalition includes all the consumers of type 1 and a fraction of those of type 2.
- (iii) $p = p_2$ and the marginal type, in this case type 2, is on the long side, i.e. C is above D . Then the objecting coalition includes all the consumers of type 2 and a fraction of those of type 1.

It is clear that at least one of the cases (i)-(iii) must occur. In the figure it is case (ii).

FIGURE 1

REMARK 7: A Walrasian objection constitutes, in particular, a Walrasian allocation for the objecting coalition. That any non-Walrasian allocation could be improved upon (even strictly) by a coalition using an allocation Walrasian for the coalition had been proved before (in Mas-Colell, 1985, Proposition 7.3.2, as an extension of a result of Townsend for the replica case). The existence of a Walrasian objection is however a much stronger property. For example, going back to Figure 1 it should be clear that any price intermediate between p_1 and p_2 can be used to generate a coalition improving upon at one of its own Walrasian allocations.

IV. Proof of the Propositions.

PROOF OF PROPOSITION 1: The proof is just a repetition of the familiar argument establishing the optimality of equilibrium allocations (i.e. the first fundamental theorem).

Let p be the price vector associated with the Walrasian objection (S, y) . Because $\int_S y \leq \int_S \omega$ and $p \cdot y(t) \geq p \cdot \omega(t)$ for a.e. $t \in S$ we have that y is a Walrasian allocation for S with price vector p . This also implies that $p \gg 0$ (remember that preferences are strictly monotone and $\omega(t) \gg 0$). Suppose there is a counterobjection (T, z) to (S, y) . Then for a.e. $t \in T \cap S$ we have $z(t) \succ_t y(t)$ and therefore $p \cdot z(t) \geq p \cdot y(t) \geq p \cdot \omega(t)$, with strict inequality if $z(t) \succ_t y(t)$. For a.e. $t \in T \setminus S$ we have $z(t) \succ_t x(t)$ and therefore $p \cdot z(t) \geq p \cdot \omega(t)$, with strict inequality if $z(t) \succ_t x(t)$. We conclude that $\int_T p \cdot z(t) > \int_T p \cdot \omega(t)$ which contradicts $\int_T z \leq \int_T \omega$.

PROOF OF PROPOSITION 2: The proof amounts to an adaptation of the familiar arguments establishing the existence of equilibrium in economies with a continuum of traders and non-convex preferences. It is analogous to the proof of Proposition 7.3.2 in Mas-Colell, 1985.

Let x be an allocation. For every $p \geq 0$, $p \neq 0$, denote $C(p) = \{t : \text{there is } v \text{ such that } v \succ_t x(t) \text{ and } p \cdot v < p \cdot \omega(t)\}$. Observe that if $\lambda(C(p)) = 0$ for some p then x is Walrasian. Hence we assume from now on that $\lambda(C(p)) > 0$ for all p .

Denote $B = \{p \in R^\ell : \|p\| = 1, p \gg 0\}$ and let $f : B \times I \rightarrow R^\ell$ be the excess demand correspondence generated by our economy. We now define a modified excess demand

correspondence $f^* : B \times I \rightarrow R^\ell$ by

$$f^*(p, t) = \begin{cases} f(p, t) & \text{if } f(p, t) + \omega(t) \succ_t x(t) \\ f(p, t) \cup \{0\} & \text{if } f(p, t) + \omega(t) \sim_t x(t) \\ \{0\} & \text{if } f(p, t) + \omega(t) \prec_t x(t). \end{cases}$$

Finally, put $F^*(p) = \int f^*(p, t) dt$. The correspondence $F^* : B \rightarrow R^\ell$ satisfies the following standard properties: (i) $p \cdot F^*(p) = 0$ for every p , (ii) F^* is upper hemicontinuous and bounded below, (iii) $F^*(p)$ is non-empty and convex for every p , and (iv) if $p_m \rightarrow p$, $p^j = 0$ for some j , and $v_m \in F^*(p_m)$ then $\|v_m\| \rightarrow \infty$. All this is easily verified; see Mas-Colell (1985, page 270) for references to the technical facts. Note that the proof of (iii) requires a convexifying result (the Lyapunov-Richter Theorem) even if preferences are convex. Property (iv) follows from strict monotonicity and $\lambda(C(p)) > 0$.

The aggregate excess demand correspondence F^* satisfies, therefore, all the conditions for the existence of an equilibrium, i.e., there is $p \gg 0$ such that $F^*(p) = 0$ (see, e.g., Debreu, 1970, for the argument). Let $w : I \rightarrow R^\ell$ be such that $w(t) \in f^*(p, t)$ for all $t \in I$ and $\int w = 0$. Take $S = \{t : w(t) \in f(p, t)\}$ and define $y : S \rightarrow R_+^\ell$ by $y(t) = w(t) + \omega(t)$. We claim that (S, y) is a Walrasian objection to x with the price vector p . Indeed: (i) $\lambda(S) > 0$ because $C(p) \subset S$, (ii) $\int_S y \leq \int_S \omega$ because $\int w = 0$ and, also, $w(t) = 0$ whenever $t \notin S$, (iii) if $t \in S$ and $v \succsim_t y(t)$ then $v \succsim_t f(p, t) + \omega(t)$ and so $p \cdot v \geq p \cdot \omega(t)$, (iv) if $t \in I \setminus S$ then $x(t) \succsim_t f(p, t) + \omega(t)$ and so $v \succsim_t x(t)$ implies $p \cdot v \geq p \cdot \omega(t)$.

PROOF OF PROPOSITION 3: It amounts to a variation of the familiar Schmeidler's proof of the Aumann equivalence theorem (see, e.g., Hildenbrand, 1974) which can in turn be viewed as a sophisticated version of the second fundamental theorem.

Define $w : I \rightarrow R_+^\ell$ by $w(t) = y(t)$ if $t \in S$ and $w(t) = x(t)$ if $t \notin S$. Let then $V(t) = \{v - \omega(t) : v \succsim_t w(t)\} \cup \{0\}$ and $V = \int V(t) dt$. By Lyapunov's theorem (e.g., L.1.3. in Mas-Colell, 1985) the set V is convex.

If $V \cap (-R_{++}^\ell) \neq \emptyset$ then there would be a counterobjection to (S, y) . Therefore we can assume that $0 \notin \int V$. If we now let $p \neq 0$ support V at 0 we have that, for a.e. t , $p \cdot v \geq p \cdot \omega(t)$ whenever $v \succsim_t w(t)$ which, of course, means that (S, y) is a Walrasian objection.

V. A Refinement.

This section is in the spirit of an extended remark. The following definition iterates one more step the objection-counterobjection logic.

DEFINITION. Let (T, z) be a counterobjection to the objection (S, y) to an allocation x . We say that (T, z) is justified if there is no (V, v) such that $\lambda(V) > 0$, $\int_V v \leq \int_V \omega$ and, for $t \in V$,

$$\begin{aligned} v(t) &>_t z(t) \text{ if } z \in V \cap T \\ v(t) &>_t y(t) \text{ if } z \in V \cap S \\ v(t) &>_t x(t) \text{ if } z \in V \setminus (S \cup T) \end{aligned}$$

Suppose now that we modify our definition of counterobjection in Section II to allow for a weak preference (except for a positive measure subset of T). Then we can strengthen our results by showing that any objection which admits a counterobjection (i.e., any non-Walrasian objection) admits in fact a justified counterobjection. The key is the following concept of Walrasian counterobjection:

DEFINITION. The counterobjection (T, z) to the objection (S, y) to the allocation x is Walrasian if there is a price $p \neq 0$ such that, for a.e. t ,

- (i) $p \cdot v \geq p \cdot \omega(t)$ for $v \succsim_t z(t), t \in T$
- (ii) $p \cdot v \geq p \cdot \omega(t)$ for $v \succsim_t y(t), t \in S$
- (iii) $p \cdot v \geq p \cdot \omega(t)$ for $v \succsim_t x(t), t \in I \setminus (S \cup T)$.

The proofs of Propositions 1 and 2 can then be easily adapted to show that, respectively: (i) a Walrasian counterobjection is justified, and (ii) if an objection is not Walrasian (hence, by Proposition 1, not justified) then there is a Walrasian counterobjection against it. In the proofs of the two Propositions we only have to replace x by a $x' : I \rightarrow R_+^L$ defined by $x'(t) = y(t)$ if $t \in S$, and $x'(t) = x(t)$ if $t \notin S$. Substitute also the term objection by counterobjection and the symbols S, y, T, z by, respectively, T, z, V, v .

VI. Comments on General Games.

Our Bargaining Set concept is well defined for general games. Suppose that I is a (finite) set of players and $V : 2^I \rightarrow 2^{R^I}$ the characteristic form of a cooperative game. Here $V(S) \subset R^I$ is the set of payoffs that coalition S can attain by itself.

Suppose that $x \in V(N)$. We say that (S, y) is an *objection* to x if $y \in V(S)$ and $y_t \geq x_t$ for all $t \in S$, where at least one of the inequalities must be strict. A *counterobjection* to (S, y) is then a (T, z) such that $z \in V(T)$ and $z_t \geq y_t$ (resp. $z_t \geq x_t$) for $t \in T \cap S$ (resp. $t \in T \setminus S$). At least one of the inequalities must be strict. An objection is *justified* if it has no counterobjection. A $x \in V(I)$ is an *imputation* if it is weakly optimal (i.e., $x' \gg x$ implies $x' \notin V(I)$). The *Bargaining Set* is formed by the set of imputations against which there is no justified objection.

Except for the addition of weak optimality (which disposes of some triviality) the above is the exact analog of the definition given for economies in Section II. We know very little about this Bargaining Set. For transferrable utility games it is not difficult to verify that it contains the pre-Kernel of the game (see Shubik, 1983, for the definition) and it is thus non-empty. For non-superadditive general games the set may be empty (Peleg, 1986). No counterexample is yet available for the superadditive case. In fact it appears that in many examples the set can be quite large. Settling this existence issue seems particularly important.

We now give a transferrable utility example showing that for totally balanced games (with at least four persons) our Bargaining Set may indeed be larger than the Core. This is of special interest to us because totally balanced games can be generated from exchange economies fitting the framework of Section II (see Shapley and Shubik, 1969).

EXAMPLE: $I = \{1, 2, 3, 4\}$ The game $v: 2^I \rightarrow R$ is normalized to $v(t) = 0$ for all $t \in I$ and is the minimal superadditive game compatible with the values $v(1234) = 4$, $v(123) = 3.1$ and $v(24) = v(34) = 2.06$. The game is totally balanced (a Core imputation is $(0, 1.9, 1.9, .2)$). The imputation $(1, 1, 1, 1)$ does not belong to the Core since it can be improved upon by several coalitions. It can also be seen that it does not belong to the Bargaining Set used by Shapley and Shubik (see Shubik, 1984). Nonetheless, in our sense every objection against it admits a counterobjection and it thus belongs to our Bargaining Set.

What is the relation of our definition of the Bargaining Set to the previous ones? Our Bargaining Set contains the one used by Shapley and Shubik in Shubik (1984). Strictly speaking the relation to the Aumann-Maschler Bargaining Set is one of non-comparability. This is because on the one hand we make counterobjecting easier (no member of the

objecting coalition is excluded a priori from belonging to a counterobjecting group) but on the other we make it a bit harder by requiring that at least one of the inequalities defining the counterobjection be strict.

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