Cooperation under the shadow of the future: experimental evidence from in…nitely repeated games

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Abstract

While there is an extensive literature on the theory of infinitely repeated games, empirical evidence on how "the shadow of the future" affects behavior is scarce and inconclusive. We simulate infinitely repeated prisoner's dilemma games in the lab by having a random continuation rule. The experimental design represents an improvement over the existing literature by including sessions with finite repeated games as controls and a large number of players per session (which allows for learning without contagion effects). We find strong evidence that the higher the probability of continuation, the higher the levels of cooperation. We compare the behavior from these infinitely repeated games with behavior from finitely repeated games of the same expected length and we find that there is more cooperation in the infinitely repeated games. Finally, we consider different payoffs matrices that result in different equilibrium outcomes for some probabilities of continuation, and find that the set of observed outcomes closely follows the set of equilibrium outcomes.

Keywords: infinitely repeated games, prisoner's dilemma, cooperation, experimental economics.

JEL Classification: C72, C73, C91, C92.

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1 Introduction

Game theorists have long recognized that repeated playing and the possibility of future interaction may modify current behavior. The possibility of future interaction may enable players to establish punishment and reward structures to prevent or limit opportunistic behavior.

While there has been a large number of theoretical papers on this subject, the empirical and experimental evidence is scarce and in most cases inconclusive or characterized by methodological problems. We run a series of experiments to study whether the possibility of future interaction modifies players' behavior, allowing them to prevent opportunistic actions.

Infinitely repeated prisoner's dilemma games are simulated in the experiment by having a random continuation rule. The experimental design represents an improvement over the existing literature by including sessions with finite repeated games as controls and a large number of players per session (which allows for learning without contagion effects).

We find strong evidence that the higher the probability of continuation, the higher the levels of cooperation. While in one shot prisoner's dilemma games the cooperation rate is 9%, for a probability of continuation of 3/4 it is 38%. The effect of the shadow of future on the levels of cooperation is greater than previous studies have shown and suggests that self-enforcing reward and punishment schemes that eliminate opportunistic behavior are important in practice as well as in theory.

In addition, we compare the results from the infinitely repeated games with the results from finitely repeated games to test whether cooperation depends on "the shadow of the future," as theory predicts, or merely on the length of the games. The lengths of the finitely repeated games were chosen to coincide with the expected lengths of the infinitely repeated ones. In the finitely repeated games the levels of cooperation are significantly lower than in the infinitely repeated ones. For example, in repeated games with a finite horizon of 4 rounds the cooperation rate is 21% against 38% in the infinitely repeated games with a probability of continuation of 3/4.

Finally, to study how closely the behavior of the subjects matches the theoretical predictions, we use the fact that different prisoner's dilemma payoff matrices result in different sets of equilibrium outcomes. We used two different payoff matrices in the experiment with the peculiarity that, for a probability of continuation of 1/2, cooperation for both players is an equilibrium in one but not in the other. We find that the percentage of outcomes in which both subject cooperate is almost 19% when it is an equilibrium, while it is less than 3% when it is not. These experimental results show that behavior closely, but not perfectly, follows the theoretical predictions that are dependent on the payoff details of the stage game, providing further support to the theory of repeated games.

The experimental evidence presented here shows that the shadow of the future matters and it significantly reduces opportunistic behavior as predicted by theory.

The next section summarizes previous experimental research on the topic. Section 3 describes the experimental design and section 4 describes the theoretical predictions. Section 5 presents the results of the experiment and the last section concludes.

2 Previous Experiments

While there exists extensive experimental literature on finitely repeated games, the experimental evidence on infinitely repeated games is scarce and in most cases inconclusive or exhibits methodological drawbacks.

Previous experiments on infinitely repeated games are of two types: 1) experiments with a random continuation rule known to the subjects and 2) experiments with a finite number of repetitions known to the experimenter but unknown to the subjects. In the first type, subjects knew that there was always a positive probability of continuation. In the second type, games were not infinitely repeated since there was a final round, but this round was unknown to the players. Therefore, in each round the subjects may have assigned a positive probability of continuation.

Experiments that fall into the first category are those of Roth and Murnighan [16] and Murnighan and Roth [13]. These two papers present results of experiments with infinitely repeated prisoner's dilemma for different continuation probabilities. Roth and Murnighan [16] find that the higher the probability of continuation, the higher the number of players that cooperated in the first period of the game, see Table 1. Murnighan and Roth [13] present results for experiments with twelve different variations of prisoner's dilemma. Considering the results of the twelve variations together, higher probabilities of continuation did not result in more cooperation in the first round, in contrast to the results of Roth and Murnighan [16], see Table 1.

Table 1: Percentage of cooperation in the first round game

	Probability of continuation		
	0.105	0.5	0.895
Roth and Murnighan [16][a]	19	29.75	36.36
Murnighan and Roth [13][b]	17.83	37.48	29.07

a) Over 121 subjects. b) Over 252 subjects

In addition to presenting contradictory evidence (and offering little hope that opportunistic behavior can be limited by increases on the shadow of the future), these two papers display methodological problems which are discussed in Roth [15]. In both experiments, subjects played against the experimenter instead of playing against each other. In Roth and Murnighan [16] subjects were told that they were playing against the experimenter but were not told that the experimenter was following the tit-for-tat strategy. In Murnighan and Roth [13] subjects where told that they where playing against each other while in fact they where playing against the experimenter who was following either the tit-for-tat or grim strategy. In addition, in both experiments subjects where not paid proportionately to the "points" they earned during the experiments. In Roth and Murnighan [16] “the best player” in the experiment received a $10 price, while in Murnighan and Roth [13] the player with the highest average score in each session received $40 and the second one $20.

Another experiment that employed a random continuation rule is Feinberg and Husted [5]. They combine a fixed continuation probability with different discount factors (they shrink the payoffs in every round) to study the effect of repetition on the levels of cooperation in a prisoner’s dilemma game disguised as a duopoly game. They find that the levels of cooperation increase as the discount factor increases. Nevertheless, that increase is small and far from the increase needed to fully exploit the possible benefits from cooperation even when the experiment and it instructions were purposely designed to facilitate cooperation. In addition, these results are weakened because the payments made to the subjects were quite low and the basic payoffs were not the same in all treatments[1].

Another experiment in which subjects faced a random continuation rule was conducted by Palfrey and Rosenthal [14]. This paper presents an experiment designed to test whether the possibility of future interaction leads to greater cooperation in public good games with incomplete information. They compare the rate of contribution to a public good when players meet only once with each other and when they meet repeatedly with a probability of continuation of 0.9[2]. They find that repetition leads to more cooperation than one shot games but this increase is small (the percentage of contribution goes from 29% to 40%). They concluded that “This contrast between our one-shot and repeated play results is not encouraging news for those who might wish to interpret as gospel the oft-spoken suggestion that repeated play with discount rates close to one leads to more cooperative behavior. True enough it does-but not by much.”[3] As

[1] Another experiment that used a random continuation rule to study repeated oligopoly games is Holt [8]. Since this experiment was designed to test for consistent-conjectures, the results do not provide information regarding cooperation.

[2] There were at least 20 rounds, after which the probability of continuation was 0.9.

[3] Palfrey and Rosenthal [14], pag. 548.

the authors suggest later, the power of repeated play may be more evident in a simpler environment.

One drawback to the experiments with a random continuation rule is that it is not clear that as the probability of continuation increases any increase of cooperation that we witness is due to an increase in the importance of the future as theory predicts or if it is merely due to an increase of the repeated game expected horizon. There is experimental evidence that subjects cooperate more in finitely repeated prisoner's dilemma games than in one-shot ones (see Andreoni and Miller [2] and Cooper et al. [4]). One reason for this effect is that in finitely repeated games subjects may have incentives to build reputations if there is incomplete information (see Kreps et al. [12]). Therefore, if we observe an increase in cooperation as the probability of continuation increases, it could be due to an increase on reputation effects as the expected horizon of the game increases and not to the infinitely repeated feature of the game.

There are some old repeated oligopoly experiments, like the ones presented in Fouraker and Siegel [6], that fall into the second category of games in which the number of repetitions was known to the experimenter but not to the subjects. In each round the subjects may assign a positive probability of continuation and we may consider these experiments of infinitely repeated games, at least in the minds of the subjects. Fouraker and Siegel [6] find some cooperation in Cournot duopoly markets but not in triopoly markets.

All experiments with a fixed number of rounds unknown to subjects raise the problem that the experimenter can not control for the players' beliefs with respect to the continuation of the game[4].

A more recent paper in this category is Brown Kruse et al. [3] which presents an experiment on repeated price competition in an oligopoly market with fixed capacity constraints. While they observe prices above competitive levels, those prices are far below the monopoly price. In addition, in the treatments in which collusion is more

[4] This type of design also adds a source of incomplete information since subjects may not know what others subjects beliefs are.

easily supported (requires a lower belief of continuation) the prices are lower. This contradicts what we would expect from infinitely repeated game theory, which predicts that when collusion is easier to support, higher prices should be observed if some of the subjects coordinate in collusive equilibria.

Previous experimental results do not provide much support for the theory of infinitely repeated games and that self-enforcing reward and punishment schemes are used to overcome opportunistic behavior. But given the shortfalls of some experiments' design, (i.e. no real interaction among subjects, final earnings that are not proportional to the payoffs during the game, low earnings, fixed number of rounds unknown to the subjects and lack of control sessions), and the complicated environment of others (i.e. environments of incomplete information), previous experimental evidence is insufficient to assess the degree in which the theory of infinitely repeated games is supported empirically. This paper presents results from an experiment that was designed to overcome the above mentioned shortcomings and shows not only that the shadow of the future matters, but that its effect is significant and that it closely, but not perfectly, follows the theoretical predictions.

3 Experiment design

The design of this experiment allows for a better testing of the theory of infinitely repeated games. We used simple stage games: prisoner's dilemma games. The subjects interacted with each other through computer terminals anonymously (see Figure 1) and the pairing of subjects was done such that there was no possibility of interaction or contagion effects among the different repeated games. We controlled for the subjects' discount factors by having a know probability of continuation. The subjects' final earnings were proportional to the points earned during the experiment plus a show up fee. The exchange rate points/$ ensure that subjects had significant incentives to try to increase their earnings.

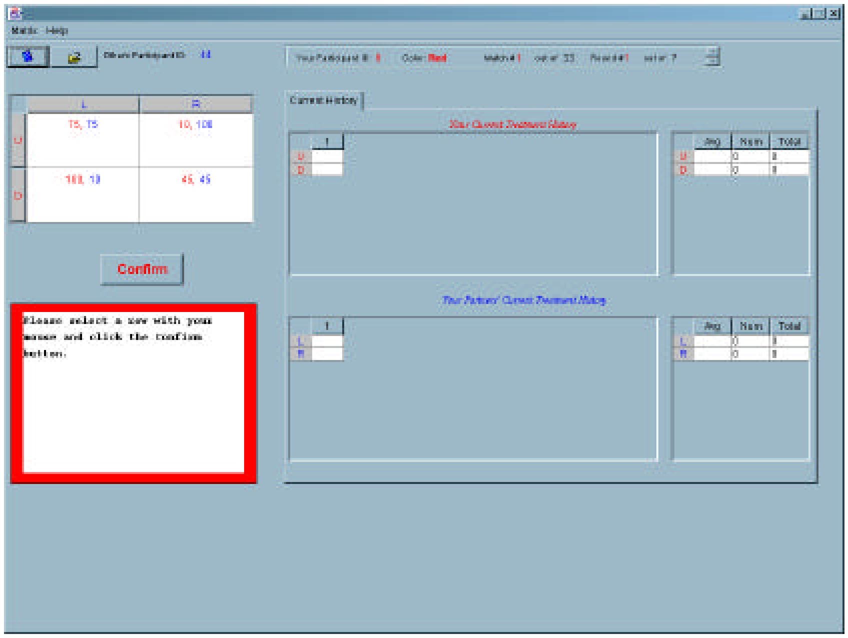

Figure 1: Computer screen that subjects saw before each interaction.

In addition, the experimental design incorporates three important new elements. First, in addition to the random continuation rule sessions, we run sessions with …xed …nite horizon games. The length of the …xed …nite horizon sessions were chosen to coincide with the expected length of the random continuation rule ones. Therefore, for the …rst time in the literature, the experimental design allows us to compare the results from in…nitely repeated games with the results from …nitely repeated games to test whether cooperation depends on "the shadow of the future", as theory predicts, or merely on the length of the games.

Second, we considered two di¤erent prisoner's dilemma games that result in di¤erent sets of equilibrium outcomes for some discount factors. In this way we can study how closely the experimental results follow theoretical predictions that depend on details of the payo¤ matrices.

Third, a large number of players participated in each session resulting in a large number of interactions for each treatment and allowing for learning without contagion e¤ects.

Next we describe the main characteristics of the experiment in greater detail.

Stage game payo¤s: We consider two di¤erent stage games payo¤s, denoted PD1 and PD2[5]:

Table 2: Stage game payo¤s in points

PD1

		Blue player C	Blue player D
Red player	C	65 , 65	10 , 100
	D	100 , 10	35 , 35

PD2

		Blue player C	Blue player D
Red player	C	75 , 75	10 , 100
	D	100 , 10	45 , 45

The sets of equilibrium outcomes for the in…nitely repeated version of these games are described in the next section.

Public randomization device: To allow subjects to coordinate actions and rotate through di¤erent outcomes, every ten seconds a random number between 1 and 1000 was displayed on a screen at front of the room.

Subjects' total earnings: All payo¤s in the game were in points. At the end of each session, the points earned by each subject were converted into dollars at the exchange rate 200 points=$1 and paid privately in cash. In addition, subjects were paid a 5 dollar show up fee. In this way, subjects' real earnings in dollars are proportional (up to a constant) to the "points" obtained during the experiment. In addition, these amounts seem signi…cant enough to in‡uence subjects' behavior. In a session with …xed …nite horizon games and 30 subjects the di¤erence between the maximum and minimum possible earning is above 15 dollars[6].

[5] While in the experiment the actions were called U and D for Red subjects and L and R for Blue subjects, we will use here the usual names C and D.

[6] In the sessions with a random continuation rule this di¤erence depends, of course, on the realization of the random continuation rule.

Infinitely repeated games: In half of the sessions a random continuation rule was used to induce infinitely repeated games. This was done by having one of the subjects -who had been selected as the monitor- roll publicly a four sided die after each round. The randomization generates an infinitely repeated game given that at the moment of choosing an action there is always the possibility of interacting in future rounds with the same subject.

The probability of continuation δ, of which three different values were considered, is the principal treatment variable in these sessions. One treatment corresponds with the one-shot game case: $\delta = 0$ and the rest corresponds with positive probability of continuations: $\delta = 0.5$ and 0.75. This treatment variable allows us to control for the subjects' beliefs regarding the probability of continuation. We call these sessions "Dice" sessions.

Finitely repeated games: In the other half of the sessions fixed finite horizon games were used. We considered three treatments that allows one to compare results with the infinitely repeated games experimental results: 1) one-shot game: $H = 1$, 2) two rounds repeated game: $H = 2$ and 3) four rounds repeated game: $H = 4$. Note that the number of rounds for these treatments corresponds to the expected number of rounds in the random continuation rule treatments[7]. The number of rounds was common knowledge among the subjects. We call these sessions "Finite" sessions.

Order of treatments: To control for learning effects from one treatment to another, two sessions were run for each kind of continuation rule (Dice and Finite) and payoff matrix (PD1 and PD2). For example, for PD1 and Dice we run one session with the order ($\delta = 0, \delta = .5, \delta = .75$) and another with the inverse order ($\delta = .75, \delta = .5, \delta = 0$). We call the first kind of session "Normal" and the last kind "USD" (up-side-down).

[7] In infinitely repeated games with a continuation probability of δ, the expected number of rounds is equal to $\frac{1}{1-\delta}$. Therefore, the expected number of rounds in the random continuation session will be 1, 2 and 4 for δ equal to 0, 0.5 and 0.75, respectively.

Matching procedure: A rotation matching scheme was used to avoid potential interaction and contagion e¤ects between the di¤erent repeated games[8]. In each session subjects were divided in two groups: Red and Blue. In each match every Red subject was paired with a Blue subject. Subjects were not paired with each other more than once. In addition, subjects were not paired with someone that had played with someone that had played with him or her or with someone that had played with someone that had played with someone that had played with him or her, and so on. Thus, the pairing was done in such a way that the decisions one subject made in one match could not a¤ect, in any way, the decision of subjects he or her would meet in the future. All these features were explained and made clear to the subjects.

Given that each subject was only matched once with each subject of the other color, the total number of matches in a session is $\frac{N}{2}$, where N is the number of subject in a session. Given that there are three treatment per session, in each treatment there are $\frac{N}{6}$ matches. The size of the experimental lab CASSEL allowed us to run experiments with up to sixty subjects, providing up to ten matches per treatment per subject. This large number of matches has the advantage of allowing subjects to familiarize with each treatment while also providing a large number of observations to study.

Sessions: Given the two stage games (PD1 and PD2), the di¤erent continuation rules (Dice and Finite), the di¤erent treatments ($\pm = 0; .5; .75$, and $H = 1; 2; 4$), and the change in the order of the treatments (Normal and USD), this experiment consists of eight sessions with three treatments each. Each treatment, or part, consists of one practice match for which subject are not paid and $\frac{N}{6}$ real matches. Each match consists of as many rounds as the continuation rule indicates.

[8] Note that, given Kandori [11]'s contagious equilibrium, random matching is not enough to isolate the di¤erent games.

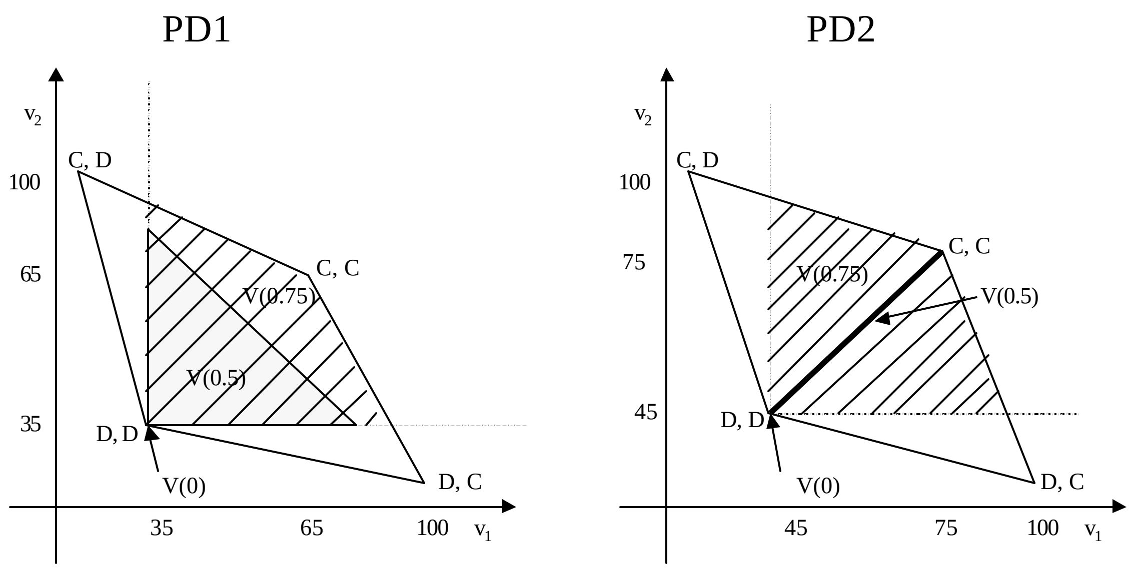

Figure 2: Equilibrium average payo¤s V (±)

4 Theoretical predictions

If we assume that the payo¤s in Table 2 are the actual total payo¤s that the subjects obtain from the game and this is common knowledge, that is if we abstract from problems of interdependent utilities, altruism, taste for cooperation and reputation e¤ects, the set of subgame perfect equilibria can be calculated using the results in Stahl [17]. Figure 2 shows the set of equilibrium average payo¤s (V (±)) in each game for each of the discount factors used in the experiment. The outcomes that can be supported in equilibrium for the di¤erent discount factors -and therefore the outcomes that according to theory we should observe- are presented in Table 3.

Table 3: Equilibrium outcomes

±	PD1	PD2
0	DD	DD
0.5	DD, CD, DC	DD, CC
0.75	DD, CD, DC, CC	DD, CD, DC, CC

New equilibria appear as the discount factor increases, allowing the subjects to reach -in principle- higher levels of cooperation and payo¤s. We can think that some subjects will make the most of this opportunity to cooperate, regardless of the fact that DD remains an equilibrium for high discount factors. Therefore, we have the following testable hypothesis[9]:

Hypothesis 1: The larger ±, the higher the levels of cooperation.

In the …nitely repeated games the theoretical prediction is that no cooperation is possible. Therefore I have the following testable hypothesis[10]:

Hypothesis 2: In…nitely repeated games (± = :5 and ± = :75) result in higher levels of cooperation than …nitely repeated games ($H = 2$ and $H = 4$).

From Table 3 we see that the set of equilibrium outcomes is di¤erent for PD1 and PD2 for ± = :5. Under that discount factor, CC can be observed in equilibrium for PD1 but not for PD2[11]. Therefore, we have the following testable hypothesis:

Hypothesis 3: For ± = :5, PD2 results in more outcomes CC than PD1.

The …rst two hypotheses are quite general in the sense that they do not depend on speci…c details of the payo¤ matrices and are robust to perturbations of the stage games. In contrast, the last hypothesis is quite speci…c in the sense that it is closely based on

[9] It is important to note that for this hypothesis it is not necessary to assume that the subjects' only payo¤s from the stage game are the ones in Table 2. With di¤erent payo¤s the predictions presented in Figure 2 and Table 3 may not be appropriate, but Hypothesis 1 can still be true. Abreu, Pearce and Stacchetti [1] showed that the set of equilibrium payo¤s (and consequently the set of outcomes) that can be observed in a in…nitely repeated game (even with imperfect monitoring), can not decrease when the discount factor increases. Then, for any stage game in which DD is the only Nash equilibrium, increases in the discount factor result in increases in the levels of cooperation.

[10] As mentioned before, the levels of cooperation in a …nitely repeated game may be positive given reputation e¤ects. Unfortunately, to my knowledge, there is no theoretical result that allow us to compare the set of equilibrium outcomes between …nitely and in…nitely repeated games under incomplete information. Therefore, the following proposition is based solely on the theory for repeated games under complete information.

[11] Note that cooperation can still be observed in equilibrium for PD1 given that the outcomes CD and DC can be part of an equilibrium.

the specified payoff matrixes.

5 Experimental results

The experimental sessions were run between November 2001 and April 2002 with an average length of one hour (without counting the time to pay subjects). The descriptive statistics are in Table 4. Excluding the subjects selected to be monitors, 390 subjects participated in the experiment, an average of 48.75 subjects per session with a maximum of 60 and a minimum of 30. The subjects were UCLA undergraduates recruited through advertisement in university webpages and signs posted on campus. 22.31% of the subjects indicated that they were in one of the Economics major programs (Economics, Business Economics, Mathematics/Economics and Economics/International Area Studies). The subjects performed a total of 22,482 actions and earned an average of $18.94 with a maximum of $25.85 and a minimum of $12.

Table 4: Sessions descriptive data

		PD1		PD2	
		Dice	Finite	Dice	Finite
	Date	11/6/01	11/13/01	2/7/02	4/18/02
	Time*	2:30-3:28	4:45-5:31	1:45-2.56	5:15-6:25
	Subjects	42	30	54	48
	Any Econ+	23.81%	23.33%	12.96%	18.75%
Normal	Actions	2268	1050	3132	2688
	Ave Earning	17.09	13.03	19.91	19.36
	Max Earning	19.40	15.23	22.18	21.88
	Min Earning	13.48	12.05	15.98	15.48
	Total $	717.7	390.85	1075.10	929.20
	Date	11/29/01	11/20/01	4/9/02	4/15/02
	Time*	5:10-6:05	5:10-6:05	4:45-5:53	4:45-5:54
	Subjects	42	54	60	60
	Any Econ+	16.67%	12.96%	31.67%	35%
USD	Actions	1722	3402	4020	4200
	Ave Earning	14.37	17.77	23.09	22.11
	Max Earning	16.23	21.55	25.85	25.10
	Min Earning	12.18	12	19.93	17.15
	Total $	603.65	959.45	1385.10	1326.50

*Starting Scheduled time and …nal actual time.

+Percentage of all Economics majors in the session.

Even when subjects participated in a practice match before the real matches of each treatment, we should expect to see during the …rst matches of each treatment some learning regarding the treatment characteristics and other's subjects behavior. As you can see in Table 5, there is clear learning regarding the possibilities of cooperation in the ± = 0 treatment of the Dice sessions and all the treatments of the Finite sessions (that is, in all the treatments with …xed horizons). For example, in the ± = 0 treatment, cooperation goes from above 26% in the …rst match to less than 11% in the third match.

Table 5: Percentage of cooperation by match and treatment*

	Match									
Dice	1	2	3	4	5	6	7	8	9	10
± = 0	26.26	18.18	10.61	11.62	12.63	12.63	5.56	5.26	5.26	5
± = :5	28.36	27.12	34.58	35.53	21.60	19.08	29.84	35.96	28.16	50
± = :75	40.44	28.57	27.78	32.92	46.51	33.09	44.05	53.51	42.26	45.83
Finite										
H = 1	26.56	18.23	16.67	17.19	11.98	8.02	6.79	10.49	6.14	6.67
H = 2	19.79	15.89	14.84	9.64	11.46	10.80	12.04	10.19	6.58	6.67
H = 4	31.64	30.34	30.47	25.52	25.13	23.77	16.36	19.75	14.91	20.83

*All rounds.

Given this learning regarding the treatments, in the analysis of the experimental results we focus on the matches after the third.

5.1 Does cooperation increase with the shadow of the future?

Our …rst objective is to study how changes in the probability of future interaction a¤ect the levels of cooperation. The experimental results show that the greater the shadow of the future, the larger the levels of cooperation. Considering the aggregate results for the Dice sessions (matches after third and all rounds) we see that cooperation is just above 9% for the one shot treatment, while it is above 27% and 37% for ± = :5 and ± = :75, respectively -see Table 6 and Figure 3. These di¤erences are statistically signi…cant with p values of less than 0.001. Therefore, the experimental results support Hypothesis 1: the larger ±, the larger the levels of cooperation.

Table 6: Percentage of cooperation by treatment*

Dice		Finite	
± = 0	9.17	H = 1	10.34
± = :5	27.41	H = 2	10.11
± = :75	37.64	H = 4	21.43

*Matches after third and all rounds.

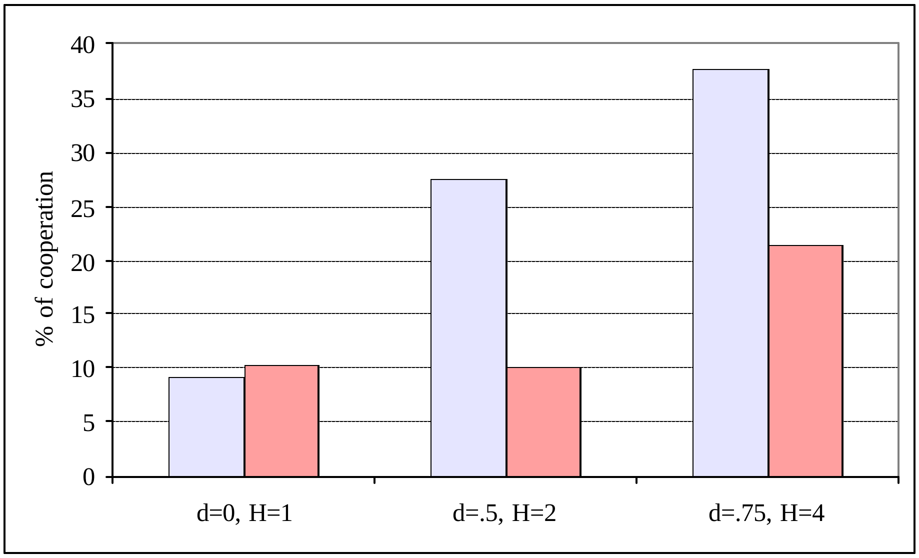

Figure 3: Cooperation by treatment (matches after third and all rounds)

In addition, these results show that the e¤ect of the shadow of the future is large: the percentage of cooperation for ± = :75 is almost four times greater than for the one shot treatment. The magnitude of this di¤erence is greater than previously found. For example, in the public good experiments with incomplete information of Palfrey and Rosenthal [14] the percentage of contributions increases only from 29% to 40% when the treatment changes from one shot games to a random continuation rule with ± = :9. This is also the case if we compare the results of this experiment with the results from Roth and Murnighan [16] and Murnighan and Roth [13][12]. While in those experiments the percentage of cooperation in the …rst round less than doubles when the probability of continuation increases from 0.105 to 0.895, in this experiment the percentage cooperation is four times higher with a probability of continuation of 0.75 than in one shot games. These results support the idea that in…nitely repeated interaction can signi…cantly reduce opportunistic behavior.

[12] Given the described characteristics of these experiments we compare the results for the …rst round of each match.

5.2 In…nitely repeated games vs. …nitely repeated games

Our second objective is to compare the levels of cooperation in the Dice and Finite sessions. As Table 6 shows, the percentage of cooperation is similar for the one shot treatments in both types of sessions (p value = 0.507), showing that there are no signi…cant di¤erences in the "kind" of people that participated in each session. More importantly, the percentage of cooperation in in…nitely repeated games (± = :5 and ± = :75) is greater than in …nitely repeated games ($H = 2$ and $H = 4$), with p values of less than 0.001. Therefore, the experimental results support Hypothesis 2: in…nitely repeated games result in larger levels of cooperation than …nitely repeated games.

Studying the levels of cooperation by round for each of the treatments (Table 7) further supports the theory of repeated games. In the fourth round of the ± = :75 treatment the level of cooperation is signi…cantly greater than in the fourth (and last) round of the $H = 4$ treatment (34.58% against 10.63%, with p value of less than 0.001). The level of cooperation in the …nal round of the $H = 4$ treatment is similar to the level of cooperation in one shot games. Therefore, the absence of a future a¤ects subjects behavior in the …nal round of …nitely repeated games: they cooperate less when there is no future. This seems to be understood by the subjects at the beginning of the game, resulting in greater levels of cooperation in the …rst round of an in…nitely repeated game than in the …rst round of a …nitely repeated game (46.20% against 34.58%, with p value of less than 0.001). Similar reasoning applies to the comparison of the behavior for ± = :5 and $H = 2$.

Table 7: Percentage of cooperation by round and treatment

	Round											
Dice	1	2	3	4	5	6	7	8	9	10	11	12
± = 0	9.17											
± = :5	30.93	26.10	19.87	12.50	12.96							
± = :75	46.20	40.76	38.76	34.58	33.04	27.27	24.75	26.28	29.17	26.04	32.29	31.25
Finite												
H = 1	10.34											
H = 2	13.31	6.90										
H = 4	34.58	21.55	18.97	10.63								

*Matches after third.

5.3 Do payo¤ details matter?

Our third objective is to compare the outcomes under PD1 and PD2 when ± = :5. Remember that CC is not an equilibrium outcome under PD1 but it is under PD2. Consistent with that, the percentage of outcomes in which both players cooperate is signi…cantly lower under the payo¤ matrix PD1 than under PD2 when ± = :5 (3.17% against 18.83% with a p value of less than 0.001). Note that this is not the case when ± = 0, implying that the di¤erence in the percentage of CC when ± = :5 can not be attributed to di¤erences in the subjects that participated in the sessions under PD1 and PD2. Thus, the experimental results support Hypothesis 3: For ± = :5, the payo¤s PD2 result in more outcomes CC than PD1.

Table 8: Distribution of outcomes by stage game and treatment*

	± = 0		± = :5		± = :75	
	PD1	PD2	PD1	PD2	PD1	PD2
CC	2.98	0.27	3.17	18.83	20.68	25.64
CD	12.50	7.26	16.67	11.00	16.05	10.57
DC	8.33	6.72	11.90	14.50	14.29	15.46
DD	76.19	85.75	68.25	55.67	48.98	48.33

*Matches after third and all rounds.

The percentage of outcomes in which only one subject cooperates (CD and DC) is greater under PD1 than under PD2 (28,57% against 25.50%) as theory predicts. Nevertheless, this difference is not statistically significant (p value of 0.19) showing the difficulty of coordinating on alternating asymmetric outcomes even when there is a public randomization device available.

5.4 Do Economics majors behave differently?

It is important to note that the support for all three hypotheses does not depend on the major of the subjects. All three hypotheses are supported by the experimental results for students in any of the Economics majors and students in the rest of the majors. With respect to the first two hypothesis, for both Economics majors and Non-Economics majors cooperation increases as the probability of future interaction increases and cooperation is greater in infinitely repeated games than in finitely repeated games -see Table 9.

However, there are differences in behavior across majors. Economics majors cooperate significantly less than Non-Economics majors in games with a fixed finite horizon (this difference is significant for the Finite sessions with p values of 0.009, 0.042 and less than 0.001 for H=1, 2 and 4, respectively, but it is not significant for $\delta = 0$ with p value of 0.45). But the evidence is contradictory regarding infinitely repeated games. While Economics majors cooperate more than Non-Economics majors for $\delta = .5$ (p value of less than 0.001), that is not the case for $\delta = .75$. In fact, the percentage of cooperation is lower for Economics majors, but this difference is not significant (p value of 0.159).

Table 9: Percentage of cooperation by treatment and major*

	Dice			Finite	
	Non-Econ	Econ		Non-Econ	Econ
$\delta = 0$	9.68	7.41	H = 1	12.19	4.44
$\delta = .5$	26.65	29.97	H = 2	11.12	6.85
$\delta = .75$	38.93	33.15	H = 4	23.81	13.81

*Matches after third and all rounds.

With respect to the third hypothesis, PD1 results in a lower percentage of CC than PD2 when ± = :5 (p values of less than 0.001 for both types of majors) for all subjects. Nevertheless, it is interesting to note that this e¤ect is stronger for Economics majors.

Table 10: Distribution of outcomes for ± = :5 by major*

	PD1		PD2	
	Non-Econ	Econ	Non-Econ	Econ
CC	2.55	5.36	14.02	30.81
CD	18.88	8.93	10.51	12.21
DC	12.76	8.93	14.25	15.12
DD	65.82	76.79	61.21	41.86

*Matches after third and all rounds.

6 Conclusions

The experimental evidence presented in this paper provides strong support for the extensive use of the theory of in…nitely repeated games by showing that the shadow of the future matters and it signi…cantly reduces opportunistic behavior, closely following the theoretical predictions.

The data produced in this experiment deserve further study. It remains for future work to analyze the reward and punishment schemes used by the subjects. It would also be important to study whether, given these schemes, subjects' behavior constitutes an equilibrium, or how close they are to an equilibrium, by measuring subjects' average losses as in Fudenberg and Levine [7].

7 Appendix: Instructions for PD2-Dice-USD Session (4/9/02)

Welcome

You are about to participate in a session on decision-making, and you will be paid for your participation in cash, privately at the end of the session. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

Please turn o¤ pagers and cellular phones now. Please close any program you may have open on the computer.

The entire session will take place through computer terminals, and all interaction between you will take place through the computers. It is important that you not talk or in any way try to communicate with other participants during the session.

We will start with a brief instruction period. During the instruction period you will be given a description of the main features of the session and will be shown how to use the computers. If you have any questions during this period, raise your hand and your question will be answered so everyone can hear.

General Instructions

In this session one participant will act as a monitor. The monitor will be paid a …xed amount for the session. The monitor will assist in running the session and checking that the session is run correctly. We will select the monitor now.

Open your envelope, and read the record sheet inside. If your sheet says "monitor" you are the monitor. Will the monitor please come to the master computer. If your sheet does not say "monitor" you will use this sheet later to record your participant number that will be assigned by the computer and your …nal score. Keep your sheet in a safe place, you will need it at the end of the session to receive your payment.

At this time, please pull out the dividers that separate you from your neighbors. During the course of this session, please refrain from communicating with your neighbors.

Please double click on the Dice Icon.

In the dialog box, please enter your full name and select server #128.97.190.171, as shown on the screen at the front of the room, and click OK. This will log you on to the session. In the upper side of your screen you can see you ID number for this session and your color - please look at the example on the screen in the front of the room. Please write your participation ID number in the record sheet that came in the envelope.

Any question?

The session you are participating in is broken down into 3 separate parts. At the end of the last part, you will be paid the total amount you have accumulated during the course of the 3 parts in addition to the show-up fee. Everybody will be paid in private after showing the record sheet. You are under no obligation to tell others how much you earned.

During the session all the earnings are denominated in points. Your dollar earnings at the end of the session are determined by the points/$ exchange rate posted on the board in the front and back of the room. This exchange rate is equal to 200points/$. Therefore, 200 points are equivalent to $1.

The participants are divided in two groups: Red and Blue.

Red and Blue participants will be matched together to interact in the following way. As you see on the screen at the front of the room, the Red participant can choose between U or D and the Blue participant can choose between L and R.

If the Red participant chooses U and the Blue participant chooses L, both earn 75 points.

If the Red participant chooses U and the Blue participant chooses R, the Red participant earns 10 and the Blue participant earns 100 points.

If the Red participant chooses D and the Blue participant chooses L, the Red participant earns 100 and the Blue participant earns 10 points.

If the Red participant chooses D and the Blue participant chooses R, both earn 45 points.

The points of the Red participants are indicated on the screen in red, and the Blue participant points are indicated in blue.

In addition, the screen will show on the right hand side the result of previous rounds of the current match.

Every ten seconds, we will generate a random number between 1 and 1000 and project this number on the screens in the front of the room. You can use this number to select one of the actions, if you want, like the ‡ip of a coin. For example, if you are a Red participant, you can decide to choose U any time the random number is above, say, 200.

Part 1

We will begin the …rst part now. This …rst part will consist of 10 matches. In each match every Red participant is paired with a Blue participant. You will not be paired twice with the same participant during the session or with a participant that was paired with someone that was paired with you or with someone that was paired with someone that was paired with someone that was paired with you, and so on. Thus, the pairing is done in such a way that the decisions you make in one match cannot a¤ect the decisions of the participants you will be paired with in later matches or later parts of the session.

In this part, after each round the monitor will roll a four sided dice. If the numbers 1, 2 or 3 appear, the participants will interact again without changing pairs. If a 4 appears, the match ends and participants are re-matched to interact with other participants. Therefore, in this part, each pair will interact until a 4 appears. After that, a new match will start with di¤erent pairs. Therefore you will interact until a 4 appears, with 10 di¤erent participants.

But …rst, we are going to teach you about this part of the session and how to use the computer by going through one practice match. During the practice part do not hit any keys until you are told to do so. You are not paid for the practice match; it is just for you to familiarize yourself with the session and the computer program.

Your screen shows the possible actions you can choose, the actions the participant you are matched with can choose, and the points. You may choose your action by pressing the desired action at the side of the matrix now. If you are a Red participant you can press the actions in red, U or D, and if you are a Blue participant you can press the actions in Blue, L or R. Make your choices now. Once everyone in the room has made their selections and pressed con…rm, your results from this round will appear on the screen.

Monitor, would you please roll the dice?

[1) If a 1, 2 or 3 appeared] A __ appeared therefore this match continues. Now you are in the second (third, fourth, …fth,) round of the same match. You are still interacting with the same participant. Your screen shows all the same information as before. In addition you can see on your right the result of the previous rounds. You may choose your action by pressing the desired action at the side of the matrix now. Make your choices now. Once everyone in the room has made their selections and pressed con…rm, your results from this round will appear on the screen. Monitor, would you please roll the dice? [If 1, 2 or 3 appeared go to 1). If 4 appeared go to 2)]

[2) If a 4 appeared] A 4 appeared therefore this match ended. On the screen you see a dialog box with the points you earned during the practice match. Press OK to end the practice match.

We have …nished with the practice match. Any questions?

We start now with the …rst part of the session. You will now participate in 10 matches, each match paired with a di¤erent participant. In each match you will interact with the same person until a 4 appears. Remember: your decisions in one match cannot a¤ect the decisions of the people you will interact with in future matches. This is not a practice; you will be paid!

Make your choices now. Remember to press con…rm.

Monitor, would you please roll the dice?

[1) If 1, 2 or 3 appears] A __ appeared. This match continues. You are still interacting with the same participant. Make your choices now. Remember to press con…rm. Monitor, would you please roll the dice? [If 1, 2 or 3 appeared go to 1). If 4 appeared go to 2)]

[2) If 4 appears] A 4 appeared. This match ends. On the screen you will see a dialog box with the points you earned during this match. Press OK to be matched with the next participant.

. . . .

This is the end of Part 1. On your screen you will see a dialog box indicating your point and dollar points for this part. Press OK to move to the next part.

Part 2

We will begin the second part now. This part will consist of 10 matches. In each match every Red participant is paired with a Blue participant. No pair will consist of the same participants as in Part 1. As before, you will not be paired twice with the same participant during the session or with a participant that was paired with someone that was paired with you or with someone that was paired with someone that was paired with someone that was paired with you, and so on. Thus, the pairing is done in such a way that the decisions you make in one match cannot a¤ect the decisions of the participants you will be paired with in later matches or later parts of the session.

In this part, after each round the monitor will roll a four sided dice. If the numbers 1 or 2 appear, the participants will interact again without changing pairs. If 3 or 4 appear, the match ends and participants are re-matched to interact with other participants. Therefore, in this part, each pair will interact until a 3 or 4 appear. After that, a new match will start with di¤erent pairs. Therefore you will interact until a 3 or 4 appear, with 10 di¤erent participants.

But …rst, we are going to teach you about this part of the session and how to use the computer by going through one practice match. During the practice part do not hit any keys until you are told to do so. You are not paid for the practice match; it is just for you to familiarize yourself with the session and the computer program.

As before, your screen shows the possible actions you can choose, the actions the participant you are matched with can choose, and the points. You may choose your action by pressing the desired action at the side of the matrix now. Make your choices now. Once everyone in the room has made their selections and pressed con…rm, your results from this round will appear on the screen.

Monitor, would you please roll the dice?

[1) If a 1 or 2 appeared] A __ appeared therefore this match continues. Now you are in the second (third, fourth, …fth,) round of the same match. You are still interacting with the same participant. Your screen shows all the same information as before. In addition you can see on your right the result of the previous rounds. You may choose your action by pressing the desired action at the side of the matrix now. Make your choices now. Once everyone in the room has made their selections and pressed con…rm, your results from this round will appear on the screen. Monitor, would you please roll the dice? [If 1 or 2 appeared go to 1). If 3 or 4 appeared go to 2)]

[2) If a 3 or 4 appeared] A __ appeared therefore this match ended. On the screen you see a dialog box with the points you earned during the practice match.

Press OK to end the practice match.

We have …nished with the practice match. Any questions?

We start now with the second part of the session. You will now participat in 10 matches, each match paired with a di¤erent participant. In each match you will interact with the same participant until a 3 or 4 appear. Remember: your decisions in one match cannot a¤ect the decisions of the people you will interact with in future matches. This is not a practice; you will be paid!

Make your choices now. Remember to press con…rm.

Monitor, would you please roll the dice?

[1) If 1 or 2 appear] A __ appeared. This match continues. You are still interacting with the same participant. Make your choices now. Remember to press con…rm. Monitor, would you please roll the dice? [If 1 or 2 appeared go to 1). If 3 or 4 appeared go to 2)]

[2) If 3 or 4 appear] A __ appeared. This match ends. On the screen you will see a dialog box with the points you earned during this match. Press OK to be matched with the next participant.

. . . .

This is the end of Part 2. On your screen you will see a dialog box indicating your point and dollar points for this part and your cumulative total points for the …rst two parts. Press OK to move to the next part.

Part 3

We will begin the third part now. This part will consist of 10 matches. In each match every Red participant is paired with a Blue participant. No pair will consist of the same participants as in Part 1 or 2. As before, you will not be paired twice with the same participant during the session or with a participant that was paired with someone that was paired with you or with someone that was paired with someone that was paired with someone that was paired with you, and so on. Thus, the pairing is done in such a way that the decisions you make in one match cannot a¤ect the decisions of the participants you will be paired with in later matches.

In this part, each pair will interact once. After that, a new match will start with di¤erent pairs. Therefore, you will interact once with 10 di¤erent participants.

But …rst, we are going to teach you about this part of the session and how to use the computer by going through one practice match. During the practice do not hit any keys until you are told to do so. You are not paid for the practice match; it is just for you to familiarize yourself with the session and the computer program.

As before, your screen shows the possible actions you can choose, the actions the participant you are matched with can choose, and the points. You may choose your action by pressing the desired action at the side of the matrix now. Make your choices now. Once everyone in the room has made their selections and pressed con…rm, your results from this round will appear on the screen.

You have interacted once so this match ends. On the screen you will see a dialog box with the points you earned during the practice match. Press OK to end the practice match.

We have …nished with the practice match. Any questions?

We start now with the third part of the session. You will now participate in 10 matches, each match paired with a di¤erent participant. In each match you will interact with the same participant once. Remember: your decisions in one match cannot a¤ect the decisions of the people you will interact with in future matches. This is not a practice; you will be paid!

Make your choices now. Remember to press con…rm.

Press OK to be matched with the next participant.

Make your choices now. Remember to press con…rm.

Press OK to be matched with the next participant.

. . . . .

Make your choices now. Remember to press con…rm.

This is the end of Part 3. On your screen you will see a dialog box indicating your point and dollar points for this part and your cumulative total points for the three parts. Press OK to end this part.

Farewell

The session has ended. On your screen you will see a dialog box indicating your total earnings for the session. Please make sure you record the dollar points in your record sheet. Press OK to end the session. Take this sheet to the counter for payment. This sheet will be matched to our computer print out of results for payment. Your payments will be rounded up to the nearest quarter. Thank you for your participation.

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