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NOTE

An Anti-folk Theorem in Overlapping Generations Games with Limited Observability

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We study the effect of limited observability on the possibility of cooperation in a simple overlapping generations model. If new entrants can observe only the recent history of the game, then cooperation cannot be sustained for certain classes of games. *Journal of Economic Literature* Classification Numbers: C72, D82. © 2001 Academic Press

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1. INTRODUCTION

We study the effect of limited observability on the possibility of cooperation in a simple overlapping generations model. We show that if new entrants can observe only the recent history of the game, then cooperation cannot be sustained for certain classes of games. Specifically, (i) if the stage game is one with a dominant action for the old player or (ii) if the stage game is a 2×2 symmetric game, then players play short-run best responses along the equilibrium path.[2]

This result is in sharp contrast with the existing works on overlapping generations games, which prove that any feasible and strictly individually rational payoff vector can be supported as a repeated game equilibrium outcome as long as players live for sufficiently long periods and the

[1] I thank a co-editor of this journal for helpful suggestions.

[2] Bhaskar (1998) obtained a similar anti-folk theorem for the consumption loan model, which is a game with a dominant action. In contrast, we deal with general stage games.

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discount factor is large enough. See, for example, Cremer (1986), Salant (1991), Kandori (1992), and Smith (1992). The divergence of the results in this paper from those in earlier works is due to the assumption of limited observability: Folk theorem results are derived under the assumption that each generation observes all the previous action choices, whereas the anti-folk theorems in this paper are derived under the assumption that each generation observes only the recent history of the game. The intuition can be explained with the following prisoners' dilemma game:

	C	D
C	$1, 1$	$-1, 2$
D	$2, -1$	$0, 0$

Suppose that player t is born in period t and lives for two periods, t and $t+1$. In each period t, the old player (player $t-1$) and the young player (player t) play the prisoners' dilemma game. If we assume that every player observes the entire history of the game, then we can support an equilibrium in which everybody plays C when young and D when old. The strategy is as follows: (i) Play C when young and play D when old as long as this play has been observed; and (ii) play D both when young and old otherwise.

It is easy to see that the old player's strategy is optimal, because the action D is a strictly dominant action. The young player would like to play C if the past play has been (C, D) all the time because, by doing so, she can ensure a payoff of -1 for this period and a payoff of 2 for the next period. But if the young player deviated to play D, then she would get a higher payoff of 0 for this period but a lower payoff of 0 for the next period. Thus, as long as the discount factor δ is greater than $1/2$, it is optimal to play C when young. On the other hand, if somebody in the past has deviated, then it is optimal for the young player to play D, because everybody will play D in every period. The reason that the young player cooperates (i.e., plays C instead of the dominant action D) in the equilibrium path is that she knows that, by not playing C, she will destroy the intergenerational cooperation in the future.

Now let us change the assumption on the observability of the history. Assume that player t is only aware of the actions taken in period $t-1$ when she enters the game. We now show that cooperation can no longer be sustained. Suppose that player $t-1$ plays D instead of C when young. Player t observes this deviation, but the following generations (player $t+1$, player $t+2$, and so on) do not. Player t has two choices: play D as supposed, or ignore the deviation and play C instead. If player t plays D, then her lifetime payoff is 0, because the action profile (D, D) will be played in periods t and $t+1$. But if player t plays C instead, then player

$t + 1$ will assume that cooperation has been sustained in the past and play C in period $t + 1$. Thus, player t's lifetime payoff from playing C when young is $-1 + 2\delta$, which is greater than the lifetime payoff from playing D. Therefore, player t will play C even when she observes a deviation. Knowing this, player $t - 1$ will definitely play D when young. Therefore, cooperation cannot be sustained. The key to this result lies in player t's incentive. She does not want to pass the information of deviation to the next generation, because that will result in the breakdown of cooperation from which she will suffer. This in turn makes player $t - 1$ deviate when young.

In addition to the incentive to conceal a deviation, another kind of incentive results from limited observability—namely, the incentive to fabricate a deviation. A player may pretend to have observed a deviation if he or she can benefit from doing so. These two incentives—the incentive to conceal a deviation and the incentive to fabricate one—arising from limited observability, together with the special structure of the overlapping generations model, give quite tight restrictions on the repeated game equilibria. In Section 3, we first characterize necessary conditions that any repeated game equilibrium must satisfy (Proposition 1). Then, while restricting our attention to the case when only (finite) pure actions are allowed (Assumption 2), we apply the necessary conditions to (generic) games with a dominant action for the old player to prove that players play short-run best responses in every period along the equilibrium path (Proposition 2). Finally, we show that the same conclusion holds for 2×2 symmetric games (Proposition 3).[3]

Although the model in this paper is restricted in several ways, we feel that this is an important step toward understanding many economic and social phenomena. Our framework is particularly suited to explaining situations or institutions with high turnover rates, such as big cities. When people are constantly entering and exiting an institution, new entrants may not fully observe what has been going on, but instead have a limited observation of the recent history.

The rest of the paper is organized as follows. Section 2 introduces the model. Main results are presented in Section 3. We present some counterexamples in Section 4 to show that the anti-folk theorem cannot be readily extended to more general games.

[3] We provide an example in Section 4 showing that similar results cannot be obtained for the observable mixed actions case. The case where mixed actions are used but only realizations are observed merits further research.

2. THE MODEL

This is a game played by overlapping generations. Each generation consists of one player who lives for two periods. We will call the player born in period t for $t \geq 1$ player t. In addition, there is the initial old player, called player 0, in period 1. In each period t, the old player (player $t-1$) and the young player (player t) play a stage game G. We will denote the sets of actions for the young player and the old player by A^1 and A^2, respectively. A typical element of A^1 (A^2, resp.) is a^1 (a^2, resp.). The payoff for the young (old, resp.) player when the chosen actions are a^1 and a^2 is $u^1(a^1, a^2)$ ($u^2(a^1, a^2)$, resp.). The sets A^1 and A^2 can be identified either as the sets of pure actions or as the sets of mixed actions, i.e., randomizations over the pure actions. In particular, we will not consider randomizations over the sets A^1 and A^2. We assume that the action choices are observable.[4] A t-history $h(t)$ for $t \geq 2$ is $(a(1), a(2), \ldots, a(t-1))$, where $a(\tau) = (a^1(\tau), a^2(\tau))$ for $\tau = 1, \ldots, t-1$. The set of all possible t histories is denoted by $H(t)$.

For player t, let h_t^1 represent a personal observation of the history when young, and let h_t^2 represent a personal observation of the history when old. It is possible that $h_t^1 = h(t)$ and $h_t^2 = h(t+1)$, which means that each young player observes all the action choices of her ancestors. Instead, we are interested in the cases when the young player observes only the action choices of her immediate ancestor.

ASSUMPTION 1 (Limited Observability). Player t's observation is limited to the actions of players $t-1$ and t. Given a t-history $h(t) = (a(1), a(2), \ldots, a(t-1))$, we assume that $h_t^1 = a^1(t-1)$ and $h_{t-1}^2 = (a^1(t-2), a^1(t-1), a^2(t-1))$.[5]

Let H_t^1 (H_t^2, resp.) denote the set of all h_t^1's (h_t^2's, resp.). A repeated game strategy for player $t \geq 1$ is $\sigma_t = (\sigma_t^1, \sigma_t^2)$, where $\sigma_t^1\colon H_t^1 \to A^1$ and $\sigma_t^2\colon H_t^2 \to A^2$. For player 0, this is $\sigma_0 \in A^2$. A repeated game strategy profile is $\sigma = \{\sigma_t\}_{t=0}^{\infty}$. It is clear that, given a strategy profile σ, we can extract the corresponding path $h(\infty)$. The players' objective is to maximize the lifetime payoff $u^1 + u^2$.[6]

[4] Therefore, we assume observable mixed actions when the sets are interpreted as the sets of mixed actions.

[5] Obviously, $h_0^2 = h_1^1 = \emptyset$ and $h_1^2 = (a^1(1), a^2(1))$. Therefore, strictly speaking, Assumption 1 is the previous sentence together with the statement in the assumption applied to players $t \geq 2$.

[6] We assume that the discount factor δ is 1. Because players live for two periods, this specification only simplifies the exposition without changing the results.

We use the sequential equilibrium concept.[7] In this environment, the sequential equilibrium concept can be expressed in the following way. Note that we intentionally suppress the belief part of the definition.

DEFINITION 1. A strategy profile σ is a *repeated game equilibrium* if

(1) $u^2(\sigma_1^1(h_1^1), \sigma_0) \geq u^2(\sigma_1^1(h_1^1), a^2)$ for all $a^2 \in A^2$;

(2) For all $t \geq 1$ and $h(t)$,

$$u^1\left(\sigma_t^1\left(h_t^1\right), \sigma_{t-1}^2\left(h_{t-1}^2\right)\right) + u^2\left(\sigma_{t+1}^1\left(h_{t+1}^1\right), \sigma_t^2\left(h_t^2\right)\right)$$
$$\geq u^1\left(a^1, \sigma_{t-1}^2\left(h_{t-1}^2\right)\right) + u^2\left(\sigma_{t+1}^1\left(\tilde{h}_{t+1}^1\right), a^2\right)$$

for all $a^1 \in A^1$, $a^2 \in A^2$,[8] and

(3) For all $t \geq 1$ and $h(t+1)$,

$$u^2\left(\sigma_{t+1}^1\left(h_{t+1}^1\right), \sigma_t^2\left(h_t^2\right)\right) \geq u^2\left(\sigma_{t+1}^1\left(h_{t+1}^1\right), a^2\right) \qquad \text{for all } a^2 \in A^2.$$

3. MAIN RESULTS

It is clear that, in any repeated game equilibrium σ^*, and for any $t \geq 0$ and h_t^2,

$$\sigma_t^{2*}\left(h_t^2\right) \in BR\left(\sigma_{t+1}^{1*}\left(h_{t+1}^1\right)\right),$$

where $BR(\cdot)$ stands for the best response correspondence. Now let σ^* be an equilibrium, and suppose that player $t-1$ deviates in period $t-1$ when the history is $h(t-1)$ by playing $a^1 \in A^1$, which is different from $\sigma_{t-1}^{1*}(h_{t-1}^1)$. Then, because there is no profitable one-shot deviation in a sequential equilibrium, we have

$$u^1\left(\sigma_{t-1}^{1*}\left(h_{t-1}^1\right), \sigma_{t-2}^{2*}\left(h_{t-2}^2\right)\right) + u^2\left(\sigma_t^{1*}\left(h_t^{1*}\right), \sigma_{t-1}^{2*}\left(h_{t-1}^{2*}\right)\right)$$
$$\geq u^1\left(a^1, \sigma_{t-2}^{2*}\left(h_{t-2}^2\right)\right) + u^2\left(\sigma_t^{1*}\left(h_t^{1d}\right), \sigma_{t-1}^{2*}\left(h_{t-1}^{2d}\right)\right), \tag{1}$$

where the terms with the superscript d are the terms corresponding to the deviation and the terms with the superscript * are the terms under the

[7] For a precise definition, see Kreps and Wilson (1982).
[8] Observe that $h_{t+1}^1 = \sigma_t^1(h_t^1)$ and $\tilde{h}_{t+1}^1 = a^1$.

equilibrium play. This inequality can be rewritten in a simplified form as

$$u^2\left(\sigma_t^{1*}, \sigma_{t-1}^{2*}\right) - u^2\left(\sigma_t^{1d}, \sigma_{t-1}^{2d}\right) \geq u^1\left(a^1, \sigma_{t-2}^{2*}\right) - u^1\left(\sigma_{t-1}^{1*}, \sigma_{t-2}^{2*}\right). \quad (2)$$

Inequality (2) implies that player t must respond to any profitable deviation by player $t-1$ and punish player $t-1$ sufficiently so that the overall gain from deviation is nonpositive for player $t-1$. However, because player t is the only player who observed player $t-1$'s deviation, she may not want to punish player $t-1$ if the cost of doing so is excessive. Instead, player t may pretend to have observed an equilibrium play of player $t-1$ by simply choosing action σ_t^{1*} rather than action σ_t^{1d}. In this case, player $t+1$ must believe that the equilibrium strategies have been played throughout the history. Thus, giving a proper incentive to the punisher requires

$$u^1\left(\sigma_t^{1d}, \sigma_{t-1}^{2d}\right) + u^2\left(\sigma_{t+1}^{1d}, \sigma_t^{2d}\right) \geq u^1\left(\sigma_t^{1*}, \sigma_{t-1}^{2d}\right) + u^2\left(\sigma_{t+1}^{1*}, \sigma_t^{2*}\right). \quad (3)$$

On the other hand, it is also possible that player t behaves as if she has observed player $t-1$'s deviation even though player $t-1$ did not in fact deviate. Preventing this incentive to fabricate a deviation requires

$$u^1\left(\sigma_t^{1d}, \sigma_{t-1}^{2*}\right) + u^2\left(\sigma_{t+1}^{1d}, \sigma_t^{2d}\right) \leq u^1\left(\sigma_t^{1*}, \sigma_{t-1}^{2*}\right) + u^2\left(\sigma_{t+1}^{1*}, \sigma_t^{2*}\right) \quad (4)$$

for all σ_t^{1d}'s that belong to the set R of player t's reactions to player $t-1$'s deviation under the equilibrium, i.e., for all $\sigma_t^{1d} \in R = \{a^1 \in A^1 | a^1 = \sigma_t^{1*}(h_t^1)$ for some $h_t^1 \equiv a_{t-1}^1 \in A^1\}$. Observe, however, that inequality (4) is implied by inequality (2) when the latter is applied to player t.

Summarizing the foregoing discussion, we have:

PROPOSITION 1. *Suppose that σ^* is a repeated game equilibrium. Then for any $t \geq 1$ and for any deviation of player $t-1$ in period $t-1$, the subsequent play satisfies*

(1) $u^1(\sigma_t^{1d}, \sigma_{t-1}^{2d}) - u^1(\sigma_t^{1*}, \sigma_{t-1}^{2d}) \geq u^2(\sigma_{t+1}^{1*}, \sigma_t^{2*}) - u^2(\sigma_{t+1}^{1d}, \sigma_t^{2d})$,

(2) $u^2(\sigma_{t+1}^{1*}, \sigma_t^{2*}) - u^2(\sigma_{t+1}^{1d}, \sigma_t^{2d}) \geq u^1(\sigma_t^{1d}, \sigma_{t-1}^{2*}) - u^1(\sigma_t^{1*}, \sigma_{t-1}^{2*})$,

and

(3) $\sigma_{t-1}^{2*} \in BR(\sigma_t^{1*})$, $\sigma_{t-1}^{2d} \in BR(\sigma_t^{1d})$, $\sigma_t^{2*} \in BR(\sigma_{t+1}^{1*})$, *and* $\sigma_t^{2d} \in BR(\sigma_{t+1}^{1d})$.

For the remainder of this section, we assume that the action sets A^1 and A^2 are finite. Thus, we do not consider mixed actions.

ASSUMPTION 2. The sets A^1 and A^2 are finite.

We now give our second result. This result not only is interesting in itself, but also is used heavily in the proof of Proposition 3.

PROPOSITION 2. *Suppose that the stage game is the one with a dominant action for the old player. Then generically, in any equilibrium of the repeated game, everybody plays a short-run best response in each period. In particular, the old player plays the dominant action and the young player plays a best response to it.*

Proof. Let the dominant action in A^2 be $\hat{a}$. Then $\sigma_{t-1}^{2d} = \sigma_{t-1}^{2*} = \sigma_t^{2d} = \sigma_t^{2*} = \hat{a}$ by condition (3) of Proposition 1. Now let σ^* be a repeated game equilibrium and suppose that $\sigma_{t-1}^{1*} \notin BR(\hat{a})$ for some t. Consider player $t-1$'s deviation to a best response to $\hat{a}$. If $\sigma_t^{1*} = \sigma_t^{1d}$, then player $t-1$ will benefit from this deviation. Thus $\sigma_t^{1*} \neq \sigma_t^{1d}$ must hold.

On the other hand, conditions (1) and (2) of Proposition 1 imply that

$$u^1\left(\sigma_t^{1d}, \hat{a}\right) - u^1\left(\sigma_t^{1*}, \hat{a}\right) = u^2\left(\sigma_{t+1}^{1*}, \hat{a}\right) - u^2\left(\sigma_{t+1}^{1d}, \hat{a}\right), \tag{5}$$

which cannot be satisfied generically when $\sigma_t^{1*} \neq \sigma_t^{1d}$. *Q.E.D.*

Proposition 2 is applicable to any game with a dominant action for the old player, either symmetric or asymmetric. In particular, for the prisoners' dilemma game, the only repeated game equilibrium is the one in which every generation deviates in every period. To see what we mean by "genericity," consider the following general prisoners' dilemma game, where $g > 0$ and $l \geq 0$:

	C	D
C	$1, 1$	$-l, 1+g$
D	$1+g, -l$	$0, 0$

The conclusion of Proposition 2 does not hold only when $1 + g = l$. In other words, Eq. (5) is satisfied only when $1 + g = l$. Our next result concerns 2×2 symmetric games.

PROPOSITION 3. *Suppose that the stage game is a 2×2 symmetric game. Then generically, a stage-game Nash equilibrium is played in each period of any repeated game equilibrium.*

Proof. Let σ^* be a repeated game equilibrium and suppose that $(\sigma_{t-1}^{1*}, \sigma_{t-2}^{2*})$ is not a stage game Nash equilibrium. By condition (3) of Proposition 1, $\sigma_{t-2}^{2*} \in BR(\sigma_{t-1}^{1*})$. Therefore, $\sigma_{t-1}^{1*} \notin BR(\sigma_{t-2}^{2*})$.

Now consider player $t-1$'s deviation to $\sigma_{t-1}^{1d}(\neq \sigma_{t-1}^{1*})$ in period $t-1$. Because σ_{t-1}^{1*} is not a best response and there are only two actions,

$$u^1\left(\sigma_{t-1}^{1d}, \sigma_{t-2}^{2*}\right) > u^1\left(\sigma_{t-1}^{1*}, \sigma_{t-2}^{2*}\right).$$

If $\sigma_t^{1*} = \sigma_t^{1d}$, then player $(t-1)$ will be better off by this deviation. Thus, we must have

Claim 1. $\sigma_t^{1*} \neq \sigma_t^{1d}$.

We now claim that

Claim 2. $\sigma_{t-1}^{2*} \neq \sigma_{t-1}^{2d}$.

Proof. Suppose otherwise and let $\sigma_{t-1}^{2*} = \sigma_{t-1}^{2d} = a^2$. Then, by condition (3) of Proposition 1, we have $a^2 \in BR(\sigma_t^{1*})$ and $a^2 \in BR(\sigma_t^{1d})$. Because $\sigma_t^{1*} \neq \sigma_t^{1d}$ by Claim 1, this implies that a^2 is a dominant action for the old player. Proposition 2 then implies that $\sigma_{t-1}^{1*} \in BR(\sigma_{t-2}^{2*})$, which contradicts our initial supposition. ∎

Claim 3. $(\sigma_t^{1*}, \sigma_{t-1}^{2*})$ is a stage game Nash equilibrium.

Proof. Suppose otherwise. Then $\sigma_t^{1*} \notin BR(\sigma_{t-1}^{2*})$ by condition (3) of Proposition 1. We thus have

$$u^1\left(\sigma_t^{1d}, \sigma_{t-1}^{2*}\right) > u^1\left(\sigma_t^{1*}, \sigma_{t-1}^{2*}\right).$$

Then, by conditions (1) and (2) of Proposition 1,

$$u^1\left(\sigma_t^{1d}, \sigma_{t-1}^{2d}\right) > u^1\left(\sigma_t^{1*}, \sigma_{t-1}^{2d}\right).$$

Because $\sigma_{t-1}^{2*} \neq \sigma_{t-1}^{2d}$ by Claim 2, this implies that σ_t^{1d} is a dominant action for the young player. Because the game is symmetric, the old player has a dominant action. This again contradicts our initial supposition by Proposition 2. ∎

Claim 4. $(\sigma_{t-1}^{1d}, \sigma_{t-2}^{2*})$ is a stage game Nash equilibrium.

Proof. Suppose otherwise. Our initial supposition, $\sigma_{t-1}^{1*} \notin BR(\sigma_{t-2}^{2*})$, implies that $\sigma_{t-1}^{1d} \in BR(\sigma_{t-2}^{2*})$. So we have $\sigma_{t-2}^{2*} \notin BR(\sigma_{t-1}^{1d})$. This implies that the other action, say a^2 $(\neq \sigma_{t-2}^{2*})$, is a best response to σ_{t-1}^{1d}. Now if $\sigma_{t-1}^{1d} \in BR(a^2)$, then σ_{t-1}^{1d} is a dominant action, which leads to a contradiction as before. Therefore, $\sigma_{t-1}^{1d} \notin BR(a^2)$. It is also clear that $a^2 \notin BR(\sigma_{t-1}^{1*})$ because otherwise, a^2 is a dominant action and we are led to a contradiction. Consequently, there is a unique cycle $\sigma_{t-2}^{2*} \to \sigma_{t-1}^{1d} \to a^2 \to \sigma_{t-1}^{1*} \to \sigma_{t-2}^{2*}$ of best responses. This contradicts Claim 3 that there is a Nash equilibrium in the game. ∎

By Claim 4, σ_{t-2}^{2*} is a best response to σ_{t-1}^{1d}. On the other hand, it is also a best response to σ_{t-1}^{1*} by condition (3) of Proposition 1. Thus σ_{t-2}^{2*} is a dominant action for the old player, which leads to a contradiction of our initial supposition as before. *Q.E.D.*

4. COUNTEREXAMPLES

The conclusion of Proposition 3 cannot be readily extended to more general situations. We provide counterexamples in this section.

EXAMPLE 1 (Mixed Actions). This is a chicken game. In this example, we assume that mixed actions are observable and that $\frac{1}{2} \leq \delta < 1$. The game is

	D	N
D	3, 3	1, 7
N	7, 1	0, 0

The equilibrium strategy profile is (i) play $\frac{1}{3}D + \frac{2}{3}N$ when young and play N when old as long as this play has been observed, and (ii) play N when young and play D when old, otherwise. First, observe that N is a best response to $\frac{1}{3}D + \frac{2}{3}N$ and D is a best response to N, so the old player does not have an incentive to deviate. Now if the young player deviates, then her immediate descendent will play N. Thus, the lifetime payoff from deviation is at most $1 + \delta \cdot 1$, which is less than the payoff from conforming, $\frac{1}{3} + \delta \cdot \frac{7}{3}$. The key step is checking the incentive of the young player who observed her immediate ancestor's deviation. If the young player observed the deviation, then she knows that the deviator will play D in this period. Thus it is better for the young player to play N now even though it will result in a low payoff next period; playing N will give a lifetime payoff of $7 + \delta \cdot 1$, but ignoring or concealing the deviation will give $\frac{17}{3} + \delta \cdot \frac{7}{3}$. Because $\delta < 1$, the former payoff is higher.

In the following examples, we restore our previous assumptions that randomization is not used and $\delta = 1$.[9]

[9] Again, the assumption that $\delta = 1$ is for expositional convenience. The result remains the same even when $\delta < 1$.

EXAMPLE 2 (2×2 Asymmetric Games). The game is

	L	R
U	$0, 0$	$1, 1$
D	$10, -5$	$2, -10$

The equilibrium strategy profile is (i) play U when young and play R when old as long as this play has been observed, and (ii) play D when young and play L when old otherwise. The reader can verify that this is indeed a repeated game equilibrium. The essence of this example is that the punisher gets a high payoff from punishing. Also observe that D is a strictly dominant action for the young player.

EXAMPLE 3 (3×3 Symmetric Games). The game is

	A	B	C
A	$0, 0$	$0, 2$	$-5, 0$
B	$2, 0$	$1, 1$	$-2, 0$
C	$0, -5$	$0, -2$	$-1, -1$

The equilibrium strategy profile is (i) play A when young and play B when old as long as this play has been observed, and (ii) play C when young and play C when old otherwise. Again, the reader can easily verify that this is indeed a repeated game equilibrium.

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