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**A Note on the Equivalence of Rationalizability
Concepts in Generalized Nice Games**

Alexander Zimmer*

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*Sonderforschungsbereich 504, email: zimmer@bigfoot.com



Universität Mannheim
L 13,15
68131 Mannheim

A Note on the Equivalence of Rationalizability Concepts in Generalized *Nice Games**

By Alexander Zimmer†

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Abstract

Moulin (1984) describes the class of *nice games* for which the solution concept of *point-rationalizability* coincides with *iterated elimination of strongly dominated strategies*. As a consequence *nice games* have the desirable property that all rationalizability concepts determine the same strategic solution. However, nice games are characterized by rather strong assumptions. For example, only single-valued best responses are admitted and the individual strategy sets have to be convex and compact subsets of the real line \mathbb{R} . This note shows that equivalence of all rationalizability concepts can be extended to multi-valued best response correspondences. The surprising finding is that equivalence does not hold for individual strategy sets that are compact and convex subsets of \mathbb{R}^n with $n \geq 2$.

Keywords: Rationalizability, Dominance Solutions, Nice Games

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†Sonderforschungsbereich 504, University of Mannheim, L13, 15, 68131 Mannheim, Germany. Email: zimmer@bigfoot.com

1 Introduction

Iterative solution concepts for strategic games presume that players involve into an internal process of reasoning that sequentially excludes unreasonable strategies (cf. Pearce 1984, Tan and Werlang 1988, Guesnerie 2002). There exist several iterative solution concepts in the literature which differ by their definitions of unreasonable strategies. On the one hand there are so-called rationalizability concepts for which a strategy is unreasonable if it is not a best response to some belief. These beliefs may either be described as non-additive probability measures (*Choquet rationality* of Choquet expected utility maximizers as introduced in Ghirardato and Le Breton 1997), or as additive probability measures (*correlated rationalizability*, Bernheim 1984, Pearce 1984) that can be further restricted to independent (*independent rationalizability*, Bernheim 1984, Pearce 1984) or even degenerated (probability-one) distributions (*point-rationalizability*, Bernheim 1984, Moulin 1984, Pearce 1984). On the other hand there are *dominance solution concepts* for which a strategy is unreasonable if it is dominated - strongly versus weakly - by another - mixed versus pure - strategy (cf. Moulin 1984, Milgrom and Roberts 1990, Börgers 1993).

In general different *iterative solution concepts* determine different strategic solutions. However, Moulin (1984) describes a class of strategic games, so-called *nice games*, for which the set of *point-rationalizable* strategies coincides with the set of strategies which survive *iterated elimination of strongly dominated strategies*. Since *point-rationalizability* is the strongest rationalizability concept, whereas the *iterated elimination of strongly dominated strategies* is weaker than all *rationalizability* concepts, this result establishes equivalence of all *rationalizability* concepts for *nice games*. Such an equivalence result turns the question "Which definition of beliefs is the most appropriate one?" irrelevant because the same *rationalizable* solution obtains for all different concepts of beliefs. Another, more practical, advantage arises because this rationalizable solution can be determined by the technically convenient concept of *point-rationalizability*. Since *point-rationalizability* only treats strategies as reasonable that are best responses to some pure strategy it is in general a much simpler mathematical tool than alternative rationalizability concepts which consider best responses to probability measures over pure strategies.

As a drawback this desirable equivalence result is rather restricted in its applications because *nice games* are characterized by strong assumptions. Moulin (1984) presumes individual strategy sets that are compact and convex intervals of the real line as well as individual utility functions that are strictly quasiconcave in a player's strategy choice. Especially the latter assumption of strict quasiconcavity is problematic because it excludes the possibility of multi-valued best response correspondences.

This note explores whether equivalence of *point-rationalizability* and of *iterated elimination of strongly dominated strategies* can be assured for games that result as slight generalizations of *nice games*. In particular, this paper focuses on two possible generalizations:

(i) Does equivalence still hold for games with individual strategy sets that are compact and convex intervals of \mathbb{R} such that strict quasiconcavity is weakened to quasiconcavity?

(ii) Does equivalence still hold for games with strictly quasiconcave utility functions such that individual strategy sets are compact and convex intervals of \mathbb{R}^n with $n \geq 2$?

The second question must be answered to the negative whereas the first question is answered to the affirmative. The possible relaxation of strict quasiconcavity to quasiconcavity is a nice result because it allows for equivalence of *point-rationalizability* and of *iterated elimination of strongly dominated strategies* in games with multi-valued best response correspondences. However, the fact that equivalence can not be assured for individual strategy sets that are subsets of \mathbb{R}^2 , instead of just \mathbb{R} , demonstrates that equivalence of all rationalizability concepts requires very strong assumptions.

2 Preliminaries: Notation, Definitions

For a finite set of players, I , let $G = (S_i, U_i)_{i \in I}$ denote a strategic game in *normal form* with S_i as player i 's individual strategy set and with $U_i : S_i \times S_{-i} \rightarrow \mathbb{R}_+$ as player i 's utility function. Furthermore, let $f_i : S_{-i} \rightarrow 2^{S_i}$ denote player i 's individual best response correspondence, i.e., $f_i(s_{-i}) = \arg \max_{S_i} U_i(s_i, s_{-i})$.

Definition. (Bernheim 1984, Moulin 1984, Pearce 1984): *The set of point-rationalizable strategies of a game G is given by $P(G) = \bigcap_{k=0}^{\infty} \lambda^k(S)$ such that $\lambda^k(S) = \times_{i=1}^I \lambda_i^k(S)$ with $\lambda_i^k(S) = \bigcup_{s_{-i} \in \lambda_{-i}^{k-1}(S)} f_i(s_{-i})$ and $\lambda_{-i}^0(S) = S_{-i}$.*

Definition: *The set of strategies of a game G which survive iterated elimination of strongly dominated strategies is given by $D(G) = \bigcap_{k=0}^{\infty} \theta^k(S)$ such that $\theta^k(S) = \times_{i=1}^I \theta_i^k$ whereas $s_i \in \theta_i^k$ if and only if $s_i \in \theta_i^{k-1}$, and there does not exist a $t_i \in \theta_i^{k-1}$ such that $U_i(t_i, s_{-i}) > U_i(s_i, s_{-i})$ for all $s_{-i} \in \theta_{-i}^{k-1}$. Furthermore, $\theta_{-i}^0(S) = S_{-i}$.*

A utility function U_i is (strictly) quasiconcave with respect to S_i iff

$$\begin{aligned} U_i(s_i, s_{-i}) > U_i(t_i, s_{-i}) &\Rightarrow U_i(as_i + (1-a)t_i, s_{-i}) > U_i(t_i, s_{-i}) \\ U_i(s_i, s_{-i}) = U_i(t_i, s_{-i}) &\Rightarrow U_i(as_i + (1-a)t_i, s_{-i}) \geq (>) U_i(t_i, s_{-i}) \end{aligned}$$

for all $a \in (0, 1)$ and all $s_i, t_i \in S_i$ with $s_i \neq t_i$.

A strategic game G is *nice* (Moulin 1984) iff for all $i \in I$: U_i is continuous and *strictly quasiconcave* w.r.t. S_i whereby S_i is a compact and convex subset of \mathbb{R} .

Observation: *If G is a nice game then a strategy is weakly dominated by some strategy if and only if it is strongly dominated by some strategy.*

Proof: If a strategy is strongly dominated it is clearly weakly dominated. Suppose now on the contrary that there is a strategy which is weakly but not strongly dominated; that is, there exist $s_i, t_i \in S_i$ with $s_i \neq t_i$ such that $U(t_i, s_{-i}) \geq U(s_i, s_{-i})$ for all $s_{-i} \in S_{-i}$ and $U(t_i, s_{-i}) > U(s_i, s_{-i})$ for some $s_{-i} \in S_{-i}$, but there does not exist some $r_i \in S_i$ such that $U(r_i, s_{-i}) > U(s_i, s_{-i})$ for all $s_{-i} \in S_{-i}$. By convexity of S_i just pick some $a \in (0, 1)$ and let $r_i = at_i + (1 - a)s_i$. *Strict quasiconcavity* implies then $U_i(r_i, s_{-i}) > U_i(s_i, s_{-i})$ for all $s_{-i} \in S_{-i}$. A contradiction. \square

Moulin proves that the set of *point-rationalizable* strategies of a *nice game* coincides with the set of strategies which survive *iterated elimination of weakly dominated strategies* (Lemma 2 in Moulin 1984). Since, by the observation, every *weakly dominated* strategy is also *strongly dominated* for *nice games* the following corollary to Moulin's finding immediately obtains:

Corollary: *For nice games the iterative procedure of point-rationalizability coincides with the iterated elimination of strongly dominated strategies.*

3 Results

This section presents the two main results.

Proposition 1. *Given a game G such that for all $i \in I$*

(A1) *U_i is continuous with respect to s .*

(A2) *U_i is strictly quasiconcave with respect to s_i .*

(A3) *The individual strategy sets S_i are convex and compact subsets of \mathbb{R}^n with $n \geq 1$.*

If there is some $i \in I$ such that S_i is not a subset of \mathbb{R} then the iterative process of point-rationalizability does not necessarily coincide with the iterated elimination of strongly dominated strategies.

The proof proceeds by an example. Let $I = \{A, B\}$, $S_A = [0, 1] \times [0, 1]$, $S_B = [0, 1]$. Assume that A is an expected utility maximizer such that $U_A(s_A, s_B) = -(s_B - s_{A,1})^2 - (s_B^2 - s_{A,2})^2$. Verify that U_A is strictly quasiconcave w.r.t. S_A . The best response function of A to point-beliefs is then $f_A(s_B) = (s_B, s_B^2)$, i.e., $\lambda_A^1(S) = \bigcup_{s_B \in [0,1]} \{(s_B, s_B^2)\}$. Now consider, e.g., the particular belief σ_B such that $\sigma_B(0) = \sigma_B(1) = 0.5$ and observe that $f_A(\sigma_B) = (0.5, 0.5)$. Consequently, $f_A(\sigma_B) \notin \lambda_A^1(S)$, i.e., the best response to belief σ_B is not a best response to any pure strategy of B . Since any best response to some belief must be a undominated strategy for an expected utility maximizer we obtain $\lambda_A^1(S) \neq \vartheta_A^1(S)$. Simply presume $U_B(s_B, s_A) = 0.5(s_A + s_B)$ to conclude the proof. \square

Proposition 2. *Given a game G such that for all $i \in I$*

(A1) *U_i is continuous with respect to s .*

(A2') *U_i is quasiconcave with respect to s_i .*

(A3) *The individual strategy sets S_i are convex and compact subsets of \mathbb{R} .*

Then the iterative process of point-rationalizability coincides with the iterative elimination of strongly dominated strategies.

Proof: Delegated to the appendix.

The finding that equivalence still holds when *strict quasiconcavity* is weakened to *quasiconcavity* is not surprising. The proof of proposition 2 simply demonstrates that a convex valued best response correspondence, as implied by a quasiconcave utility function, plays the same role for proving equivalence as a continuous best response function.

In contrast, it may come as surprise that the equivalence result of the corollary can not be extended from \mathbb{R} to \mathbb{R}^2 . To see the mathematical reason for this negative finding observe that equivalence, i.e., $\lambda^k(S) = \theta^k(S)$ for all $k \in \mathbf{N}$, could have been assured in the above example if $\inf \lambda^k(S) \leq s \leq \sup \lambda^k(S)$ had implied $s \in \lambda^k(S)$. For real-valued individual strategy sets this condition is satisfied for convex sets $\lambda_i^k(S)$ whereby convexity of $\lambda_i^k(S)$ results from an application of the *intermediate value theorem*. That is, the continuous function f_i assumes every value on the real line between $\sup \lambda_i^k(S)$ and $\inf \lambda_i^k(S)$ because $\lambda_{-i}^{k-1}(S)$ is a connected set.

Unfortunately, this argumentation is not at hand for individual strategy sets that are not subsets of \mathbb{R} . As a generalization of the *intermediate value theorem* $\lambda_i^k(S)$ must be connected if $\lambda_{-i}^{k-1}(S)$ is connected. However, as the above example shows, connectedness of $\lambda_i^k(S)$ is not sufficient for guaranteeing $s_i \in \lambda_i^k(S)$ for all $s_i \in S_i$, with $\inf \lambda_i^k(S) \leq s_i \leq \sup \lambda_i^k(S)$, if S_i is not an interval of the real line.

4 Appendix

The proof of proposition 2 proceeds in two steps.

Step 1 demonstrates that the sets $\lambda_i^k(S)$ are compact and convex subsets of \mathbb{R} for all $k \geq 0$ and all $i \in I$. Each f_i is upper-hemicontinuous by Berge's Maximum Theorem (Berge 1997) and because S is compact the set $\lambda_i^1(S)$ is compact as well. Since this is true for all $i \in I$ the sets $\lambda_i^k(S)$ are compact for all $k \geq 1$. It remains to show convexity of $\lambda_i^k(S) = \bigcup_{s_{-i} \in \lambda_{-i}^{k-1}(S)} f_i(s_{-i})$. Suppose on the contrary that $\lambda_i^k(S)$ is not convex, i.e., there exist $s_i, t_i \in \lambda_i^k(S)$ such that $as_i + (1-a)t_i \notin \lambda_i^k(S)$ for some $a \in (0, 1)$. Since quasiconcavity of $U_i(s)$ implies convex values $f_i(s_{-i})$ for all $s_{-i} \in S_{-i}$ we have then $s_i \in f_i(s_{-i})$ and $t_i \in f_i(t_{-i})$ for some $s_{-i}, t_{-i} \in S_{-i}$ with $s_{-i} \neq t_{-i}$. Define the sets

$$\begin{aligned} H &= \{r_i \in \lambda_i^k(S) \mid r_i > as_i + (1-a)t_i\} \\ L &= \{r_i \in \lambda_i^k(S) \mid r_i < as_i + (1-a)t_i\} \end{aligned}$$

and verify that H and L must be compact to assure compactness of $\lambda_i^k(S)$ under the assumption $as_i + (1-a)t_i \notin \lambda_i^k(S)$. Thus, there exist individual strategies $\min H, \max L \in \lambda_i^k(S)$. Let $h_{-i} \in f^{-1}(\min H)$ and $l_{-i} \in f^{-1}(\max L)$ and observe that there must exist some $b \in (0, 1]$ such that

$$f(bl_{-i} + (1-b)h_{-i}) \leq \max L$$

whereby there exists for any open neighborhood O around

$$bl_{-i} + (1-b)h_{-i}$$

some $r_{-i} \in O$ such that

$$\max L < \min H \leq f(r_{-i})$$

Consequently, there is an open set V containing $f(bl_{-i} + (1-b)h_{-i})$ such that for no neighborhood O around $bl_{-i} + (1-b)h_{-i}$ obtains $f_i(r_{-i}) \subset V$ for all $r_{-i} \in O$. A violation of upper-hemicontinuity.

Step 2. Since every set $\lambda_i^k(S)$ is a compact subset of \mathbb{R} it contains a unique maximum, $\max \lambda_i^k(S)$, and a unique minimum, $\min \lambda_i^k(S)$. Furthermore, by convexity of $\lambda_i^k(S) \subset \mathbb{R}$ we have $s_i \in \lambda_i^k(S)$ for all s_i with $\min \lambda_i^k(S) \leq s_i \leq \max \lambda_i^k(S)$. Hence, $\lambda_i^k(S) = \theta^k(S)$ iff there does not exist some $s_i \in \theta_i^k(S)$ such that $s_i < \min \lambda_i^k(S)$ or $\max \lambda_i^k(S) < s_i$. The max-case: Suppose there exists for some $i \in I$ a strategy $s_i > \max \lambda_i^k(S)$ that is not strongly dominated by some strategy in $\lambda_i^{k-1}(S)$. Since $\max \lambda_i^k(S) = as_i + (1-a)f_i(s_{-i})$ for some $a \in [0, 1)$, and $U_i(f_i(s_{-i}), s_{-i}) > U_i(s_i, s_{-i})$ for all s_{-i} - by assumption s_i is not a best response against any pure strategy profile s_{-i} - quasiconcavity

implies $U_i(\max \lambda_i^k(S), s_{-i}) > U_i(s_i, s_{-i})$ for all s_{-i} , i.e., s_i is strongly dominated by $\max \lambda_i^k(S)$. Analogously for the min-case: $U_i(\min \lambda_i^k(S), s_{-i}) > U_i(s_i, s_{-i})$ for all s_{-i} if $s_i < \min \lambda_i^k(S)$. \square

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