Strategy Choice In The Infinitely Repeated Prisoners Dilemma

Pedro Dal Bó
Brown University

Guillaume R. Fréchette*
New York University

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Abstract

We use a novel experimental design to identify the strategies used by subjects in an infinitely repeated PD experiment. We ask subjects to design strategies that will play in their place. We find that the strategy elicitation has negligible effects on behavior supporting the validity of this method. We study the strategies chosen by the subjects and find that they include some commonly mentioned strategies, such as tit-for-tat and grim trigger. However, other strategies which are thought to have some desirable properties, such as win-stay-lose-shift are not prevalent. The results indicate that what strategy is used to support cooperation changes with the parameters of the game. Finally, our results confirm that long run miss-coordination can arise.

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The theory of infinitely repeated games has been a very active area of research in recent decades and is central to many applications.[1] The main idea behind this literature is that repeated interaction may allow people to overcome opportunistic behavior. This idea has been supported by a series of experiments.[2] However, less is know about the types of strategies people actually use to overcome opportunistic behavior.

Learning what strategies are actually used is of interest on many levels. First, it can help future theoretical work to identify refinements or conditions which generate those strategies as the ones that would be played. As Rubinstein (1998) writes Folk theorems are statements about payoffs, but the equilibria are not sustained by these payoffs but by strategies. He then states "Understanding the logic of long-term interactions requires, in my opinion, the characterization of the equilibrium strategy scheme. […] The repeated games literature has made little progress toward this target." Second, it can help theorists focus their attention on empirically relevant strategies. For example, an influential literature in biology studies which strategies are likely to survive evolution. Given the complexities of working with the infinite set of all possible strategies they focus on finite subsets of strategies which are chosen to include strategies usually studied by theorists (i.e. Imhof, Fudenberg, Nowak 2007). Identifying in the laboratory strategies that are popular with humans can provide an appealing basis on which to select strategies to include. Third, it can also help identify in which environments cooperation is more likely to emerge. In other words, the theoretical

[1] Within economics, repeated games have been applied to many areas: industrial organization (see Friedman 1971, Green and Porter 1984 and Rotemberg and Saloner 1986), informal contracts (Klein and Leffler 1981), theory of the firm (Baker, Gibbons, and Murphy 2002), public finance (Phelan and Stacchetti 2001) and macroeconomics (Rotemberg and Saloner 1986 and Rotember and Woodford 1990) just to name a few.

[2] Roth and Murnighan (1978) and Murnighan and Roth (1983) were the first papers to induce infinitely repeated games in the lab by considering a random continuation rule. The probability with which the game continues for an additional round induces the discount factor. A large experimental literature now exists on infinitely repeated games. Palfrey and Rosenthal (1994) study an infinitely repeated public good game. Engle-Warnick and Slonim (2004 and 2006) study infinitely repeated trust games. Holt (1985) study a Cournot duopoly which is related to the prisoners' dilemma studied in Feinberg and Husted (1993), Dal Bó (2005), Normann and Wallace (2006), Dal Bó and Fréchette (2010), Blonski et al. (2007) who more specifically study infinitely repeated prisoners' dilemma under perfect monitoring. Schwartz, Young, and Zvinakis (2000) and Dreber, Rand, Fudenberg, and Nowak (2008) study modified prisoners' dilemmas. Aoyagi and Fréchette (2009) study infinitely repeated prisoners' dilemma under imperfect public monitoring. Fudenberg, Rand, and Dreber (2010) study infinitely repeated prisoners' dilemma where actions are implemented with noise. Duffy and Ochs (2009) and Camera and Casari (2009) and Camera, Casari, and Bigoni (2010) study repeated prisoners' dilemma with random matching. Finally, Cason and Mui (2008) study a collective resistance game and Cabral, Ozbay, and Schotter (2010) study reciprocity.

conditions needed for cooperation may need to be modified once we restrict the analysis to the set of strategies which are actually used. Fourth, identifying the set of strategies used to support cooperation can provide a tighter test of the theory than the previous study of outcomes. It allows us to test whether the strategies used coincide with the ones that theory predicts should be used (i.e. are the strategies used part of a sub-game perfect equilibrium?).

Previous papers have estimated the use of strategies from the observed realization of behavior. There are serious hurdles for identification. First, the set of possible strategies is infinite (uncountable). Second, while a strategy must specify an action after each possible history, for each repeated game we only observe one realized finite history and not what subjects would have done under other histories. Two different approaches have been used to overcome these hurdles. Both methods start by specifying a family of strategies to be considered. They differ in how the best fitting strategies are selected. One approach trade-off goodness of fit of a set of strategies versus a cost of adding more strategies (see Engle-Warnick and Slonim 2004 and 2006a, and Camera, Casari, and Bigoni 2010, for a Bayesian approach to this see Engle-Warnick, McCausland, and Miller 2004). A second approach, uses maximum likelihood estimation to either estimate the prevalence of each strategy in the set under consideration (see, Dal Bó and Fréchette 2010 and Fudenberg, Rand, and Dreber 2010) or by estimating the best fitting strategy while allowing for subject specific heterogeneity in the transitions across states of the strategy (Aoyagi and Fréchette 2009).

In this paper we propose an alternative approach to study strategies: the elicitation of strategies (i.e. a modified strategy method, Selten 1967). We ask subjects what they want to do under different circumstances, and then playing out the game by realizing the relevant contingency and the subjects' decision. A major challenge to the use of the strategy method is that it can affect behavior.[3] We show that not to be the case by combining the strategy method with the "decision by decision" method in such a way that we can compare behavior between both methods and by comparing behavior with a similar series of experiments without the elicitation of strategies.

[3] Hoffman et al. (1998), Gueth et al. (2001), and Brosig et al. (2003) for evidence that the strategy method may affect behavior. For cases in which that is not the case see Brandts and Charness (2000).

There is a long history of using computer tournaments to learn about strategies in infinitely repeated games that goes back to Axelrod (1980b). Since then the literature has moved mostly towards simulations rather than tournaments.[4] In addition to focus on a different population and vary a set of important parameters, our paper shows that the elicitation of strategies does not affect behavior supporting its use.

II. Experimental Design

The experimental design is in three phases.[5] In Phase 1 subjects simply play the randomly terminated games. A supergame is referred to as a match, and is composed of multiple rounds After each match, subjects are randomly re-matched with a subject. In between matches they are reminded of the decisions they took in this match and of the choices of the person they were matched with. The first match to end after 20 minutes of play marks the end of Phase 1.

In Phase 2, subjects are first asked to specify a *plan of action*, that is a strategy, by answering five questions: "In round 1 select {1, 2}", and the answer to the four questions covering all permutations of "After round 1 if, I last selected [1, 2] and the other selected [1, 2], then select {1, 2}". The choices are presented as drop-down menus and the order in which the 4 questions after round 1 appear is randomized.

After having specified their plan of action, subjects then play the match just as in Phase 1, taking decisions in every round. At this point, the plan of action they specified is irrelevant. After the first match, they are shown what decisions they took in this match, what decision the person they were matched with took, and what decisions the plan of action they specified would have taken, had it played in their place. They are then asked to specify a plan of action for the coming match. This process (specify a plan; play a match round by round; receive feed back and specify a plan) is repeated for 20 minutes.

4 Examples of recent papers using computer simulations are Nowak and Sigmund (1993) who introduce stochastic strategies, and Nowak, Sigmund, and El-Sedy (1995) who add mutations. Axelrod's (1981a) first competition was a finitely repeated game. Another study that estimates strategies but focuses on the case of finite repetitions is that of Selten, Mitzkewitz, and Uhlirich (1997).

5 When first reading the instructions, subjects are informed that there are multiple phases, but they are only told about the procedures for Phase 1. Additional instructions are given to them after Phase 1. All instructions and screen-shots are available in the online appendix.

After 20 minutes of play in Phase 2, the plan of action takes over for the subjects, finish the ongoing match, and play an additional 15 matches.

Table 1: Stage Game Payoffs

	C	D
C	R, R	12, 50
D	50, 12	25, 25

The stage game is as in Table 1. Each subject is exposed to only one treatment (between-subjects design). The main treatment variables are R and δ where R takes values 32 or 48 and δ takes values 0.5 or 0.75. One additional treatment is conducted with R = 32 and δ = 9/10. For each of the 5 treatments, 3 sessions are conducted.[6] Payments are based on the sum of the points accumulated in the three phases converted to dollars at the rate $0.0045 per point.

Given those parameters, cooperation can be supported as part of a subgame perfect equilibrium (henceforth SGPE) in all treatment except for the one where δ = 0.5 and R = 32. Furthermore, playing a grim trigger strategy (cooperating until the other defects and then defect forever) is risk dominant when playing against always defect in both treatments with R = 48 and in the treatment with δ = 0.9.[7]

The design considerations were the following. First, one concern is that subjects may not think in terms of strategies. That is, it may be that the behavior of humans can be thought of as them having a strategy but they may not "know" it, they may not know how to verbalize their plan. Thus, one concern is that asking subjects for a strategy might cue them to something they would not be thinking about absent our intervention. To evaluate to what extent this is a concern we will compare behavior in phase 2 with behavior in Dal Bó and Fréchette (2010), which uses the same parameter values but without the strategy method. Furthermore, the design includes Phase 1 where subjects have time to learn what they want to do in this environment. There is no "cueing" since they are not asked about their strategy at that point. An additional concern is how to get the subjects to express this

[6] Two previous sessions were conducted, however the payments were too low and thus the exchange rate was changed and those 2 sessions are not included in the analysis.
[7] The reader interested in the reasons for the choice of parameters is referred to Dal Bó and Fréchette (2010).

strategy they may not have a clear idea off. To address that concern the design gives feedback about what both subjects did and what the plan of action would have done. This gives an opportunity for subjects to realize in what situations the specified plan of action is not doing what they actually want to do. Finally, subjects are incentivized to give the plan of action that makes choices as close as possible to what they want to do since whenever they specify a plan of action, this may be the match where Phase 2 expires and where the plan of action takes over.

Another concern is whether the possible plan of action subjects can specify are sufficient to express the strategies they want. First note that even though simple, the technology at their disposal allows subjects to specify 32 strategies. Also, many of the strategies most often mentioned in the literature can be specified in this way: tit-for-tat, grim, win-stay lose-shift, and others are available – these (and other) strategies will be defined later. It will also be possible to compare decisions in Phase 2 with the decisions of the plan of action. Any persistent differences would be suggestive that no strategy available was exactly consistent with what the subject wanted to do. Finally we also conducted additional sessions with a slightly different design which allow for other strategies. These will be described later on in the paper.

III. Choices and the Impact of the Elicitation of Strategies on Behavior

A total of 246 NYU undergraduates participated in these 15 sessions, with an average of 16.73 subjects per session, a maximum of 22 and a minimum of 12. The subjects earned an average of \$24.94, with a maximum of \$42.53 and a minimum of \$12.26. In the treatments with $\delta=1/2$, $\delta=3/4$, and $\delta=9/10$ the average number of rounds per match was 1.92, 3.61, and 8.53 respectively, and the maximum was 9, 22, and 43 respectively. Table A1 in the appendix has more details on each session.

III.a Comparison with Dal Bó and Fréchette (2010)

Figure 1 allows us to compare behavior in this experiment relative to Dal Bó and Fréchette (2010) where strategies are not elicited. The evolution of behavior is extremely similar for all treatments. Even though the choices are very similar in both cases, they seems to be slightly more cooperation when strategies are elicited in the δ=1/2 and R=48 sessions and slightly less cooperation in the sessions with δ=3/4 and R=48.

Table 3: Cooperation Rate by Treatment, Phase and Elicitation of Strategies

		First Rounds Only				All Rounds			
		Elicitation of Strategies				Elicitation of Strategies			
		Yes		No		Yes		No	
		Phase		Phase		Phase		Phase	
δ	R	1	2	1	2	1	2	1	2
Panel A: All Matches									
½	32	0.12	0.09	0.14	0.06	0.09	0.07	0.12	0.08
	48	0.61	0.60	0.37	0.41	0.56	0.52	0.35	0.36
¾	32	0.23	0.24	0.25	0.26	0.19	0.21	0.18	0.23
	48	0.72	0.86	0.75	0.96	0.61	0.80	0.65	0.90
Panel B: Last Match in Each Phase									
½	32	0.04	0.06	0.14	0.02	0.02	0.06	0.10	0.05
	48	0.45	0.59	0.39	0.41	0.31	0.38	0.39	0.41
¾	32	0.23	0.23	0.25	0.30	0.22	0.20	0.16	0.21
	48	0.67	0.83	0.89	0.98	0.57	0.86	0.77	0.96

Table 2 shows the cooperation rates for both series of experiments separated by phase (as Dal Bó and Fréchette 2010 does not have phases, matches were assigned to phase 1 and 2 based on whether they started before the mid-point of the session or after the mid-point, the number of phase 1 and 2 matches in the new sessions is comparable to the total number of matches in Dal Bó and Fréchette 2010). By the end of phase 2, taken has a whole, there is only marginal evidence that the new sessions are different from those in Dal Bó and Fréchette (2010) (p-value = 0.09 for round 1 only and > 0.1 for all rounds).[8] The difference in the round 1 only case is driven by the δ=3/4 and R=48 as taken individually it is the only treatment for which there is a statistically significant difference by the end (all other p-values > 0.1). However the difference is already present at the end of phase 1 suggesting that this is not due the elicitation method. Importantly, the comparative static comparisons across treatments are unaffected by the strategy elicitation.

[8] Unless otherwise noted, statistical significance is assessed by estimating a probit and clustering the variance-covariance at the level of the experimental session.

III.a Comparison of behavior across phases

As can be seen in Figure 1, behavior changes over time in many treatments. Table 3 presents the percentages of Round 1 cooperation by treatment. In Phase 2, these are the subject's decisions, not the choice that the plan of action would have selected, whereas in phase 3 they are the decisions the plan of action selected. The top panel (panel A) reports the average for all matches and the bottom panel (panel B) gives the average for the last match of each phase.[9] It is clear from this table that in many treatments cooperation rates evolve over time. This had already been observed in Dal Bó and Fréchette 2010 and is confirmed here in this new design. It is furthermore observed in the new treatment with δ=9/10 and R=32. This evolution seems to have stopped for the most part by the end of phase 2. Comparing the last match of phase 2 to the last match of phase 3, the only treatment where choices are statistically different are δ=3/4 and R=32 when considering only round 1 choices (p-value = 0.07) and δ=3/4 and R=48 of considering all choices in the match (p-value < 0.01).

[9] For phase 3, one may wonder why the numbers are different for panels A and B since the plan of actions do not change. This is an artifact of the design, since phase 3 starts on round 1 of some sessions; while in others it starts midway through a match, panel A considers a different set of matches than panel B. If one constrained panel A to all complete matches in phase 3, than the numbers would be identical to panel B.

Table 2: Cooperation Rate by Treatment and Phase

		First Rounds Only			All Rounds		
Panel A: All Matches							
		Phase			Phase		
δ	R	1	2	3	1	2	3
½	32	0.12	0.09	0.14	0.09	0.07	0.09
	48	0.61	0.60	0.55	0.56	0.52	0.47
¾	32	0.23	0.24	0.27	0.19	0.21	0.20
	48	0.72	0.86	0.85	0.61	0.80	0.79
9/10	32	0.41	0.60	0.64	0.44	0.53	0.53
Panel B: Last Match							
½	32	0.04	0.06	0.14	0.02	0.06	0.06
	48	0.45	0.59	0.57	0.31	0.38	0.51
¾	32	0.23	0.23	0.27	0.22	0.20	0.21
	48	0.67	0.83	0.85	0.57	0.86	0.73
9/10	32	0.58	0.62	0.64	0.59	0.55	0.57

III.c Elicitation order does not affect cooperation rates

An additional piece of evidence in favor of the idea that the strategy method did not affect behavior we study the effect of the order of elicitation on behavior. The elicitation of strategies consisted on five questions (what you would do in the first round, what you would do if both cooperated, etc). The question about the first round was asked first and the order of the remaining four questions was random. Table A2 in the appendix shows that the order in which the questions were asked had no effect on the cooperation rate.

III.d Changes in Strategies

Finally, we study when subjects changed their strategies. Subjects changed strategies in 14% of all matches (past the first match). This number varies between 12% and 21% depending on the treatment. It is lowest in the δ=1/2 and R=32 treatment and highest in the δ=9/10 and R=32 treatment. The frequency with which subjects change their strategies is markedly higher following a match where their decisions were not the same as what the strategy they had specified would have taken. This can be seen in Table

4 which breaks down the frequency of changes by whether the choices in the previous match corresponded to the choices the strategy would have taken.

Table 4: Percentage of Matches Where the Strategy Is Changed

		Decision = Choice of Strategy	
δ	R	Yes	No
½	32	10.08	27.33
	48	11.75	36.25
¾	32	11.02	35.43
	48	9.38	40.32
9/10	32	15.27	45.05
Overall		11.02	35.29

IV. Description of strategies

Having shown that the strategy method is not likely to have affected behavior (and hence we believe strategies) we describe now the strategy choices made by the subjects. After first defining some strategies of interest, we describe the strategy choices at the end of phase 2, and then the evolution leading to that choice.

The simplest strategies to consider are always cooperate (AC) and always defect (AD). A strategy already mentioned is tit-for-tat (TFT). TFT starts by cooperating and in subsequent rounds matches what the other subject did in the previous round. The grim trigger strategy (Grim) also starts by cooperating, and cooperates as long as both players have cooperated last round, and defects otherwise. A final strategy that is often discussed in the literature is win-stay lose-shift (WSLS, also know as perfect TFT, or Pavlov), it starts by cooperating, and cooperates whenever both players made the same choice last round, and defects otherwise. It is considered desirable because when it plays itself, it does not remain "stuck" in defection.

What can be expected? AD is an equilibrium in every treatment and previous experiments on infinitely repeated games have observed situations where some subjects defect. Hence AD is expected to be a selected strategy. What about strategies to support cooperation? A candidate many would probably put forward is TFT because of the fact that it was the winner in Axelrod's (1982b) tournament. It is also a very intuitive strategy to specify. On the other hand, TFT is not subgame perfect. To see this, consider the subgame that follows after player 1 cooperated and player 2 defected. If both players follow TFT after that defection, they will start an infinite sequence of alternating unilateral defections. As this results in a total payoff below the payoff from mutual cooperation, both subjects have an incentive to cooperate once when TFT tells them to defect, so as to return to full cooperation for ever. Thus, maybe TFT will not be popular but instead WSLS, which has performed well in simulations, will be popular. WSLS unlike TFT can be a SPGE strategy (depending on the parameters of the game). However, WSLS cannot support cooperation for as many values of δ as grim. The grim strategy, in that sense, is more robust, and it can support cooperation for much lower values of δ. On the other hand, once it starts defecting, grim never stops. In that sense it is not very forgiving.

IV.a Final strategy choices

Table 5 shows the distribution of strategies across treatment. Strategies are described by the string of five letters, C for cooperation and D for defection, where the first entry is what it recommends in round 1, the second gives the choice following mutual cooperation, the second column give the choice following ones unilateral defection and so on..

The most popular strategies across treatments are TFT, Grim and AD. These three strategies on their own correspond to more than two thirds of the data in each treatment and as much as 80% in two treatments. As it can be expected there are large variations in the popularity of AD across treatments. While AD is more prevalent in treatments with low δ and R, TFT and Grim are more prevalent in treatments with large δ and R. Variations in the popularity of specific strategies to support cooperation across treatments is more surprising.

Table 5: Distribution of Elicited Strategies (Last Match)

	Round 1	Round > 1: Choice Previous Round					δ = ½		δ = ¾		δ = 9/10
							R		R		R
You:		C	D	C	D						
Other:		C	C	D	D	AKA	32	48	32	48	32
	C	C	C	C	C	AC		3.57	2.27	8.70	2.00
	C	C	C	C	D	AC'			2.27		4.00
	C	C	C	D	C				2.27	2.17	2.00
	C	C	C	D	D	TFT	6.00	12.50	11.36	32.61	42.00
	C	C	D	D	C	WSLS		**1.79**		**2.17**	2.00
	C	C	D	D	D	Grim	6.00	**35.71**	**4.55**	**39.13**	**12.00**
	C	D	C	D	D		2.00				
	C	D	D	D	C			1.79			
	C	D	D	D	D			1.79	4.55		
	D	C	C	C	D					2.17	
	D	C	C	D	C				2.27		
	D	C	C	D	D	STFT	12.00	5.36	18.18		10.00
	D	C	D	C	C						2.00
	D	C	D	C	D	AD'					2.00
	D	C	D	D	C				2.27		
	D	C	D	D	D	AD'	10.00	**3.57**	**9.09**	**2.17**	**6.00**
	D	D	C	D	C					2.17	2.00
	D	D	C	D	D		4.00				
	D	D	D	C	D	AD'	2.00				
	D	D	D	D	C			1.79			
	D	D	D	D	D	AD	**58.00**	**32.14**	**40.91**	**8.70**	**14.00**
	Cooperative						12.00	53.57	22.73	84.78	64.00
	Defecting						86.00	41.07	68.18	13.04	32.00
	SGPE						58.00	73.21	54.55	52.17	32.00
	SGPE if random						0.03	15.63	9.38	15.63	9.38
	Only NE						28.00	12.50	0.00	34.78	44.00
	Only NE if random						15.63	18.75	6.25	15.63	9.38
	NE						86.00	85.71	54.55	86.96	76.00

Note: AC' (AD') denotes that a strategy will behave as AC (AD) in every history it will reach if choices are perfectly implemented.

Cooperative (Defecting) denotes strategies that are fully cooperative (defecting) with themselves.

Sub-game perfect strategies are denoted in bold, and only NE are underlined.

If we aggregate strategies depending on whether they lead to cooperation or defection on the equilibrium path we find a similar pattern.[10] The prevalence of cooperative strategies increases with δ and R, while the prevalence of defecting strategies decreases.

Interestingly a large proportion of the strategies being chosen are not part of sub-game perfect equilibria (SGPE). In particular, the proportion of strategies that conform a SGPE when playing against itself reaches a low of 32% under δ=9/10 and R=32. The maximum is reached under δ=1/2 and R=48 with 73% of strategies being SGPE. The low prevalence of SGPE strategies can be attributed to three factors. First, under δ=1/2 and R=32 (that is when cooperation cannot be supported in equilibrium) a significant fraction of subjects (16%) choose defecting strategies that are equivalent in play to AD but are not SGPE. Second, in the treatments in which cooperation can be supported in equilibrium subjects not only choose SGPE cooperative strategies but also rely heavily on TFT. The famous TFT is not SGPE but can be a Nash equilibrium (see Table A3 in the appendix).

IV.b. Evolution of strategies

Table 6 shows the evolution in the prevalence of the most important strategies (AC, AD, TFT, Grim and STFT) for the first and last repeated game in phase 2, with the exception of WSLS because as can be seen in Table 5 it is not a popular strategy. See also Figure 2. These allow us to study how subjects' choice of strategies evolved. The observed evolution may be due to subjects changing their desired behavior or their better understanding of the functioning of strategies.

[10] We define a strategy as cooperative (defecting) if it would lead to full cooperation on the path of play against itself (regardless of equilibrium considerations).

Table 6: Evolution of Main Strategies (First and Last Match in Phase 2)

	δ = ½						δ = ¾						δ = 9/10		
	R=32			R=48			R=32			R=48			R=32		
	Match		p-v	Match		p-v	Match		p-v	Match		p-v	Match		p-v
Strategy	First	Last		First	Last		First	Last		First	Last		First	Last	
AC	0.00	0.00	-	8.93	3.57	0.05	2.27	2.27	-	6.52	8.70	0.73	2.00	2.00	-
AD	46.00	58.00	0.00	19.64	32.14	0.00	38.64	40.91	0.70	8.70	8.70	-	12.00	14.00	0.30
TFT	8.00	6.00	0.43	21.43	12.50	0.24	18.18	11.36	0.35	28.26	32.61	0.54	28.00	42.00	0.00
Grim	0.00	6.00	0.00	28.57	35.71	0.00	2.27	4.55	0.39	30.43	39.13	0.01	20.00	12.00	0.00
STFT	16.00	12.00	0.35	5.36	5.36	-	11.36	18.18	0.01	2.17	0.00	-	10.00	10.00	-
SGPE	46.00	58.00	0.00	53.57	73.21	0.00	52.27	54.55	0.61	41.30	52.17	0.00	42.00	32.00	0.00
Only NE	38.00	28.00	0.07	23.21	12.50	0.24	0.00	0.00	-	32.61	34.78	0.80	28.00	44.00	0.00

There are no clear patterns in the evolution of strategies over all treatments. It must be noted that it is not the case that the prevalence of SGPE strategies increases with experience. The prevalence of SGPE strategies increases significantly with experience in 3 out of 5 treatments and in one treatment it decreases significantly.

Interestingly the evolution is not always clear in terms of cooperation. For example, under δ=1/2 and R=48 the prevalence of both AD and Grim increase with experience. This suggest that even when subjects gain significant experience they may fail to coordinate on one equilibrium (consistently with Dal Bó and Fréchette 2010).

V. Is Memory 1 Enough?

In the experiments presented in the previous sections subjects could only choose strategies that condition behavior on the outcome of the previous period. While we show that this has little effect on behavior, it could still be the case that this restriction in the elicitation of strategies greatly affects the strategies chosen by the subjects.

In this section we present strategy choices when a grater set of possible strategies is given to the subjects. In this menu condition, subjects are offered a menu of strategies. These included some of the strategies they could build in the original sessions (AC, AD, Grim, TFT, STFT, and WSLS), but it also included some additional strategies. In particular it allowed for some strategies with “softer” triggers, such as Grim-X which is a grim trigger strategy that requires X defections before changing states. X is a parameter to be selected by the subject. Similarly there is a TFXT which is similar to TFT but requires X consecutive defect choices before it defects. It also includes a trigger strategy with a finite number of D choices before reverting back to cooperation, and a few other strategies. Subjects always had the opportunity to "build" their plan of action using the same machinery as in the original sessions. The order in which these appeared was randomized. Our goal was to include the most obvious possibilities in terms of strategies in this game. The same R and δ as in the original sessions are used, with the exception of δ=1/2 and R=32 since that treatment is unlikely to generate interesting results. A total of 182 NYU undergraduates participated in these 12 sessions, with an average of 15.54 subjects per session, a maximum of 20 and a minimum of 12. The subjects earned an average of $27.51, with a maximum of $43.13 and a minimum of $10.55. In the treatments with δ=1/2, δ=3/4, and δ=9/10 the average number of rounds per match was 2.14, 4.16, and 9.42 respectively, and the maximum was 9, 34, and 42 respectively. Table A2 summarizes the treatments that were conducted and basic information about the sessions. Table A3 reports the cooperation rates in these additional sessions as well as in the other sessions for comparisons. The key feature to note is that when compared to the decisions in Dal Bó and Fréchette 2010, the choices in these additional sessions taken jointly are not statistically different at the end of phase 2 (for either all rounds or round 1 only).

The main result from these additional sessions is that over three quarters of the final strategies in each treatment could be defined using the apparatus of the original sessions. More specifically, 90% of the strategies in the last match for δ=1/2 and R=32; 92% and 77% for δ=3/4 and R=32 and 48 respectively; and 85% for δ=9/10 and R=32. Furthermore, in all but one treatment the most popular strategy that cannot be expressed using the original method ranks as fifth most popular. In the only treatment where it does better, δ=9/10 and R=32, it comes in tied for 3rd, but accounts for only 7% of the strategies.

Table 7: Distribution of Elicited Strategies in Additional Sessions (Last Match)

Round 1	Round > 1: Choice Previous Round CC	DC	CD	DD	AKA	δ = ½ R = 48	δ = ¾ R = 32	δ = ¾ R = 48	δ = 9/10 R = 32
C	C	C	C	C	AC		0.03	0.11	
C	C	C	D	D	TFT	0.21	0.21	0.25	0.24
C	C	D	D	C	WSLS	**0.08**	0.08	**0.11**	0.07
C	C	D	D	D	Grim	**0.33**	**0.08**	**0.18**	**0.07**
C	D	C	C	C				0.02	
C	D	D	D	D					0.02
D	C	C	C	D				0.02	
D	C	C	D	D	STFT		0.08	0.02	0.04
D	C	D	D	D	AD'	**0.02**			
D	D	C	D	D			0.08		
D	D	D	D	D	AD	**0.25**	**0.38**	**0.05**	**0.41**
Memory 1 Total						0.90	0.92	0.77	0.85
					CD		0.03	0.02	0.04
					CTFT	0.02		0.09	0.02
					GRIMX	0.04			0.02
					RX	0.02		0.02	0.07
					TFXT			0.07	0.02
					TX	0.02		0.02	

Note: AC' (AD') denotes that a strategy will behave as AC (AD) in every history it will reach if choices are perfectly implemented.

Sub-game perfect strategies are denoted in bold, and only NE are underlined.

Table 7 reports the percentages of each strategy in the last match of Phase 2. Many of the results from the original session carry over. In particular, AD is still a popular strategy. When it comes to strategies to support cooperation, both TFT and grim are the most common strategies. It is also still the case that the specific game being played affects the strategy choice. In other words, which strategy is used to support cooperation changes with the parameters R and δ. Finally, it is also the case that some non-SGPE are popular, however much of the choices of strategy favor NE strategies.

There are some differences however. Although it is still the case that AD, TFT, and grim together account for the majority of the data, it is no longer true in each treatment taken individually. In particular, when δ=3/4 and R=48, these three strategies now account for 48% of the strategies. In the other treatments they always account for at least two thirds of the data. The next most popular strategy is WSLS. Hence, in these additional sessions, AD, TFT, grim, and WSLS taken together account for the majority of the strategy choice by the end of phase 2 in every treatment. This is surprising given that WSLS was almost completely absent in the original sessions, representing at most less than 3% of choices in any given treatment. In these new sessions its popularity goes up to 11% of choices in one treatment. Another change is the popularity is STFT which is substantially decreased in these additional sessions. However, the treatment where it was most popular in the original sessions (δ=3/4 and R=32) is still the treatment where it is most popular in the additional sessions.

VI. Does econometric estimation recovers the same strategies?

VII. Conclusions

A growing recent literature has study the strategies used in infinitely repeated games. Several identification hurdles limit the capacity to infer strategies from observed behavior. We overcome this hurdles by asking subjects to design strategies that will play in their place. We find that the strategy elicitation has negligible effects on behavior supporting the validity of this method. We study the strategies chosen by the subjects and find that they include some commonly mentioned strategies, such as tit-for-tat and grim trigger. However, other strategies which are thought to have some desirable properties, such as win-stay-lose-shift are not prevalent. We also find that the strategies used to support cooperation change with the parameters of the game. Moreover, we find that a significant portion of the chosen strategies are not part of a sub-game perfect equilibrium.

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Appendix A: Tables

Table A1: Session characteristics

Variable	δ = ½		δ = ¾		δ = 9/10
Payoff from cooperation	**32**	**48**	**32**	**48**	**32**
Number of subjects	18	16	14	18	18
Number of Games	86	63	50	44	25
Phase 1	37	25	16	14	5
Phase 2	35	23	20	16	7
Phase 3	*14*	15	*14*	*14*	*13*
Number of subjects	16	18	16	12	18
Number of Games	82	92	60	54	31
Phase 1	35	46	25	24	8
Phase 2	32	33	21	17	10
Phase 3	15	*13*	*14*	*13*	*13*
Number of subjects	16	22	14	16	14
Number of Games	72	70	43	55	38
Phase 1	24	28	17	23	12
Phase 2	33	28	11	18	13
Phase 3	15	14	15	14	*13*

Note: Italics indicate a phase that started midway through a match.[11]

[11] In phase 3 there should always be 14 or 15 complete matches (depending on whether the match started in round 1 or midway through a match). The few sessions with 13 complete matches are the results of a parameter in the software that was inadvertently limiting the total number of match/rounds. This was corrected in the additional sessions.

Table A2: Additional Session Characteristics

Variable	**δ = ½**	**δ = ¾**		**δ = 9/10**
Payoff from cooperation	**48**	**32**	**48**	**32**
Number of subjects	18	16	14	20
Number of Games	42	41	44	30
Phase 1	19	13	17	6
Phase 2	8	14	13	9
Phase 3	15	*14*	*14*	15
Number of subjects	18	12	16	12
Number of Games	67	49	41	30
Phase 1	33	19	19	9
Phase 2	20	16	8	7
Phase 3	*14*	*14*	*14*	*14*
Number of subjects	14	14	14	14
Number of Games	63	43	48	31
Phase 1	29	18	22	9
Phase 2	19	11	12	8
Phase 3	15	*14*	*14*	*14*

Note: Italics indicate a phase that started midway through a match.

Table A3: Cooperation Rate by Treatment, Phase and Elicitation of Strategies (in Additional Sessions)

		First Rounds Only						All Rounds					
		Phase 1			Phase 2			Phase 1			Phase 2		
		Elicitation of Strategies			Elicitation of Strategies			Elicitation of Strategies			Elicitation of Strategies		
			Original	Additional		Original	Additional		Original	Additional		Original	Additional
δ	R	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Panel A: All Matches													
½	32	0.14	0.12		0.06	0.09		0.12	0.09		0.08	0.07	
	48	0.37	0.61	0.41	0.41	0.60	0.70	0.35	0.56	0.34	0.36	0.52	0.62
¾	32	0.25	0.23	0.24	0.26	0.24	0.39	0.18	0.19	0.23	0.23	0.21	0.28
	48	0.75	0.72	0.66	0.96	0.86	0.90	0.65	0.61	0.58	0.90	0.80	0.88
9/10	32		0.41	0.32		0.60	0.54		0.44	0.25		0.53	0.37
Panel B: Last Match in Each Phase													
½	32	0.14	0.04		0.02	0.06		0.10	0.02		0.10	0.06	
	48	0.39	0.45	0.44	0.41	0.59	0.62	0.39	0.31	0.30	0.39	0.38	0.62
¾	32	0.25	0.23	0.31	0.30	0.23	0.33	0.16	0.22	0.30	0.16	0.20	0.30
	48	0.89	0.67	0.82	0.98	0.83	0.91	0.77	0.57	0.57	0.77	0.86	0.94
9/10	32		0.58	0.33		0.62	0.52		0.59	0.28		0.55	0.27

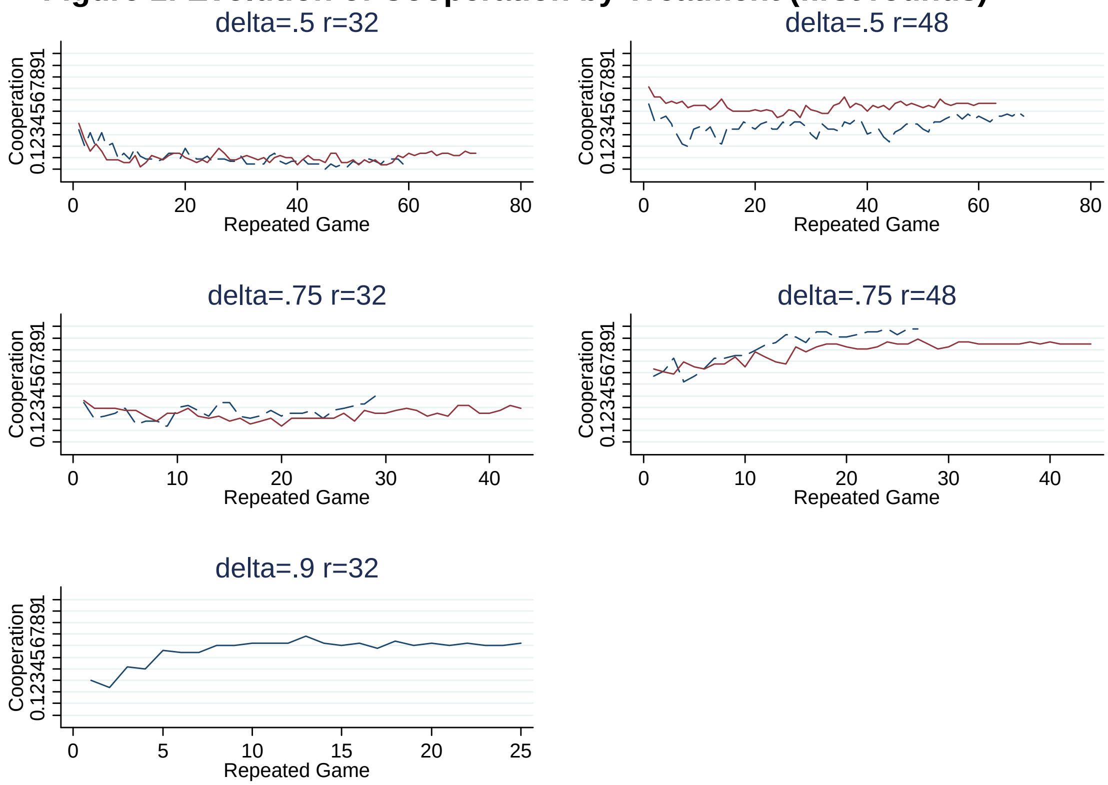
Appendix B: Options in the sessions with a menu of strategies.

(what is in parentheses was not presented to the subjects):

- Select 1 in every round. (AC)
- Select 2 in every round. (AD)
- Select 1 for X rounds, then select 2 until the end. (CD-X)
- Select 1 X% of the time and 2 1-X% of the time. (RANDOM-X)
- In round 1 select 1. After round 1: if both always selected 1 in previous rounds, then select 1 otherwise select 2. (GRIM)
- In round 1 select [1 or 2]. After round 1: if the other selected 1 in the previous round, then select 1. Else if the other selected 2 in the previous round, then select 2. (TFT or STFT)
- In Round 1 select [1 or 2]. After round 1: if both made the same choice (both selected 1 or both selected 2) in the previous round, then select 1. Otherwise select 2. (WSLS or D WSLS)
- In round 1 select 1. After round 1: if the other or me selected 2 X times before then select 2. Otherwise select 1. (GRIM-X)
- In round 1 select 1. After round 1: Select 2 if other selected 2 in all of the previous X [select number] rounds, Otherwise select 1. (TFXT)
- Starts by selecting 1, and keeps selecting 1 until someone selects 2, in that case selects 2 for X periods and then goes back to select 1 until someone selects 2 again, and so on. (T-X)
- In Round 1 select [1 or 2]. After round 1: if the other selected 1 in the previous round then select 1. In round 2 select 1 if other selected 1 in the previous round, and select 2 if other selected 2 in the previous round. If the other selected 2 in the previous round and you selected 1 two rounds prior, then select 2. Else, if the other selected 2 in the previous round and you selected 2 two rounds prior, then select 1. (CTFT or D CTFT).
- Build your own. (This offers the same option as in the memory-1 treatment.)

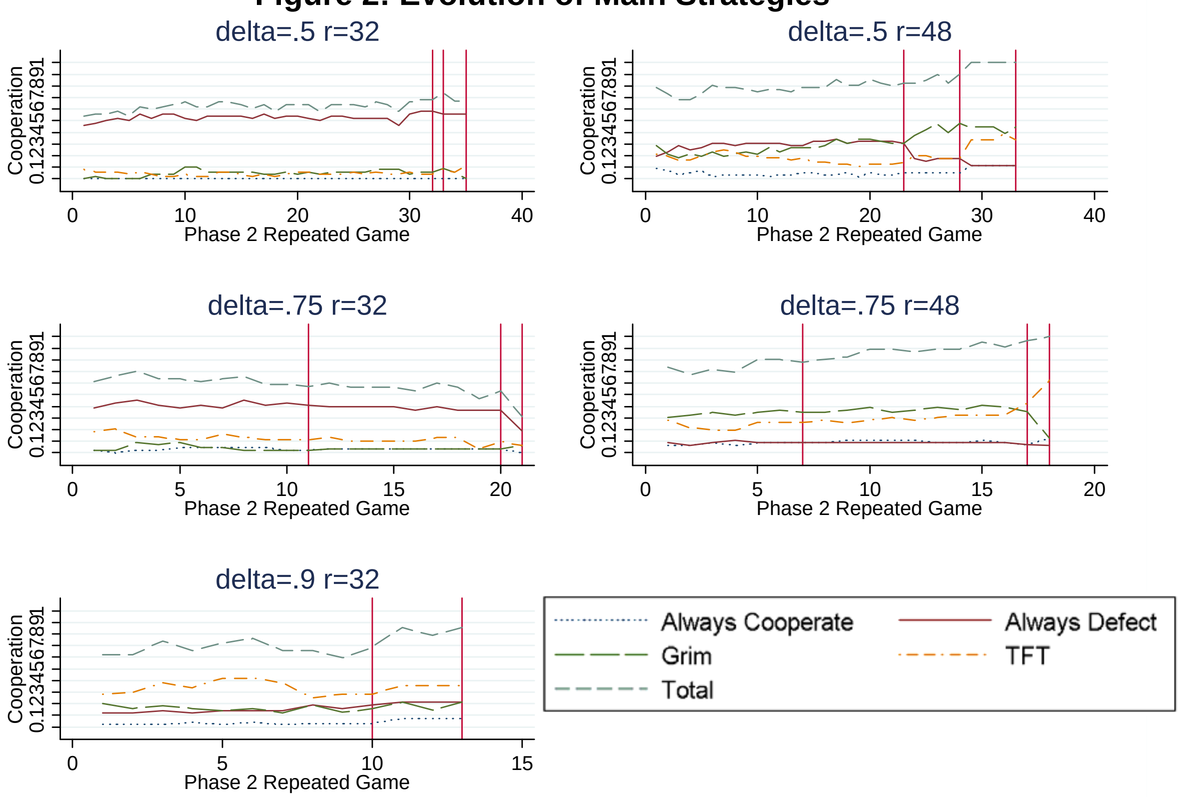
When [1 or 2] is an option, it was presented as a drop-down menu, and when X needs to be specified, subjects could enter a number in the appropriate box.

Figure 1: Evolution of Cooperation by Treatment (first rounds)



Note: Solid lines show average cooperation rates from this experiment. Dashed lines show average cooperation when strategies are not elicited from Dal Bo and Frechette (2010).

Figure 2: Evolution of Main Strategies



Note: vertical lines denote the end of a a session.

Figure 3: Evolution of Sub-Game Perfect Strategies