Wealth Differences in a Centipede Game: Backward Induction in an Experimental Economics Framework

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Abstract

In this paper we report the results of a laboratory experiment of a six stage centipede game played with partners from the same income group as opposed to a partner from a different income group. The results of our experiment were not very different from those obtained in earlier experiments in the sense that there was very little evidence of either backward induction or outright cooperation. Few subjects (<20%) adopted the backward induction strategy to take in the first round, while there was no partner combination that carried out the game till the final or sixth stage. Moreover, playing with same income group partner and playing with different income group partner does induce remarkably different behavior.
JEL Classification: C91, C92

Key Words: Centipede Game, Experiment.

1. Introduction

The rationality of backward induction in a multi-stage game between two players most definitely has a theoretical elegance. When the number and description of the sub-games are known to both players, the rational move would be for each player to solve for the equilibrium for the terminal stage and then work backwards to the first stage. Yet, an interesting question to ask is whether otherwise rational players do in fact behave in this manner, that is, whether they use backward induction to decide on their strategic moves in the initial stages of the game. Further, as the complexity of the game increases due to their being many stages, would the players rather use some hunch or heuristic rule to decide strategy? The centipede game, being a multi-stage game, allows us an opportunity to test this premise in an experimental setting.

In this paper we report the results of a laboratory experiment of a six stage centipede game. The centipede game is an extensive form game played between two players who get alternating opportunities to end the game, receiving a favorable payoff for herself. However, if they choose to continue, the payoff gets increased at every stage. Thus, like the Prisoner's Dilemma, this game presents a social dilemma that is, a conflict between self-interest and mutual benefits. In this game, first conceived by Rosenthal (1981), subjects can mutually earn a large pay-off by playing cooperatively, even though, backward induction suggests that the first player should choose to defect in the very first round, resulting in a very low pay-off for both subjects. Experiments with this game have shown that the subjects reveal partial cooperation and results have been inconsistent with the traditional game-theoretic analysis of backward induction and this has raised much controversy about the application of backward induction in deriving solutions to social interactions (McKelvey and Palfrey, 1991).

In the present experiment we have tried to compare the consequences on strategy choice of one player playing with partners from the same income group as opposed to a partner from a different income group. However, the subjects were always paired with varying partners in every period, to rule out any scope of signaling or retaliation.

The results of our experiment were not very different from those obtained in earlier experiments in the sense that there was very little evidence of either backward induction or outright cooperation. What we found interesting was the presence of subjects in every treatment who did not terminate the game in any of the periods throughout the treatment, even though their partners terminated the game at an early stage in the preceding rounds. The paper is broken up into four sections. In the next section we present the design of the experiment, followed by a section on results of the experiment. In the last section we present some concluding remarks.

2. The Experimental Design

a. Creating the Groups

There were eighteen subjects who were students of the English Department of Jadavpur University, Kolkata, India. The eighteen subjects were divided into 9 pairs. In each pair, one subject each was designated as a Red player and a Blue player who got alternating opportunities of passing the offer or accepting and terminating the game. However, the partners kept on changing in after every round. Also, the 18 subjects were classified into three income groups, high income group (HIG), middle income group (MIG) and low income group (LIG) on the basis of their monthly family income and their personal monthly expenditure. The players actually ranged from middle class to lower middle class families with annual income ranging from Rs 480000 (highest income) to Rs 21600 (lowest income) in the present subject pool. When arranged in descending order of income, the first 6 subjects were designated HIG with an average monthly income of Rs 24,800 and average monthly expenditure of Rs 1180. The next 6 subjects were designated MIG with an average monthly income of Rs 19,600 and average monthly expenditure of Rs 916 while the last 6 subjects were designated LIG who had an average monthly income of Rs 7,730 and average monthly expenditure of Rs 1200.

There were three Treatments in the experiment and each treatment had five periods or rounds. In the first treatment (Treatment 1) the game was conducted by pairing subjects randomly across income groups. In the second treatment (Treatment 2) partners in a pair belonged to the same income group (HIG player paired with another HIG player, etc). In the last 5 rounds (Treatment 3), each subject was paired with a subject of a different income group (HIG player with MIG or LIG player, etc). Thus the subjects had two identities in the experiment, their income and their color. The subjects were made aware of their income groups at all rounds of the game in Treatments 2 and 3.

b. The Pay-off Structure

The following table (Table 1) shows the payoff structure of the game in any one round. Suppose a Red player gets to start the game. He has two options:

i. Either to take Rs. 25 and terminate the game, in which case her partner (a blue player) receives Rs. 10, or

ii. To pass the game to her partner.

If Red chooses to continue the game to the second stage by choosing *pass* her partner (Blue player) gets the opportunity to choose whether to continue the game or terminate it. If the Blue player chooses to take the offer she gets Rs 50 and the partner (Red player) gets Rs 20. Alternatively the Blue player can pass and the decision passes on to the Red player. In this way, the opportunity to choose whether to take or pass keeps on alternating till the end of the sixth stage.

Table 1: The Payoff Structure and Flow of the Game

Stages	**1**	**2**	**3**	**4**	**5**	**6**	
Decision maker	**RED**	**BLUE**	**RED**	**BLUE**	**RED**	**BLUE**	
Payoff	Pass → Take ↓	Pass → Take ↓	Pass → Take ↓	Pass → Take ↓	Pass → Take ↓	Pass → Take ↓	↴
Me (RED)	25	20	100	80	400	320	320
My Partner (BLUE)	10	50	40	200	160	800	320
Status	Game Ends	Game Ends	Game Ends	Game Ends	Game Ends	Game Ends	Game Ends

Here it may be noted that the payoff of the decision maker (Rs.25, Rs.50, Rs.100, Rs.200, Rs. 400,Rs.800) as well as that of the passive partner (Rs.10, Rs.20, Rs.40, Rs. 80, Rs. 160, Rs.320) keeps on doubling at the end of each stage, till the sixth stage. At the sixth stage if the Blue player decides to take then she gets Rs.800 and her partner, the Red player gets Rs.320. However, if she decides to pass then each player gets Rs.320.

c. Rationality of Backward Induction

It can be seen from Table 1 that the decision maker in the 6th stage is the Blue player. If she passes at this stage her earning is Rs. 320 but if she accepts the offer she can earn Rs. 800. Hence she will always accept at this stage. But the Red player knows this. Given this knowledge, the Red player should take in the fifth stage while Red still is the decision maker. But the Blue player knows this. Given this knowledge, the Blue player will take in the fourth stage, and so on till the first stage. So, given the rationality of backward induction, every round of this game should get terminated in the first stage only. At least that is the theoretical prediction.

3. Results

According to traditional game theory, the equilibrium (SGPN) of the centipede game should be that whoever makes the first move should take the initial endowment (i.e. Rs.25 in this game) and terminate the game. This follows from the logic of backward induction. Suppose (as in Table 1) the game is in the sixth stage, then the profit-maximizing choice for player Blue is to take Rs.800 and terminate the game. Else, if she passes in this stage, she would get only Rs.320. If this is anticipated by player Red in the fifth stage then she would choose to take in the fifth stage to get Rs.400 (> Rs.320 in the sixth stage) and terminate the game. Like this, if the first moving player moves backward, then the optimal strategy for the first mover is to take in the first stage and end the game. However, majority of the subjects in our experiment did not apply the logic of backward induction to terminate the game in the first stage.

Table 2: Number of Players who chose to take in the first stage

Treatments	1					2					3				
Rounds	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
No. of Players who took in 1st stage (out of 9 first movers)	2	1	1	2	2	1	2	1	2	3	1	1	1	2	3
No. of Players who did not take at any round	1					4					3				

In Table 2, above we present the number of subjects (out of nine first movers in each game) who chose to take in the first stage in the different rounds. Clearly, in all the rounds the numbers are much less than fifty percent and we can conclude that the outcome is not consistent with the predictions of backward induction logic. Similar results have also been observed in earlier centipede game experiments (McKelvey& Palfrey, 1991). The logic of backward induction works on the basis of the assumptions of Common Knowledge and Rationality (CKR). That is, the assumptions that each and every agent is rational and that this fact is common knowledge among the agents.

As pointed out by Coleman 2003, "*when a decision involves two or more interactive decision makers, each have only partial control over the outcomes, an individual may have no basis for rational choice without strong assumptions about how the other(s) will act.*" Thus backward induction seems to hold only if the players have no doubt about each other's rationality (Rationality, as is usually defined in economics, that is, in terms of self-interest). Backward induction in the centipede game would then follow from the Red player's expectation that a cooperative (i.e. pass) opening move by her would be met with a take in the second stage by the Blue player. But in the event of an opening cooperative (pass) move, the Blue player would be facing an irrational Red player and consequently it would not be possible for the Blue player to play rationally, because the whole logic now breaks down. So the move of the Blue player now becomes indeterminate. Thus it is no longer possible for the Red player to anticipate the move of the Blue player or calculate the expected utility of a cooperative move and neither player can now play rationally as the game theoretic rationality no longer holds (Cubitt and Sugden1994;Coleman 2003)

Following Monderer & Samet (1989) and Sugden (1992), Coleman(2003) suggests replacement of the CKR assumption with an assumption of Common Belief of Rationality, which would allow the Red player to evaluate the response of the Blue player from a cooperative opening move made by her. Her cooperative move may be interpreted as an irrational move by player Blue and if she expects player Red to continue playing irrationally in subsequent stages then she too may choose to make a cooperative move in the second stage. And if this is anticipated by the Red player she would make a cooperative move, and in this way a series of cooperative moves may be undertaken. Alternatively, the opening player Red may move *pass* in the expectation that Blue will interpret this as a signal for cooperation and will then reciprocate with a pass as meeting cooperation with cooperation. The question then remains as to how long this implicit pact of cooperation will last.

In this case, we should note that such cooperative moves were mostly restricted to the first or second stages. Only for two pairs did the game continue till the fifth stage and for sixteen pairs up to the fourth stage. Thus there was mostly partial cooperation. Another interesting outcome of the experiment was the presence of some players in each treatment who did not take in any round of the treatment (fourth row of Table 2). The profit data also revealed that some of these non-takers were matched with cooperative players in the first round and earned high profits. The correlation between the aggregate profits of the first treatment and number of takes in the second and third treatments are -0.5256 and -0.66802 respectively. That is for those subjects who played cooperatively and earned high profits (being paired with other cooperative players in the first treatment) also played cooperatively (low takes) in the subsequent treatments. Here we should also mention that the correlation between the aggregate subject profits between treatment 1 & 2 and treatment 1 & 3 were very low.

Table 3: Correlation between distributions of Takes at different stages

	Trt. 1	**Trt. 2**	**Trt. 3**
Trt. 1 (R 1-5)	**1**		
Trt2 (R 6-10)	**0.8543****	**1**	
Trt3 (R 11-15)	**0.8036****	**0.9076***	**1**

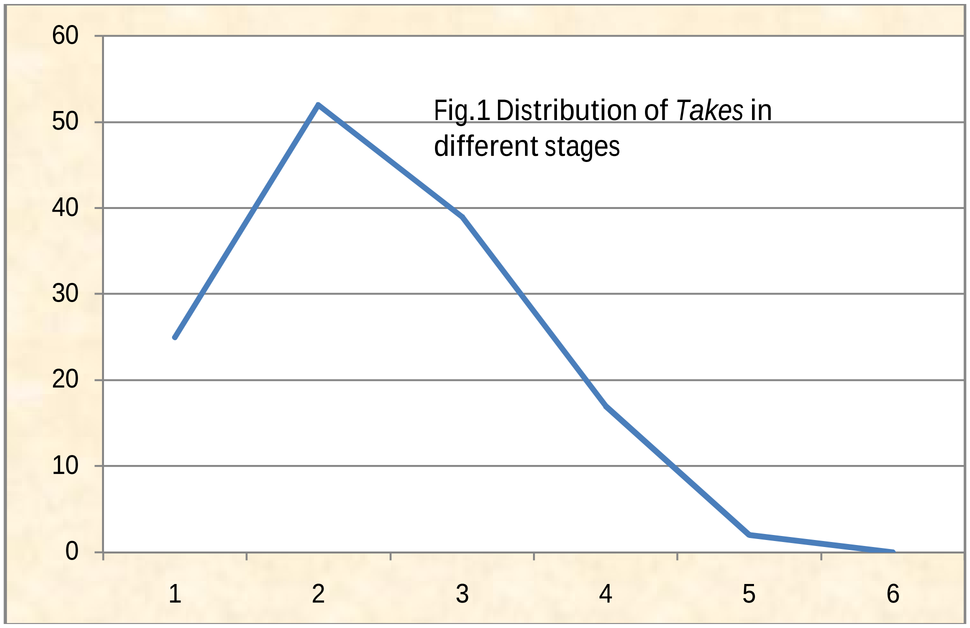
**: 5% level of Significance **: 10% level of Significance*

As for the income group effect, there were significant difference between the paired t-tests of number of takes by individual subjects between treatments 1 & 2 (90 percent), treatments 1 & 3 (again, 90 percent), and treatments 2 & 3 (95 percent, in this case). Thus pairing players with own income group as well as pairing them with different income group did have significant difference over pairings when choice of income group between partners was random as far as the cooperative behavior of the subjects. We can definitely say that knowing the income class of the partner, behavior differs compared to not knowing. Playing with same income group partner and playing with different income group partner does induce remarkably different behavior.

4. Concluding Remarks

The results of the present centipede experiment are not very different from results of earlier centipede experiments. Few subjects (<20%) adopted the backward induction strategy to take in the first round, while there was no partner combination that carried out the game till the final or sixth stage. The distribution of *takes* in the six stages for all the three treatments is shown in Fig. 1, below.

From the figure it is clear that maximum number of acceptance takes place in the second stage (39%) and only 2 acceptances (1.48%) in stage 5. Thus there was only partial cooperation. This implies that even though there may not be common knowledge of acceptance at the first stage but surely the data reveals a common belief of early acceptance. Moreover, the presence of some players who do not accept/take at any stage and the negative but high correlation between profit in the first treatment and takes in the second and third treatment points to cooperative behavior induced by profits. The presence of these subjects strengthens the concept of common belief.



References

Colman, A.M. (2003) Cooperation, psychological game theory, and limitations of rationality in Social Interactions. *Behavioral & Brain Sciences* 26: 139-198.

Sugden, R. (1992) Inductive reasoning in games. In: *Rational interaction: Essays in honor of John C. Harsanyi*, ed. R. Selten. Springer-Verlag.

Monderer, D. & Samet, D. (1989) Approximating common knowledge with common beliefs. *Games and Economic Behavior* 1:170–90.

Rosenthal, R. W. (1981) Games of perfect information, predatory pricing and the chain-store paradox. *Journal of Economic Theory* 25:92–100.

Cubitt, R. P. & Sugden, R. (1994) Rationally justifiable play and the theory of noncooperative games. *Economic Journal* 104:798–803.

McKelvey, R. D. & Palfrey, T. R. (1992) An experimental study of the Centipede game. *Econometrica* 60:803–36.