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Experimental study of repeated team-games

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Abstract

We report an experiment in which the Intergroup Prisoner's Dilemma (IPD) game was contrasted with a structurally identical (single-group) Prisoner's Dilemma (PD). The games were played repeatedly for 40 rounds. We found that subjects were initially more likely to cooperate in the IPD game than in the PD game. However, cooperation rates decreased as the game progressed and, as a result, the differences between the two games disappeared. This pattern is consistent with the hypothesis that subjects learn the structure of the game and adapt their behavior accordingly. Computer simulations based on a simple learning model by Roth and Erev (Learning in extensive-form games: Experimental data and simple dynamic models in the intermediate term, Games and Economic Behavior 8, 164–212, 1995) support this interpretation.

JEL classification: C70

Keywords: Repeated team-games; Intergroup Prisoner's Dilemma game; Intergroup conflict

1. Introduction

Our interest in this paper is in intergroup conflicts and competitions (e.g., elections, military confrontations, team sports) where the payoffs associated with the outcome of the conflict (e.g., political influence, territory, group pride) are public goods that are non-excludable with respect to the members of a groups involved in the competition. In these intergroup conflicts the individual group member gains from not contributing to the collective group effort (i.e., taking a

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free ride), but the group loses. The following example by Dawes (1980) illustrates this point: "Soldiers who fight in a large battle can reasonably conclude that no matter what their comrades do they personally are better off taking no chances; yet if no one takes chances, the result will be a rout and slaughter worse for all the soldiers than is taking chances" (p. 170).

Obviously, the free-rider problem that arises when groups, as opposed to individuals, are in conflict cannot be studied in the context of two-person games that treat the conflicting groups as unitary players. Traditional n-person games, which have been used as a paradigm for the collective action problem, are also too restrictive for this purpose, as they ignore the conflict of interests between the groups. Because the intergroup conflict motivates the need for intragroup collective action, and its outcome is determined by the groups' respective success in solving the internal dilemma, the intergroup and intragroup levels should be considered simultaneously.

Following the pioneering work of Palfrey and Rosenthal (1983), we model such intergroup conflict as a team game. A team game involves two groups, or teams of players. Each player chooses how much to contribute towards his or her team effort. Contribution is assumed to be costly (e.g., in terms of effort, time, money, or risk-taking). Payoff to a player is an increasing (or at least non-decreasing) function of the total contribution made by members of his or her own team, and a decreasing (or at least non-increasing) function of the total contribution made by members of the opposing team. Net of cost, all players on the same team receive the same payoff. A simplified team game where each player faces a binary choice between a costly and a noncostly action (contributing or not contributing) is referred to as a participation game.

The present study focuses on one such participation game, called the Intergroup Prisoner's Dilemma (IPD) game (Bornstein, 1992). The IPD game as operationalized in our study is a six-person game in normal form described as follows. The set of players is partitioned into two groups of three players each. Each player in each group receives an endowment at the beginning of the game and has to decide whether to contribute his or her endowment. After decisions are made, payoffs are allocated to each player based on the difference between the number of contributors in his or her group and the number of contributors in the opposing group. The payoffs are determined such that a Prisoner's Dilemma game is created both between and within the teams. Formally, the strategy set of player i is $\{0, 1\}$, where 1 stands for contribution (C) and 0 stands for no contribution (D). Given a strategy combination $(\sigma_1, \ldots, \sigma_6)$ the payoff for i is determined according to the following expression:

$$h_i(\sigma) = \alpha\left(\sum_{j \in A(i)} \sigma_j - \sum_{j \in N \setminus A(i)} \sigma_j \right) + 3\alpha + e(1 - \sigma_i),$$

where N is the set of players and $A(i)$ is the group to which i belongs, $\alpha > 0$ is the players' incremental payoff for each additional contribution by an ingroup member, and $e > 0$ is the initial endowment the individual gets (the cost of contribution). We impose that $\alpha < e < 3\alpha$. It is straightforward to see that, given the first inequality, playing 0 (not contributing) is the dominating strategy for each player. This is because, independently of the strategies of the remaining players, by contributing a player increases his or her reward by α but pays e, hence reducing his or her net payoff by $e - \alpha > 0$. The second inequality ensures that the dominant joint strategy for each team is to have all of its members contribute. This is because, regardless of the actions taken by the outgroup, each player's contribution increases the total team payoff by $3\alpha - e > 0$.[1] Hence, by our conditions on α and e, the intragroup game defined on each team by fixing a joint strategy for the other team is a three-person Prisoner's Dilemma game. More specifically, there are four such intragroup PD games, $\Gamma_0, \Gamma_1, \Gamma_2, \Gamma_3$, (corresponding to 0, 1, 2, and 3, outgroup contributors, respectively, in the IPD game). The payoff for player i in game k is given by

$$h_i^k(\sigma) = \alpha\left(\sum_{j \in N} \sigma_j - k\right) + 3\alpha + e(1 - \sigma_1) \quad (k = 0, 1, 2, 3).$$

Note that for each of the five games (i.e., the four three-person PD games and the one six-person IPD game) the unique Nash equilibrium uses dominating strategies, namely non-contribution. Also note that, although neither game has strong equilibria, the unique Nash equilibrium satisfies the coalition proofness criteria of Berenheim et al. (1987). This means that there always exists some group of players that can improve upon the Nash equilibrium outcome by coordinating their strategies, but no such coordination can be self-enforcing.

The intergroup and intragroup PD games above are equivalent from a strategic point of view. Nevertheless, as a recent experiment by Bornstein and Ben-Yossef (1994) demonstrated, people are much more likely to cooperate in the Prisoner's Dilemma game when the game is embedded in the context of an intergroup conflict than when it is played as a single-group game. Bornstein and Ben-Yossef compared the IPD and PD games played once. The purpose of the present experiment is to compare the IPD and PD games played repetitively. Our objective is not to provide a full analysis of the repeated games, or account for all their strategic aspects. Rather, we attempt merely to examine whether the difference in behavior between the IPD and the PD games observed in the context of one-shot games persists when the games are played repeatedly.

Repeated games are different from one-shot games in two important ways: First, in an iterated game behavior can be dependent on the earlier choices of other players, whereas in a one-shot game this is not possible. As a result, behavior which may be regarded as irrational in a one-shot game may be rational when the game is repeated. Game-theoretical analysis shows that infinitely repeated games

[1] The constant $+ 3\alpha$ is included to guarantee positive payoffs to the subjects.

induce the phenomenon of the 'Folk Theorem'. Namely, every feasible and individually rational payoff vector is supported by some Nash equilibrium of the game. In a finitely repeated game with incomplete information about the length of the horizon (as is the case in our experiment), the set of Nash equilibria is typically much larger than that in the one-shot game (e.g., Neyman, 1995). In the context of the IPD and PD paradigms this means that the outcome of no one contributing is no longer the only Nash equilibrium of the games.

Second, an iterated game provides players with an opportunity to learn the structure of the game and adapt their behavior accordingly – an opportunity that they do not have in a one-shot game. The dynamic context of a repeated game thus provides a different, and perhaps more realistic, justification for the theory of equilibrium that does not assume strategic rationality (e.g., Smith, 1984; Harley, 1982; Selten, 1991). Instead, it assumes that equilibrium is a result of learning (Boyd and Richerson, 1985). Learning does not require any insight into the situation. Rather, simple trial-and-error adaptation to success and failure can steer players in the direction of the game-theoretic equilibrium.

Previous experiments on the repeated Prisoner's Dilemma game (Radlow, 1965; Rapoport and Chammah, 1965; Guttman, 1986) have shown that subjects first learn the payoff structure of the one-shot (constituent) game, treating the behavior of the other player(s) as invariant. It takes subjects much longer to realize that the behavior of the others may be contingent on their own behavior. The result is a U-shaped trend – a decrease in contribution rates at the beginning of the game and then a rise, or a recovery as players start reciprocating. The present experiment involved a relatively small number of repetitions (i.e., 40) and therefore focused primarily on the first, short-term learning phase.

2. The experiment

2.1. Experimental procedure

The subjects were 120 male undergraduate students at the Hebrew University of Jerusalem with no previous experience with the task. Subjects participated in the experiment in sets of six with 10 such sets participating in the IPD experimental condition and 10 sets in the PD control condition. Since the IPD game necessarily involves the co-presence of two distinct teams and to prevent the possibility that the mere categorization of subjects into teams is responsible for potential effects, we included two teams in each session of the PD control condition as well. However, rather than competing against each other, each three-person team in the control condition played a separate (independent) PD game.

Upon arrival the subjects were seated in a single room with arrangements to ensure their privacy. Subjects were randomly divided into two three-person teams and were given verbal and written instructions concerning the rules and payoffs of the game. The instructions were phrased in terms of the individual's payoffs as a function of his own decision (to contribute or not) and the decisions made by the other five players in his set (in the IPD condition) or the other two players in his team (in the PD condition). The payoffs were summarized in a table which was available to the subjects throughout the experiment (see Appendix A). Subjects were not instructed to maximize their earnings, and no reference to cooperation or defection was made. Subjects were given a quiz to test their understanding, and explanations were repeated until the experimenter was convinced that all subjects understood the payoff matrix. Subjects were also told that to ensure the confidentiality of their decisions they would receive their payment in sealed envelopes and leave the laboratory one at a time with no opportunity to meet the other participants.

In the IPD condition, the two groups competed against each other in 40 rounds (iterations) of the IPD game (with $\alpha = 1$ point and $e = 2$ points). In the PD condition each three-person group independently played 40 rounds of a PD (Γ_1) game (corresponding to the case where there is one outgroup contributor in the IPD game with $\alpha = 1$ and $e = 2$, see Appendix A). The number of rounds to be played was not made known to the subjects. Each subject had an electric switch that controlled a green or a red light bulb (according to group membership) on an electric board at the front of the room. Each subject could identify his own light bulb (and, thus, his group membership) but could not associate any of the other participants with a particular light bulb (or group). At the beginning of each round, all the switches were off. Subjects had 15 seconds to decide between contributing and not contributing. If a subject decided to contribute, he was to turn on his electric switch. The room was arranged such that subjects could not see what the others are doing. The decision was not indicated on the board until the 15 seconds were up, at which time the lights were turned on automatically according to the decisions made by each subject (e.g., if there were two contributors in the red group and one in the green group, two red lights and one green one came on). This procedure ensured that each round (constituent game) was played simultaneously. Following the completion of a round the decisions were recorded by the experimenter (subjects were also given 15 seconds to record the outcome of each round which enabled them to double-check their earning at the end of the experiment). The lights on the board were turned off and the sequence was repeated.

Following the last round, the points were added up by the experimenter and cashed in at the rate of IS 1 for 5 points (1 Israeli Shekel was equal to $0.40 at the time the experiment took place, and the average subject earned IS 34.8, about $14). Subjects were then debriefed on the rationale and purpose of the study, and were paid and dismissed individually.

3. Results

Fig. 1 presents the proportion of contributing players, averaged for each five-round block in the IPD and PD games. The mean number of contributions per

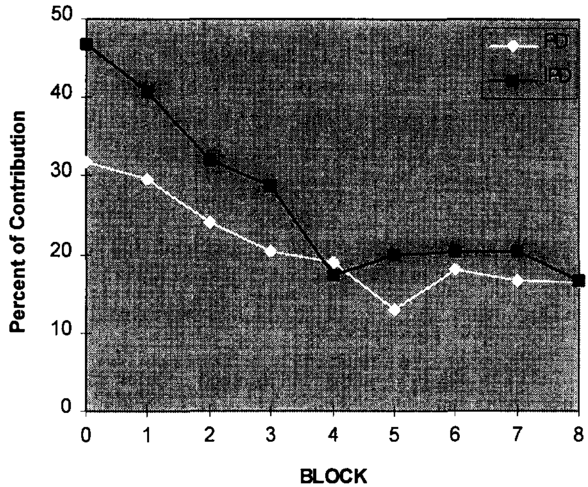

Fig. 1. Proportion of contribution per block in the IPD and PD games: Empirical results.

round in the first five-round block in the IPD game was 2.44 (40.67%) as compared with a mean of 1.78 (29.67%) contributors per round in the PD game. This difference was analyzed using t-test procedure and was found statistically significant both when the analysis was performed at the level of the individual subject, [$t(118) = 2.37$, $p < 0.02$], and when the six-person group was used as the unit for statistical analysis, [$t(18) = 2.07$, $p < 0.053$]. The mean number of contributions per round in the second five-round block was 1.92 in the IPD game and 1.44 in the PD game. This difference in contribution rates is significant at the individual level, [$t(118) = 2.37$, $p < 0.02$], and only marginally significant when the analysis is done at the group level, [$t(18) = 1.43$, $p < 0.085$ one-tailed]. The same is true for the third five-round block. The mean number of contributors in the IPD game (1.72) is significantly higher than that in the PD game (1.22) when the analysis is done at the individual level, [$t(118) = 1.83$, $p < 0.035$ one tailed]; and marginally significant when the analysis is performed at the group level, [$t(18) = 1.39$, $p < 0.09$, one-tailed]. From the fourth block on, the contribution rates in the two games are not significantly different. Over all 40 rounds, the mean number of contribution was 1.47 out of 6 (24.50%) in the IPD game and 1.17 out of 6 (19.97%) in the PD game. The difference in the total contribution rates is not statistically significant.

To test for learning effects we also calculated a linear trend for each group using the number of the round as the measure of experience. A t-test performed on these contrasts revealed a significant decrease in contribution rates over time in the IPD game [$t(9) = 3.07$, $p < 0.02$], and a smaller but still significant decrease in contribution rates over time in the PD game [$t(9) = 1.87$, $p < 0.05$; one-tailed].

It is clear from the results in Fig. 1 and from the above analyses that subjects, as they gain more experience, became more likely to choose the equilibrium strategy of the constituent (one-shot) game. In other words, subjects in both games seem to be learning. To further examine this possibility, we applied the learning model recently suggested by Roth and Erev (1995). The basic principle underlying the Roth and Erev model is that choices which have led to good outcomes in the past are more likely to be repeated in the future. This principle, known as the 'Law of Effect' (Thorndike, 1898), has been confirmed in a wide variety of environments and seems to be a robust property of both human and animal learning. Roth and Erev (1995) demonstrated that their simple model does a surprisingly good job of reproducing the major features of choice behavior observed in experimental games.

The basic version of the model assumes that Player i, when deciding how to act in the IPD or PD game, considers the two pure strategies: contribution (C) and non-contribution (D). At time $t = 1$ (before any experience with the task has been acquired) Player i has some initial propensity to play each of these two strategies. His propensity to select a particular strategy, say strategy C, at time $t = 1$ is denoted by $q_{iC}(1)$. If Player i plays strategy C at time t and receives a payoff of x, then the propensity to play C is updated by setting $q_{iC}(t+1) = q_{iC}(t) + x$, while for the other strategy, D, $q_{iD}(t+1) = q_{iD}(t)$. The probability $p_{iC}(t)$ that Player i will play strategy C at time t is $p_{iC}(t) = q_{iC}(t)/q_{iC}(t) + q_{iD}(t)$, the ratio of the propensity to play C divided by the sum of the propensities to play each of the two strategies. Thus, the probability of playing strategy C increases the more successful that strategy has been on previous rounds.

To test this learning model we conducted computer simulations. In performing these simulations we assumed that at $t = 1$ all players in the same game condition have the same initial propensity to cooperate. In setting these initial propensities we considered two factors: the ratio $q_{iC}(1)/q_{iD}(1)$ of the propensities to play strategy C and D, which determines the probability that C will be played at time $t = 1$; and the sum of the initial propensities over the two strategies C and D, $S(1) = q_{iC}(1) + q_{iD}(1)$. This second factor can be thought of as the *strength* of the initial propensities. When the value of $S(1)$ is large, the initial propensities are strong and learning is relatively slow. When the value of $S(1)$ is small, the initial propensities are weak and adaptation occurs more quickly. Following Roth and Erev, we set $S(1) = 10$ and calculated the ratio $q_{iC}(1)/q_{iD}(1)$ for the IPD and the PD games from the observed choices in the first *five* rounds in each game. Thus, the initial propensities for the computer simulations were set at 4.22 and 5.78 for C and D respectively in the IPD game, and at 2.97 and 7.03 for C and D respectively in the PD game.

The upper line for each game type in Fig. 2 presents the mean contribution rate in 100 simulated groups, each playing 40 rounds of the IPD or the PD game. (Note that since the initial propensities of the simulated subjects are based on the first five responses of the actual subjects, the observations at time 1 in Fig. 2 are not identical to these in Fig. 1). As can be seen in the figure, the simulated data

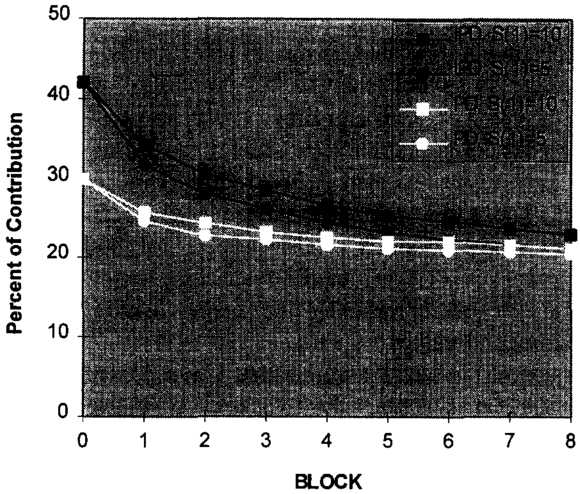

Fig. 2. Proportion of contribution per block in the IPD and PD games: Simulated results.

Note: The upper line for each game presents the mean of 100 simulations with $S(1) = 10$. The lower line for each game presents the mean of 100 simulations with $S(1) = 5$.

reproduce the actual data quite nicely. The simulated subjects, like the real ones, contributed less over time in both games, and most of the decrease in contribution rates occurred in the first 20 rounds of the game. Comparing Fig. 2 with Fig. 1 suggests that the simulated subjects learned somewhat more slowly than the real subjects. Therefore, we ran the simulation once again with $S(1) = 5$. The mean contribution rates (of 100 simulated groups) are presented by the lower line for each game in Fig. 2. As is clear from the graph, reducing the value of $S(1)$ did increase the speed of learning, rendering the simulated results more similar to the behavior of the actual subjects. However, it did not change the general pattern of the results. Thus, the Roth and Erev learning model seems to be quite robust to changes of parameters.

4. Discussion

Both the IPD game and the PD game possess a unique Nash equilibrium with defection as the dominating strategy. The notion of dominant strategies is perhaps the least controversial solution concept in game theory. Unlike Nash equilibria, the epistemic conditions for playing a dominant strategy require only that players are rational (see Aumann and Brandenburger, 1994). Yet, as the present study demonstrates, subjects are initially more likely to cooperate in the IPD than the PD game, and this difference in contribution rates persists for the first fifteen or so rounds of the game.

We do not intend to offer a complete explanation for these results. However, our experimental design does enable us to attribute this difference to the conflict of interests between the groups that exists in IPD game but not in the PD game. It seems that intergroup conflict increases individual willingness to sacrifice self-interest for group causes, as argued by many sociologists and social psychologists (Campbell, 1965, 1972; Coser, 1956; Stein, 1976; Sherif, 1966). This increased 'altruism' is indeed paradoxical if one takes Pareto efficiency into consideration. In intergroup conflicts as modeled by the IPD game, universal cooperation is Pareto deficient, whereas in single-group PD game it is Pareto optimal. In his paper on 'ethnocentric and other altruistic motives', Campbell (1965), following a similar observation, remarks: "... We have tended to see the altruistic as moral, as the imposed achievement of civilization. Under a broader framework we must now, in some cases, be willing to see altruistic social motives as irrational and immoral, or at least amoral" (p. 307). Another major finding is that the difference in contribution rates between the two games decreases as the games progressed. This pattern of results supports the hypothesis that subjects learn the structure of the game and adapt their behavior accordingly, and is consistent with the simple learning model of Roth and Erev (1995). The model predicted relatively quick learning at the beginning of the game (particularly in the IPD game), and quite slow learning during later stages. These predictions, as reflected by the simulated results, were nicely confirmed by the experimental data.

The finding that in both the PD and the IPD games the propensity of cooperation decreases in time suggests that the effect of learning is indeed more decisive than the effect of within-group reciprocity as suggested earlier. Nevertheless, that fact that our data provide little support for the reciprocal cooperation hypothesis does not rule out the possibility that, had the game lasted longer, some form of reciprocation would have evolved and, as a result, the level of cooperation will increase. Whereas the present study looked at the short-term effects of repetition (Roth and Erev, 1995), future research will examine the long-term interaction effects in the IPD and PD games. Allowing enough time for the upward-sloping part of the U-shaped function to appear, will enable us to identify possible differences in the onset and extent of the recovery in the two games.

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Appendix A

Subjects participating in the IPD condition were told that each has to decide whether to keep the 2-point endowment or 'invest' it. The number of investors in the two teams is counted and a bonus is given to each member of a team depending on the difference between the number of ingroup and outgroup contributors. If all members of Team A contribute, while no members of Team B contribute, members of Team A receive a bonus of 6 points while those in Team B receive no bonus. If there are two more contributors in Team A than in Team B, each member of Team A receives a bonus of 5 points, while each member of Team B receives 1 point. If Team A has one more contributor than Team B, each member of Team A receives 4 points, whereas each member of Team B receives 2. Finally, in case of a tie (an equal number of contributors in both teams), each member of both teams receives a reward of 3 points. In addition to the bonus, each player keeps his endowment if he does not invest it. The payoffs are summarized in the following table.

(Ingroup–outgroup)	More investors in your group				More investors in other group		
	3	2	1	0	−1	−2	−3
You invest	6	5	4	3	2	1	–
You do not invest	–	7	6	5	4	3	2

In the PD condition, each group member is paid a bonus of 5 points if all three members invest their 2-point endowments, 4 points if two members invest, 3 points if only one contribute, and 2 points if none do. In addition to the bonus, each player keeps his endowment if he does not invest it. The payoffs are summarized in the following table.

	Number of investors			
	3	2	1	0
You invest	5	4	3	–
You do not invest	–	6	5	4

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