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Cooperation in a sequential N-person prisoner's dilemma: The role of information and reciprocity

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Abstract

We investigate experimentally the possibility of cooperation in a sequential prisoners' dilemma game under the conditions identified by Nishihara (1997). He shows for (a subclass of) n-person prisoners' dilemma games that when players move sequentially, but the order of moves is not known, full cooperation can be attained in a Nash equilibrium under an information structure allowing for trigger strategies. In our experiments, we find that subjects do not coordinate frequently on the payoff dominant equilibrium identified by Nishihara. Moreover, cooperation is more frequent in the same sequential game played with a known order of moves. We relate this theoretically contraintuitive observation to the role of reciprocity.

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Abstract

We investigate experimentally the possibility of cooperation in a sequential prisoners' dilemma game under the conditions identified by Nishihara (1997). He shows for (a subclass of) n-person prisoners' dilemma games that when players move sequentially, but the order of moves is not known, full cooperation can be attained in a Nash equilibrium under an information structure allowing for trigger strategies. In our experiments, we find that subjects do not coordinate frequently on the payoff dominant equilibrium identified by Nishihara. Moreover, cooperation is more frequent in the same sequential game played with a known order of moves. We relate this theoretically contraintuitive observation to the role of reciprocity.

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Key words: n-person prisoner's dilemma game, sequential moves, information, reciprocity, laboratory experiment.

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1 Introduction

When the order of moves is known to the players in a sequential prisoners' dilemma game, the only rational choice of a player moving as the last one in the sequence is to freeride. Consequently, the play of the game unravels and cooperation cannot be sustained in an equilibrium. Nishihara (1997) shows that under certain information and payoff structure of the game, when the order of moves in which players move is not known, players can use trigger strategies under which cooperation can be sustained as a Nash equilibrium in the sequential prisoners' dilemma game.

In this paper, we use the experimental method to study this innovative view on the dilemma of cooperation, and we address two points. First, the game introduced by Nishihara (1997) has multiple equilibria. We therefore investigate experimentally whether the attractive payoff dominant equilibrium with cooperation has not only a normative but also a descriptive appeal. Second, the game provides players with just enough information to enable the use of trigger strategies in an equilibrium. We argue that the information removed from the game, but available in the sequential version of the game, is relevant when reciprocity plays a role among the game players. In particular, when individual preferences are private information, but it is known that some players hold preferences for reciprocity, the information on the order of move could generate strategic incentives for cooperation in the spirit of explaining cooperation in a finitely repeated 2-person's prisoner 's dilemma by Kreps et al. (1982). Consequently, even if the game innovation proposed by Nishihara (1997) is not conductive to cooperation (when players do not select the cooperative equilibrium), the standard sequential game might be, due to the strategic response of some players to the possibility of a reciprocal behavior by others.

An experimental investigation of the Nishihara's model is at hand as the information and payoff conditions identified by the author are intuitive and their appeal for explaining rational cooperation in the identified subclass of sequential prisoners' dilemma games is therefore large. With respect to information structure, it is assumed that players know that the order of moves is randomly assigned so that every ordering is equally likely, but they do not learn the actual order in which they move. When asked to choose an action, a player only observes whether someone chose the freerider's action before his/her move, or not. Consequently, players cannot distinguish states in which (i) nobody has chosen an action in the game yet; (ii) some players have already chosen an action, but they all chose the cooperative action, or (iii) all players chose the cooperative action, and the player him/herself moves as the last in the sequence. With respect to the payoff structure, gains from full cooperation have to be sufficiently large compared to the average gains from freeriding (Nishihara 1997, Theorem A), or gains from cooperation have to be convex and gains from defection concave in the number of cooperators (Nishihara 1997, Proposition 3).

When the conditions described above are satisfied, players can use trigger strategies that prescribe the cooperative action unless a player reaches an information set according to which someone has already chosen the free-rider's action. In that case, the deciding player chooses the freerider's action as well. If the expected payoff from cooperation (taking into account the probability of each order of players being the same) is greater than the expected payoff from triggering the freeriding, then cooperation can be sustained in a Nash equilibrium of the game. Of course, the equilibrium without any cooperation is still feasible as well.

The conditions identified by Nishihara can apply to a range of real-life situations in which individuals sequentially take actions in a social dilemma. The decision whether to litter the street, or to take illegally an emergency lane on the highway may serve as examples. In both cases, an individual cannot asses whether a clean street or the part of the free highway in sight are due to the full cooperation of all players moving in the game before him/her, or whether he/she is the first player to move. However, a freerider's action is easily observed (dirty street, clogging emergency lane) and can promptly lead to unravelling of cooperation. Moreover, the benefits from freeriding decrease fast with the number of other freeriders, just as is assumed above.

In this paper, we report experiments on a sequential prisoners' dilemma game satisfying Nishihara's payoff conditions. Each experiment participant is exposed both to this game with an unknown order of moves, as assumed by Nishihara, and to the game with the same payoff structure but with a known order of moves. Data on the subjects' behavior in the sequential prisoner's dilemma game with the known order of moves allows us to separate the equilibrium selection explanations of behavior in the Nishihara's game from the explanations related to the preferences for reciprocity, and to evaluate the behavioral relevance of the trigger strategy equilibrium in both cases.

The remainder of the paper is organized as follows. The theory and hypotheses are explained in section 2. Section 3 discusses the experiment design and our observations. Section 4 concludes.

2 Theory and hypotheses

The game we study is an n-person sequential prisoner's dilemma game with players $i = 1, ..., n$, $n \geq 2$, and with payoff function $f_i(a_i|k)$ where $a_i \in \{C, D\}$, and $k \in \{1, ..., n-1\}$ is the number of other players choosing the action C. We refer to action C as the "cooperative" action, and to action D as the "freerider's" action. It is assumed that for $i = 1, .., n$, it holds:

(i) $f_i(C|k) < f_i(D|k)$ for any $k = 0, ..., n-1$;

(ii) $f_i(C|n-1) > f_i(D|0)$;

(iii) $f_i(C|k)$ and $f_i(D|k)$ are increasing in k;

The game with the payoff function $f_i(a_i|k)$ satisfying (i)-(iii) is a prisoners' dilemma game: (i) it has strictly dominant strategy D;(ii) full cooperation is Pareto efficient; (iii) choosing action C imposes positive externality on all players.

The game is played sequentially and we will focus on the equilibrium predictions for two possible information structures of the game: the structure proposed by Nishihara (1997), denoting the game with such a structure by G_N, and a sequential move game with a known order of moves, denoted by G_S. In the game G_N, the order of moves in which players move is assigned randomly in such a way that every possible ordering of players in the game is equally likely, and the order of moves is not known to the players. In the game G_S, the order of moves is common knowledge among the players. In each move, a player knows how many players have decided before him/her.

Additionally, we assume for comparability reasons that in both games, G_N and G_S, a player asked to choose an action can only distinguish whether someone has chosen the action D before or not, but not how many players did so. Let us denote the information set at which nobody has chosen action D before by I_C, and denote the complementary information set at which somebody has already chosen action D before by I_D.

In the game G_N, subjects can distinguish only between these two information sets, I_C and I_D. Hence, a pure strategy in the G_N game is a pair $\sigma = (\sigma_C, \sigma_D)$ where σ_C is chosen in the information I_C, and σ_D is chosen in the complementary information set I_D. The strategy of a player i in the game G_S may additionally also depend on the order of move $o(i) \in \{1, 2, ..., n\}$, assigned the player, $\sigma = (\sigma^1, (\sigma_C^2, \sigma_D^2), ..., (\sigma_C^n, \sigma_D^n))$. Note, in particular, that a player in the game G_S either knows that he/she is the first one to move in the game and all players are yet to choose their actions, or that at least one player moving before him/her chose action D; or, that all players moving before him/her chose action C. This is different from a usual sequential game, where each player not only knows how many players have made their decision before, but also all the decisions they have made. In our game G_S, we restricted the information to facilitate the comparison with the game G_N.

Due to the information on the order of move, backwards induction excludes rational cooperation along an equilibrium path in the game G_S. Contrary to this, Nishihara shows (Nishihara (1997), Theorem A) that when the order of moves is not known to the players, and every player ordering is equally likely, and condition (*) $f_i(C|n-1) \geq \frac{1}{n}\sum_{k=0}^{n-1} f_i(D|k)$ for all $i = 1, ..., n$, is satisfied, then full cooperation is a Nash equilibrium in the game G_N. The cooperation can be sustained by the following trigger strategy $\sigma^* = (C, D)$: player i chooses action C if the information set he/she reached is one at which nobody choose action D until his/her move; and chooses action D otherwise. To see this, it is sufficient to show that no player has an incentive to deviate from action C in the information set I_C. If player i obeys the trigger strategy, then his/her payoff will be $f_i(C|n-1)$. If he chooses action D, then he triggers action D to be chosen by all players ordered in the game after him, i.e. the if his order of move is $m = 1, ..., n$, then the payoff he'll receive is $f_i(D|m-1)$, resulting in expected payoff from deviating from the trigger strategy $\sum_{k=0}^{n-1} f_i(D|k)$. The player has no motivation to deviate as long as $f_i(C|n-1) \geq \frac{1}{n}\sum_{k=0}^{n-1} f_i(D|k)$ for all $i = 1, ..., n$, i.e. if the condition (*) is satisfied.

In the experiment, we parametrize the sequential prisoner's dilemma game satisfying Nishihara's condition (*) as a five-player game, $n = 5$. It is induced from the payoff function $g_i(x_i, k) = (k + x_i)^2 + 10(1 - x_i)$, for $i = 1, ..., 5$ where $k = 1, 2, 3, 4$ is the number of other players choosing C. Then, the payoff function of the game we study in this paper is given by $f_i(C, k) = g_i(1, k)$ and $f_i(D, k) = g_i(0, k)$. This payoff function satisfies the condition (*)[1], as well as conditions (i), (ii) and (iii).

The game G_N has two types of equilibria: one resulting in full cooperation, where all players use the trigger strategy $\sigma^* = (C, D)$, and one resulting in no cooperation, where all players use the strategy $\sigma^D = (D, D)$.[2] The first one, referred hereafter as "cooperative ", gives a higher payoff to all players than the second one, referred to as "uncooperative". Therefore, payoff dominance as an equilibrium selection argument favors the cooperative equilibrium. Our discussion so far assumes that the game and its payoffs fully represent the players' preferences, i.e. that the game is played by rational and payoff-maximizing subjects. Assuming rational and payoff maximizing players only, however, would amount to ignoring a vast experimental evidence that human subjects, interacting in a given game, care not only for own material payoffs but also for material payoffs of their co-players. In order to focus on the equilibrium selection process in the game G_N, we first identify the subset of the experimental subjects who reveal to act as rational money-maximizers. These are the subjects who behave rationally in the game G_S, choosing action D at each information set. Do these rational subjects select the payoff dominant equilibrium in the game G_N? We formulate the following hypothesis:

> **Equilibrium selection hypothesis:** *Rational money-maximizing subjects select an equilibrium in the game G_N guided by the payoff dominance criterion. They play the strategy $\sigma^* = (C, D)$.*

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[1]It holds: $f_i(C|n-1) = 25$ and $\frac{1}{n}\sum_{k=0}^{n-1} f_i(D|k) = 16$, so that $f_i(C|n-1) > \frac{1}{n}\sum_{k=0}^{n-1} f_i(D|k)$.

[2]There are only these two equilibria, σ^* and σ^D, in the game G_N, if the conditions (i)-(iii) below are satisfied. Let m be the number of players who choose σ^* other than player i, and $F_i(\sigma^*|m)$, or $F_i(\sigma^D|m)$ is the expected payoff of player i when he chooses σ^*, or σ^D, respectively, in that situation.
(i) $F_i(\sigma^*|0) < F_i(\sigma^D|0)$,
(ii) $F_i(\sigma^*|n-1) > F_i(\sigma^D|n-1)$,
(iii) $F_i(\sigma^*|m) - F_i(\sigma^D|m)$ is increasing in m.
These conditions are satisfied by our experimental parametrization.

Two issues have to be discussed in relation to this hypothesis. While payoff dominance may seem an attractive rational equilibrium criterion, it has often been defeated in the presence of strategic risk. Previous experimental evidence shows that even in simple two-player coordination games, strategic risk (e.g. measured by risk dominance, see Harsanyi and Selten, 1988) intervenes with the equilibrium selection and defeats the payoff dominant equilibrium (see e.g. Van Huyck, Battalio and Beil, 1990, Berninghaus et al. 2000, Cabrales et al. 2000). Besides strategic risk, complexity might also affect the attraction of the trigger-strategy equilibrium in the game G_N. Subjects are expected to evaluate the expected payoffs from each of the possible strategies, in order to find the trigger strategy to be the most attractive choice. In an experimental setup, unlike in a theoretical analysis, subjects might be prone to calculation or implementation mistakes, both resulting in a lower likelihood of the trigger strategy equilibrium. Whatever the underlying reasons, the game G_N can be seen as a solution to the social dilemma the players face only if they indeed (frequently) select to play the cooperative equilibrium. We put the equilibrium selection hypothesis to an empirical test.

Addressing the role of the information in the game G_N, we further discuss the behavior of the subset of subjects choosing (at least at some occasions) a strategy different from the strategy $(D, (D, D), ..., (D, D))$ in the game G_S. If the game the experimental subjects play is not described in terms of preference orderings, but merely in terms of monetary outcomes, as it usually is the case in experimental studies, then pro-social preferences held by some players may affect the play of the game. We therefore need to address the effect of pro-social preferences on the play of the cooperative equilibrium in the game G_N. One pervasive behavioral regularity which is relevant here is the propensity to reciprocate positively to actions of players who benefited the reciprocator, and negatively to actions that hurt the reciprocator.[3] Positive reciprocity implies the use of action C in the information set I_C; negative reciprocity the use of action D in the information set I_D, independent of whether such strategy maximizes the player's material payoff.[4]

[3]For a seminal paper reporting positive reciprocity in an experiment, see Berg, Dickhaut and McCabe (1995), for negative reciprocity, see Fehr and Gaechter (2000).

[4]Reciprocity is thus idetified with a trigger-type startegy in the game G_S, $\sigma = (\sigma_C^1, (\sigma_C^2, \sigma_D^2)$ $...., (\sigma_C^5, \sigma_D^5)) = (C, (C, D), ...(C, D), (C, D))$, which starts-off by cooperation, and prescribes to use of

In theory, the information structure of the game G_N creates a possibility of rational cooperation. At the same time, the information on the order of moves, not available in the game G_N, prevents identification of situations meriting positive reciprocity. When a player is ordered as a second or later player in the game G_S, he/she knows for sure that this information set I_C has been reached thanks to the cooperation of the players ranked before him/her. In the game G_N, when a player has reached the information set I_C, he/she might be ordered as first in the sequence, and hence obtain no incentives for positive reciprocity. In this way, removing information on the order of move in the game G_N dilutes the incentives for positive reciprocity at the information set I_C. More importantly, the missing information on the order of moves in the game G_N is also crucial for generating strategic incentives to cooperate in the game G_S for the money-maximizing subjects. Such incentives arise when preferences are private information, and reciprocators are known to populate the game with a sufficiently high probability. To demonstrate this point, let us assume that the players of the 5-player game G_S implemented in the experiment are drawn from a population from which contains a fraction $r \in (0,1)$ of reciprocal players, and a fraction $(1-r)$ of money-maximizing players. Reciprocal players use the strategy $\sigma = (\sigma_C^1, (\sigma_C^2, \sigma_D^2)....,(\sigma_C^5, \sigma_D^5)) = (C,(C,D),...,(C,D))$ in the game G_S : they always choose action C in the information set I_C, even if ordered as last. Money-maximizing players choose action C or D depending on which gives them a higher expected payoff. The population composition is common knowledge.

Lemma 1 *If the fraction $r \in (0,1)$ of reciprocators in the population exceeds a certain threshold, $r \geq \frac{1}{3}$, money-maximizing players will choose action C in the information set I_C in the game G_S up to the order of move $t = 4$. Otherwise, they choose action D.*

Proof. Let us analyze the optimal choice of a money-maximizer by backwards induction. Such a player will always choose D at the order of move $t = 5$. If ordered at $t = 4$, and upon reaching information set I_C, money-maximizer weakly prefers action C to action D iff $19 \leq 25r + 16(1-r)$ i.e. $r \geq \frac{1}{3}$.

action C unless a subjects has previously observed action D at any moment in the game.

- Assuming that $r < \frac{1}{3}$, and upon reaching information set I_C, money-maximizer prefers action C to action D if ordered at

  - $t = 3$, iff $14 \leq 9(1-r) + r[25r + 16(1-r)]$ i.e. $r \geq \frac{-15+\sqrt{205}}{-2} > \frac{1}{3}$; so that a money-maximizer will always choose D at $t = 3$ when $r < \frac{1}{3}$.
  - $t = 2$, iff $11 \leq 4(1-r) + r[9(1-r) + r[25r + 16(1-r)]]$; where the resulting polynomial of the 3r^d order has one real root, and implies a threshold value for the satisfaction of the inequality $r > 0.6122... > \frac{1}{3}$; so that a money-maximizer will always choose D at $t = 2$ when $r < \frac{1}{3}$.
  - $t = 1$, iff $10 \leq (1-r) + r[4(1-r) + r[9(1-r) + r[25r + 16(1-r)]]]$; where the resulting polynomial of 4^{th} order has one real root, and implies a threshold value for the satisfaction of the inequality $r > 0.933... > \frac{1}{3}$; so that a money-maximizer will always choose D at $t = 1$ when $r < \frac{1}{3}$.

- Assuming that $r \geq \frac{1}{3}$, and upon reaching information set I_C, a money-maximizer will prefer action C to action D if ordered at $t = 3, 2, 1$ because the payoff from choosing D at $t = 3, 2, 1$ equals to 14, 11, 10, respectively, and is lower than the expected payoff from choosing C, equal to $25r + 16(1-r) \geq 19$ for $r \geq \frac{1}{3}$.

■

Hence, the information on the order of move available in the game G_S gives incentives to the money-maximizing rational players to choose the cooperative action C in the information set I_C if they believe that the population consists of sufficiently many reciprocal players. This threshold, implied in the experiment parametrization, is conductive to holding such beliefs[5].

Reciprocity hypothesis: *In the game G_S, reciprocal subjects play the strategy* $\sigma = (\sigma_C^1, (\sigma_C^2, \sigma_D^2) \ ...., (\sigma_C^5, \sigma_D^5)) = (C, (C, D), ...(C, D), (C, D))$, *and money-maximizers respond strategically to the presence of reciprocators by playing the strategy,* $\sigma = (\sigma_C^1, (\sigma_C^2, \sigma_D^2), ..., (\sigma_C^5, \sigma_D^5)) = (C, (C, D), ..., (C, D), (D, D))$.

[5] In experimental studies, the propensity to reciprocate positively is frequently observed among participants, see e.g. Fischbacher et al. (2001) who find that half of their subject pool uses strategies corresponding to positive reciprocity.

Consequently, we expect that at least some cooperation will be observed in the game G_S. This cooperation will be driven by the presence of reciprocators, expressing their preferences for (positive) reciprocity when asked to choose an action in the information set I_C. This cooperation will also be driven by money-maximizors, with strategic incentives to sustain cooperation in the presence of reciprocators.

The presence and belief in reciprocity has thus impact on the extent of cooperation in the game G_S. Does the presence of reciprocators also affect behavior in the game G_N? Reciprocal players will simply follow their preferences, and therefore play strategy (C, D) in the game G_N, just as they would reciprocate in the game G_S. So, the main question is whether the money-maximizing subjects are affected by the presence of reciprocators when choosing which of the two equilibria to play. Reciprocators use the strategy (C, D) in the game G_N with probability 1. This alleviates the equilibrium selection problem in the game G_N in the sense that the number of the players coordinating between the cooperative and the uncooperative equilibrium decreases from the number of all players of the game to the number of the money-maximizors. The equilibrium selection problem disappears only if a strategic money-maximizing player believes that all other subjects are reciprocal - an unlikely situation. The equilibrium selection problem remains relevant in the presence of reciprocators as soon as at least one other player in the game is believed to be a money-maximizer, seeking to choose the payoff-maximizing strategy in a coordination game with other money-maximizing player(s).

In short, the presence of reciprocators alleviates, but does not remove the coordination problem faced by the money-maximizers in the game G_N. At the same time, the presence of reciprocators in the game G_S generates incentives to choose action C in the information set I_C for the money-maximizers with beliefs in sufficiently many reciprocators in the population.

In the light of the discussion above, we argue that the impact of imposing the information structure of the game G_N in a sequential prisoner's dilemma game on the players' ability to cooperate is not necessarily positive. For one, rational money-maximizing players face an equilibrium selection problem in the game G_N, also when accounting for the presence for some reciprocators. Second, removing information on the order of

Session	Treatment	Number of participants	Rounds 1 - 10	Rounds 11-20
S1	T_{NS}	15	G_N	G_S
S2	T_{NS}	20	G_N	G_S
S3	T_{NS}	20	G_N	G_S
S4	T_{SN}	20	G_S	G_N
S5	T_{SN}	20	G_S	G_N

Table 1: Session Table.

moves available in the game G_S, and transforming it into the information structure of the game G_N, negatively affects both strategic and nonstrategic incentives to cooperate. The money-maximizers lack the strategic incentives to sustain the cooperation in the game G_N because they lack the ability to signal that an information set I_C has been reached in an order of move higher than 1, but they have strategic incentives to cooperate if they believe sufficiently many reciprocators populate the game G_S. And, reciprocators in the game G_N lack the information on the extent of the previous cooperation, which would give them nonstrategic, preference-driven incentives to cooperate. Such information is available in the game G_S.

In the following section, we address the extent of cooperation and impact of reciprocity in both games, G_N and G_S, using our experimental data. Ultimately, we ask which of the two information structures - of the game G_N or the game G_S - is empirically revealed as more suitable for sustaining cooperation in the N-person prisoner's dilemma game.

3 Experiment design and analysis

We report data on 95 student participants. The experiments took place in the CentERlab at Tilburg University, The Netherlands, and were computerized using the software z–Tree (Fischbacher, 2007).[6] Each session lasted about 1,5 hours and subjects earned 3 Euro participation fee plus on average 9 Euro.

In the experiment, subjects participated in two tasks, each consisting of 10 rounds of the sequential-move prisoner's dilemma game. We randomly re-matched groups after each round. At the beginning of an experimental session, we first read instructions for

[6] Instructions, computer screenshots, and software are available from the authors upon request.

Number of others choosing C	If I choose ...	
	... C	... D
0	1	10
1	4	11
2	9	14
3	16	19
4	25	26

Table 2: Payoff Table.

Task 1 (students knew that there is also Task 2 but were not informed its content until it started). Then, students answered a written test with understanding questions. After checking these for correctness, we run Task 1. We then repeated the same sequence of events for Task 2. In the experiment, we implemented two sequential-move prisoner's dilemma games, G_N and G_S. In each of them, five subjects were randomly assigned the order of move, and sequentially prompted to choose action in the game. The information structure varied in these two games: in the game G_N, the information structure defined in Nishihara (1997) was used; in the game G_S, the information structure was extended by informing the players on the order in which they move[7]. Besides this difference, the games were kept the same. For example, a subject in each game was only informed on the information set he/she reached in the moment of move, I_C or I_D. The payoff function was presented in the form of a table, see Table 2.[8]

We used two experimental treatments, T_{SN} and T_{NS}, reversing the order in which the games were played and controlling thus for the order/learning effects. In the treatment T_{SN}, Task 1 was game G_S, while Task 2 was the game G_N. In the treatment T_{NS}, Task 1 was the game G_N, and Task 2 was the game G_S.

We start analyzing our data by summarizing the action choices in both games, and

[7]In order to disguise the order of move of a player in the game G_N, we used a sequence of screens in which subjects were asked to click on the screen using their mouse, but only some of these screens were identified as "Decision Screens" and represented a decision in a given round of the game. Moreover, we never announced the start of a new round, so that when a subject was asked to make a decision, an unknown number of other subjects could have already made decisions before this subject. Based on our post-experiment debriefing with the students, we believe that we managed to achieve our goal to implement a game with an unknown order of moves.

[8]The experiment exchange rate was 1 point=4 Eurocents. Subjects were paid for all decisions they made in the experiment.

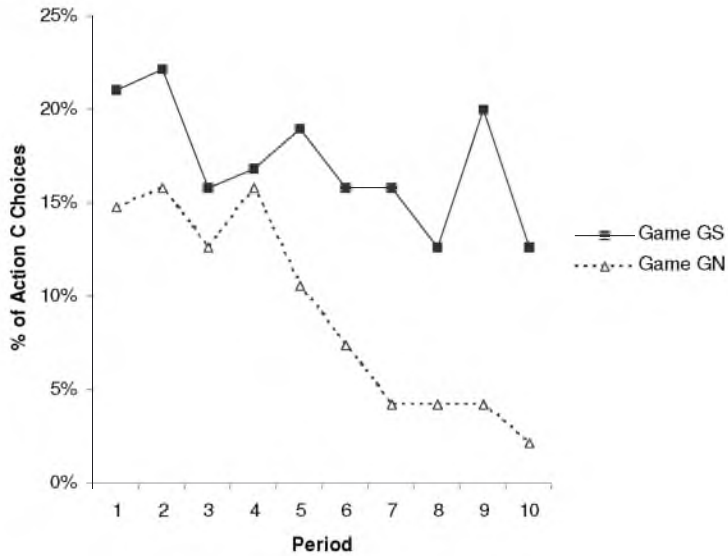

Figure 1: Frequency of Action C Choices per Game and per Period.

discussing the individual subject strategies. We then support our findings by a regression analysis. To start with, we present Figure 1 with the information on the average occurrence of the cooperative action C in the game G_S and G_N over time. This figure motivates further discussion, as cooperation seems to be more frequent, and to unravel less over time, in the game G_S than in the game G_N. Let us discuss the data in a more detail, though.

The information on the occurrence of the cooperative action C in both games, per treatment and per information set can be found in Table 3. Based on this data, we observe that: (i) subjects condition the choice of action C on the information set: controlling for the treatment and the game, choosing action C is always more likely in the information set I_C than in the information set I_D. This suggests that the action C choices are more than mere errors. And, (ii) within a treatment, subjects are more likely to choose action C upon reaching the information set C when they *do* have information on the order in which they move, in the game G_S, than under the information structure of the game G_N.

One puzzling observation in our data at the first sight is the difference in the levels of cooperation across the treatments, see Table 3. In any information set, subjects are observed to cooperate more frequently in the treatment T_{NS} than in the treatment T_{SN}.

Game	Treatment	Information set I_D	Information set I_C
G_S	T_{SN}	16/295 (5%)	25/105 (24%)
G_N	T_{SN}	6/304 (2%)	16/96 (17%)
G_S	T_{NS}	36/362 (10%)	86/188 (46%)
G_N	T_{NS}	30/405 (7%)	35/145 (24%)

Table 3: Frequency of the Action C Choices per Information Set, Game and Treatment.

In both treatments, however, more cooperation in the information set I_C is found in the game G_S than in the game G_N. The level difference of cooperation seems therefore to be merely a sampling effect, due to the number of observations we have. Can we support this suggestion?

Indeed, more light can be shed on the differences in the level of cooperation across treatments by looking more closely at the behavior in the game G_S. In the reciprocity hypothesis, we argued that cooperation will decrease abruptly at the end of a game, because strategic money-maximizers have no incentives to cooperate when ordered as the last. Only the reciprocators choose action C in the information set I_C when ordered as last in the game G_S. Indeed, the cooperation decreases for the players ordered in the second half of the game, see Figure 2.[9] But, cooperation rates remain strictly positive in the last order of move in the treatment T_{NS}, while they are equal to zero in the treatment T_{SN}. This supports the idea that subjects sampled for the treatment T_{NS} were more likely to be conditionally cooperative, and willing to cooperate also in the last order of move, when all strategic incentives to cooperate were foregone. Note that the sampling effect does not prevent us from evaluating the willingness of the subjects to cooperate in either of the game - by controlling for the treatment. We do that in the regression analysis presented later in this section.

Returning back to the Table 3, conditioning of the action C choice on the reached information set resembles the use of trigger strategies, which could sustain the coopera-

[9]The maximal willingness to cooperate is not obtained at the first order of move, as predicted by the reciprocity hypothesis, but between the order of move 3 and 4. The initial increase of cooperation is thus not correctly captured by the reciprocity hypothesis. Lacking to predict the non-linear pattern of cooperation rates, visible in Figure 2, is likely due to the simple form of static expectations we postulated for the money-maximizers. If, for example, money-maximizers, upon observing others' cooperation in the early moves in the game, update their beliefs about the presence of reciprocators, then cooperation rates could increase first, before dropping down.

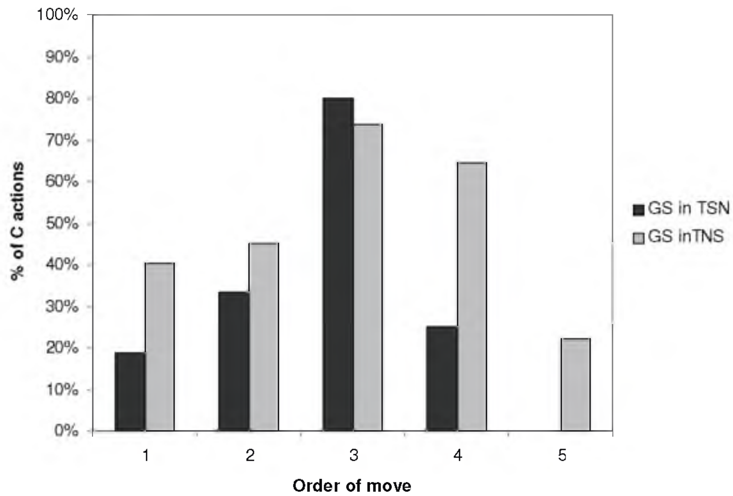

Figure 2: Frequency of Action C Choices in the Game G_S per Order of Move and per Treatment.

tive play in the game G_N in theory. However, cooperation - and trigger strategies - occur not only in the game G_N, but also in the game G_S, where rational cooperation is excluded by backwards induction. This finding is systematic. On an individual level, across treatments, 34/95 (36%) of subjects use consistently trigger strategies in the game G_S, and 24/95 (25%) in the game G_N. In other words - conditioning the action chosen on the information set reached is not found in the game G_N only, but is also applied by numerous subjects in the game G_S.

Having found cooperation - and trigger-type of strategies - both in the game G_N and G_S, we proceed now to evaluate first the way in which rational subjects choose between the cooperative and the uncooperative equilibrium in the game G_N. Afterwards, we address the comparison of the two informations structures, of the game G_N and G_S, with respect to their ability to support cooperation.

In order to test the rational equilibrium selection hypothesis conservatively, we focus for now only on the subset of the subjects who reveal to be pure money-maximizers in the game G_S. These are the subjects whose behavior can be captured by the model proposed by Nishihara (1997). When identifying such subjects, we use the fact they are bound to always choose action D in the game G_S, independent of the order of move and/or actions

Treatment	Always D in G_S		Sometimes C in G_S		
	Always D in G_N	Sometimes C in G_N	Always D in G_N	Sometimes C in G_N	Total
T_{NS}	15	2	15	23	55
T_{SN}	15	3	14	8	40

Table 4: Number of Experiment Participants per Strategy and Treatment.

chosen by other players of the game. In our dataset, these are 17/55 (31%) and 18/40 (45%) subjects in the treatment T_{NS} and T_{SN}, respectively (see Table 4). We now ask whether these rational subjects select the cooperative equilibrium proposed by Nishihara (1997) in the game G_N. Disappointingly, only very few do so: 2/17 (12%) and 3/18 (17%) in treatment T_{NS} and T_{SN}, respectively; the remaining subjects always play D in the game G_N. This leads us to the conclusion that the rational money-maximizing subjects do not play the payoff dominant equilibrium, allowing us to we reject the equilibrium selection hypothesis.

Observation **(Equilibrium selection)** Among subjects reveling to maximize their material payoffs (in the game G_S), only very few, less than 15%, choose the cooperative and payoff dominant equilibrium of the game G_N.

We now proceed by investigating the behavior of the remaining players, those who choose action C (on at least on some occasions) in the game G_S. Among them, we actually find a higher number of individuals cooperating in the information set I_C more frequently in the game G_S than in the game G_N (see Table 5, where this is the case for 23/55 (42%) vs. 17/55 (31%) of the subjects in the treatment T_{NS}, and for 15/40 (38%) vs. 10/40 (25%) of the subjects in the treatment T_{SN}). Notably, a nonegligible fraction of subjects (in particular 15/55 (27%), and 14/40 (35%) subjects in the treatment T_{NS} and T_{SN}, respectively, see Table 4) always choose D in the game G_N, but they do cooperate at least on some occasions in the game G_S. The game with the known order of moves G_S seems to support cooperation in a higher number of individuals than the game G_N.

These individual strategy findings can be complemented by a regression analysis in the form of a logit model explaining the action C choices, while accounting for individual random effects, see Table 6.[10] Based on it, the action C is significantly more likely to

[10]Treatment T_{NS} equals 1 for the the treatment T_{NS} and equals 0 otherwise; I_C equals 1 in the

Treatment	Number of C choices in $I_{\mathbf{C}}$ in G_N as compared to $G_{\mathbf{S}}$		Never C choice	Total
	higher or equal	strictly lower		
T_{NS}	17/55 (31%)	23/55 (42%)	15/55 (27%)	55 (100%)
T_{SN}	10/40 (25%)	15/40 (38%)	15/40 (38%)	40 (100%)

Table 5: Comparision of Action C Choices in the information set Ic of an Experiment Participant, per Treatment.

be chosen in the information set I_C in both games, G_N and G_S (see the positive and significant coefficient on the variable indicating the information set I_C in the columns 2 and 4, respectively). This supports the significance of the trigger strategy in both games, not only in the game G_N.[11]

Most importantly, though, we can use the regression analysis to evaluate the overall contribution of the information set-up of the game G_N to the cooperation in the sequential prisoner's dilemma game. We find the the interaction term $I_C * GameG_N$ in column 6, in a regression merging the data on both games, to be negative and significant. After controlling for possible treatment effects, sampling effects and the period of interaction, the conclusion of the regression analysis is thus not favorable to the plan to create cooperation opportunities by transforming the game G_S into the game G_N. The cooperation in the information set I_C is less likely in the game G_N than in the game G_S, implying that the potential increase in cooperation due the information removed from the game G_S, by creating information structure of the game G_N, as suggested by the theory, is empirically not supported.

Observation **(Reciprocity)** Reciprocity is frequent and affects behavior in the game G_S. (i) On an individual level, between one quarter and one third of subjects use consistently trigger-like strategies, conditioning on the informations et reached in a game.

information set I_C, and 0 in the information set I_D; Period ranges from 1 to 10; Order attains the value of the order in which a subject moves in the game G_S, and attains value 0 in the game G_N.

[11] The treatment variable T_{NS} is significant in both games as well (see columns 2-3 and 4-5), with more unconditional cooperation found in the game implemented as Task 1 (see the positive and significant effect on the variable Treatment T_{NS} for the data from the game G_N, in column 2, and the negative and significant coefficient on the variable Treatment T_{NS} for the data from the game G_S). This reveals that subjects are more willing to cooperate, independent of the information set reached, when they play a game as the first in the experiment. Subjects obviously have to learn to play the games, and they make more mistakes by cooperating unconditionally at the start of the experiment, than later in the experiment.

Data	Game G_N		Game G_S		Both games	
	Coef.	Std.Err.	Coef.	Std.Err.	Coef.	Std.Err
Game G_N					0.366	0.287
Treatment T_{NS}	2.263***	0.752	-2.283***	0.770	0.952***	0.319
I_C	2.511***	0.552	3.207***	0.093	3.422***	0.275
I_C*Treatment T_{NS}	-0.795	0.633	2.739***	0.658		
I_C*Game G_N					-1.621***	0.369
Period	-0.138	0.100	-0.219***	0.073	-0.140***	0.030
Period*Treatment T_{NS}	-0.155	0.112	0.201**	0.093		
Order			2.071***	0.537		
Order*Order			-0.294***	0.091		
Constant	-3.952***	0.684	-5.939***	0.961	-3.725***	0.369
N	950		950		1900	
Log likelihood	-234.198		-263.512		-529.346	
*sig.level 10%; **sig.level 5%; ***sig.level 1%						

Table 6: Logit Model Explaining Action C Choices.

(ii) Upon reaching the information set I_C, subjects cooperate more frequently in the game G_S, with the know order of move, than in the game G_N, without the information on the order of move.

In summary, both individual strategies and regression analysis show that cooperation is more likely in the sequential prisoner's dilemma game with a known order of moves G_S, than in the game with possible rational cooperation G_N. There may be environments which promote coordination more than the one used in our experimental design, and hence it is an open question whether rational subjects can learn to coordinate on the payoff dominant equilibrium in the game G_N. At the same time, the information structure of the game G_S proves to have advantages related to the strategic behavior in the presence of reciprocity.

4 Conclusions

Cooperation in the sequential prisoner's dilemma game can be obtained in a Nash equilibrium if the game satisfies the payoff and information conditions identified by Nishihara (1997). The order of moves in the game is assumed to be randomly assigned, and not known to the players. This construction, together with a restriction on the payoff function, guarantees that trigger strategies constitute a Nash equilibrium. We implement a game satisfying the conditions identified by Nishihara (1997) in an experimental laboratory, and observe the behavior of subjects in this game, as well as in a game with the same payoff function and with the known order of moves. We analyze the data separately for subjects who reveal to behave as rational payoff-maximizers, as well as for subjects who reveal to hold preferences and/or believe in preferences for reciprocity in others. In short, the first point we make in this paper is on a behavioral validation of the rational equilibrium selection of the cooperative equilibrium in the game introduced by Nishihara (1997). The second point we make can be seen as a behavioral robustness check, allowing for some uncertainty about others' preferences being fully captured by the material payoffs of the game.

On the first subset of our data, we find that cooperation is scarce in the game with the unknown order of moves G_N among the rational players. Hence, we reject the payoff dominance as the equilibrium selection criterion. This conclusion raises questions about the behavioral relevance of the cooperative equilibrium in the game G_N. A future research is needed to study environments supporting the coordination on the payoff dominant equilibrium among the rational, money-maximizing players (e.g. communication). On the second subset of our data, when analyzing the behavior in the game with the known order of moves, we often observe the use of the trigger strategies. Subjects seem to behave consistent with positive reciprocity and/or belief in positive reciprocity.

Finally, the overall effect is not favorable for the innovative solution to the social dilemma problem proposed in Nishihara (1997). The cooperation rates are higher in the sequential prisoners' dilemma game with the known order of moves than in the game without the know order of moves. We consider our experimental observations instructive in that a theoretically interesting result with respect to the possibility of cooperation among rational players is in contrast with the actual play of the game, when the game outcomes implementing the game do not represent players 'preferences, but only the economic outcomes from the game.

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