Cooperation in prisoner's dilemma by letting bygones be bygones: an inter-generational experiment

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Abstract

For achieving cooperation in interactions lasting over generations, ethics and game theory propose opposite guidelines against defection---ethics proposes "let bygones be bygones" whereas game theory proposes "retaliate against defects." To study which of guidelines is correct, we conducted a laboratory experiment of an inter-generational prisoner's dilemma game, and compared the cooperation rates of the following two treatments. In one treatment, each subject, playing the role of one generation of a group, had to choose action independent of the previous action pair, and hence had to let bygones be bygones. In the other treatment, each subject was able to choose action depending on the action pair realized in the immediately preceding generation, and hence was able to retaliate against defects. Our experimental results show that cooperation rate when subjects have to let bygones be bygones is higher than that when they can retaliate against defects. This implies that, by making players let bygones be bygones, we may be able to solve conflicts lasting over generations.

Keywords Cooperation・Inter-generation・Laboratory experiment・Prisoner’s dilemma

JEL Classification C91・D64・C72

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1. Introduction

Historically, we have observed many examples of conflicts lasting over generations between two competing groups, e.g., two families, two races, two countries. In these conflicts, a sequence of generations in both groups has adopted a chain of retaliation in repeated prisoner's dilemma-like interactions. For example, in generation t, members of group A (A_t) retaliates members of the other group B (B_t) because, in the previous generation $t-1$, the members of the same group (A_{t-1}) were attacked by the members of the other group (B_{t-1}). Although this strategy, "retaliate against defects", is what game theory has proposed as a guideline to achieve cooperative relationships,[1] history, as mentioned above, has shown that this guideline sometimes causes considerable welfare loss on both groups. Therefore, other guidelines that can achieve cooperative relationships, if ever, need to be proposed to both groups involved in these conflicts.

One of these candidates is "let bygones be bygones." This guideline has been proposed by some ethics, or the wisdom of ancients, to prevent a chain of retaliation since long time before the advent of game theory; these ethics seem to have noticed the ineffectiveness of "retaliate against defects."[2] From the game theoretical point of view, however, cooperation by letting bygones be bygones can never be achieved because, if members in one of two groups follow this guideline, monetary profits for members of the other group become larger when they defect than when they cooperate. Therefore, game theory and the ethics give opposite predictions as to whether cooperative relationships can be achieved by letting bygones be bygones.

The purpose of this study was to determine whether cooperative relationship in an interaction lasting over generations is more likely to be achieved when all players cannot retaliate against defects and has to let bygones be bygones than when they can retaliate against defects if they prefer. Games that involves inter-generational structures have been analyzed experimentally (Schotter and Sopher 2003; Schotter and Sopher 2006; Chaudhuri, Graziano, and Maitra 2006; Schotter and Sopher 2007; Chaudhuri, Schotter, and Sopher 2009) as well as theoretically (Lagunoff and Matsui 2004; Anderlini and Lagunoff 2005; Kobayashi 2007; Anderlini, Gerardi, and Lagunoff 2008; Anderlini, Gerardi, and Lagunoff 2010; Acemoglu and Wolitzky 2014). In these studies, players in generation t participated in at least one stage game. Then players in generation $t+1$ replaced generation t and continued the game in their role. Payoff to a player was his/her payoff in the stage game(s) he/she played plus discounted payoff of his/her immediate successor. Although these structures can be applied also to ours, the main focus of these studies was different from ours; these experimental studies focused only on the effect of advice for the next generation.[3] Therefore, to best of our knowledge, there is no experimental answer to our question.

To answer our question, we conducted a laboratory experiment. In our experiment, we adopted prisoner's dilemma game as a stage game, and compared the cooperation rates between two treatments. In one treatment, we tried to study what happens if all players have to let bygones be bygones. One

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[1] Theoretically, if players punish their opponents' deviation by choosing the worst action for the opponents, cooperation can be achieved in inter-generational repeated games (Lagunoff and Matsui 2004; Anderlini and Lagunoff 2005; Kobayashi 2007; Anderlini, Gerardi, and Lagunoff 2008; Anderlini, Gerardi, and Lagunoff 2010; Acemoglu and Wolitzky 2014) as well as in non inter-generational repeated games (Fudenberg and Maskin 1986; Abreu 1988).

[2] Some of these examples are "you shall not take vengeance, nor bear any grudge against the sons of your people" in the Old Testament (Lev. 19:18), "you need to forgive each other's sins" in the Buddhist sutra (*Taishō Tripiaka*, vol. 4, no. 208, p.580, authors' translation), and "if revenge breeds revenge, will there ever be an end to it?" in a Chinese saying. An example that prohibits inter-generational punishment is "the fathers shall not be put to death for the sons, nor the sons be put to death for the fathers" in the law in the book of Moses, referred in the Old Testament (2 Chron. 25:4).

[3] The theoretical answer to our question is trivially no, so the previous theoretical studies have mainly focused on when and how retaliation induces cooperation.

interpretation of "let bygones be bygones" would be that an action has to be history-independent. That is, each player has to choose either to cooperate (C) or defect (D) whatever actions the immediately preceding generation adopted. That is, in this treatment, each player's strategy is limited either to "all-C strategy" or "all-D strategy." In the other treatment, we tried to study what happens if players can adopt whatever strategy they prefer including "retaliate against defects." In this treatment, each subject was able to choose respective actions for each pair of actions in the immediately preceding generation (i.e., action pair of his/her "parent's" and his/her opponent's "parent's").

From the experiment, we found that subjects cooperate more when they have to let bygones be bygones than when they can retaliate against defects if they prefer. This result supports the ethical predictions, and suggests that conflicts lasting over generations in real situations may be improved if we can make both groups let bygones be bygones.

The paper is structured as follows. The next section explains our model and experimental design. In Section 3, we present results. The final section discusses and concludes.

2. Theoretical considerations and experimental design

2.1. Theoretical environment

We modeled, as in Anderlini and Lagunoff (2005), Kobayashi (2007), and Anderlini, Gerardi, and Lagunoff (2008), conflicts between two groups lasting over generations as an infinitely repeated inter-generational prisoner's dilemma game.[4] In our model, a symmetric prisoner's dilemma game is played in each period ($t = 0,1, \ldots$) between a member of group A and a member of group B. Each group consists of an infinite sequence of players and each of them plays the game only once as in Schotter and Sopher (2003), Anderlini and Lagunoff (2005), Schotter and Sopher (2006), and Schotter and Sopher (2007). Two players who take part in the game in period t are called generation t. A player in group $i \in \{A, B\}$ in generation t is denoted by i_t, and i_t's action by $a_{i_t} \in \{C, D\}$ where C represents cooperation and D defection. When i_0 plays a_{i_0} and j_0 ($j \neq i$) plays a_{j_0} in period $t = 0$.[5] The player i_0 obtains a stage payoff $\pi(a_{i_0}, a_{j_0})$. When i_t plays a_{i_t} and j_t ($j \neq i$) plays a_{j_t} in period $t > 0$, not only i_t obtains a payoff of $\pi(a_{i_t}, a_{j_t})$ but also i_{t-1} (i.e., "parent" of i_t) obtains a payoff of $\delta_{t-1}\pi(a_{i_t}, a_{j_t})$ where $\delta_{t-1} \in (0,1]$ is a discount factor for generation $t-1$. This structure makes the game an inter-generational one. The expected utility player i_t gets (v_{i_t}) becomes the following additively separable form: $v_{i_t} = \pi(a_{i_t}, a_{j_t}) + \delta_t \pi(a_{i_{t+1}}, a_{j_{t+1}})$, which corresponds to those in previous intergenerational game experiments.

2.2. Experimental designs

To determine whether relationships between two groups improves if each member of the groups lets bygones be bygones, we designed the following experiment. In this experiment, we adopted strategy method where each subject chose C or D respectively for multiple information sets before knowing which information set they arrived. That is, although subjects had to choose C or D before

[4] In the previous experimental studies of inter-generational game, various types of a stage game were adopted: battle of sexes game in Schotter and Sopher (2003), trust game in Schotter and Sopher (2006), public goods game between five members in Chaudhuri, Graziano, and Maitra (2006), ultimatum game in Schotter and Sopher (2007), and minimum effort game in Chaudhuri, Schotter, and Sopher (2009).

[5] The player of generation $t = 0$ was called "Progenitor" in Chaudhuri, Graziano, and Maitra (2006) and Chaudhuri, Schotter, and Sopher (2009).

knowing which generation they belonged to, they were able to choose them differently depending on which generations they belonged to. To best of our knowledge, this study is the first to adopt the strategy method in the inter-generational game experiment. By adopting this method, not only we were able to collect data of subjects' choices in various situations (i.e., information sets), we were able to make the level of δ_t more credible than we did not adopt it.

The experiment consisted of two treatments: history-dependent treatment and history-independent treatment. History-dependent treatment represents the current situation of inter-generational conflicts. In this treatment, each subject was able to choose C or D not only as a "Progenitor" (i.e., as a generation $t = 0$), but also as a "child" (i.e., as generations $t > 0$). As generations $t > 0$, they were able to choose C or D respectively for each of all possible combinations of the actions by the subject's "parent" and the other's parent: i.e., immediately after mutual cooperation (C, C), mutual defection (D, D), cooperation by subject's "parent" and defection by the other's (C, D), and defection by subject's "parent" and cooperation by the other's (D, C). However, we made each subject's choices independent of the previous histories in more than one generation before in order to minimize the difference in designs with history-independent treatment and to make the number of choices manageable one for subjects (five choices in history-dependent treatment). This independence was implemented by making these old histories invisible to subjects.

In history-independent treatment, each subject, as generations $t > 0$, had to select C or D regardless of what histories had been realized. That is, each subject's strategy was limited to either all-C strategy or all-D strategy, and hence, each subject had to let bygones be bygones. We implemented history-independency of choice by making all of previous histories invisible to subjects. That is, subjects in this treatment had to choose C or D without knowing the previous histories. As in history-dependent treatment, subjects also chose C or D as a generation $t = 0$. So, the number of choices was two (as a generation $t = 0$ and as generations $t > 0$) in history-independent treatment.

To conduct this experiment in the laboratory, we still needed to solve a problem: we were not able to recruit infinite number of subjects. That is, using finite number of subjects, we needed to create situations where, as we have considered in the model above, players choose C or D assuming that probability the next generation (subjects) exists is always positive (i.e., $\delta_t > 0$), and expect the reward their "child" will bring to them. We were able to do this by introducing new design that can perfectly control the level of discount factor δ_t. This means that we were able to implement the expected utility function v_{i_t} described above.

Suppose the number of the subjects in a session was $2(T + 1)$ and that, in each generation $t \in \{0, \ldots, T\}$, two players (one for each group) existed. We randomly decided which generations $t \in \{0, \ldots, T\}$ subjects belonged to after all the choices were made. Once we decided it, we calculated rewards to them differently depending on which generations they belonged to. When $t \in \{0, \ldots, T - 1\}$, reward to the subjects u_{i_t} was $u_{i_t} = \pi(a_{i_t}, a_{j_t}) + \pi(a_{i_{t+1}}, a_{j_{t+1}})$, whereas when $t = T$, it was $u_{i_T} = \pi(a_{i_T}, a_{j_T})$. So, when subjects decides which of C or D to choose, they faced the following expected reward functions $v_{i_t} : v_{i_t} = E[u_{i_t}] = \pi(a_{i_t}, a_{j_t}) + \delta_t \pi(a_{i_{t+1}}, a_{j_{t+1}})$, where $\delta_0 = 1$ and $\delta_{t>0} = (T - 1)/T$. That is, when the subject became i_0 ($i_{t>0}$), δ_t was 1 ($(T - 1)/T$).

Because of these new designs, subjects in our experiment faced the situations that perfectly correspond to what we have considered in the model above: players choose C or D assuming the next generation exists with credible probabilities ($\delta_t = 1$ when $t = 0$ and $\delta_t = (T - 1)/T$ when $t > 0$) and considering the reward their "children" will bring to them.

2.3. Theoretical predictions

Theoretically, when payoff function is represented by Table 1 and $T = 7$ (i.e., 16 subjects in a session), no equilibrium produces cooperation in history-independent treatment whereas two types of symmetric sequential equilibria produce a continuous cooperation in history-dependent treatment. In one of these cooperative equilibria, all players adopt Trigger strategy, i.e., player $i_{t>0}$ cooperates when $(a_{i_{t-1}}, a_{j_{t-1}}) = (C, C)$ and defects otherwise. In the other cooperative equilibrium, all players adopt Pavlov strategy, i.e., player $i_{t>0}$ cooperates when $(a_{i_{t-1}}, a_{j_{t-1}}) \in \{(C, C), (D, D)\}$ and defects otherwise. In both cases, when both players in generation $t = 0$ cooperate, only mutual cooperation is realized. Only in the latter case, when both players in generation $t = 0$ defect, although mutual defection is realized in $t = 0$, mutual cooperation is realized thereafter. Therefore, game theoretical predictions we can obtain are that "let bygones be bygones" will not work, and hence, that cooperation rate in history-dependent treatment is higher than that in history-independent treatment.

Table 1. *Payoff matrix*

	Cooperate	Defect
Cooperate	(18,18)	(9,19)
Defect	(19,9)	(10,10)

2.4. Experimental procedures

The experiments were run at the experimental laboratory of the *Center for Experimental Economics Laboratory* at Kansai University. Undergraduate students were recruited from the subjects pool via E-mail solicitations. In total 128 subjects participated in the experiments. We used a two-treatment between-subject design. A total of eight sessions were conducted: four sessions for history-independent treatment and the other four sessions for history-dependent treatment. In each session, 16 subjects participated. No subjects participated more than one session.

At the beginning of the session, instructions and accompanying materials were distributed to subjects and they were read aloud by electronic reading software. Neutral terminology was used throughout the session.[6] After the instructions, examinations were held. The session proceeded after all subjects could correctly answer all the questions. We used z-Tree software (Fischbacher 2007) for the examinations and the following decision making. Then eight subjects were assigned the role of a player in group A, and the other eight in group B. Since each group contained eight subjects, each session consisted of generations 0 to 7.

In each session, one realized path were randomly generated and subjects were paid based on them. Once each of 16 subjects' choices between C and D were finished, we randomly selected one member each in groups A and B out of all 16 subjects as generation 0. The combination of the actions these two players had chosen when $t = 0$ was determined to be the actually adopted action-pair in generation 0. Then, we randomly selected one member each in groups A and B out of remaining 14 subjects as the generation 1. Suppose that these action-pair (a_{A_0}, a_{B_0}) was (C, D). In history-dependent treatment, if the group A member assigned to generation 1 had chosen D after (C, D) and

[6] For example, X and Y were used instead of Cooperate or Defect. Furthermore, 1st group to 8th group were used instead of generation 0 to 7.

the group B member assigned to generation 1 had chosen C after (D, C), the actually adopted action-pair in generation 1, (a_{A_1}, a_{B_1}), was (D, C). Then, we randomly selected one member each in groups A and B out of remaining 12 subjects as the generation 2, and determined the actually adopted action-pair in generation 2. In the same manner, we randomly selected one member each in groups A and B out of remaining $16 - 2t$ subjects as the tth generation, and the actually adopted action-pairs by group A (B) in generation t was determined by what this player had chosen after $(a_{A_{t-1}}, a_{B_{t-1}})$ $((a_{B_{t-1}}, a_{A_{t-1}}))$. In history-independent treatment, the actually adopted action-pair in all generations as well as generation 1 was determined by what group A member and group B member assigned to generation t had chosen when they become $t > 0$. This actually adopted action-pair were irrelevant to the actually adopted action-pair in $t - 1$ because of history-independency. The rewards to subjects were determined based on these adopted action sequences.

The maximum (minimum) reward to subjects was 5,000 (2,100) yen. The average reward was 3,800 yen. They were paid in cash immediately when the experiment was over. It took 2.5 hours from the beginning of the experiment to the end of the payment per session.

3. Results

Although one realized path was randomly generated to determine rewards to subjects for each session, this path was only one possibility: $16! - 1$ other possible paths could have realized. So, to determine which of two treatments can achieve more cooperative paths, we need to enumerate all of $16!$ realized paths for each session and to calculate paths of mean cooperation rates for each of them.

These paths show that, except generation $t = 0$, all of four sessions in history-independent treatment attained higher mean cooperation rate than all of four sessions in history-dependent treatment (Figure 1).

These paths above were obtained by "sampling without replacement," so we can obtain other paths using "sampling with replacement." That is, in obtaining realized paths, we can select generation $t > 0$ from all of 16 subjects that include subjects who have already been selected as the previous generation(s). The obtained paths of cooperation rate were almost the same between sampling without replacement and sampling with replacement; out of 64 mean cooperation rates ($= 8$ generations $\times\ 4$ sessions $\times\ 2$ treatments), the largest difference was 0.011.

To statistically test the difference of cooperation rates between sessions of history-independent and history-dependent treatments, we regressed these 64 mean cooperation rates on history-independent dummy variable and generations (t), both for sampling without replacement and sampling with replacement. The regression results show that mean realized path in history-independent sessions is statistically higher than that in history-dependent sessions both for sample without replacement and sampling with replacement (Table 2).

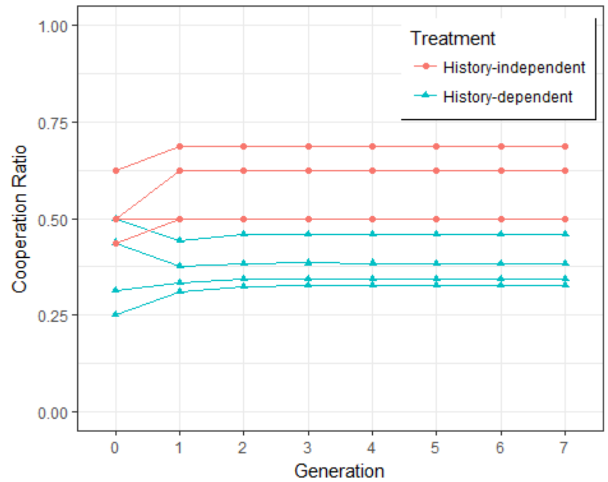

Figure 1. *Cooperation rate paths of history-independent and history-dependent sessions*

Table 2. *Regression of cooperation rate on history-independency*

	Dependent variable: cooperation rate	
	without replacement	with replacement
	(1)	(2)
History independency	0.194***	0.191***
	(0.052)	(0.053)
Generation	0.003	0.003
	(0.002)	(0.002)
Constant	0.365***	0.368***
	(0.034)	(0.036)
Observations	64	64
R^2	0.651	0.636
Adjusted R^2	0.640	0.624

Note: This table reports coefficient estimates from OLS models. The dependent variables are cooperation rates that can be realized for each generation in each session. Each of these realized cooperation rates were calculated by sampling without replacement in (1) and with replacement in (2) from 16 subjects' choices. There are 64 observations (=8 generations x 4 sessions x 2 treatments) respectively for sampling without and with replacement. History independency is a dummy variable that equals 1 in the sessions of history-independent treatment and 0 in the sessions of history-dependent treatment. Generation is t from 0 to 7. Robust standard errors clustered for sessions are reported in parentheses. *** Significant at the 1 percent level. ** Significant at the 5 percent level. * Significant at the 10 percent level.

4. Discussion

Our results indicate that, if all players in an interaction lasting over generations were to let bygones be bygones (i.e., have to follow an ethical guideline), they are more likely to achieve cooperative relationships than when they can retaliate against defects (i.e., can adopt the game theoretical guideline). In our experiment, cooperation rate when subjects had to let bygones be bygones (history-independent treatment) was statistically higher than that when subjects were able to retaliate against defects (history-dependent treatment).

Our findings imply that, if we can make all players adopt history-independent strategy in real situations, we are able not only to achieve cooperative relationships between two groups that start new interactions, but also to improve conflicts that have been lasting over generations. Our findings also imply that an advice to the next generation should be "let bygones be bygones." Although Chaudhuri, Graziano, and Maitra (2006) have found that, when the contents of the advice are common knowledge, advice to the next generation increases donation to the public goods, what type of advice is effective has been unclear yet. From our experimental finding, we expect that both groups achieve cooperative relationships further if they advices to the next generation to let bygones be bygones.

5. Conclusions

We have shown that, if all players in an interaction lasting over generations were to let bygones be bygones, they are more likely to achieve cooperative relationships than when they can retaliate against defects. That is, the ethical guideline, which was proposed to prevent a chain of retaliation long time before the advent of game theory, works. Our finding implies that if we can make all players let bygones be bygones (i.e., adopt history-independent strategy), we may be able to improve conflicts lasting over generations. Questions remain regarding why restricting strategy to history-independent one induces more cooperative behavior, and how we can make each player adopt history-independent one. The answers to them must contribute to actually solve conflicts lasting over generations.

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