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Experimental Evidence: Equilibrium Selection and Cognitive Ability in Infinitely Repeated Public Goods Game*

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Abstract

We experimentally investigate the relationship between the equilibrium selection and cognitive ability in infinitely repeated public goods (PG) game under the increasing probability of continuations. We also study the relationship between cognitive ability and strategy profile. We use two methods to investigate the types of strategies employed by the subjects: the strategy frequency estimation method and one period ahead strategy method. We find that fully cooperative strategies are mostly lenient and forgiving. We find that subjects with higher cognitive ability tend to be more cooperative, forgiving and lenient when cooperative strategy is supported as risk dominance. However, we cannot find the same trend among low cognitive ability groups. They behave similarly even the probability of continuations increase. These results show that subjects with high cognitive ability behave according to risk dominance, but not subjects with low cognitive ability.

JEL Classification: C72, C73, C91, C92

Keywords: cognitive ability; infinitely repeated game; strategy method; strategic risk; subgame perfect equilibrium

1. Introduction

Greenhouse gases from human activities are the most significant driver of observed climate change since the mid-20th century. Individuals who fail to reduce carbon emission can result in negative externalities that affect others. Socially optimal carbon reduction can be achieved through cooperation among individuals. For examples, the cooperative behavior to reduce carbon emission includes reducing electricity use, recycling and reusing and minimizing driving.

Many economic experiments have investigated the incentives in sustaining cooperation in social dilemma situations, such as the public goods (PG) game. Most settings of the PG game are one-shot or finitely repeated situations, but in the real world, the long-term impacts of environmental problems do not have a fixed end date. A situation may be infinitely repeated under a low or high probability of continuation δ, and an individual's contribution to public goods affects the future behaviors of the individual's partners. Thus, an infinitely repeated game is a prominent tool for modeling the interaction.

Under the finitely repeated situation, defection is the rational choice based on backward induction, but under the infinitely repeated situation, cooperation may be the rational choice. We can use two criteria to determine the threshold level of δ at which cooperation is the rational choice in the infinitely repeated situation: the sub-game perfect Nash equilibrium (SPE) and risk dominance equilibrium (RDE) (Blonski et al. 2011). The threshold level of δ at which cooperative strategies are supported as SPE is called δ_{SPE}, and the threshold level of δ at which cooperative strategies to minimize the strategic risk are supported as RDE is called δ_{RDE}.

Under different levels of δ, each player may vary their contribution. A growing number of experimental studies examine the effect of δ on the level of cooperation in an infinitely repeated prisoner's dilemma (PD) game. Many experimental studies show that cooperation tends to increase when the δ is set to exceed δ_{SPE} and δ_{RDE}. (Aoyagi et al. 2019; Blonski et al. 2011; Dal Bó and Fréchette 2011, 2019; Fréchette and Sevgi 2017). The same can be true for a PG game experiment, wherein the contribution to public goods (cooperative choice) is strategically dominated by no contribution (defective choice) as in the PD game. Sell and Wilson (1991) show that the contribution level significantly increases when the δ exceeds δ_{SPE} in the infinitely repeated PG game experiment. However, no study has investigated whether the contribution level increases when the δ exceeds δ_{SPE} and δ_{RDE}. Our study is the first to experimentally investigate the effect of the strategic riskiness of cooperation in the infinitely repeated PG game.

Unlike finitely repeated games, infinitely repeated games allow players to employ a large set of strategies based on an infinite number of information sets. With the development of a strategy analysis methodology, we can study how players employ strategies by observing the experimental data. We use two methods to investigate the types of strategies employed by the subjects in infinitely repeated PG games: the strategy frequency estimation method (SFEM) and strategy methods.

The SFEM, introduced by Dal Bó and Fréchette (2011), has become a popular methodology to study the strategies in infinitely repeated games, especially infinitely repeated PD games (Bigoni et al. 2015; Camera et al. 2012; Dal Bó and Fréchette 2011; 2019; Fréchette and Sevgi 2017; Fudenberg et al. 2012; Romero and Rosokha 2018). These studies find that the estimated frequency of cooperative strategy increases when δ exceeds δ_{SPE} and δ_{RDE}. To the best of our knowledge, no study has employed the SFEM for an infinitely repeated PG game experiment.

The strategy elicitation method for infinitely repeated games is introduced by Selten (1967). Vespa (2015) extends the strategy method into a one-period-ahead strategy method, while Romero and Rosokha (2018) introduce the constructing strategy method. There is still no evidence that players employ strategies larger than two or above ahead history in an infinitely repeated PG game. Additionally, to reduce players' difficulty in eliciting strategies, following Vespa (2015) and Dal Bó and Fréchette (2019), we use the one-period-ahead strategy method to investigate one-period-ahead history strategies in an infinitely repeated PG game.

Following Dal Bó and Fréchette (2019), we divide the experiment into two stages: the direct-response and strategy method stages. In the direct-response-method stage, players make their choices in every stage directly, and they can learn the nature of the game through the infinitely repeated interaction. Meanwhile, in the strategy method stage, players set up their strategies at the beginning of the super game, and their strategies are played automatically.

Many experimental studies show that subjects deviate from the equilibrium strategy, a reason for which is bounded rationality. It is natural to assume the positive correlation between cognitive ability and rationality, and we can expect that the subjects with high cognitive ability more frequently employ the equilibrium strategy. Jones (2008) conducts a meta-analysis of the PD game and finds that students with higher SAT scores cooperate more often, while Burks et al. (2009) find a positive relationship between cognitive ability, measured by the Raven Progressive Matrices Test (Raven, 1936), and cooperation rate in a sequential one-shot PD game. Proto et al. (2019) investigate the relationship between the cognitive ability, as measured by the Raven Progressive Matrices Test and cooperation rate in an infinitely repeated PD game, with the δ of 0.5 and 0.75 exceeding δ_{SPE} and δ_{RDE}, respectively, and they find a positive correlation between cognitive ability and cooperation rate only in the treatment with the δ of 0.75. They also suggest that the high-cognitive-ability group more frequently employs cooperative strategies, but the low-cognitive-ability group more frequently employs unconditional defection (UD).

To the best of our knowledge, no study has investigated the relationship between cognitive ability and strategy profile in an infinitely repeated PG game experiment. In doing so, we measure the players' cognitive ability using the Raven Progressive Matrices Test. We estimate the strategy using the SFEM in the direct-response-method stage, and we elicit the strategy using the one-period-ahead strategy method in the strategy method stage.

The rest of this paper is organized as follows. In the second section, we introduce our experimental design and propose our hypothesis based on the two equilibrium concepts (SPE and RDE) in the infinitely repeated game theory. We explain our experimental procedures in the third section. In the fourth section, we show our experimental results. In the fifth section, we discuss our findings, and in the sixth section, we conclude our findings.

2. Experimental Design

A group is comprised of four players, who infinitely repeatedly play the PG game. In the PG game, the players make the binary choice of whether to contribute or not. We set the initial endowment at 10 and the marginal per capita return at 0.5. The payoff of player *i* is given by

$$\pi_i = 10 - x_i + 0.5 \sum_{j=1}^{4} x_j \qquad (1)$$

Here, x_i denotes player *i*'s contribution level. Taking the infinitely repeated PG game as δ, we focus our attention on the case wherein the Grim trigger strategy (GRIM) (i.e., players contribute if all partners cooperate; otherwise, they defect) is supported as SPE.

2.1 Subgame perfect equilibrium

To prove that GRIM is a subgame perfect Nash equilibrium, we need to show that no subject has an incentive to deviate from the equilibrium path.

On the equilibrium path, if player *i* follows GRIM, his payoff is given by:

$$\pi_i(GRIM) = \frac{1}{1-\delta}\left(0.5\sum_{i=1}^{4} 10\right) = \frac{20}{1-\delta}$$

While if he deviates, he receives a one-shot gain followed by lower future payoffs:

$$\pi_i(D|GRIM) = (10 + 0.5\sum_{i\neq j} 10) + \frac{\delta}{1-\delta}10 = 25 + \frac{10\delta}{1-\delta}$$

Thus, a player has no incentive to deviate from the equilibrium path when

$$\pi_i(GRIM) \geq \pi_i(D|GRIM)$$

$$\frac{20}{1-\delta} \geq 25 + \frac{10\delta}{1-\delta}$$

$$\delta_{SPE} \geq \frac{1}{3}$$

2.2 Risk Dominance

In Harsanyi and Selten's (1988) notion of risk dominance, a strategy is risk dominant if it is the best response to the other player randomizing by the same probability (50-50) between the two strategies in symmetric coordination games with two strategies. In an infinitely repeated two-player PD game, we can focus on two strategies: UD and GRIM. If GRIM is risk dominant over UD, we say that cooperation is risk dominant (see Blonski and Spagnolo, 2015).

Carlsson and van Damme (1993) and Kim (1996) explore Harsanyi and Selten's (1988) notion of risk dominance captures in two-person games to n-person games. By using Kim's (1996) calculation method of expected payoff, we show the expected payoff using the possible SPE strategies (UD and GRIM) by the same probability to find the possible RDE strategies that can minimize the strategic risk.

We consider the game with two pure SPE strategies (UD and GRIM). The possible situations for a given individual are thus all combinations of that individual playing GRIM or UD against three partners, with k partners playing GRIM and (3-k) partners playing UD, for any $0 \leq k \leq 3$. We denote the payoff when a player plays GRIM against k partners play GRIM by α_k and the payoff when a player plays UD against k partners play GRIM by β_k.

There are four possible events: "Three partners choose UD"; "One partner chooses GRIM and two partners choose UD"; "Two partners choose GRIM and one partner chooses UD"; and "Three partners choose GRIM." Each partner chooses GRIM with probability y_{Grim} and UD with probability y_{UD}, where $y_{UD} = 1 - y_{Grim}$. To simplify, by following Dal Bó and Fréchette (2011), we assume that each partner chooses GRIM and UD with the same probability, where $y_{GRIM} = \frac{1}{2}$ and $y_{UD} = \frac{1}{2}$. The probability of each event is calculated by

$$\text{Probability} = \binom{3}{k} \times (y_{Grim})^k \times (y_{UD})^{3-k} = \binom{3}{k} \times \left(\frac{1}{2}\right)^k \times \left(\frac{1}{2}\right)^{3-k} = \binom{3}{k} \times \left(\frac{1}{8}\right)$$

where k is the number of partners choosing GRIM. $\binom{3}{k}$ indicates the probability of combination that select k partners choosing GRIM from all three partners. $(y_{Grim})^k$ indicates the combined probability of the multiple individual probabilities of k partners employing GRIM. $(y_{UD})^{3-k}$indicates the combined probability of the multiple individual probabilities of (3-k) partners employing UD. Table 1 shows the expected payoff using UD and GRIM against three partners.

Table 1. Expected payoff using the possible SPE strategies (UD and GRIM)

	Partners			
Player *i*	3UD	1GRIM+2UD	2GRIM+1UD	3GRIM
GRIM	$5 + \frac{10\delta}{1-\delta}$	$10 + \frac{10\delta}{1-\delta}$	$15 + \frac{10\delta}{1-\delta}$	$\frac{20}{1-\delta}$
UD	$\frac{10}{1-\delta}$	$15 + \frac{10\delta}{1-\delta}$	$20 + \frac{10\delta}{1-\delta}$	$25 + \frac{10\delta}{1-\delta}$
Probability	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{8}$

GRIM risk dominates UD if

$$\pi_{GRIM} = \sum_{k=0}^{3} \binom{3}{k} \left(\frac{1}{8}\right) \alpha_k \geq \sum_{k=0}^{3} \binom{3}{k} \left(\frac{1}{8}\right) \beta_k = \pi_{UD}$$

$$\frac{1}{8}\left(5 + \frac{10\delta}{1-\delta}\right) + \frac{3}{8}\left(10 + \frac{10\delta}{1-\delta}\right) + \frac{3}{8}\left(15 + \frac{10\delta}{1-\delta}\right) + \frac{1}{8}\left(\frac{20}{1-\delta}\right) \geq$$

$$\geq \frac{1}{8}\left(\frac{10}{1-\delta}\right) + \frac{3}{8}\left(15 + \frac{10\delta}{1-\delta}\right) + \frac{3}{8}\left(20 + \frac{10\delta}{1-\delta}\right) + \frac{1}{8}\left(25 + \frac{10\delta}{1-\delta}\right)$$

$$\delta_{RDE} \geq \frac{4}{5}$$

We conduct three treatments with δ= 0.4 (treatment 1), δ=0.8 (treatment 2) and δ=0.9 (treatment 3), wherein GRIM is supported as SPE. Table 2 summarizes the SPE and RDE strategies in the three treatments.

Table 2. Summary of SPE and RDE strategies in the three treatments

	Treatment 1 (δ = 0.4)	Treatment 2 (δ = 0.8)	Treatment 3 (δ = 0.9)
SPE strategies	UD, GRIM	UD, GRIM	UD, GRIM
RDE strategies	UD	GRIM	GRIM

2.3. Hypothesis

Dal Bó and Fréchette (2011, 2019) find that cooperation is more frequently observed if GRIM is supported as RDE. We can expect the same trends in our infinitely repeated public goods game experiment. Because UD risk dominates GRIM in treatment 1 and GRIM risk dominates UD in treatments 2 and 3, we have the first hypothesis.

Hypothesis 1-1: The contribution level is higher when GRIM is supported as RDE.

Hypothesis 1-2: The frequency of cooperative strategies is higher when GRIM is supported as RDE.

Proto et al., (2019) show that subjects with high intelligence find a better strategy and conceive a larger set of strategies in a given environment, and are more consistent in their implementation of complex strategies. In other words, higher intelligence subjects will achieve, in general, higher rates of cooperation. We can expect the same trends in PG game. Thus, we propose the following experimental hypothesis regarding the risk dominance equilibrium concept.

Hypothesis 2-1: Higher cognitive ability subjects will achieve higher contribution levels when GRIM is supported as RDE.

Hypothesis 2-2: Higher cognitive ability subjects more frequently employ cooperative strategies when GRIM is supported as RDE.

3. Experimental Procedure

The experimental sessions are conducted in the laboratory of the Center for Experimental Economics at Kansai University. Each session lasts about 120 minutes in treatment 1 and 2, and 180 minutes in treatment 3 and is conducted by the same experimenter.

After the subjects are randomly assigned to seats, they are asked to sign the participation agreement sheet. After confirming that all the subjects have signed the agreement sheet, the experimenter starts the instruction. Each subject receives paper handouts of the instructions and listens to the audio instructions. The subjects could ask any questions about the experiment at any time during the instruction. After the instruction, a three-question review test about the payoff calculation is conducted to check the subjects' understanding of the game. After all the subjects answer every question correctly, the experiment proceeds.

The experiment is implemented using the z-tree (Zurich Toolbox for Ready-made Economic Experiments) (Fischbacher 2007). Each session consists of 10 rounds, and in each round, subjects repeatedly play the PG game with their fixed partners. The number of periods in a round is determined by the given continuation probability of the corresponding treatment (0.4 in treatment 1, 0.8 in treatment 2 and 0.9 in treatment 3). At the end of each period, the experimenter draws one card from five cards, which consist of three (one) jokers and two (four) spade cards in treatment 1(2). The experimenter draws one card from ten cards, which consist of one joker and nine spade cards in treatment 3. When the experimenter draws a joker, the round is finished, all the members are randomly re-matched, and the next round starts with new four members. The process of drawing cards is shown on the screen located in front of the laboratory. Therefore, the continuation of every period by the given probability is common knowledge.

The ways of decision making in the first five rounds and the last five rounds differ. The subjects decide whether they contribute or not in every period in the first five rounds. We call the direct response method stage.

In the last five rounds, the subjects construct their strategy for repeated PG games at the beginning of each round. We call the strategy method stage. The subjects are asked to decide whether they contribute or not in all the possible one-period-ahead histories and the first period. There are eight one-period-ahead histories (two levels of each player's contribution, multiplied by four levels of the other players' total contribution in the previous period). The nine questions of all the possible one-period-ahead histories and the first period are shown randomly. Subjects can take notes about their strategic choices after finish constructing their strategies. Their strategies are then played automatically. The details of strategic choices are shown in Table 3.

Table 3. Description of a strategic plan

Choice	Own Contribution at t-1	Partners' Contribution at t-1	What is your contribution at t?
1	0	0	0 or 10?
2	0	10	0 or 10?
3	0	20	0 or 10?
4	0	30	0 or 10?
5	10	0	0 or 10?
6	10	10	0 or 10?
7	10	20	0 or 10?
8	10	30	0 or 10?

9	First Period	0 or 10?

After the ten rounds of repeated PG games, the subjects proceed to answer the 16 questions[1] from the Raven Progressive Matrices Test within 10 minutes. The total score of the test is 16.

The total profit in all rounds and periods is exchanged according to the rate of 3 JPY per point. The total payment is the sum of the show-up fee (1,000 JPY) and the earnings in the game.

4. Experimental Results

We conduct an experiment with a total of eight sessions between July and September 2018 and May 2019. We implement one treatment in each session. Therefore, subjects participate in only one treatment. We use an online bulletin board of Kansai University to recruit subjects who do not have any experience in PG and PD game experiments. The experiment involves 132 subjects, who are given a show-up fee of JPY1,000 and profit from the repeated public goods game. The exchange rate is 1 point = JPY 3. The average payment is JPY 1,568 in treatment 1, JPY 3,029 in treatment 2 and JPY 4,128 in treatment 3. Each session lasts for two hours in treatment 1 and 2 and three hours in treatment 3. On average, there are 1.5 periods per round in treatment 1, 6 periods per round in treatment 2 and 9 periods per round in treatment 3.

Table 4. Summary of the experiment

	Treatment 1	Treatment 2	Treatment 3
Number of sessions	3	3	2
Number of subjects	48	44	40

[1] The selected 16 questions are commonly used in Japan and Europe (Hanaki et al. 2016; Ogawa et al. 2018). These 16 questions are selected from the whole 48 questions based on the sequence from the easy level to difficult level.

Number of rounds[2]	10	10	9.5
The average number of periods per round	1.5	6	9
Number of males	27	25	23
Number of females	21	19	17
Average age	21.021	20.773	20
Economics or business students	4	9	13
Average payment (JPY)	1568	3029	4128
Exchange rate (JPY/point)	3	3	3
Raven score	11.25	11.545	11.1

To check the balance of cognitive ability among three treatments, we conduct the one-way ANOVA to compare the average Raven scores among treatments. The average Raven scores are 11.250 in treatment 1, 11.545 in treatment 2, and 11.1 in treatment 3, which shows no significant difference (p = 0.340). We consider the subjects who have Raven scores larger than the mean before the high-cognitive-ability group and the subjects who have Raven scores smaller or equal to the mean for the low-cognitive-ability group. There are 28, 26 and 22 subjects whose Raven scores are larger than 11 in treatments 1, 2 and 3, respectively. Meanwhile, there are 20, 18 and 18 subjects whose Raven scores are smaller or equal to 11 in treatments 1, 2 and 3, respectively.

4.1 Average Contribution Levels

We examine our hypothesis that the contribution levels are higher in treatment 2 and 3 than in treatment 1, in which subjects behave according to risk dominance. We use first-period decision making, before any effect of other partners' decision. Table 5 shows the first-period average

[2] Due to the time constraint, we conduct nine rounds in one session in treatment 3.

contribution level (%) among treatments in overall, high and low cognitive ability groups. Table 6 shows odds ratio estimates and average marginal effect of the logistic regression of treatments on contribution, with standard error clustered by session.[3] It derives the significance level on the comparison of first-period contribution level among treatments in overall, high and low cognitive ability groups.

Overall, the first-period average contribution levels are 28% in treatment 1, 37% in treatment 2 and 39% in treatment 3, with no significance level between treatment 1 and 2 (p-value =0.258), a 1% significance level between treatment 1 and 3, and no significance level between treatment 2 and 3 (p-value = 0.836). Thus, Hypothesis 1-1 is partly supported.

For high cognitive ability group, the first-period average contribution levels are 21% in treatment 1, 41% in treatment 2 and 44% in treatment 3, with a 5% significance level between treatment 1 and 2, a 1% significance level between treatment 1 and 3, and no significance level between treatment 2 and 3 (p-value = 0.756). For low cognitive ability group, the first-period average contribution levels are 38% in treatment 1, 32% in treatment 2, and 33% in treatment 3 with no significance level between treatment 1 and 2 (p-value=0.552), between treatment 1 and 3 (p value=0.448), and between treatment 2 and 3 (p-value = 0.862). Thus, Hypothesis 2-1 is supported.

Table 5. Summary of first-period average contribution levels (%)

Cognitive Ability Group	**Treatment 1**		**Treatment 2**		**Treatment 3**	
	Mean	Obs.	Mean	Obs.	Mean	Obs.
Overall	28.125	480	37.045	440	38.802	384
	(2.054)		(2.305)		(2.490)	

[3] By following Fréchette (2012), we use the standard errors clustered by sessions.

High	21.429	280	40.769	260	43.602	211
	(2.457)		(3.053)		(3.422)	
Low	37.5	200	31.667	180	32.948	173
	(3.432)		(3.477)		(3.584)	

[a]: The unit of observation is the decision making in the first period in every round. The total number of observations is the number of subjects × number of rounds.

[b]: The standard errors are in parentheses.

Table 6. Odds ratio estimates and average marginal effect of logistic regression of treatments on contribution, with standard error clustered by session.

	(1)		(2)		(3)	
VARIABLES	Contribution		Contribution		Contribution	
	Odds ratio	Average marginal effect	Odds ratio	Average marginal effect	Odds ratio	Average marginal effect
Treatment dummy						
Treatment 2	0.408	0.089	0.926**	0.193*	-0.258	-0.058
	(0.361)	(0.084)	(0.465)	(0.102)	(0.435)	(0.097)
Treatment 3	0.483***	0.107***	1.042***	0.222***	-0.200	-0.046
	(0.044)	(0.009)	(0.276)	(0.047)	(0.278)	(0.065)
Constant	-0.938***		-1.299***		-0.511*	
	(0.041)		(0.276)		(0.276)	
Observations	1,304	1,304	751	751	553	553
Cognitive Ability	Overall	Overall	High	High	Low	Low

Group			
Clusters	8	8	8
Wald chi2	121.966	14.324	0.550
Prob > chi2	0.000	0.001	0.759
Pseudo R2	0.008	0.036	0.002

[a]: Treatment 2 dummy = 1 for treatment 2 and 0 for other treatments. Treatment 3 dummy = 1 for treatment 3 and 0 for other treatments. The default is treatment 1.

[b]: The unit of observation is the decision making in the first period in every round. The total number of observations is the number of subjects × number of rounds.

[c]: The standard errors clustered by session are in parentheses. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

Table 7 shows the odds ratio estimates of logistic regression of RDE on the contribution, with the standard error clustered by session[4]. We make RDE dummy which equals to 1 when GRIM is supported as RDE in treatment 2 and 3, and equal to 0 when GRIM is not supported as RDE in treatment 1. We control the RDE dummy in Model (4) to determine whether contribution level increase when GRIM is supported as RDE. In Model (5), we control the learning effect by adding the experience variable (i.e., reciprocal of the round number) to determine how the method effect or/and learning effect affects decision making. In Model (6), we study how cognitive ability affect contribution levels when GRIM is supported as RDE by adding the variable standardized Raven score and the cross term of RDE dummy and variable standardized Raven score. We standardize the variable Raven score (i.e., Standardized Raven score = (Raven score –Mean)/standard deviation).

Model (4) shows that the coefficient of the RDE dummy is 0.443, with a 5% significance level, while Model (5) shows that the coefficient of the RDE dummy is 0.444, with a 5% significance level. Model (6) shows that the coefficient of the RDE dummy is 0.450, with a 5% significance level. For

[4] By following Fréchette (2012), we use the standard errors clustered by sessions.

all models, the RDE dummy is positive, with a 5% significance level, indicating that the subjects more frequently contribute when GRIM is supported as RDE.

In Model (5), the coefficient of the method dummy is -0.258, with 10% significance level, and the coefficient of experience is 0.453, with a 5% significance level. This result indicates that subjects less frequently contribute in strategy method stage than in direct response method stage. At the same time, the subjects decrease their contribution after learning over time.

In Model (6), the coefficient of RDE dummy × standardized Raven score is 0.502, with a 10% significance level, which indicates that subjects more frequently contribute when their Raven score increases in the treatments that GRIM is supported as RDE. These results show evidence that the subjects with high cognitive ability more frequently behave according to the riskiness of cooperation than the subjects with low cognitive ability. Thus, Hypothesis 2-1 is supported.

Table 7. Odds ratio estimates of logistic regression of RDE on contribution, with standard error clustered by session.

	(4)	(5)	(6)
VARIABLES	Contribution	Contribution	Contribution
RDE dummy	0.443**	0.444**	0.450**
	(0.193)	(0.195)	(0.185)
Method dummy		-0.258*	-0.262*
		(0.153)	(0.155)
Experience		0.453**	0.460**
		(0.221)	(0.223)
Standardized Raven score			-0.235
			(0.268)
RDE dummy × Standardized Raven score			0.502*

			(0.280)
Constant	-0.938***	-0.953***	-0.971***
	(0.041)	(0.138)	(0.134)
Observations	1,304	1,304	1,304
Clusters	8	8	8
Wald chi2	5.271	42.999	117.982
Prob > chi2	0.022	0.000	0.000
Pseudo R2	0.008	0.017	0.027

[a]: RDE dummy = 0 for treatment 1 and 1 for treatment 2 and 3. Method dummy = 0 for direct-response-method stage and 1 for strategy-method stage. Experience = 1/Round.

[b]: The unit of observation is the decision making in the first period in every round. The total number of observations is the number of subjects × number of rounds.

[c]: The standard errors clustered by session are in parentheses. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

4.2 Strategic Analysis

We investigate how subjects employ strategies conditional on a history and partner's contribution. Firstly, we confirm whether the subjects employ strategies conditional on a history that is longer than one period. We adopt Fudenberg et al.'s (2012) regression models, regressing a player's contribution in period t against the same player's contribution in period t-1, the total contribution of the player's partners in period t-1, the player's contribution in period t-2, and the total contribution of the player's partners in period t-2, including controls for treatments which GRIM is supported as RDE, and the player's average contribution in the first period and all periods.

Table 8 shows the odds ratio estimates of the panel data logistic regression of decision-making history on the contribution with a correlated random effect and standard errors clustered by individual. Model (7) uses the entire sample, including both the high- and low-cognitive-ability groups. Model (8) uses the high-cognitive-ability group subsample, while Model (9) uses the low-cognitive-ability group subsample.

The results from Model (7) show a significant positive effect of the partners' total contribution one and two periods ago, and the results from Model (8) show a significant positive effect of the partners' total contribution one period ago in the high-cognitive-ability group. Meanwhile, the results from Model (9) show a significant positive effect of the partners' total contribution two periods ago in the low-cognitive-ability group. The results indicate that the high--ability group is fast to forgive, as they only use their partners' one-period-ahead history, and the low-cognitive-ability group is slow to forgive, as they use their partners' two-periods-ahead history.

Table 8. Odds ratio estimates from panel data logistic regression of decision-making history on contribution, with standard errors clustered by individual

	(7)	(8)	(9)
VARIABLES	Contribution	Contribution	Contribution
Contribution at t-1	0.129***	0.153***	0.107***
	(0.015)	(0.020)	(0.024)
Contribution at t-2	0.010	0.008	0.015
	(0.016)	(0.020)	(0.026)
Partners' contribution at t-1	0.071***	0.093***	0.040***
	(0.010)	(0.013)	(0.016)
Partners' contribution at t-2	0.023**	-0.011	0.069***
	(0.010)	(0.013)	(0.015)

Average overall contribution	0.652***	0.617***	0.705***
	(0.064)	(0.077)	(0.094)
Average Contribution in First Period	-0.135***	-0.099**	-0.178***
	(0.036)	(0.048)	(0.047)
RDE dummy	0.156	0.104	0.122
	(0.374)	(0.507)	(0.552)
Constant	-4.253***	-4.250***	-4.309***
	(0.411)	(0.529)	(0.617)
lnsig2u	-4.812	-13.674	-9.123
	(8.255)	(33.452)	(47.852)
Observations	2,284	1,302	982
Number of subjects	132	76	56
Groups	Overall	High cognitive ability group	Low cognitive ability group
Wald chi2	423.434	294.218	178.959
Prob > chi2	0.000	0.000	0.000

[a]: RDE dummy = 0 for treatment 1 and 1 for other treatments.

[b]: The unit of observation is the decision making in the direct response method stage.

[c]: The standard errors clustered by individual in parentheses. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

Secondly, we confirm whether the subjects employ strategies conditional on their partners. We estimate the odds ratios and average marginal effect of partner's one period ahead history on contribution in direct response method stage. Table 9 shows odds ratio estimates and average marginal effect of logistic regression of one period ahead history of partners on contribution in direct response method stage, with standard error clustered by individual. When the total contribution of partners increases from 0 to 10 at t-1, players increase their contribution at t by 18% in treatment 1, 15% in treatment 2 and 17% in treatment 3. When the total contribution of partners increases from 0 to 20 at t-1, players increase their contribution at t by 52% in treatment 1, 35 % in treatment 2 and 22% in treatment 3. When the total contribution of partners increases from 0 to 30 at t-1, players increase their contribution at t by 29% in treatment 2 and 67% in treatment 3, but no significance in treatment 1. Based on the results, we consider the strategies which are lenient and forgiving, and conditional on one period ahead history for strategy classification.

Table 9. Odds ratio estimates and average marginal effect of logistic regression of one period ahead history of partners on contribution in direct response method stage, with standard error clustered by individual

	(10)		(11)		(12)	
VARIABLES	Contribution		Contribution		Contribution	
At t-1 Partners' contribution	Odds ratio	Average marginal effect	Odds ratio	Average marginal effect	Odds ratio	Average marginal effect
=10	1.185**	0.183***	0.964***	0.145***	1.230***	0.171***
	(0.462)	(0.064)	(0.185)	(0.030)	(0.277)	(0.040)
=20	2.607***	0.522***	1.869***	0.352***	1.479***	0.222***
	(0.572)	(0.116)	(0.294)	(0.059)	(0.309)	(0.055)
=30	2.048	0.386	1.595***	0.285***	3.411***	0.667***
	(1.320)	(0.313)	(0.462)	(0.105)	(0.495)	(0.082)
Constant	-2.048 ***		-1.970 ***		-2.241 ***	
	(0.441)		(0.226)		(0.307)	

Observations	160	160	1,036	1,036	1,576	1,576
Treatment	1	1	2	2	3	3
Clusters	48		44		40	
Wald chi2	21.711		44.218		51.149	
Prob > chi2	0.000		0.000		0.000	
Pseudo R2	0.130		0.083		0.127	

[a]: The total number of observations is the number of subjects × number of periods except for the first period in direct response methods stage.

[b]: The standard errors clustered by individuals are in parentheses. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

4.2.1 Description of strategies

We consider 35 simplified strategies with a one-period ahead history, which includes 20 commonly studied strategies in PD games (Fudenberg et al. 2012). The strategy dataset includes unconditional cooperation (UC), GRIM, other trigger types, tit-for-tat (TFT) types, defective TFT (DTFT, also called suspicious TFT) types, C to All D, DC Alternative, D to All C, and UD strategies. The definition of each strategy is provided in Table 12. Following Fudenberg et al.'s (2012) classification approach, we classify the strategies into fully cooperative, fully non-cooperative, partially cooperative, lenient, forgiving, and unforgiving strategies, as shown in Table 10.

Table 10. Description of strategy types

Strategy	**Description**
UC	Players always cooperate.

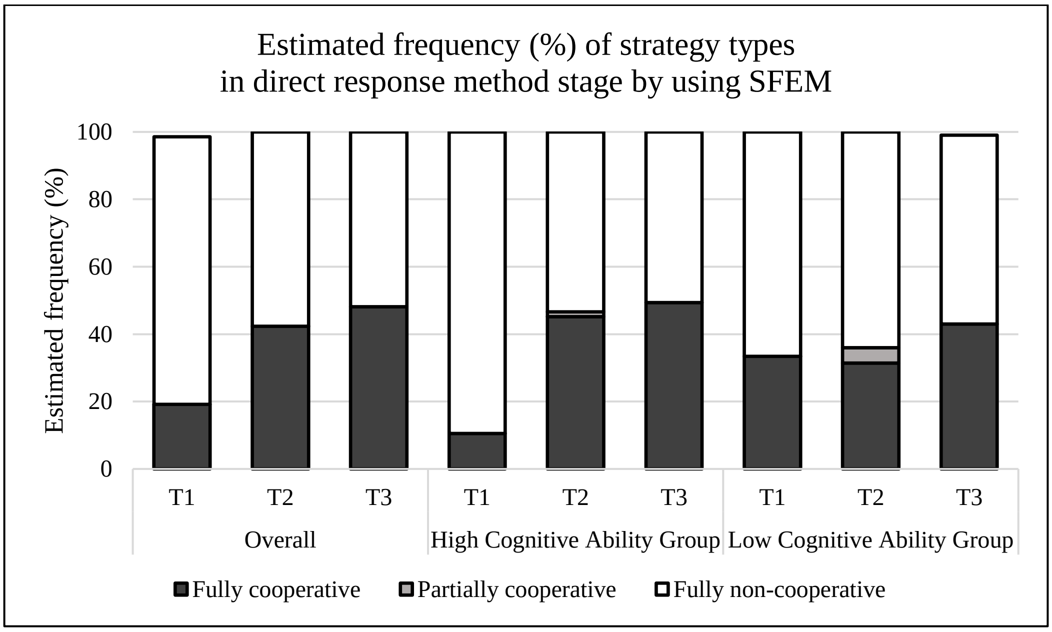
Grim	Players cooperate if all partners cooperate; otherwise, they defect.
Trigger*X*	Players cooperate in the first period and continue cooperating if at least *X* partners cooperate in the previous period; otherwise, they defect forever.
TFT	Players cooperate if all partners cooperate in the previous period.
TFTc*X*d*Y*	Players cooperate in the first period, and they cooperate in the current period if the players cooperate and at least *X* partners cooperate in the previous period. They also cooperate in the current period if the players defect and at least *Y* partners cooperate in the previous period.
DTFT	Players defect in the first period. They cooperate if all partners cooperate in the previous period.
DTFTc*X*d*Y*	Players defect in the first period, and they cooperate in the current period if the players cooperate and at least *X* partners cooperate in the previous period. They also cooperate in the current period if the players defect and at least *Y* partners cooperate in the previous period.
D to All C	Players defect first and then cooperate forever.
C to All D	Players cooperate first and then defect forever.
DC alternative	Players start with defection and then alternate between cooperation and defection.
UD	Players always defect.

Strategy Types

Fully cooperative	The strategies obtain full cooperation when subjects who employ the same type of strategies are matched with each other.
Partially cooperative	The strategies obtain a mixture of cooperation and defection when subjects who employ the same type of strategies are matched with each other.
Fully non-cooperative	The strategies obtain full defection when subjects who employ the same type of strategies are matched with each other.
Lenient	These are fully cooperative strategies that are slower to resort to punishment. They include all fully cooperative strategies, except UC, GRIM, and TFT; In the UC strategy, a player cooperates

	infinitely, while in the GRIM and TFT, a player cooperates infinitely only when all partners contribute fully.
Forgiving	These are fully cooperative strategies that are fast to forgive. They include all cooperative TFT types.
Unforgiving	These are fully cooperative strategies that never forgive. They include all cooperative trigger types.

4.2.2 Direct-Response-Method Stage



[a]: T1 for treatment 1. T2 for treatment 2. T3 for treatment 3.

[b]: Overall uses all samples. High cognitive ability group uses the subsample of high cognitive ability group. Low cognitive ability group uses the subsample of low cognitive ability group.

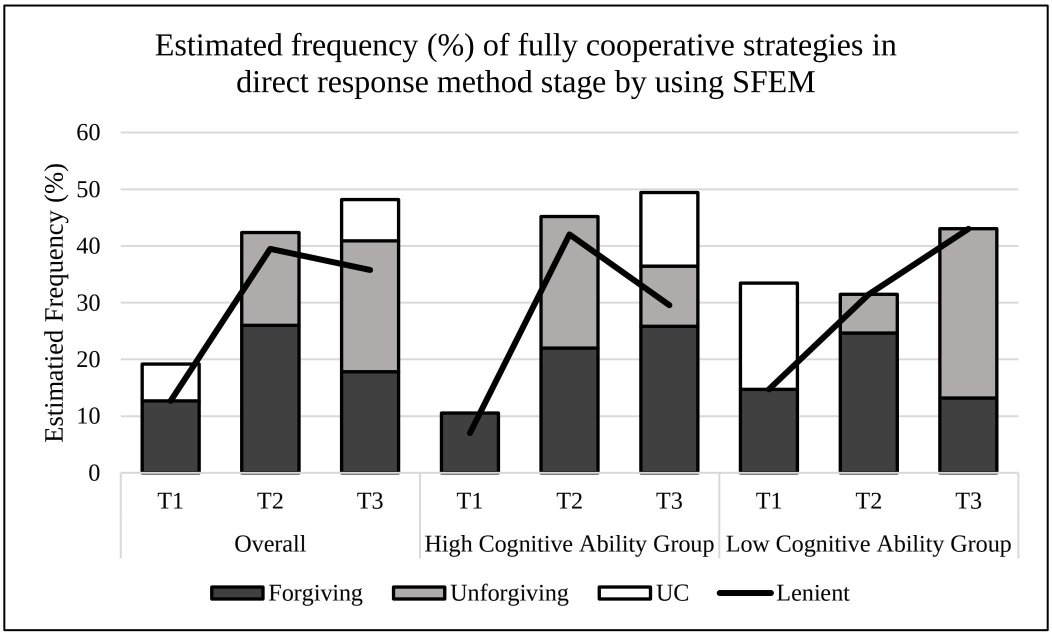
Fig 1. Estimated frequency (%) of strategy types in direct response method stage by using SFEM

We use the SFEM to investigate the types of strategies employed by the subjects in the direct response method stage in infinitely repeated PG games.[5] The SFEM procedure details are explained in the appendix. Figure 1 shows the estimated frequency of strategy types in the direct response method stage. We show the results for the overall sample, the high cognitive ability group subsample, and the low cognitive ability subsample separately.

Overall, fully cooperative strategies are 19% in treatment 1, 42% in treatment 2, and 48% in treatment 3. Subjects more frequently employ fully cooperative strategies in treatments 2 and treatment 3 than in treatment 1. Hypothesis 1-2 is supported.

For the high-cognitive-ability group, the frequencies of the fully cooperative strategies are 11% in treatment 1, 45% in treatment 2, and 49% in treatment 3. Subjects with high cognitive ability more frequently employ fully cooperative strategies in treatments 2 and treatment 3 than in treatment 1. For the low-cognitive-ability group, the frequencies of the fully cooperative strategies are 33 % in treatment 1, 32% in treatment 2, and 43% in treatment 3. Subjects with low cognitive ability employ fully cooperative strategies with similar frequencies among the three treatments. Hypothesis 2-2 is supported.

[5] We thank you Dal Bó and Fréchette (2011) and Bigoni et al., (2015) for providing their code for strategy estimation. We based on Bigoni et al.'s (2015) code for our strategy estimation.



[a]: T1 for treatment 1. T2 for treatment 2. T3 for treatment 3. Overall uses all samples.

[b]: High cognitive ability group uses the subsample of high cognitive ability group. Low cognitive ability group uses the subsample of low cognitive ability group.

Fig 2. Estimated frequency (%) of fully cooperative strategies in direct response method stage by using SFEM

Figure 2 shows the estimated frequency of fully cooperative strategies in the direct response method stage using SFEM. Fully cooperative strategies include forgiving strategies, unforgiving strategies, UC, and lenient strategies. Forgiving strategies include all TFT types. Unforgiving strategies include all trigger type strategies. Lenient strategies include all fully cooperative strategies, except UC, GRIM, and TFT.

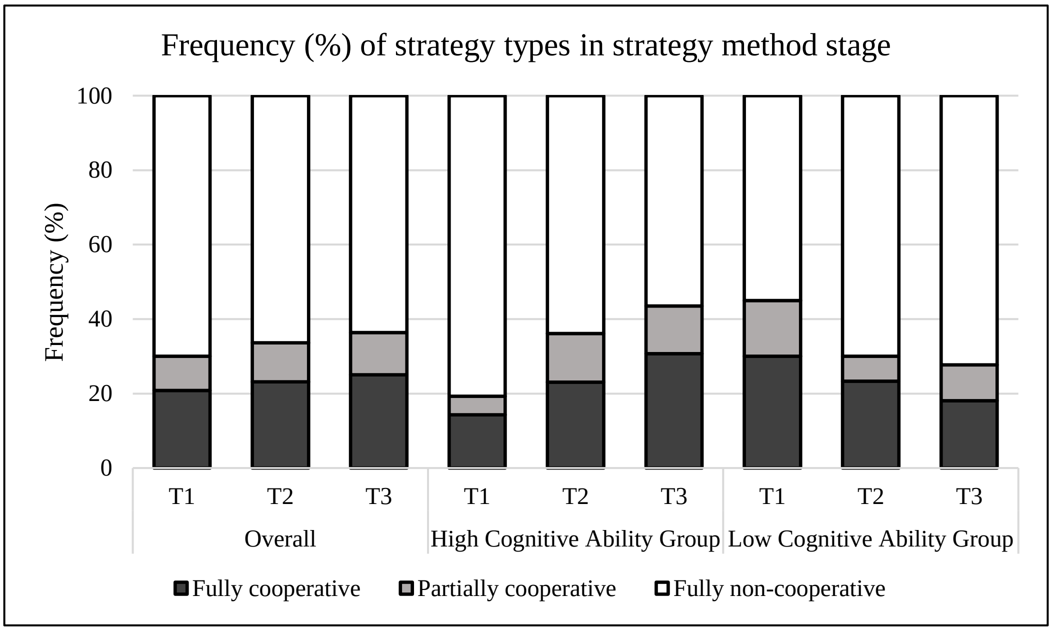
Lenient strategies are more frequently observed in treatment 2 and treatment 3 than in treatment 1. Overall, lenient strategies are 13% in treatment 1, 39 % in treatment 2, and 36% in treatment 3. For the high cognitive ability group, lenient strategies are 7% in treatment 1, 42% in treatment 2, and 30% in treatment 3. For the low cognitive ability group, lenient strategies are 15% in treatment 1, 31% in treatment 2 and 43% in treatment 3. It indicates that subjects always become more lenient when GRIM is supported as RDE. Forgiving strategies are more frequently observed in treatments 2 and treatment 3 than in treatment 1 for the high cognitive ability group which is 11% in treatment 1, 22% in treatment 2, 26% in treatment 3, but not for the low cognitive ability group or overall which is 15% in treatment 1, 25% in treatment 2, 13% in treatment 3.[6]

UC is unconditionally contributing to the public goods, no matter how their partners contribute. We consider the combination of lenient strategies and UC and the combination of forgiving strategies and UC to discuss leniency and forgivingness. When the δ increases, the total frequency of UC and lenient strategies increases in high cognitive ability group which is 7% in treatment 1, 42% in treatment 2 and 43% in treatment 3, but become similar in low cognitive ability group which is 33% in treatment 1, 31% in treatment 2, 43% in treatment 3.

When the δ increases, the total frequency of UC and forgiving strategies increases among high cognitive ability group which is 11% in treatment 1, 22% in treatment 2, 39% in treatment 3, but decreases among low cognitive ability group which is 33% in treatment 1, 25% in treatment 2, 13% in treatment 3.

4.2.3 Strategy Method Stage

[6] In treatment 1, due to the short length of the game, we cannot differentiate TFT types and trigger types. Therefore, we cannot clearly classify the strategies into forgiving strategies or unforgiving strategies.



[a]: T1 for treatment 1. T2 for treatment 2. T3 for treatment 3.

[b]: Overall uses all samples. High cognitive ability group uses the subsample of high cognitive ability group. Low cognitive ability group uses the subsample of low cognitive ability group.

Fig 3. Frequency (%) of strategy types in strategy method stage

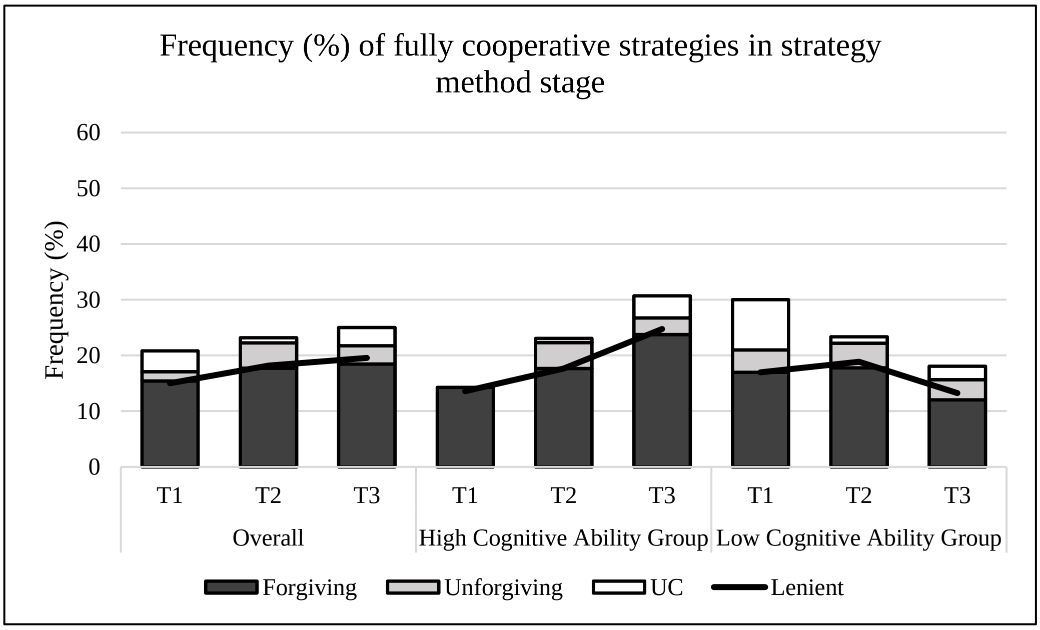
We classify the strategies based on the strategic plan. The details of strategy classification are shown in the appendix. Figure 3 shows the frequency of strategy types in the strategy methods stage for overall, high and low cognitive ability group. We derive the significance level of the comparison of strategy types among treatments based on a logistic regression of the treatment dummy in each strategy type, with standard errors clustered by sessions.[7]

Overall, fully cooperative strategies are 21% in treatment 1, 23% in treatment 2, and 25% in treatment 3. The subjects employ fully cooperative strategies with similar frequency among treatments (T1 vs. T2: p-value =0.754; T1 vs. T3: p-value=0.347). Hypothesis 1-2 is not supported.

For the high cognitive ability group, fully cooperative strategies are 14% in treatment 1, 23% in treatment 2, and 31% in treatment 3. The subjects with high cognitive ability more frequently employ

[7] The results are shown in the appendix.

fully cooperative strategies in treatment 3 than in treatment 1 (T1 vs. T3: p-value<0.001), but there is no significant difference between treatments 1 and 2 (T1 vs. T2: p-value=0.289). For the low cognitive ability group, fully cooperative strategies are 30% in treatment 1, 23% in treatment 2, and 18% in treatment 3. The subjects employ fully cooperative strategies with a similar frequency among treatments (T1 vs. T2: p-value=0.554; T1 vs. T3: p-value=0.297). The results show that only the subjects with high cognitive ability become more cooperative when GRIM is supported as RDE. Hypothesis 2-2 is partly supported.



[a]: T1 for treatment 1. T2 for treatment 2. T3 for treatment 3.

[b]: High cognitive ability group only uses the subsample of high cognitive ability group. Low cognitive ability group only uses the subsample of low cognitive ability group.

Fig 4. Frequency (%) of fully cooperative strategies in the strategy method stage

Figure 4 shows the frequency of fully cooperative strategies in the strategy method stage. For overall, the frequencies of lenient strategies are 15% in treatment 1, 18% in treatment 2, 20% in treatment 3. For high cognitive ability, the frequency of lenient strategies is 14% in treatment 1, 18% in treatment

2, 25% in treatment 3. For low cognitive ability, the frequency of lenient strategies is 17% in treatment 1, 19% in treatment 2, 13% in treatment 3. The frequencies of lenient strategies are similar among treatments overall (T1 vs. T2: p-value=0.611; T1 vs. T3: p-value=0.311), for the high cognitive ability group (T1 vs. T2: p-value=0.631; T1 vs. T3: p-value=0.118) and the low cognitive ability group (T1 vs. T2: p-value=0.784; T1 vs. T3: p-value=0.585). The results show that leniency to their partners is similar across cognitive ability among treatments in the strategy method stage.

For overall, the frequencies of forgiving strategies are 15% in treatment 1, 18% in treatment 2, 18% in treatment 3. For high cognitive ability, the frequency of forgiving strategies is 14% in treatment 1, 18% in treatment 2, 24% in treatment 3. For low cognitive ability, the frequency of forgiving strategies is 17% in treatment 1, 18% in treatment 2, 12% in treatment 3. The frequencies of forgiving strategies are similar among treatments overall (T1 vs. T2: p-value=0.702; T1 vs. T3: p-value=0.594), for the high cognitive ability group (T1 vs. T2: p-value=0.666; T1 vs. T3: p-value=0.166) and the low cognitive ability group (T1 vs. T2: p-value=0.877; T1 vs. T3: p-value=0.508). The results show that forgiveness to their partners is similar across cognitive ability among treatments in the strategy method stage.

When the δ increases, the total frequency of UC and lenient strategies increases in high cognitive ability group which is 14% in treatment 1, 18% in treatment 2, 29% in treatment 3 (T1 vs. T2: p-value=0.564; T1 vs. T3: p-value=0.022), but remains similar in low cognitive ability group which is 26% in treatment 1, 20% in treatment 2, 16% in treatment 3 (T1 vs. T2: p-value=0.594; T1 vs. T3: p-value=0.358). Besides, when the δ increases, the total frequency of UC and forgiving strategies increases among high cognitive ability group which is 14% in treatment 1, 18% in treatment 3, 28% in treatment 3 (T1 vs. T2: p-value=0.568; T1 vs. T3: p-value=0.017), but keeps similar among low cognitive ability group which is 26% in treatment 1, 19% in treatment 2, 14% in treatment 3 (T1 vs. T2: p-value=0.428; T1 vs. T3: p-value=0.306).

5. Discussion

We discuss the reasons that the hypothesis 1-1 is partly supported and hypothesis 1-2 is supported in direct response method stage but not supported in the strategy method stage. Firstly, let us discuss the hypothesis 1-1 case. For overall, compared with treatment 1, the first-period average contribution level is higher in treatment 3 but not in treatment 2. Although subjects with high cognitive ability increase their first-period contribution level when GRIM is supported as RDE, subjects with low cognitive ability behave similarly among treatments. Secondly, let us discuss hypothesis 1-2. It is supported in the direct response method stage, but not in strategy method stage. In strategy method stage, subjects with high cognitive ability employ more fully cooperative strategies when the δ increase, but subjects with low cognitive ability employ less fully cooperative strategies when the δ increase. Therefore, for overall, the frequency of fully cooperatives is similar among treatments in strategy method stage.

We cannot explain the behavior among subjects with low cognitive ability. We suggest that the possible reasons that may be the differences in the belief on partners between high cognitive ability group and low cognitive ability group. There is still not enough evidence to explain the behavior of low cognitive ability group. When there are more studies about the cognitive ability on repeated behavior in the future, we may explain the low cognitive ability group's behavior.

To discuss leniency and forgivingness, we consider the combination of lenient strategies and UC and the combination of forgiving strategies and UC. When the δ increases, the total frequency of UC and lenient strategies increases in high cognitive ability group, but remains similar in low cognitive ability. Although there is no significant difference in the total frequency of lenient strategies and UC among treatments in low cognitive ability, there is a slight increasing trend in direct response method and slightly decreasing trend in strategy method trend. In direct response method stage, low cognitive ability subjects can update their action by observing their partners. Therefore, they become lenient by learning from their partners. However, in strategy method stage, subjects cannot update their action in the middle of the game. It becomes the possible reasons to explain why low cognitive ability subjects behave differently on leniency between direct response method stage and strategy method stage.

When the δ increases, the total frequency of UC and forgiving strategies increases among high cognitive ability group, but decreases among low cognitive ability group in direct response method stage. We show that high cognitive ability subjects employ strategies by taking one period of history, but low cognitive ability subjects employ strategies by taking two periods of history, which means high cognitive ability subjects are fast to forgive, but low cognitive ability subjects are slow to forgiving. With the long history in high δ, low cognitive ability subjects are less likely to forgive their defective partners.

6. Conclusion

We experimentally investigate the infinitely repeated PG game under the increasing δ. In treatment 1, the cooperative strategy is not supported as RDE, while in treatment 2 and 3, the cooperative strategy is. The results of these experiments demonstrate cognitive ability's effect on the equilibrium selection in the infinitely repeated PG game. Compared with the low-cognitive-ability group, the subjects with high cognitive ability tend to be more cooperative in treatment 2 and 3. These results show that the subjects with high cognitive ability more frequently behave according to a more efficient equilibrium RDE, but it cannot reflect among the subjects with low cognitive ability.

We consider the combination of lenient strategies and UC and the combination of forgiving strategies and UC to discuss the leniency and forgiving. In the direct-response-method stage, subjects with high cognitive ability tend to be more cooperative, lenient and forgiving in treatment 2 and treatment 3 than in treatment 1, but subjects with low cognitive ability tend to be less forgiving in treatment 2 and treatment 3 than in treatment 1, but remains similar leniency across treatments. In the strategy method stage, the subjects with high cognitive ability tend to be more cooperative, lenient and forgiving in treatment 3 than in treatment 1, but no significant difference between treatment 1 and 2. For the subjects with low cognitive ability, there is no significant difference in cooperativeness, forgiveness, and leniency among treatments.

GRIM does not describe the subjects' actions well. Rather, the subjects employ a wide diversity of strategies. The frequency of players employing GRIM when it is supported as SPE and RDE is very low compared with the experimental results in the infinitely repeated PD game. However, most players employ a wide range of lenient and forgiving TFT-type strategies. The subjects with higher cognitive ability are slower to anger (lenient) and faster to forgive (forgiving) when the cooperative strategy is supported as RDE.

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Appendix

Strategy Frequency Estimation Method (SFEM)

We employ the SFEM, following Dal Bó and Fréchette (2011) and Fudenberg et al. (2012), to estimate the subjects' strategies in the first five rounds (direct-response method stage).

The method works on the history of play as follows. First, we generate the simulated action sequence by following the constructed strategy set which 35 simplified strategies considered in Table 10. We compare a subject's actual action sequence against the simulated action sequence generated by a given strategy from constructed strategy set s^k. Then, strategy s^k correctly matches the subject's action sequence C times and does not match the sequence E times. Therefore, the probability that player i employs strategy k is given by

$$P_i(s^k) = \prod_{round} \prod_{period} \beta^C (1-\beta)^E$$

β is the probability of correctly matching actions from the constructed strategy set and actions from the subjects. In each period, the subject plays according to the chosen strategy with probability $\beta \in (\frac{1}{2}, 1)$and makes a mistake with probability (1-β). When β is close to $\frac{1}{2}$, choices are almost random, and when it is close to 1, choices are almost perfectly predicted. In addition, the likelihood function is given by

$$\mathcal{L}(\beta, \phi) = \sum_{i \in Subjects} \ln\left(\sum_{k \in Strategies} \phi^k P_i(s^k) \right)$$

ϕ^k is the frequency of strategy k.

For each treatment, we draw 100 random samples to calculate bootstrapped standard deviations. Firstly, we generate random samples using the following two ways. For the analysis of the entire sample, we take all subjects in a given treatment and draw them at random with replacement until the random sample has as many subjects as in the treatment. For the analysis of the high-/low-cognitive-ability group subsample, we take all subjects from each subsample in a given treatment and draw them at random with replacement until the random sample has as many subjects as in the corresponding cognitive ability group in the treatment. Secondly, we estimate the strategy frequencies for each random sample. Finally, we calculate the bootstrapped standard deviations.

Table A1. Description of strategy choices 1–9 and strategy types in strategy method stage

Strategic choices			Strategy Types					Strategies			
Choice	Own Contribution at t-1	Partners' Contribution at t-1	Fully Cooperative	Partially Cooperative 1	Partially Cooperative 2	Fully non-cooperative	Unforgiving	UC	UD	GRIM	TFT
1	0	0	0 or 10	0 or 10	10	0	0	0 or 10	0	0	0
2	0	10	0 or 10	0 or 10	0 or 10	0 or 10	0	0 or 10	0	0	0
3	0	20	0 or 10	0 or 10	0 or 10	0 or 10	0	0 or 10	0	0	0
4	0	30	0 or 10	0 or 10	0 or 10	0 or 10	0	0 or 10	0	0	10
5	10	0	0 or 10	0 or 10	0 or 10	0 or 10	0 or 10	10	0 or 10	0	0
6	10	10	0 or 10	0 or 10	0 or 10	0 or 10	0 or 10	10	0 or 10	0	0
7	10	20	0 or 10	0 or 10	0 or 10	0 or 10	0 or 10	10	0 or 10	0	0
8	10	30	10	0	0 or 10	0 or 10	10	10	0 or 10	10	10
9	First Period		10	10	0	0	10	10	0	10	10

[a]: The conditions of each strategy types are as follows. When Choice 8 and 9 is 10, they are fully cooperative strategies because the strategies obtain full cooperation when subjects who employ the same type of strategies are matched with each other. When Choice 9 is 10 and Choice 8 is 0 or Choice 9 is 0 or Choice1 is 10, they are partially cooperative strategies because the strategies obtain a mixture of cooperation and defection when subjects who employ the same type of strategies are matched with each other. When Choice 1 and 9 are 0, they are fully non-cooperative strategies because the strategies obtain full defection when subjects who employ the same type of strategies are matched with each other. When Choice 9 is 10 and Choice 1 to 4 is 0, they are unforgiving strategies.

[b]: Forgiving strategies are all TFT types. Lenient strategies are all fully cooperative strategies which are not GRIM and TFT and UC.

Table A2. Estimation of strategies used in treatment 1(data from the direct-response-method stage)

Overall				High cognitive ability group				Low cognitive ability group			
Strategy	Freq. (%)	SD	p-value	Strategy	Freq. (%)	SD	p-value	Strategy	Freq. (%)	SD	p-value
UC	6.512	0.046	0.080	TFT	3.506	0.017	0.019	UC	18.702	0.110	0.045
TFTc3d2	6.392	0.041	0.058	TFTc2d3	3.507	0.017	0.019	TFTc3d2	7.377	0.056	0.093
TFTc1d2	6.298	0.041	0.062	TFTc1d3	3.506	0.017	0.019	TFTc1d2	7.365	0.055	0.092
DTFT2	25.958	0.138	0.030	DTFT1	9.851	0.079	0.106	DTFT2	62.004	0.242	0.005
DTFT1	7.281	0.070	0.150	DTFTc2d3	7.555	0.066	0.127	DTFTc3d0	1.517	0.019	0.217
DTFT	3.838	0.045	0.197	DTFTc1d3	7.498	0.066	0.128	DTFTc1d0	1.517	0.019	0.217
DTFTc2d3	3.846	0.045	0.197	DTFT	7.442	0.066	0.130	DTFTc2d0	1.517	0.019	0.217
DTFTc1d3	3.820	0.045	0.198	DTFTc0d3	7.498	0.066	0.128	γ	72.426	0.088	0.000
DTFTc0d3	3.820	0.045	0.198	UD	49.632	0.256	0.026	β	79.911		
UD	30.834	0.224	0.084	γ	53.485	0.061	0.000				
γ	61.857	0.066	0.000	β	86.642						
β	83.433										

[a]: The table reports the estimated frequency of each strategy in the population. We show the strategies which their estimated frequencies are larger than 1%.

[b]: The parameter γ is used in estimation with $\beta = \frac{1}{1+\exp(^{-1}/_{\gamma})}$.

Table A3. Estimation of strategies used in treatment 2 (data from the direct-response-method stage)

Overall				High cognitive ability group				Low cognitive ability group			
Strategy	Freq. (%)	SD	p-value	Strategy	Freq. (%)	SD	p-value	Strategy	Freq. (%)	SD	p-value
Trigger1	12.426	0.058	0.017	Trigger1	20.565	0.113	0.034	Trigger2	6.793	0.058	0.123
Trigger2	3.930	0.050	0.217	Trigger2	2.662	0.046	0.283	TFT2	19.199	0.126	0.063
TFT1	15.955	0.054	0.002	TFT1	18.788	0.065	0.002	TFT1	5.474	0.071	0.222
TFT2	7.178	0.056	0.101	TFT	3.190	0.042	0.222	DTFT1	5.152	0.072	0.236
TFT	2.870	0.030	0.166	DC alternative	1.377	0.000	0.000	C to All D	4.511	0.049	0.180
DTFTc3d2	1.114	0.018	0.267	DTFT	8.446	0.100	0.199	UD	58.870	0.157	0.000
DTFTc1d2	1.114	0.018	0.267	DTFTc3d2	2.663	0.024	0.129	γ	56.506	0.095	0.000
DTFTc0d2	1.114	0.018	0.267	DTFTc1d0	2.663	0.024	0.129	β	85.442		
UD	54.299	0.105	0.000	DTFTc0d2	2.663	0.024	0.129				
γ	64.511	0.070	0.000	UD	36.983	0.197	0.030				
β	82.493			γ	68.832	0.092	0.000				
				β	81.043						

[a]: The table reports the estimated frequency of each strategy in the population. We show the strategies which their estimated frequencies are larger than 1%.

[b]: The parameter γ is used in estimation with $\beta = \frac{1}{1+\exp(-1/\gamma)}$.

Table A4. Estimation of strategies used in treatment 3 (data from the direct-response-method stage)

Overall				High cognitive ability group				Low cognitive ability group			
Strategy	Freq. (%)	SD	p-value	Strategy	Freq. (%)	SD	p-value	Strategy	Freq. (%)	SD	p-value
UC	7.289	0.050	0.070	UC	12.983	0.092	0.078	Trigger1	20.423	0.107	0.028
Grim	5.135	0.054	0.170	Grim	6.879	0.057	0.114	Trigger2	9.386	0.081	0.123
Trigger1	14.521	0.063	0.010	Trigger1	3.681	0.104	0.361	TFT2	13.209	0.084	0.058
Trigger2	3.378	0.042	0.212	TFT1	13.838	0.075	0.032	DTFT1	4.833	0.043	0.133
TFT2	10.241	0.049	0.018	TFT2	5.116	0.068	0.224	UD	51.193	0.154	0.000
TFT1	4.805	0.047	0.154	TFTc1d2	3.454	0.025	0.084	γ	46.942	0.073	0.000
TFTc1d2	1.395	0.017	0.203	TFTc3d2	3.448	0.025	0.083	β	89.381		
TFTc3d2	1.406	0.017	0.202	UD	50.601	0.199	0.005				
DTFT1	1.520	0.020	0.226	γ	54.082	0.074	0.000				
UD	50.312	0.147	0.000	β	86.401						
γ	50.847	0.052	0.000								
β	87.725										

[a]: The table reports the estimated frequency of each strategy in the population. We show the strategies which their estimated frequencies are larger than 1%.

[b]: The parameter γ is used in estimation with $\beta = \frac{1}{1+\exp(-1/\gamma)}$.

Table A5. Summary of estimated frequency (%) of strategy types in direct response method by using SFEM

Strategy Types	Overall			High Cognitive Ability Group			Low Cognitive Ability Group		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
Fully cooperative	19.202	42.359	48.170	10.519	45.205	49.399	33.444	31.466	43.018
UC	6.512	0	7.289	0	0	12.983	18.702	0	0
Lenient	12.690	39.489	35.746	7.013	42.015	29.537	14.742	31.466	43.018
Forgiving	12.690	26.003	17.847	10.519	21.978	25.856	14.742	24.673	13.209
Unforgiving	0	16.356	23.034	0	23.227	10.560	0	6.793	29.809
Partially cooperative	0	0	0	0	1.377	0	0	4.511	0
Fully non-cooperative	79.397	57.641	51.832	89.476	53.418	50.601	66.555	64.022	56.026

[a]: T1 indicates treatment 1. T2 indicates treatment 2. T3 indicates treatment 3.

Table A6. Estimation of strategies used in the strategy method stage

Treatment 1		Treatment 2		Treatment 3	
Strategy	Freq.	Strategy	Freq.	Strategy	Freq.
UC	9	UC	2	UC	6
GRIM	2	GRIM	6	GRIM	3
Trigger 1	1	Trigger 2	4	Trigger 1	1
Trigger 2	1	TFT	3	Trigger 2	2
TFT	3	TFTc1d1	2	TFT	1
TFTc1d1	1	TFTc1d2	8	TFTc1d1	5
TFTc1d2	17	TFTc1d3	1	TFTc1d2	10
TFTc1d3	2	TFTc2d2	3	TFTc2d1	1
TFTc2d2	1	TFTc2d0	1	TFTc2d2	5
TFTc2d3	4	TFTc2d3	8	TFTc2d3	6
TFTc3d2	1	TFTc3d0	1	TFTc3d0	1
C to All D	4	TFTc3d2	1	C to All D	5
DTFT	5	C to All D	3	D to All C	1
DTFTc1d2	10	DTFT	2	DTFT	7
DTFTc1d3	1	DTFTc0d2	1	DTFTc1d2	8
DTFTc2d2	10	DTFTc1d2	1	DTFTc1d3	3
DTFTc2d3	19	DTFTc1d3	1	DTFTc2d2	3
DTFTc3d1	1	DTFTc2d2	2	DTFTc2d3	6
DTFTc3d2	2	DTFTc2d3	8	UD	72
UD	99	DTFTc3d2	2	Unclassified	38
Unclassified	47	UD	105	Obs.	184
Obs.	240	Unclassified	55		
		Obs.	220		

[a]: The unit of observation is the decision making in every round in the strategy-method stage.

[b]: The total number of observations is the number of subjects × the number of rounds in the strategy method stage.

Table A7. Estimation of strategies used in the strategy method stage in high cognitive ability group

Treatment 1		Treatment 2		Treatment 3	
Strategy	Freq.	Strategy	Freq.	Strategy	Freq.
TFT	1	UC	1	UC	4
TFTc1d2	11	GRIM	4	GRIM	1
TFTc2d2	1	Trigger 2	2	Trigger 1	1
TFTc2d3	3	TFT	2	Trigger 2	1
TFTc3d2	1	TFTc1d1	2	TFT	1
C to All D	4	TFTc1d2	4	TFTc1d1	4
DTFT	4	TFTc2d0	1	TFTc1d2	6
DTFTc1d2	8	TFTc2d3	5	TFTc2d1	1
DTFTc1d3	1	TFTc3d0	1	TFTc2d2	4
DTFTc2d2	10	TFTc3d2	1	TFTc2d3	4
DTFTc2d3	14	C to All D	2	C to All D	4
UD	62	DTFT	2	D to All C	1
Unclassified	20	DTFTc1d3	1	DTFT	5
Obs.	140	DTFTc2d2	2	DTFTc1d2	3
		DTFTc2d3	2	DTFTc2d2	2
		DTFTc3d2	2	DTFTc2d3	2
		UD	60	UD	32
		Unclassified	36	Unclassified	25
		Obs.	130	Obs.	101

[a]: The unit of observation is the decision making in every round in the strategy-method stage.

[b]: The total number of observations is the number of subjects with high cognitive ability× the number of rounds in the strategy method stage.

Table A8. Estimation of strategies used in the strategy method stage in low cognitive ability group

Treatment 1		Treatment 2		Treatment 3	
Strategy	Freq.	Strategy	Freq.	Strategy	Freq.
UC	9	UC	1	UC	2
GRIM	2	GRIM	2	GRIM	2
Trigger 1	1	Trigger 2	2	Trigger 2	1
Trigger 2	1	TFT	1	TFTc1d1	1
TFT	2	TFTc1d2	4	TFTc1d2	4
TFTc1d1	1	TFTc1d3	1	TFTc2d2	1
TFTc1d2	6	TFTc2d2	3	TFTc2d3	2
TFTc1d3	2	TFTc2d3	3	TFTc3d0	1
TFTc2d3	1	C to All D	1	C to All D	1
DTFT	1	DTFTc0d2	1	DTFT	2
DTFTc1d2	2	DTFTc1d2	1	DTFTc1d2	5
DTFTc2d3	5	DTFTc2d3	6	DTFTc1d3	3
DTFTc3d1	1	UD	45	DTFTc2d2	1
DTFTc3d2	2	Unclassified	19	DTFTc2d3	4
UD	37	Obs.	90	UD	40
Unclassified	27			Unclassified	13
Obs.	100			Obs.	83

[a]: The unit of observation is the decision making in every round in the strategy-method stage.

[b]: The total number of observations is the number of subjects with low cognitive ability× the number of rounds in the strategy method stage.

Table A9. Summary of frequency (%) of strategy types in strategy method stage

	Overall			High Cognitive Ability Group			Low Cognitive Ability Group		
Strategy Types	T1	T2	T3	T1	T2	T3	T1	T2	T3
Fully cooperative	20.833	23.182	25	14.286	23.077	30.693	30	23.333	18.072
UC	3.750	0.909	3.261	0.000	0.769	3.960	9.000	1.111	2.410
Lenient	15	18.182	19.565	13.571	17.692	24.752	17	18.889	13.253
Forgiving	15.417	17.727	18.478	14.286	17.692	23.762	17	17.778	12.048
Unforgiving	1.667	4.545	3.261	0	4.615	2.970	4	4.444	3.614
Partially cooperative	9.167	10.455	11.413	5.000	13.077	12.871	15	6.667	9.639
Fully non-cooperative	70	66.364	63.587	80.714	63.846	56.436	55	70	72.289
Obs.	240	220	184	140	130	101	100	90	83

[a]: T1 for treatment 1. T2 for treatment 2. T3 for treatment 3.

[b]: The total number of observations is the number of subjects with overall or high or low cognitive ability× the number of rounds in the strategy method stage.

Table A10. Odds ratio estimates of logistic regression of treatments on the strategy types, with standard error clustered by session.

VARIABLES	(1) Fully cooperative	(2) Lenient	(3) Forgiving	(4) Fully cooperative	(5) Lenient	(6) Forgiving	(7) Fully cooperative	(8) Lenient	(9) Forgiving
Treatment 2 dummy	0.137	0.231	0.167	0.588	0.314	0.254	-0.342	0.128	0.054
	(0.437)	(0.453)	(0.438)	(0.554)	(0.654)	(0.589)	(0.578)	(0.467)	(0.351)
Treatment 3 dummy	0.236	0.321	0.218	0.977***	0.739	0.626	-0.664	-0.293	-0.402
	(0.251)	(0.317)	(0.409)	(0.351)	(0.474)	(0.452)	(0.637)	(0.537)	(0.608)
Constant	-1.335***	-1.735***	-1.702***	-1.792***	-1.851***	-1.792***	-0.847**	-1.586***	-1.586***
	(0.123)	(0.131)	(0.170)	(0.343)	(0.412)	(0.343)	(0.396)	(0.322)	(0.181)
Observations	644	644	644	371	371	371	273	273	273
Clusters	8	8	8	8	8	8	8	8	8
Data		Overall			High Cognitive Ability Group			Low Cognitive Ability Group	
Wald chi2	0.920	1.180	0.374	8.375	2.639	1.963	1.113	0.600	0.506
Prob > chi2	0.631	0.554	0.829	0.015	0.267	0.375	0.573	0.741	0.777
Pseudo R2	0.002	0.003	0.001	0.025	0.014	0.010	0.012	0.004	0.005

[a]: Treatment 2 dummy = 1 for treatment 2 and 0 for other treatments. Treatment 3 dummy = 1 for treatment 3 and 0 for other treatments. The default is treatment 1.
[b]: Fully cooperative =1 for fully cooperative strategies and 0 for other strategy types. Lenient=1 for lenient strategies and 0 for other strategy types. Forgiving=1 for forgiving strategies and 0 for unforgiving strategies. [c]: The total number of observations is the number of subjects × number of rounds in strategy methods stage. The standard errors clustered by session are in parentheses. *** p < 0.01, ** p < 0.05, and * p < 0.1

Table A11. Odds ratio estimates of logistic regression of treatments on the strategy types, with standard error clustered by session.

VARIABLES	(10) Lenient and UC	(11) Lenient and UC	(12) Forgiving and UC	(13) Forgiving and UC
Treatment 2 dummy	0.366	-0.340	0.306	-0.411
	(0.634)	(0.638)	(0.562)	(0.519)
Treatment 3 dummy	0.942**	-0.638	0.834**	-0.732
	(0.412)	(0.694)	(0.351)	(0.714)
Constant	-1.851***	-1.046**	-1.792***	-1.046***
	(0.412)	(0.514)	(0.343)	(0.393)
Observations	371	273	371	273
Clusters	8.000	8.000	8.000	8.000
Cognitive ability group	High	Low	High	Low
Wald chi2	6.625	0.844	6.834	1.211
Prob > chi2	0.036	0.656	0.033	0.546
Pseudo R2	0.023	0.011	0.018	0.014

[a]: Treatment 2 dummy = 1 for treatment 2 and 0 for other treatments. Treatment 3 dummy = 1 for treatment 3 and 0 for other treatments. The default is treatment 1.

[b]: Lenient and UC =1 for lenient strategies or UC and 0 for other strategy types. Forgiving and UC =1 for forgiving strategies or UC and 0 for other strategy types.

[c]: The total number of observations is the number of subjects × number of rounds in strategy methods stage. The standard errors clustered by session are in parentheses. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

Sample of Experimental Instruction for treatment 3 (in Japanese)

経済実験説明書

実験にご参加いただきありがとうございます。これから、経済実験を行います。説明書をよく読み、内容を完全に理解して参加ください。何か不明な点があれば、すぐに手を上げスタッフにお知らせください。

1. 配布資料

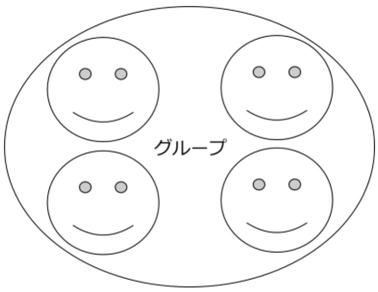
席に着いたら、A4 用紙の紙が 5 種類あることを確認して下さい。

1. 実験参加同意書　2. 実験説明書　3. 画面説明書　4. 記録用紙　5. 領収書

2. 実験の報酬について

実験の報酬は 2 つの部分からなります。1 つは**参加報酬**です。参加報酬として皆様全員に 1000 円をお支払いします。もう 1 つは**成果報酬**です。成果報酬は実験の結果によって決まります。

3. グループの決まり方

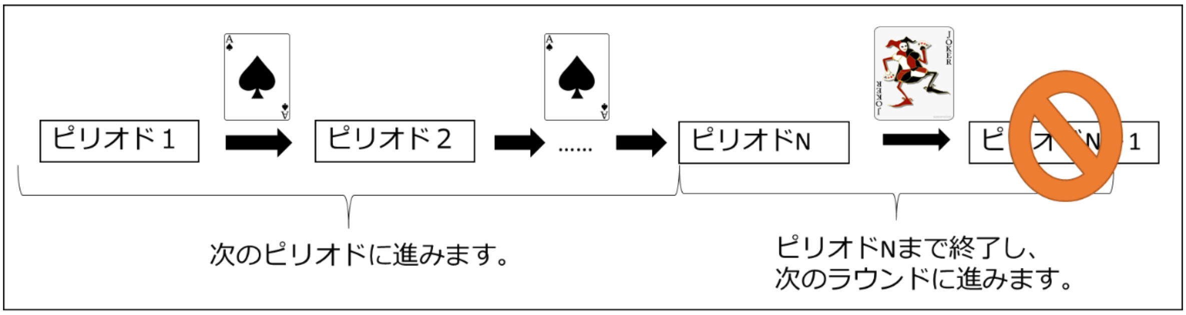


- ゲーム開始時に、グループがランダムに決まります。全てのグループは **4 人**の参加者からなります。グループ番号がコンピュータ画面に表示されます。
- 各ラウンドで、グループは同じです。あなたは、グループのメンバーが誰なのかを知ることはできません。
- 実験は **10 ラウンド**からなります。この実験は、**前半 5** ラウンドと**後半 5** ラウンドで意思決定の仕方が異なりますが、グループの決まり方とピリオドの決まり方は同じです。
- 各ラウンドの開始時点で、全てのグループはランダムに組みなおされます。従って、あなたはもう一度同じメンバーとグループを組むかもしれませんし、まったく新しいメンバーとグループを組むかもしれません。
- グループ番号を確認したら、次の意思決定に進んでください。

4. 各ラウンドでのピリオドの決まり方

実験は１０ラウンドからなります。

- 各ラウンドが何ピリオド続くのかは、実験者がくじで決めます。
- 実験者は各ピリオド終了時に、10 枚のカードから 1 枚を引きます。
- 10 枚のカードは、スペード（♠）が 9 枚、ジョーカーが 1 枚です。
- ピリオド終了時に、実験者がこの 10 枚のカードから 1 枚をランダムに引きます。
- 実験者が引いたカードが、スペード（♠）だった場合、次のピリオドに進みます。
- 実験者がジョーカーを引いた場合、ピリオドは終了し、次のラウンドに進みます。
- 従って、各ピリオドは 90%(=9/10) で続き、10%(=1/10) で終了します。



5-1. 意思決定（前半パート）

はじめに、1～５ラウンドの前半パートでの意思決定を説明します。

各参加者は、各ピリオドのはじめに初期保有ポイントとして 10 ポイントを与えられます。10 ポイントから、グループの公共財に**全額拠出する**または**拠出しない**から選んで下さい。

5-2. 意思決定（後半パート）

- 次に、6～10 ラウンドの後半ラウンドでの意思決定について説明します。後半ラウンドのはじめに、各ラウンドにおける意思決定の方針を定めます。後半ラウンドでは、あなたの定めた行動方針によって、公共財に**全額拠出する**または**拠出しないが**決定されます。
- 具体的には、9 問の質問に回答することで、あなたの行動方針が定まります。各設問は、①第 1 ピリオドで公共財に全額拠出するか否か（全 1 問）、
②1 期前にあなたの選択（拠出する、拠出しない）及びグループの拠出額（0, 10, 20, 30、40）に応じて、今期あなたは公共財に拠出するか否か（全 8 問）です。
- 各設問はランダムな順番で画面に表示されます。全てに回答して下さい。
- 全ての質問（合計 9 問）の回答が終わると、あなたの選んだ方針を確認する画面が表示されます。自分の選んだ方針を記録用紙にメモしてください。
- 後半ラウンドでは、行動方針が定まった後は、その方針に基づいて自動的にゲームがプレイされ、あなたは各ピリオドで結果を確認するだけです。
- 各ラウンドのはじめに、同じ 9 の質問が表示されます。過去のラウンドと同じ方針を採用する場合、記録用紙を見ながら前のラウンドと同じ回答を入力してください。

6. 利得の決まり方

あなたはグループの総拠出額を知ることができます。

あなたのポイントは、グループの総拠出額によって決まります。あるピリオドのあなたの利得は以下の式で計算されます。

あるピリオドにおけるあなたのポイント

＝10－自分の拠出額＋0.5×（グループの総拠出額）

例えば、あなたが 10 ポイントを全額拠出し、グループの総拠出額が 40 ポイントの場合を考えましょう。このピリオドのあなたの利得は以下のようになります。

このピリオドのあなたのポイント＝(10－10)+0.5×40＝0+20＝20

例えば、あなたが拠出しない、グループの総拠出額が 0 ポイントの場合を考えましょう。こ

のピリオドのあなたの利得は以下のようになります。
　このピリオドのあなたのポイント＝(10－0)+0.5×0＝10+0＝10

7. 報酬額

あなたの最終ポイントは、10 ラウンドの合計ポイントで計算されます。1 ポイント=3 円で計算され、参加報酬 1000 円と合計してあなたへの報酬額が決定されます。
あなたの報酬額
＝￥１０００＋　10 ラウンドの合計ポイント×￥3

以上