COOPERATION IN FINITELY REPEATED PRISONER'S DILEMMA

ANUJIT CHAKRABORTY*

ABSTRACT. This paper designs an experiment to horse-race four theories of other-regarding motives that are popularly used to justify cooperation in FRPD games. Our experimental design implements a exponentially declining profile of rewards in Finitely Repeated Prisoner's Dilemma (FRPD) games, with the treatment variation being the rate of decline. This design feature implies that for treatments with high rates of decline, most of the surplus from interaction is realized in the early periods of the game. We find the following features in the data: Cooperation rates in the first and last round of an FRPD game are respectively decreasing and increasing in the decline-rate of rewards within a FRPD game. Cooperation is reciprocity motivated and within a match, irredeemably unfair (Dufwenberg and Kirchsteiger [2004]) early actions are discounted in favor of more recent cooperative actions. These features in our data are best explained by the model of Reciprocal Cooperation by Kreps et al. [1982], which suggests that players enjoy an additional non-pecuniary utility from successfully coordinating on cooperative actions.

* Department of Economics, University of California, Davis.

** I would like to thank Ryan Oprea, Yoram Halevy and seminar & conference attendants at UBC, IIMA, IIMB, IITK, and the Rady School of Economics 2017 for useful comments, discussions, and suggestions. Financial support from SSHRC (FAS # F11-04991) is gratefully acknowledged.

*** For the most recent draft please click here.

Prisoner's dilemma is probably one of the most popular games in economics literature as it pits two fundamental human actions against one another - socially efficient Cooperation and individually selfish Defection. If both players are driven by self-interest and this is common knowledge, then no cooperation can be justified in any subgame perfect Nash equilibrium of a One-Shot or a Finitely Repeated Prisoner's dilemma (FRPD henceforth) game. Contrary to this theoretical prediction, the evidence from lab experiments show significant cooperation in the initial rounds of a FRPD game: subjects reciprocate to cooperation and defection with like, and cooperation unravels in the last few rounds of a FRPD game (Cooper et al. [1992], Bo [2005], Roth and Murnighan [1983]). The pattern of play looks consistent with the use of threshold strategies.

		Column Player	
		Defect (F)	Cooperate (C)
Row Player	Defect (F)	b,b	c,d
	Cooperate (C)	d,c	a,a
		c>a>b>d>	

FIGURE 0.1. Prisoner's Dilemma Payoff Matrix

Kreps et al. [1982] proposed that cooperation and use of threshold strategies in the FRPD game are not necessarily at odds with selfish behavior: If both players *mistakenly* believe that their opponent might respond with Cooperate against Cooperate and with Fink against Fink (and is thus not the typical selfish player), they both might find it temporarily worthwhile to mimic such behavior and sustain a (C,C) outcome in the near future. Since such cooperation serves the egoistical purpose of maintaining an appearance of a non-selfish player into the future, such cooperation is classified as *reputational cooperation*. Andreoni and Miller [1993] found evidence for reputational cooperation (and altruism) in their experiments, and noted that there were two ways to interpret the reputational model. The strict interpretation of Kreps et al. [1982], also called the *rationality hypothesis,* assumes that everyone is purely self interested (and hence can only be egoistically cooperative) but they hold wrong beliefs about existence of non-selfish types. It is difficult to reconcile this with the evidence of cooperation in the terminal periods of finitely repeated games. A different interpretation of the Kreps model, identified as the *warm glow hypothesis,* assumes the presence of additional non-pecuniary motives in a subset of the population. Andreoni and Miller [1993] proposed the following models of other-regarding behavior under the warm glow hypothesis, that differ in the mechanism through which the non-pecuniary rewards work:

i) **Pure Altruism:** The utility of player i is $u_i = p_i + \alpha p_j$, where $\alpha \in [0, 1)$ and p_i is the pecuniary payoff of player i.

ii) **Duty:** The utility of player i is $u_i = p_i + \alpha$, where $\alpha \in [0, \infty)$ as long as player i cooperates and is zero otherwise.

iii) **Reciprocal Cooperation:** The utility of player i is $u_i = p_i + \alpha$, where $\alpha \in [0, \infty)$ as long as the two players successfully coordinate on the (C,C) outcome and is zero otherwise.

Each of the above mentioned specifications contain the self-interested individual as the $\alpha = 0$ case. Under appropriate assumptions on the distribution of α in these models, observed cooperative actions in a FRPD game could be justied as reputational, reciprocal, dutiful or truly altruistic in nature. Within the same warm glow framework, one could alternatively imagine:

iv) Dufwenberg and Kirchsteiger [2004]'s extension of the Rabin [1993]'s framework to extensive form game. In this model subjects judge the fairness of partner's actions *and* intentions, and reciprocate to it.

In Section 2, we also discuss *sizeBAD* (Dal Bó and Fréchette [2011], Embrey et al. [2015]), a concept closely related to reputational cooperation, in the context of our experimental design. This wealth of modeling choices, especially those under the warm glow hypothesis, raises the following question: *How are we to know which is the better model of behavior for observed cooperation in FRPD games?*

This paper provides an experimental set-up under which the above discussed theoretical models predict unique testable patterns of behavior that is almost always different from playing threshold strategies. The altruistic parameters α in the models *(i)-(iii)* are independent of the game-payoffs and our experimental design uses this to its advantage[1]. In our design, we varied the future gains in a 5-period Perturbed Finite Repeated Prisoner's Dilemma (P-FRPD) game by implementing a declining profile of rewards, with the treatment variation being the rate of decline. For the sake of simplicity, we use an exponential function

[1]In Section 5, we also discuss what would happen if α were instead proportional to the corresponding pecuniary component.

(discounting-like, δ^t, where $\delta \in (0,1)$ acts like a "discount factor") to achieve the declining profile. The discount factors used were $\delta = 1, 3/4, 3/8, 1/4$. As δ decreases, for any fixed first-period payoff matrix, the payments diminish at a higher rate across rounds 1 to 5. The game horizon and payoffs were chosen in such a way that the predictions from theories based on egoistic cooperation contrast sharply with those from *warm glow* theories described above. For example, the Duty model and Reciprocal cooperation model are unique in predicting that terminal period cooperation should be higher in the lower δ treatments, when the pecuniary losses from not playing the payoff-dominant strategy become miniscule compared to the constant utility gain from sustaining cooperating outcomes (Proposition 4), and this forms the basis of our Hypothesis 2. The Duty model further predicts that any cooperation in the first period of the $\delta = \frac{1}{4}$ Treatment implies a lower bound on the altruism parameter α for a subject, and hence implies her unconditional cooperation in all the last two rounds of that game as a strictly dominant strategy (Proposition 5). This prediction runs against the predictions of the other *warm glow* models, and this forms the basis of our Hypothesis 3. Dufwenberg and Kirchsteiger [2004]'s Reciprocal Altruism framework suggests that any subject who has defected in Period 1 of the $\delta = \frac{1}{4}$ or $\delta = \frac{3}{4}$ treatment (the periods when the gains from cooperation were highest) has *irredeemably* signalled herself as unfair, and hence the opponent must reciprocate with playing defect (unkindness) at *all histories* in periods 2-4. We test this strictly unforgiving behavior in Hypothesis 4.

We find the following results: 1) Cooperation in the first period of a P-FRPD game *decreases* under a higher rate of decline of future rewards. 2) Cooperation in the final period of a P-FRPD game *increases* under a higher rate of decline of future rewards., and this is robust to subjects gaining a considerable amount of game-experience. 3) Cooperation is reciprocity motivated and irredeemably unfair (Dufwenberg and Kirchsteiger [2004]) early actions are discounted in favor of more recent cooperative actions. 4) The P-FRPD experimental data is most consistent with Reciprocal Cooperation suggested in Kreps et al. [1982].

Section 1 discusses the experimental design. Section 2 provides the theoretical results that form the backbone of the hypotheses that we test in Section 3, and Section 6 concludes. In Section 5, we provide an overview of the related literature, and in Section 4 we suggest how the current experiment could inform existing theory.

1. Experimental design

A total of 222 subjects participated in 9 sessions between November, 2015 to April, 2017. We ran both Between and Within treatments for robustness (with 90 and 132 subjects respectively). The average payment in the two treatments were identical, and the subjects received \$6 as show-up fee in the Within sessions and \$5 in the Between sessions. The subject instructions and screen shots of the GUI are included in the Appendix.

Between Treatment:

There were a total of 4 sessions of the Between treatments, two each for the $\delta = \frac{3}{4}$ and $\delta = \frac{1}{4}$ treatments. Each session, subjects were be divided into two groups. In each pair-match within a session, a subject from the first group was matched with a new subject from the second group using turn-pike matching. At the beginning of a session the subjects were first explained the game and the matching protocol in detail, before they played 8 P-FRPD games under the same δ treatment. Each game lasted for 5 periods with the period $t \in \{1, 2, 3, 4, 5\}$ stage game being given in Table **??**.

		Column Player	
		Defect	Cooperate
Row Player	Defect	$1200\delta^{t-1}, 1200\delta^{t-1}$	$2600\delta^{t-1}, 200\delta^{t-1}$
	Cooperate	$200\delta^{t-1}, 2600\delta^{t-1}$	$2000\delta^{t-1}, 2000\delta^{t-1}$

Figure 1.1. Stage-game payoffs in period t for δ treatment

Thus any δ treatment had the same first period stage game, but the stage game payoffs diminished at different rates with higher t. Further, lower the δ in a treatment, faster was the rate of decline of the payoffs. For example, $(\frac{3}{4})^4 = .3164$, whereas, $(\frac{1}{4})^4 = .0039$, and hence, the fifth period stage-games of the $\delta = \frac{1}{4}$ treatment and $\delta = \frac{3}{4}$ treatment were magnitude-wise separated by a approximate factor of 80. In between two FRPD games the subjects were randomly matched with another player in the session, using turn-pike matching, and they were notified of this rematching every game, for the sake of emphasis.

The subjects could see the exact payoffs for all the stage-games on their instruction sheet before making any decisions in a game, and they also saw the current stage-game on their screen as they made each decision. Within every game or match, the subjects saw the past actions taken by their partner in previous periods, but they could not see their partner's actions from previous games. A considerable time was spent at the beginning of each session, to make sure that the subjects understood the different treatments, the payment schemes, the matching-information protocol and the interface thoroughly. The session sizes were maintained such that no two players could play each other more than once. For any subject, at the end of a session one of her 8 games was randomly chosen, and she was paid her total earnings from the 5 rounds of tht game.

The Between sessions gaves subjects sufficient time to learn about the particular treatment, and the results can be interpreted without any fear of of cross-treatment contamination. The subjects were also asked about some of their believes about their partner's play prior to taking their actions. The belief questions were not incentivized, to make sure that prediction incentives could not influence P-FRPD play in any way. We describe the belief-related quetions in Appendix II.

Within Treatment:

A total of 132 subjects participated in the five sessions that were run under the Within design. In a Within session, each subject played under all of the four treatments $\delta = 1, {}^3\!/_4, {}^3\!/_8, {}^1\!/_4$. The stage payments were as shown in Figure 1.1. Each session, the four treatments were repeated in two blocks, so that each subject played 2 games under each treatment and a total of $(2 \times 4) = 8$ games. As in the Between treatment, at the end of the experimental session, one of the 8 games was randomly chosen, the total points or lab currency earned by the subject in that game was converted into dollars at the pre-announced rate and paid to the subject.

The order of treatments in the Within sessions was randomized at the session level: At the beginning of each session, a coin toss by the experimenter decided if the treatments in that session were arranged in the order

$$\delta = 1,\ {}^3\!/_4,\ {}^3\!/_8,\ {}^1\!/_4,\ \ 1,\ {}^3\!/_4,\ {}^3\!/_8,\ {}^1\!/_4$$

(block of treatments repeated twice) or in the opposite order

$$\delta = {}^1\!/_4,\ {}^3\!/_8,\ {}^3\!/_4,\ 1\ {}^1\!/_4,\ {}^3\!/_8,\ {}^3\!/_4,\ 1,$$

Over all, 3 sessions were ran in the former order and 2 in the latter order. The matching and information protocol were identical across the Within and Between sessions. The Within sessions provide an independent sample to test our central hypotheses, and conditional on replicating the same treatment effects on higher number of treatment levels, they would help us present our results with a higher degree of confidence.

2. Theories

To separate the behavioral theories of behavior, we would depend on two classes of results described in a series of *Propositions*. The first class of results are about the average levels of cooperation predicted by a theory of behavior, and those propositions assume that everyone knows about everyone else behaving according to that behavioral model. For example, to understand what a particular model (for e.g, the Pure Altruism model) would predict about aggregate cooperation in a session, we would assume that all subjects behave according to that model and everyone knows that players are drawn from some distribution of the relevant behavioral parameter (α). The second class of results would characterize cooperation and defection behavior predicted by the particular model at the individual level, and are proved usings notions of (sequential) rationalizability and dominant strategies. To emphasize the difference between the two classes of results, we will asterisk the first class of results. For example, Proposition 7 belongs to the first class, and Proposition 5 belongs to the second class, and only the former is asterisked.

Embrey et al. [2015] and Dal Bó and Fréchette [2011] introduce the size of the basin of attraction (ρ_0) of Always Defect against the Grim Trigger strategy, as a measure of the value-risk tradeoff of cooperation. They assign ρ_0 the moniker *sizeBAD* and find it to be a significant predictor of cooperation (especially early cooperation) in finitely and infinitely repeated PD games. Below we modify *sizeBAD* to fit our FRPD games. Following Embrey et al. [2015] we assume that an egoistic player (P1) playing a T period FRPD game in δ treatment is deciding between playing Grim Trigger and Always Defect strategies, and she believes that the other player (P2) too is limited to playing only these two strategies. Let ρ_0 be the the belief on P2 playing Grim Trigger that would make P1 indifferent between playing Grim Trigger and Always Defect.

Let

$$x_n(\delta) \quad = \begin{cases} \dfrac{1-\delta^n}{1-\delta} & \text{if } \delta < 1 \\ n & \text{if } \delta = 1 \end{cases}$$

P1's indifference implies

$$\begin{aligned} \rho_0(\pi_{cc}x_T) + (1-\rho_0)(\pi_{cd} + \pi_{dd}\delta x_{T-1}) &= \rho_0(\pi_{dc} + \pi_{dd}\delta x_{T-1}) + (1-\rho_0)(\pi_{dd}x_T) \\ \iff \rho_0((\pi_{cc}-\pi_{dd})x_T - \pi_{cd} - \pi_{dc} + 2\pi_{dd}) &= \pi_{dd} - \pi_{cd} \\ \iff \rho_0 &= \frac{\pi_{dd}-\pi_{cd}}{((\pi_{cc}-\pi_{dd})x_T - \pi_{cd} - \pi_{dc} + 2\pi_{dd})} \end{aligned} \tag{1}$$

A high ρ_0 implies that the belief on the other player playing Grim Trigger needs to be high before P1 can play Grim Trigger herself, thus, a higher ρ_0 implies an environment less conducive to cooperation. In equation (1), as δ decreases, the numerator decreases, thus predicting declining cooperation. This brings us to our first result.

Proposition 1. ***SizeBAD*:*** *The sizeBAD (Embrey et al. [2015]) measure of the of the value-risk trade-off of cooperation, decreases as δ decreases in the FRPD treatments and predicts that initial cooperation (but perhaps also total and later-priod cooperation) would be lower in lower δ treatments.*

Note that Equation equation (1) would be undefined for low values of δ (as the denominator would be negative), and it would definitely not be worth playing Grim Trigger. Proposition 2 formalizes this observation, and Proposition 3 provides a stronger result.

Proposition 2. ***Reputational Cooperation for Egoists:****In any period of the FRPD game with $\delta \leq 3/8$, an egoist believing that she is facing either a Grim Trigger player or an Always Defect player, has a unique best response of playing Defect for the rest of the game.*

Proof. At any period $t{+}1$, for any belief ρ_{t+1}, the egoist should consider the tradeoff between "cooperating in this round and defecting next round onwards" vs "defecting right away". By playing the latter strategy, the egoist gains atleast $600\delta^t$ from the stage game, and loses at most $(2600-1200) \times \delta^{t+1}$ in the following stage games combined. For $\delta < \frac{3}{7}$ (and hence, for $\delta \leq 3/8$), $600 > 1400\delta$ holds and hence, the egoist would always find it worthwhile to defect in an earlier period. When applied inductively to all periods, this implies that the egoist should Defect starting immediately. □

Proposition 3. ***Cooperation for Egoists:*** *In treatments with $\delta \leq 1/4$, the egoist has a strictly dominant strategy of playing Defect throughout the game.*

Proof. By playing Defect in any period, the egoist gains atleast $600\delta^t$ from the stage game, and loses at most $(2600 - 1200) \times (\delta^{t+1} + \delta^{t+2} .. + \delta^4)$ in the following stage games. For the range of δ under consideration, the first number is always higher than the second, and hence, the egoist would always find it worthwhile to defect in an earlier period. When applied inductively to all periods, this immediately implies that the egoist should Defect throughout the course of the game. □

Proposition 4. ***Duty and Reciprocal Cooperation Models:*** *For any subject whose preferences are given by the Duty model (or by the Reciprocal Cooperation model)*
i) As δ decreases, the future gain from sustained cooperation diminishes compared to the option of Defecting right away. Thus, a lower δ is less conducive to initial cooperation.
ii) Any subject who finds "final period cooperation" rationalizable in a high δ treatment would find the same to be a strictly dominant strategy in the low δ treatment. There would also exist preference parameters for whom "final period cooperation" would only become rationalizable in a lower δ treatment.

Proof. Under the Duty model subject preferences are given by

$$U_i = p_i + \alpha_{coop} \text{ where } \alpha_{coop} \geq 0 \text{ if Cooperate is played}$$

And, under the Reciprocal Cooperation model, subject preferences are given by

$$U_i = p_i + \alpha \text{ where } \alpha \geq 0 \text{ when both players have cooperated}$$

That with higher δ the continuation payoff of sustained cooperation is strictly higher, is easy to show. An immediate corollary is that, whenever reputational or altruistic cooperation is rationalizable for a subject in a low δ treatment it is also rationalizable in higher δ treatments for the same subject (similar results are shown in Propositions 2, 3).

Last period cooperation is never reputational and always altruistic or warm-glow in nature. In the final period if a subject believes that the other player is going to cooperate with probability p, then she would find it worth cooperating as long as

$$\alpha \geq \delta^4[p(2600-2000)+(1-p)(1200-200)]$$

The RHS is bounded above by $1000\delta^4$ and bounded below by $600\delta^4$. The next set of inequalities show that the mentioned lower bound for any δ used in our treatments is larger than the corresponding upper bound for the subsequently lower δ.

$$\begin{aligned} 600 &> 1000\times(3/4)^4 \\ 600\times(3/4)^4 &> 1000\times(3/8)^4 \\ 600\times(3/8)^4 &> 1000\times(1/4)^4 \end{aligned}$$

Thus, any player who finds altruistic cooperation in the final period rationalizable in a high δ treatment would find the same to be a dominant strategy in the low δ treatment. Thus, as long as there are subjects in the experimental population with α in the relevant range, one would expect to see higher last period cooperation as δ decreases.

Example 1 provides further insights into this result through a particular equilibrium analysis. Proposition 5 provides some more intuition about terminal period cooperation. □

Example 1. Reciprocal Cooperation Equilibrium: Suppose in a population of players with Reciprocation Cooperation preferences, it is common knowledge that 20%, 20%, 60% of the players have αs equal to 450, 70 and 0 respectively. Let us call them Types 1, 2 and 3 respectively. Cooperation is strictly dominated in the final period for any Type in the $\delta = 1$ treatment. But cooperation is definitely rationalizable in the $\delta \in \{\frac{3}{8}, \frac{1}{4}\}$ treatments. In the $\delta = \frac{3}{8}$ treatment, there is a Perfect Bayesian Equilibrium, where only Type 1 cooperates in the period 1 and continues cooperation till period 5 conditional on reciprocation, Everyone else defects in both the first and second periods. In the third period Type 2 reveals itself, to Type 1, by cooperating only if it is matched to Type 1. Type 1 and Type 2 matched together, both cooperate for the last 2 periods. Type 3 never cooperates. Cooperation rates in the 5 rounds in this equilibrium would be .20, .04, .08, .12, .12.

Proposition 5. ***Duty Model:*** *For any player, whose preferences are guided by the Duty model, if Cooperation is rationalizable in the first period of the* $\delta = \frac{1}{4}$ *Treatment, then Cooperating in all the last two rounds of that game is a dominant strategy for her.*

Proof. Let the preferences of the player under consideration be $U_i = p_i + \alpha_{coop}$. We will prove this proposition by first establishing a lower bound on α_{coop} necessary for a player to cooperate in the first period, and then show that for even the lowest such possible α_{coop}, it becomes a strictly best response for the player to cooperate in the last two periods at all histories, and for all beliefs.

The highest possible expected payoff from an extensive form strategy that cooperates in the first period is no more than the maximum of the four following quantities, where in Π^i_{max} she defects i times in periods 2-5 .

$$\Pi^1_{\text{max}} = \rho_0 200 + (1-\rho_0)2000 + 863.28 + \alpha_{coop}$$
$$\Pi^2_{\text{max}} = \rho_0 200 + (1-\rho_0)2000 + 860.94 + 2\alpha_{coop}$$
$$\Pi^3_{\text{max}} = \rho_0 200 + (1-\rho_0)2000 + 851.56 + 3\alpha_{coop}$$
$$\Pi^4_{\text{max}} = \rho_0 200 + (1-\rho_0)2000 + 814.06 + 4\alpha_{coop}$$

This "unrealistically generous" upper bound is obtained when we allow the player to enjoy both the (D, C) outcome for the periods 2-5 whenever she Defects, and, the (C,C) outcome and the non-pecuniary payoffs of α_{coop} whenever she Cooperates. The alternative strategy of Always Defect provides a payoff no less than

$$\Pi = \rho_0 1200 + (1-\rho_0)2600 + 398.43$$

with this lower bound being obtained by assuming that a Defect is always met with a Defect from the partner. Hence, for Cooperation to be rationalizable in the first period, one must have $\min_i \Pi^i_{max} \geq \Pi$, which in turn gives us four inequalities. For example, the first inequality is

$$\begin{array}{rcl} \Pi^1_{\max} & \geq & \Pi \\ \iff \rho_0 200 + (1-\rho_0)2000 + 863.28 + \alpha_{coop} & \geq & \rho_0 1200 + (1-\rho_0)2600 + 398.43 \\ \alpha_{coop} & \geq & 135.16 \end{array}$$

The next three inequalities result in $\alpha_{coop} \geq 68.75$, $\alpha_{coop} \geq 48.96$, and $\alpha_{coop} \geq 46.09$. Thus rationalizability of first period cooperation requires atleast $\alpha > 46$. (The payoff parameters from the last three rounds of the $\delta = \frac{1}{4}$ game are given in Table 1.) Such a player would find it a dominant strategy to Cooperate in the last round. Next, she would also find it to be a dominant strategy to Cooperate in the fourth round, losing at most 15.62 in fourth-round payoff (depending on what the partner is playing in the fourth round) and at most 7.03 in the last round payoff in case the partner is playing a contingent strategy that "punishes" cooperation in the fourth round.

	(D,D)	(D,C)	(C,D)	(C,C)
1	1200	2600	200	2000
2	300	650	50	500
3	75	162.5	12.5	125
4	18.75	40.63	3.13	31.25
5	4.69	10.16	.78	7.81

TABLE 1. Payoff parameters in the five rounds of the $\delta = \frac{1}{4}$ game approximated to 2 decimal places.

Such a player would cooperate in the last two periods, at all histories, and for all beliefs that she might have how her actions might affect her opponent's play. □

Proposition 6. ***Sequential Reciprocity:*** *Any player, whose preferences are guided by the Sequential Reciprocity model of Dufwenberg and Kirchsteiger [2004], must find it a strictly dominant strategy to Defect at all histories in periods 2-5 if her partner has Defected in Period 1 of the $\delta = \frac{1}{4}$ or $\delta = \frac{3}{8}$ treatment, irrespective of the first and second order beliefs she might have about her partner.*

Proof. We will show that defection from the partner in the Quarter (and Three Quarters) treatment is considered irreversibly unfair in the Dufwenberg and

Kirchsteiger [2004] formulation, irrespective of first and second order beliefs that a player might have. Below we will prove it only for the Quarter Treatment, as the proof for Three Quarters Treatment is identical.

Suppose that Player 1's second order belief be s_{121},that is is Player 1 thinks that Player 2 believes that Player 1 is going to play an extensive form strategy s_{121} that involves playing C in the first period of the Quarter Treatment. Let a generic instance of Player 2's strategy be given by s_2. Let S_{AC} (and S_{DC}) be the strategies where Player 2 cooperates (and defects) at every history. Thus, in the Quarter Treatment, the maximum that Player 2 can allow Player 1 to get from any extensive form strategy is no less than .

$$\begin{aligned} \Pi_1 = \inf_{s_{121}} \max_{s^2} \pi_i(s_{121}, s^2) &\geq \inf_{s_{121}} \pi_i(s_{121}, S_{AC}) \\ &= 2664.03 \end{aligned}$$

The infimum is obtained when s_{121} is also a strategy of cooperation at every history.

Similarly, the minimum that Player 1 can get in any Pareto efficient outcome is no less than

$$\begin{aligned} \Pi_2 = \inf_{s_{121}} \min_{\{s^2:(s_{121},s^2) \text{ is Pareto Efficient}\}} \pi_i(s_{121}, s^2) &\geq \inf_{s_{121}} \pi_i(s_{121}, S_{DC}) \\ &= 266.403 \end{aligned}$$

Therefore, the outcome considered as fair by Player 1 is no less than

$$\Pi_{fair} = \frac{(2664.03 + 266.403)}{2} = 1465.234$$

The maximum Player 1 could get by playing s_{121} if Player 2 has already Defected in the first round is $\Pi_m = 1063.281$, a generous bound that is obtained when the outcomes of Periods 2-4 has been (Defect, Cooperate) in favor of Player 1. Thus, any possible continual outcome of the game after partner's Defection is dominated by the fair outcome, and hence, must be considered unfair by Player 1. Thus, reciprocity concerns dictate that she must also act as unfair as possibleto Player 1, Period 2 onwards. Given playing selfishly coincides with playing unfairly towards ones partner in this game, this implies that Player 1 should Defect unconditionally hereon.

The proof for the case where s_{121} involves a second order believe about Player 1 playing D in the first period of the Quarter treatment is very similar, with Π_1, Π_2, Π_{fair} and Π_m equal to 3264, 1266.41, 2265.23 and 2063.28 respectively. The proof for the Three Quarter treatment would be identical. □

Pure Altruism: The preferences of any player under this model is given by

$$U_i = p_i + xp_j, \quad 0 < x < 1$$

Under the current parametrization, playing Defect is a weakly best response in any stage game of any δ treatment as long as

$$1200 + 1200x \geq 200 + 2600x \quad \text{and} \quad 2600 + 200x \geq 2000 + 2000x$$

which gives $x \leq \frac{1}{3}$. Similarly, for $x \geq \frac{5}{7}$ players, playing Cooperation is a weakly best response in any stage game of any δ treatment. For $x \in (\frac{1}{3}, \frac{5}{7})$ types, Defect is a strict best response to Defect, and Cooperate is a strict best response to Cooperate in any stage game[2]. When two $x \in (\frac{1}{3}, \frac{5}{7})$ types play each other, both (D,D) and (C,C) are equilibria of the game, the latter being the payoff dominant outcome. This type would try to coordinate on (C,C) or (D,D) depending on whichever action they think their partners are more likely to play.

In any δ treatment of an P-FRPD game, first period cooperation might be driven by one of the following: Unconditional cooperation from the second type, or, attempts at coordination at (C,C) by the third type, or, reputational cooperation by the first type. As the P-FRPD game progresses from the first period to later periods, reputational cooperation from a $x < \frac{1}{3}$ player if any, would die out, thus also snuffing out any cooperation by the partner, in case she was a $x \in (\frac{1}{3}, \frac{5}{7})$ player. Thus, in the later stages of the game, any cooperation by a $x \in (\frac{1}{3}, \frac{5}{7})$ player can only be sustained if she succesfully manages to coordinate with another $x \in (\frac{1}{3}, \frac{5}{7})$ player, or if she is matched with a $x > \frac{5}{7}$ player. Similarly, conditional on cooperation later in the game,

If two $x \in (\frac{1}{3}, \frac{5}{7})$ players meet over an P-FRPD game and are able to mutually convey their types through their actions, they might be able to coordinate on both (C,C) and (D,D) outcomes. We are going to assume the following condition on behavior:

Assumption 1: *Consider any two $x \in (\frac{1}{3}, \frac{5}{7})$ players who are matched together*

[2] At the two boundaries there are indifferences

in an P-FRPD game. They are no less likely to be able to coordinate on the (C,C) outcome in a high-δ P-FRPD game than in a low-δ P-FRPD game.

This is weaker than assuming that their ability of coordinating on the better outcome is uniform across δ treatments. We think that this is a natural assumption, for the following reasons

i) The payoff gain from successful coordinaion on (C,C) vs that on (D,D) at period $t > 1$ of an FPPD game, $\pi^t(C,C) - \pi^t(D,D)$, is strictly increasing in δ for any player with $x \in (\frac{1}{3}, \frac{5}{7})$. A more salient Payoff Dominance might drive $x \in (\frac{1}{3}, \frac{5}{7})$ players to coordinate on (C,C) more often in higher δ treatments. In case

ii) For any $x \in (\frac{1}{3}, \frac{5}{7})$ player, the value of α that solves the indifference condition of mixed strategies

$$\pi^t(C, \alpha C + (1-\alpha)D) - \pi^t(D, \alpha C + (1-\alpha)D) = 0$$

is independent of t and the δ treatment under consideration. In other words, the "risk factor" (from the disk dominance literature) for playing (C,C) vs (D,D) for any player is same at all rounds, of all treatments. Thus risk dominance does not predict any change of coordination behavior across δ treatments.

Proposition 7. ***Pure Altruism**:** *Under Assumption 1, in a population of Pure Altruists, cooperation should either remain the same or decrease in all periods, as δ decreases.*

Proof. In an P-FRPD game with a lower δ , the players with $x \leq \frac{1}{3}$ would play reputational cooperation less often as gains from future cooperation are diminished. The $x \in (\frac{1}{3}, \frac{5}{7})$ players matched to a $x \leq \frac{1}{3}$ player would also play cooperation less often, for coordination reasons. The $x \geq \frac{5}{7}$ type would play Cooperation after all histories as before, and any matched $x \in (\frac{1}{3}, \frac{5}{7})$ player would follow suit. Thus under Assumption 1, we can conclude that as δ decreases, cooperation across rounds should either remain the same (in absence of any $x < \frac{1}{3}$ players in the population), or strictly decrease. □

3. Hypotheses and Results

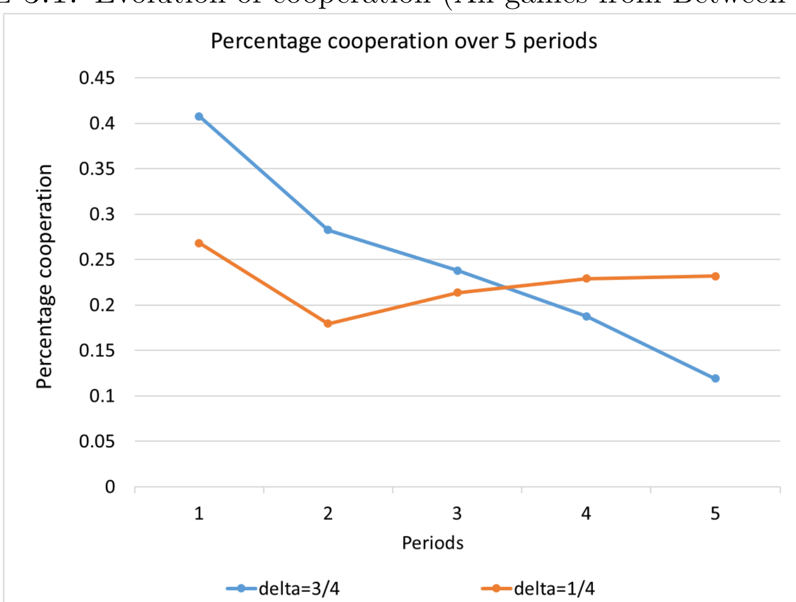
The results outlined in the previous section help us form the following hypotheses about aggregate and individual behavior in the FRPD games. 48 in quarter, 42 in 3/4

Hypothesis 1: *Average cooperation in the initial periods of an FRPD game should he comparatively higher in High δ treatments.*
This hypothesis is supported by all of the models of behavior we have analysed except that of Pure Altruism.

Hypothesis 2: *Average cooperation in the terminal periods of an FRPD game should be comparatively higher in High δ treatments.*
This hypothesis is supported by the model of Reputational cooperation by egoists (Kreps et al. [1982]), and by the meta-analysis performed on *sizeBAD* (Embrey et al. [2015]), but opposed by the models of Duty and Reciprocal Cooperation. The model of Sequential Reciprocity does not make a clear prediction for or against Hypoetheses 1 and 2.

Figure 3.1 describes the evolution of cooperation throughout Periods $1 - 5$ for the $\delta = \frac{3}{4}$ and $\delta = \frac{1}{4}$ treatments from the Within Sessions. The cooperation rates across δ treatments are increasing in δ for Period 1, and decreasing in δ for Period 5. The average cooperation in the $\delta = {}^1\!/_4$ treatment is relatively stable, whereas cooperation falls steadily in the $\delta = {}^3\!/_4$ treatment.

FIGURE 3.1. Evolution of cooperation (All games from Between Session)



Guided by our theory and hypotheses, we perform the following tests in Table 3:

- Is the Period 1 cooperation rate in $\delta = \frac{3}{4}$ treatment significantly greater than that in $\delta = \frac{1}{4}$ treatment?
- Is the Period 5 cooperation rate in $\delta = \frac{3}{4}$ treatment significantly smaller than that in $\delta = \frac{1}{4}$ treatment?

In Table 2, we compare the first and last period cooperations of the two treatments. First period cooperation is significantly higher in the $\delta = \frac{3}{4}$ treatment than that in $\delta = \frac{1}{4}$ treatment. Similarly, last period cooperation is significantly lower in the $\delta = \frac{3}{4}$ treatment than that in $\delta = \frac{1}{4}$ treatment. Dropping the first four, or the first six games (columns 2 and 3 in Table 2) of the session to allow for subject-learning does not change any of the results. The tests reconfirm our belief in Hypotheses 1 and reject Hypothesis 2.

Table 2. Comparison of cooperation rates in first and terminal periods (Between Sessions)

	Games 1-8		Games 5-8		Games 7-8	
	Period 1	Period 5	Period 1	Period 5	Period 1	Period 5
$\delta_2 = \frac{3}{4}$	40.77***	11.90***	39.29***	8.33***	36.90***	7.14***
	(5.95)	(2.54)	(6.46)	(2.89)	(7.21)	(2.72)
$\delta_4 = \frac{1}{4}$	26.82***	23.18	16.67***	19.27***	12.50***	19.79***
	(4.57)	(3.96)	(4.71)	(4.53)	(4.58)	(5.08)
δ_2 *vs* δ_4	.066	.019	.006	.045	.005	.031

Standard errors, clustered at the level of subjects (90 in total) are reported in parentheses below

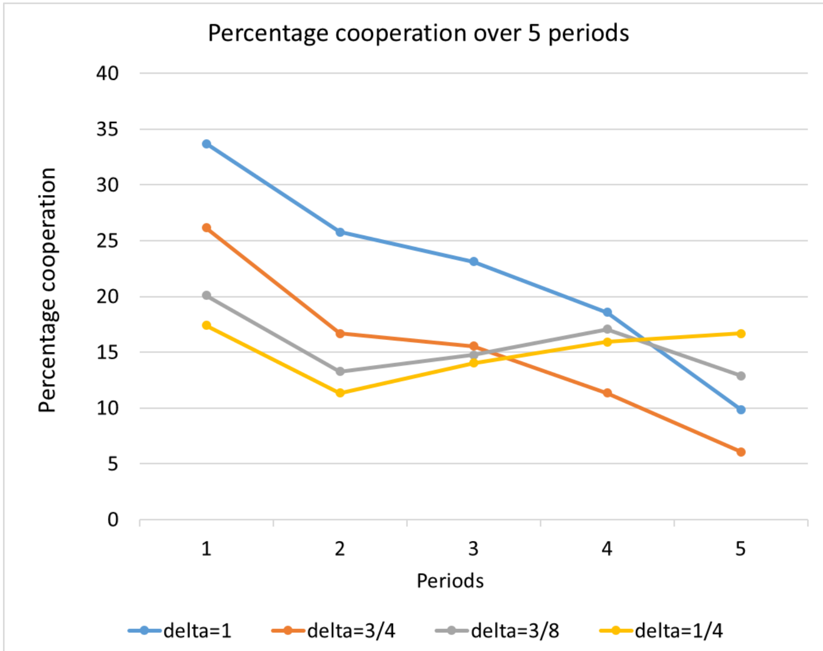
Lower panel reports p-values from F test against null $H_0 : \delta_i = \delta_j$

$* \ p < 0.05$, $** \ p < 0.01$, $*** \ p < 0.001$

We now extend the analysis to the data from our Within Sessions: In Table 3.2, we compare average cooperation profiles across all treatments. First period cooperation is higher in the $\delta = \frac{3}{4}$ treatment than that in $\delta = \frac{1}{4}$ treatment. In fact, first period cooperation across four δ treatments is increasing in δ. Similarly, last period cooperation is significantly lower in the $\delta = \frac{3}{4}$ treatment than that in $\delta = \frac{1}{4}$ treatment, and approximately decreasing in δ. The tests reconfirm our belief in Hypotheses 1 and 2.

In Table 3, we redo the previous tests, alongside a two more tests of our Hypotheses 1 ad 2. As discussed before, in the Within treatments, all subjects

FIGURE 3.2. Evolution of cooperation



played 2 blocks of all 4 treatments, and thus a total of 8 games. We drop the first block of data for all subjects, and redo our analysis as a robustness check.

As reported in Table 3, all of the tests come out to be significant, except the comparison of Period 5 cooperation rates between $\delta = 1$ and $\delta = \frac{3}{8}$ treatments: even though the $\delta = \frac{3}{8}$ treatment has a higher rate of cooperation in Period 5, compared to the $\delta = 1$ treatment, we fail to reject the null hypothesis of no significant different between those two rates.

There are two other testable hypotheses, that would help us decide between the different theories that coincide in their predictions on Hypotheses 1 and 2.

Hypothesis 3 is proposed by Proposition 5, that proves that under the Duty model, first period Cooperation in the Quarter treatment implies a lower bound on the altruism parameter of the cooperating subect. This lower bound, is shown to be large enough to imply unconditional cooperation in the last two rounds of the Quarter treatment. None of the other models of behavior link first period cooperation to unconditional cooperation in the terminal rounds. Hence this hypothesis can be used as a stand-alone falsifiable test for the Duty model.

Hypothesis 3: *If a subject Cooperates in the first period of the Quarter Treatment, then she would Cooperate unconditionally in both the last two rounds of that*

Table 3. Comparison of cooperation rates in first and terminal periods (Within Sessions)

	Blocks 1 and 2 (All Data)		Only Second Block	
	Period 1	Period 5	Period 1	Period 5
$\delta_1 = 1$	33.71***	9.85***	31.82***	8.33***
	(3.55)	(1.97)	(4.08)	(2.42)
$\delta_2 = \frac{3}{4}$	26.14***	6.06***	21.97***	6.06**
	(3.12)	(1.70)	(3.63)	(2.09)
$\delta_3 = \frac{3}{8}$	20.08***	12.88***	15.15***	12.88***
	(2.84)	(2.32)	(3.14)	(2.93)
$\delta_4 = \frac{1}{4}$	17.42***	16.67***	9.85***	17.42***
	(2.64)	(2.45)	(2.61)	(3.32)
N	1056	1056	528	528
δ_2 *vs* δ_4	.0067	.0000	.0009	.0005
δ_1 *vs* δ_4	.0000	.01	.0000	.01
δ_1 *vs* δ_3	.0000	.26	.0000	.20

Standard errors, clustered at the level of 132 subjects are reported in parentheses below

Lower panel reports p-values from F test against $H_0 : \delta_i = \delta_j$ $\quad * \; p < 0.05, \; ** \; p < 0.01, \; *** \; p < 0.001$

game. Alternatively, in the Quarter Treatment,

$$\frac{\textbf{\#games where a subject cooperated in the first period \& last 2 periods}}{\textbf{\#games where a subject cooperated in the first period}} = 1$$

In the Between sessions there are 103 total occurances when a subject has cooperated in the first round of the Quarter treatment, but in only 39 of these instances has she also cooperated in both of the last two rounds of that game, it goes without saying that 39/103 is statistically different from 1 at . Further, 27 of those 39 instances happened when the two players have successfully coordinated at a (C,C) outcome in the previous round. In the Within sessions, only 9 of the 46 subjects who cooperated in Period 1, also cooperated in Periods 4 and 5 of that game. Thus, there is very limited support for Hypothesis 3 in our data. The data seems more consistent with a model of behavior where cooperation is contingent on successful previous coordination at a (C,C) outcome, than on a model of dutiful cooperation. Or alternatively it could be explained by a model of reciprocity, where past cooperation is reciprocated by both players. Note that one could have run an even stricter version of Hypothesis 3, where for any subject who has cooperated in a first round of a Quarter Treatment game, we require her to cooperate in the last two rounds of not just the same game, but all the games that she played under the Quarter Treatment in that session. Clearly this stronger version of Hypothesis 3 would be rejected even more empatically.

In Table 4, we compare the relative frequencies of cooperation as a function of whether the partner cooperated in the last period, in the population of first period cooperators in treatments with $\delta \leq \frac{3}{8}$. Cooperation in any of the periods $2-5$ was vastly more likely if the partner had cooperated in the previous period than if she hadn't, and the differences are significant at all reasonable statistical levels (compaing data by rows). Also, whether it is Reciprocal Altruism or Reciprocal Cooperation, *the likelihood of reciprocation did not seem to be any higher in the high δ treatments where peciniary gains from reciprocation were higher* (comparing data columns 1 and 2, to 3 and 4 respectively), which hints towards *non-pecuniary gains substituting the pecuniary gains from reciprocation.* In fact in the Between treatment, the rate of cooperation in response to a previous round cooperation was higher in the low δ treatment!

	$\delta \leq \frac{3}{8}$		$\delta > \frac{3}{8}$	
Precondition	Between	Within	Between	Within
Partner has cooperated in the previous period	$\frac{158}{193}$ (83%)	$\frac{78}{123}$ (63%)	$\frac{167}{240}$ (70%)	$\frac{160}{226}$ (71%)
Partner has not cooperated in the previous period	$\frac{38}{219}$ (18%)	$\frac{43}{273}$ (16%)	$\frac{28}{280}$ (9%)	$\frac{51}{406}$ (12%)

TABLE 4. Evidence of reciprocity instead of duty: Frequency of Cooperation in Periods 2-5 by First Period Cooperators in Between and Within treatments

The Reciprocal Cooperation explanation for the data would be that past successful coordination creates positive belief in obtaining the non-pecuniary gains from sustained future coordination. Whereas Reciprocal Altruism would suggest that previous coordination on Cooperation plays an important role in determining if my and the partner's actions are considered as fair or unfair to one another, and we both get non-pecuniary utility from reciprocating that attitude back. This is where we use Proposition 6 that proves that after partner has played Defection in the first round of the Quarter treatment, all possible final outcomes that can arise are regarded as unfair by any subjects whose preferences are consistent with the Dufwenberg and Kirchsteiger [2004] model, irrespective of her first and second order beliefs. Thus a first period Defection should be unconditionally reciprocated with Defection in the following four periods by such a subect. The Dufwenberg and Kirchsteiger [2004] model of Reciprocal Altruism is unique in imposing such a strong response to first period Defection by the partner. The following hypothesis uses this to separate between Reciprocal Altruism and Reciprocal Cooperation.

Hypothesis 4: *A subject never cooperates in any of the Periods* $2-5$ *of the* $\delta \in \{\frac{3}{8}, \frac{1}{4}\}$ *treatments if the partner has played Defect in Period 1.*

In the Within sessions ($\delta = \frac{1}{4}$ treatment), 56% of the 306 total instances of Cooperation in periods 2-5 that needs to be accounted for, was by subjects whose partner Defected in Period 1. Similarly, there are 328 instances of Cooperation in periods 2-5 of the $\delta \in \{\frac{3}{8}, \frac{1}{4}\}$ treatments in the Between Treatment, and a total 138 of these instances (42% of the total) are from subects whose partner had Defected in the very first period. Thus the Dufwenberg and Kirchsteiger [2004] model cannot account for almost half of the observed cooperation in later Periods. *Instead of playing Defection throughout after facing first period Defection, people keep cooperating with a high probability as long as their partner has cooperated more recently, as seen in Table 4, and in contradiction to what the Dufwenberg and Kirchsteiger [2004] model would suggest.*

Thus, the only model that the data fails to reject is that of Reciprocal Cooperation.

4. Extending The Existing Modelds of Behavior

Equipped with the hindsight of the experimental findings (Table 5) in this paper, we discuss possible minor changes to the theories presented in Section 2, that would (or would not) make them fit our data better. We start by mentioning the two models for which we could not find a good way forward. Making the altuistic parameter α in the Duty model to be proportional to the stakes would prevent it from predicting *unconditional* cooperation in the final two rounds (a prediction rejected by our data), but the model would also no longer be able to predict the increase in cooperation at the terminal period (ala Proposition 4). The Pure Altruism model is already consistent with the reciprocity behavior in the data, given its prediction of subject coordination at one of three symmetric outcomes prediction, but we could not think of any version of it which would be consistent with increasing cooperation in the terminal periods.

A variant of the Dufwenberg and Kirchsteiger [2004] model that would allow for a short recall period for fairness calculations[3] would be closer to the "fast to forgive" behavior (subjects care more about recent actions than past "unforgiveable" actions) observed in the current paper and some other papers (Fudenberg et al. [2012]), and perform equally well as Reciprocal Cooperaion model for all purposes.

The *sizeBAD* notion could also be extended along two dimensions simultaneously: First we allow it to be defined for the $(m+1)^{th}$ period of a n-period game where $m \in \{0, ..n-1\}$, and second, we additionally consider a player whose utility function is given by the Reciprocal Cooperation model. We would get

$$\rho_{m+1}^{RecCoop} = \frac{\pi_{dd} - \pi_{cd}}{((\pi_{cc} - \pi_{dd})(1 + \delta .. + \delta^{n-m-1}) + \delta^{-m}(n-m)\alpha_{coop} - \pi_{cd} - \pi_{dc} + 2\pi_{dd})}$$

For initial cooperation, at $m = 0$, an increase in δ increases the denominator making cooperation easier. As m increases, the δ^{-m} term would eventually come to dominate the effect of m in the denominator (due to it's exponential nature), and lower the δ the more pronounced this effect would be. This would indeed predict the two central traits of our data: everything else being the same, initial cooperation would decrease and terminal period cooperation would increase as δ decreases.

5. An overview of the literature

The effect of the scope of future cooperation on current behavior has been studied in detail in the domain of infinitely repeated PD games. Roth and Murnighan [1983] vary the probability of continuation in their experimental setting and find that higher the probability, the greater the number of players who cooperated in the first round of the game. Bo [2005] replicates that higher continuation probabilities result in higher cooperation levels, and additionally shows that it is not

[3]For example, if fairness is calculated from only the last couple of rounds of payoff possibilities, taking past actions as given.

	Pure Altruism	Duty	Reciprocal Cooperation	DK (2004)
Cooperation decreases in the initial periods with decreasing δ				
Cooperation increases in the in the final period with decreasing δ	X			
No unconditional cooperation by first period cooperators in low δ treatments		X		
Cooperation following a first period Defection in low δ treatments				X

TABLE 5. Overview of features of data and what theories from Section 2 they reject

just the higher number of expected periods of play, but the higher probability of repeated interaction that drives this behavior. Andreoni and Miller [1993] control subjects' beliefs over the value of building a reputation (Kreps et al. [1982]) by varying the probability that subjects interact with a pre-programmed opponent (a computer that plays a Tit-For-Tat strategy). In their study, cooperation falls through the rounds of FRPD and higher beliefs about playing the computer are more conducive to higher cooperation. Cooper et al. [1992] compare behavior in one-shot PDs to that in FRPDs and observe higher cooperation rates in the FRPD. The authors find evidence of both reputation building and altruism and they conclude that neither model can explain all the features of the data on its own. There is some dispersed evidence about how cooperation in FRPD might be affected by the shadow of the future. Bereby-Meyer and Roth [2006] find more cooperation in the first period of FRPDs than in the one-shot games, which is equivalent to comparing first round cooperation rates of $\delta = 1$ and $\delta = 0$ in our setting. In the FRPD games conducted by Bo [2005] first round cooperation rates are higher in games with a longer horizon, consistent with the hypothesis that shadow of the future might drive cooperation even in FRPD games. Embrey et al. [2015] identify how the value of cooperation can be captured by the "size of the basin of attraction of Always Defect", and how it is an important determinant of cooperation in FRPD games in the previous literature. Beside their comprehensive meta-study, they also design a new experiment that compares two treatments in which the horizon of the repeated game is varied, but the value of cooperation is kept constant. One can think of our experiment as a dual to theirs, as, we keep the horizon of the repeated game constant, but vary the value of cooperation. Charness et al. [2016] show that higher monetary payoffs from cooperation are associated with substantially higher cooperation rates even in one shot PD games.

There is also some work about how beliefs might evolve and affect PD play. For example, Kagel and McGee [2016a,b] have both individual play and team play in their FRPD games and, analysis of team dialogues show significant discrepancies between subjects' inferred beliefs and those underlying standard models of cooperation in the FRPD. Cox et al. [2015] reveal second-mover histories from an earlier sequential-move FRPD game to the first-mover. They unexpectedly find higher cooperation rates when histories are revealed. They also provide an accompanying theory in which players decide on conditional cooperation based only on naive prior beliefs about what strategy their opponent is playing.

6. Conclusion

This paper designs an experiment to horse-race four theories of other-regarding motives, by providing an experimental set-up that allows each theoretical model to predict unique trends of behavior, that we can then test from the data. In Table 5 we have summarized the key features of the experimental evidence collected, and then matched them to the theory that they were inconsistent with. The features in our data are best explained by the model of Reciprocal Altruism by Kreps et al. [1982].

7. Appendix

In the Between sessions, the subjects were also asked to answer the following four prediction questions at the start of each game with a new partner:

- How likely is your partner to play L on the first round of the this game?
- How likely is your partner to play L in the very next round if you played T in the previous round of the game?
- How likely is your partner to play L in the very next round if you played B in the previous round of the game?
- How likely is your partner to play L on the very last (5th) round of the this game?

B and R were used as names for the strategy of Defect, and T and L were used as names for the strategy of Cooperate. At each question the subjects could respond on a scale of 0 to 10, and they were advised to enter a higher number the more likely they thought the event was. They were also provided the following the following reference points:

- A response of 0 (lowest point of the scale) would mean ”never”.
- 5 (midway point of the scale) would mean ”as likely as getting Heads on a fair coin toss/ 50-50 odds”,
- 10 (right extreme of the scale) would mean ”surely”.
- Events more likely than “never” and less likely than heads on a fair coin toss, should be rated between 0 and 5, and so on.

There was a separate paragraph in the instructions which the subjects were advised to read only if they were more comfortable in thinking of likelihoods in terms of probabilities.

In the following, we analyze the responses to the four likelihood questions. For each subject, let the quadruple $(g_1,\ g_2,\ g_3,\ g_4)$ contain responses to the four questions on the $0-10$ scale respectively.

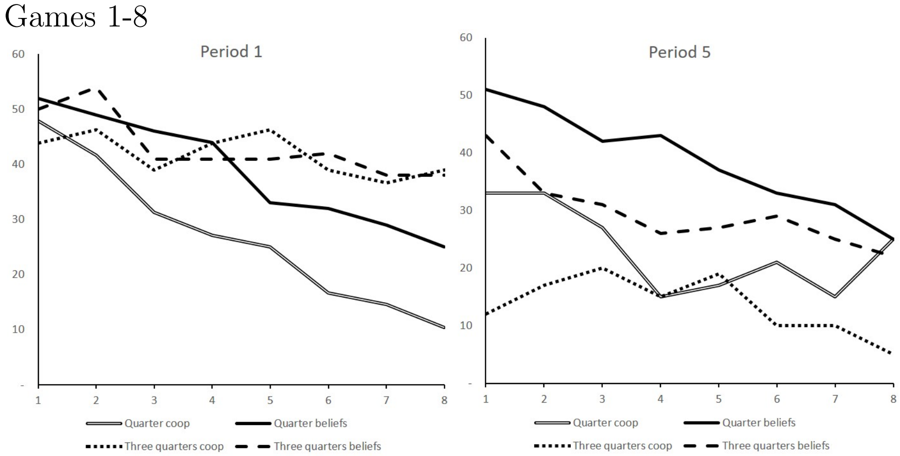
Firstly, the reported likelihoods/ beliefs seem consistent with learning. For example, subjects weakly decrease their reported g_1 ($\Delta g_1 \leq 0$) after a bad experience (their partner defecting in the first period of the last game) in 89% of all possible occasions and weakly increase g_1 after a good experience (their partner cooperating in the first period of the last game) on 86% of all occasions. These percentages are 90% and 91% respectively in case of g_4. Note that $\Delta g_i = 0$ is consistent with learning, as we only observe subject responses on a discrete grid, and for small changes in g_i we might not see any changes in their reported beliefs. We can summarize the evolution of beliefs across the games by running a regression of the beliefs against the variable (game-1), where game takes value from 1 to 8. The coefficient of regression can be read as the average change in beliefs after every passing game, whereas the coefficient on “constant” provides us average beliefs at the start of the session. As seen in Table 6, on average, subjects get more pessimistic about their partners as the session goes on and more games are played. Our finding are in contrast to Cox et al. [2015] who find that subjects might have unsophisticated priors. Further, the learning of threshold strategies (that defection should be followed by defection) is slower in the Quarter treatment.

Table 6. Change in beliefs and Forgiving across games (1-8)

	Quarter				Three Quarters			
	g_1	g_2	g_3	g_4	g_1	g_2	g_3	g_4
(game-1)	-.41	-.26	-.10	-.36	-.19	-.26	-.13	-.23
	(.07)	(.07)	(.06)	(.07)	(.07)	(.07)	(.06)	(.06)
constant	5.3	6.5	2.4	5.2	4.9	5.8	2.8	3.8
	(.39)	(.39)	(.26)	(.38)	(.37)	(.36)	(.29)	(.37)
N	384	384	384	384	336	336	336	336

In Figure 7.1, we plot the evolution of Period 1 belief g_1 (and and Period 5 belief g_4) against the average cooperation in that period, across the two treatments, throughout games $1-8$. Under the assumption that the subjects report their probabilistic assessments about the population in their response, we can meaningfully compare it to the actual average response of the population. Other than in the case of first period cooperation in the Three quarters treatment, subjects systematically overestimate the how often cooperation takes place.

Figure 7.1. Average Beliefs (g_1, g_4) vs Average cooperation across Games 1-8



Optimistic beliefs about partner's actions are also highly associated with cooperative behavior by the players themselves, as we show in Table 7. Given that subjects were provided reference points for 0, 5, 10 on their response scale, we use the most natural way to tabulate the belief data, and look at subject responses.

Fisher's exact test and the chi-squared test result in a rejection of the null of equal relative proportions of cooperation with p-values of zero for the tabulations, and suggest that more optimistic a subject was about her partner's responses, the more likely they were to cooperate.

TABLE 7. Behavior and beliefs

	Reported belief	N	% Coop
	0-4	358	16%
g_1	5	198	48%
	6-10	164	53%
	0-4	429	13%
g_4	5	155	21%
	6-10	136	30%

To take the analysis a step further, in Table 7 we run a logit regression of first and last period cooperation on the self-reported beliefs, game and treatment dummies. The standard errors are clustered at the subject level, as in the rest of this study. Even after controlling for the treatments and the games, beliefs over partner cooperating in the first period and partner's propensity to reciprocate to cooperation are significant drivers of first period cooperation. Also, as expected higher the odds of partner cooperating after facing a defection, lower is the cooperation in the first period. On the other hand, it seems that among the belief variables, belief about partner cooperating in the final period is the sole determinant of last period cooperation. This result is highly intuitive. We have focussed on forgiving behavior from only the first 4 periods to make sure we do not double account Period 5 behavior. Forgiving behavior (responding with Cooperate to Defect from partner in the last round) in the periods 2 to 4 decreases with increasing beliefs about partner cooperating in the first period, and increases with higher beliefs about the partner cooperating in the last period. The former is consistent with possible disenchantment driven aversion to forgiving, and the latter is consistent with forgiving being driven by optimism about partner's future play.

REFERENCES

M. Allais. Le comportement de l'homme rationnel devant le risque: Critique des postulats et axiomes de l'ecole americaine. *Econometrica*, 21(4):503–546, 1953.

Table 8. Logit regressions on belief variables and game dummies

	(1) Coop in Period 1	(2) Coop in Period 5	(3) Forgiving in Period<5
main			
1.game	0	0	0
	(.)	(.)	(.)
2.game	-0.0615	0.206*	-0.261*
	(0.254)	(0.309)	(0.150)
3.game	-0.299*	0.103	-0.337
	(0.282)	(0.322)	(0.195)
4.game	-0.252*	-0.508*	-0.660****
	(0.291)	(0.402)	(0.179)
5.game	-0.0443*	-0.566*	-0.533**
	(0.286)	(0.376)	(0.214)
6.game	-0.408*	-0.343	-0.297*
	(0.316)	(0.384)	(0.187)
7.game	-0.368*	-0.613*	-0.489***
	(0.317)	(0.387)	(0.188)
8.game	-0.389*	-0.271*	-0.601***
	(0.314)	(0.346)	(0.200)
T	0.902**	-0.661**	-0.139
	(0.386)	(0.319)	(0.178)
g1	0.216****	-0.0437	-0.0555*
	(0.0610)	(0.0479)	(0.0324)
g2	0.159**	0.0241	0.0166
	(0.0636)	(0.0533)	(0.0303)
g3	-0.0892*	-0.0210	0.0255
	(0.0807)	(0.0676)	(0.0411)
g4	0.0956	0.128**	0.0658*
	(0.0705)	(0.0572)	(0.0360)
_cons	-2.915****	-1.431***	-1.081****
	(0.593)	(0.461)	(0.260)
N	720	720	1594

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$

ISSN 00129682, 14680262. URL http://www.jstor.org/stable/1907921.

James Andreoni and John H Miller. Rational cooperation in the finitely repeated prisoner's dilemma: Experimental evidence. *The economic journal*, 103(418): 570–585, 1993.

Yoella Bereby-Meyer and Alvin E Roth. The speed of learning in noisy games: partial reinforcement and the sustainability of cooperation. *The American economic review*, 96(4):1029–1042, 2006.

Pedro Dal Bo. Cooperation under the shadow of the future: Experimental evidence from infinitely repeated games. *American Economic Review*, 95(5): 1591–1604, December 2005. URL http://ideas.repec.org/a/aea/aecrev/v95y2005i5p1591-1604.html.

Jordi Brandts and Gary Charness. The strategy versus the direct-response method: a first survey of experimental comparisons. *Experimental Economics*, 14(3):375–398, September 2011. URL http://ideas.repec.org/a/kap/expeco/v14y2011i3p375-398.html.

Gary Charness, Luca Rigotti, and Aldo Rustichini. Social surplus determines cooperation rates in the one-shot prisoner's dilemma. *Games and Economic Behavior*, 100:113–124, 2016.

R. Cooper, D.W. DeJong, and T.W. Ross. Cooperation without reputation: Experimental evidence from prisoner's dilemma games. Papers 36, Boston University - Industry Studies Programme, 1992. URL http://ideas.repec.org/p/fth/bostin/36.html.

Caleb A Cox, Matthew T Jones, Kevin E Pflum, and Paul J Healy. Revealed reputations in the finitely repeated prisoners dilemma. *Economic Theory*, 58 (3):441–484, 2015.

Vincent P. Crawford, Uri Gneezy, and Yuval Rottenstreich. The power of focal points is limited: Even minute payoff asymmetry may yield large coordination failures. *American Economic Review*, 98(4):1443–58, September 2008. doi: 10.1257/aer.98.4.1443. URL http://www.aeaweb.org/articles?id=10.1257/aer.98.4.1443.

Pedro Dal Bó and Guillaume R Fréchette. The evolution of cooperation in infinitely repeated games: Experimental evidence. *American Economic Review*, 101(1):411–29, 2011.

Martin Dufwenberg and Georg Kirchsteiger. A theory of sequential reciprocity. *Games and Economic Behavior*, 47(2):268 – 298, 2004. ISSN 0899-8256. doi: https://doi.org/10.1016/j.geb.2003.06.003. URL http://www.sciencedirect.com/science/article/pii/S0899825603001908.

Matthew Embrey, Guillaume R Fréchette, and Sevgi Yuksel. Cooperation in the finitely repeated prisoner's dilemma. 2015.

Jim Engle-Warnick and Robert Slonim. Inferring repeated-game strategies from actions: evidence from trust game experiments. *Economic Theory*, 28(3):603–632, 08 2006. URL http://ideas.repec.org/a/spr/joecth/v28y2006i3p603-632.html.

Urs Fischbacher. z-tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics*, 10(2):171–178, June 2007. URL http://ideas.repec.org/a/kap/expeco/v10y2007i2p171-178.html.

Daniel Friedman and Ryan Oprea. A continuous dilemma. *The American Economic Review*, 102(1):337–363, 2012.

Drew Fudenberg, David G. Rand, and Anna Dreber. Slow to anger and fast to forgive: Cooperation in an uncertain world. *American Economic Review*, 102(2):720–49, April 2012. doi: 10.1257/aer.102.2.720. URL http://www.aeaweb.org/articles?id=10.1257/aer.102.2.720.

John H. Kagel and Peter McGee. Human cooperation in the simultaneous and the alternating prisoner's dilemma: Pavlov versus generous tit-for-tat. *American Economic Journal: Microeconomics*, 8(2):253–76, May 2016a. URL http://www.pnas.org/content/93/7/2686.abstract.

John H. Kagel and Peter McGee. Team versus individual play in finitely repeated prisoner dilemma games. *American Economic Journal: Microeconomics*, 8(2):253–76, May 2016b. doi: 10.1257/mic.20140068. URL http://www.aeaweb.org/articles?id=10.1257/mic.20140068.

Daniel Kahneman and Amos Tversky. Prospect theory: An analysis of decision under risk. *Econometrica: Journal of the econometric society*, pages 263–291, 1979.

David M Kreps and Robert Wilson. Sequential equilibria. *Econometrica*, 50(4):863–94, July 1982. URL http://ideas.repec.org/a/ecm/emetrp/v50y1982i4p863-94.html.

David M Kreps, Paul Milgrom, John Roberts, and Robert Wilson. Rational cooperation in the finitely repeated prisoners' dilemma. *Journal of Economic*

Theory, 27(2):245 – 252, 1982. ISSN 0022-0531. doi: 10.1016/0022-0531(82)90029-1. URL http://www.sciencedirect.com/science/article/pii/0022053182900291.

Matthew Rabin. Incorporating Fairness into Game Theory and Economics. *American Economic Review*, 83(5):1281–1302, December 1993. URL https://ideas.repec.org/a/aea/aecrev/v83y1993i5p1281-1302.html.

Roy Radner. Can bounded rationality resolve the prisoner's dilemma? 1986.

Alvin E. Roth and J.Keith Murnighan. Expecting continued play in prisoner's dilemna games. *Journal of Conflict Resolution*, 27(2):279–300, 1983.

Thomas C Schelling. The strategy of conflict. *Cambridge, Mass*, 1960.

R Selten. Team versus individual play in finitely repeated prisoner dilemma games. *In H. Sauermann (Ed.)*, Beiträge zur experimentellen Wirtschaftsforschung. Tübingen: Mohr.:(pp. 136–168), 1967. doi: 10.1257/mic.20140068. URL http://www.aeaweb.org/articles?id=10.1257/mic.20140068.