Spillover Effects in Infinitely Repeated Games

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Abstract

Previous papers have well documented the equilibrium selection in infinitely repeated games and the spillover effects when two games are played sequentially. This paper experimentally investigates behavioral spillovers in two infinitely repeated Prisoner's Dilemma (PD) games with different strategic uncertainty and infinitely repeated alternation games. Subjects play two of these games sequentially. The results show that when subjects are immersed in the repeated PD games that support cooperation, they tend to cooperate more in the subsequent repeated PD games where cooperation is difficult to sustain, and this positive spillover effect persists long. We also distinguish between learning to cooperate and learning to achieve efficient outcomes by adopting infinitely repeated PD games and infinitely repeated alternation games in sequence. After playing infinitely repeated Prisoner's Dilemma (PD) games that support cooperation, subjects act more efficiently in the subsequent repeated alternation games. We find that positive spillover effects exist, and subjects learn to achieve efficient outcomes.

Keywords: behavioral spillover, infinitely repeated games, prisoner's dilemma, alternation game

1 Introduction

In the context of Prisoner's Dilemma (PD) games, the social dilemma arises when both players have an incentive to defect (act in their self-interest), resulting in a sub-optimal outcome for both compared to if they had cooperated. However, according to the "Folk theorem" (Fudenberg and Maskin, 1986), both cooperation and defection can be equilibria in infinitely repeated PD games, particularly when subjects exhibit patience. Equilibrium selection in infinitely repeated games has been studied extensively as a result. Dal Bó and Fréchette (2011) find that subjects learn to cooperate under favorable conditions but tend to defect when cooperation cannot be sustained in equilibrium. This paper conducts an experiment investigating equilibrium selection in two repeated games. Subjects play two Prisoner's Dilemma (PD) games with different strategic uncertainties sequentially. The experiment revealed that an individual's inclination towards cooperation is influenced by the past game, demonstrating spillover effects.

Experimental studies have uncovered "behavioral spillover," describing the occurrence of distinct behavioral patterns when a game is played simultaneously or sequentially with other games, as opposed to when the same game is played in isolation (Savikhin and Sheremeta, 2013). Our findings of behavioral spillover in games could be crucial in real-world applications. For example, it is widely recognized that organizations are composed of multiple groups, each comprising two or more individuals collaborating to fulfill specific objectives (Gersick, 1988). Previous literature has extensively addressed strategies for enhancing organizational performance (Brewer and Selden, 2000; Postrel, 2001). Absent from these discussions is the consideration of past group experiences as a factor influencing workers' behaviors. As individuals transition between different groups within an organization, their prior experiences can significantly shape their conduct and interactions, thus impacting group efficiency and overall organizational performance. Furthermore, Northcraft and Rockmann (2012) view group decision-making as a social dilemma as individuals pursue their self-interest, which may conflict with the collective interest of the group. Therefore, to assess an organization's performance, it is important to identify spillover effects in two social dilemmas, which is what this paper contributes to.

To establish two environments, I utilize infinitely repeated PD games with different strategic uncertainties proposed by Dal Bó and Fréchette (2011). Since they well document the experimental results of the evolution of cooperation in infinitely repeated PD games, it allows us to further identify the existence and persistence of spillovers between two infinitely repeated PD games. Moreover, it's essential to recognize that spillovers can be either positive, leading to increased efficiency, or negative. In practice, organizations possess the capacity to structure their work environments by assigning tasks or providing training to take an advantage from positive spillovers while mitigating negative ones.

Distinguishing between learning to cooperate and learning to achieve efficient outcomes represents an innovative approach to understanding behavioral learning in repeated game settings. Bednar et al. (2012) propose that in alternation games, individuals strategically alternate between cooperative and non-cooperative behaviors to optimize their outcomes, but it takes times to reach the alternation. We investigate whether subjects exhibit more efficient behaviors and reach alternation faster in subsequent infinitely repeated alternation games after learning to cooperate in infinitely repeated Prisoner's Dilemma (PD) games. This concept is applicable in practical scenarios where workers are assigned specific group projects that require alternation to achieve better performance. If workers have previous experience with cooperation, positive spillovers may come into play, enabling workers to achieve more effective outcome.

This paper aims to explore two main objectives: firstly, to investigate the presence and longevity of spillovers in two infinitely repeated games sequentially, and secondly, to determine whether subjects learn to achieve the efficient outcome. Our contribution lies in proposing that individuals who predominantly engage in cooperative environments not only tend to exhibit less selfish behavior but also demonstrate the ability to learn and achieve the efficient outcome.

The remainder of the paper is organized as follows: Section 2 presents the literature review. Section 3 summarizes the experimental design. Section 4 presents the hypotheses.

2 Literature Review

The experimental literature has identified negative and positive spillovers. For negative spillovers, Cason and Gangadharan (2013) find that interacting in competitive markets lowers cooperation in public good provision. Additionally, Bednar et al. (2012) and Liu et al. (2019) discover that subjects in alternation games paired with Prisoner's Dilemma (PD) games exhibit more cooperation, while subjects in PD games paired with alternation games show more alternation. Employing alternation game in our study is motivated by their work. However, our research differs from theirs as we focus solely on one game, whereas they consider two-game ensembles, which may create a more cognitively-taxing environment and hinder subjects from playing both games optimally. Regarding positive spillovers, Cason et al. (2012) report that playing median-effort games helps achieve coordination in minimum-effort games both simultaneously and sequentially. Savikhin and Sheremeta (2013) find that participating in public good games decreases overbidding in the lottery contest. Knez and Camerer (2000) discover that an efficient minimum game increases cooperation in finitely repeated PD games, although the effect depends on the descriptive similarity of strategies in the two games. Peysakhovich and Rand (2016) discover that infinitely repeated PD games, which supports cooperation, brings more prosocial behaviors in one-shot anonymous cooperation games: the public goods game, trust game, dictator game, and ultimatum game. Although our research also aims to explore spillovers in infinitely repeated PD games, our research interests differ. They measure prosocial behavior, a social behavior intended to benefit others in subsequent one-shot interactions, while we investigate whether experiences help subjects achieve an efficient outcome in subsequent infinitely repeated games.

While previous papers suggest that individuals who have previously engaged in cooperative behaviors in one setting are more likely to exhibit similar cooperative tendencies in related situations, Jin (2024) does not find the converse to be true. She discovers that simultaneous interaction in infinitely repeated PD games, where cooperation is difficult to sustain, does not significantly increase contributions in infinitely repeated public good games due to self-licensing, a term used in social psychology. Our research differs from hers in that, unlike her simultaneous experimental design, we employ a sequential experimental design. This allows subjects to accumulate more experience in the first infinitely repeated game, enabling us to observe its impact on the outcome in the second game. Besides, Duffy and Fehr (2018) find no spillover effect in infinitely repeated stag hunt games and infinitely repeated PD games, indicating strategic considerations matter in those similar repeated games.

Finally, Savikhin and Sheremeta (2013) mention that the causes of spillovers can be strategic uncertainty about each game and path-dependence within the same game. Moreover, transfer of learning can also be one of the sources of spillovers. Cason et al. (2013) demonstrate that an experienced player will sacrifice her payoff in the initial periods of play to teach the other player turn-taking, leading to a higher joint payoff for both players. This indicates that experience may also cause positive spillover effects. Regarding the direction of spillovers, Bednar et al. (2012), Liu et al. (2019), and Savikhin and Sheremeta (2013) show that it is from games with low strategic uncertainty to games with high strategic uncertainty.

3 Experimental Design

3.1 The Games

The objective of this study is to investigate spillovers between two related games and determine whether subjects learn to achieve the efficient outcome. We choose two Prisoner's Dilemma (PD) games: in PD1, cooperation is easy to achieve, while in PD2, cooperation is difficult to achieve, as the reward for cooperation is less (Dal Bó and Fréchette, 2011). In both stage games, the dominant strategy is to defect, while (C,C) is the subgame perfect equilibrium. Additionally, we consider an alternation game similar to the low conflict assignment game in Cason et al. (2013). The dominant strategy Nash equilibrium is (D,D), but the maximized joint-payoff outcome is to alternate between (C,D) and (D,C). The payoff matrices for PD1, PD2, and the alternation game are presented in Table 1, Table 2, and Table 3, respectively.

		Player 2 C	Player 2 D
Player 1	C	$(48, 48)$	$(12, 50)$
	D	$(50, 12)$	$(25, 25)$

Table 1: PD1 (easy to cooperate)

		Player 2 C	Player 2 D
Player 1	C	$(32, 32)$	$(12, 50)$
	D	$(50, 12)$	$(25, 25)$

Table 2: PD2 (difficult to cooperate)

		Player 2 C	Player 2 D
Player 1	C	$(49, 49)$	$(42, 98)$
	D	$(98, 42)$	$(43, 43)$

Table 3: Alternation game

3.2 Experimental Procedure

The experiment is conducted at the Interdisciplinary Experimental Laboratory (IELab) at Indiana University. The experiments are programmed using o-tree (Chen et al., 2016). Subjects are recruited from a subject database which includes undergraduate students at Indiana University. A total of 64 subjects participate in 8 sessions, with 8 subjects participating in each session. Subjects will first proceed through a set of instructions that describe how the decision exercise will operate. Appendix contains the instructions for treatment PD1-PD2.

Table 4 and 5 summarize the three treatments and one control of the experiment. Each treatment comprises two sequential stage games, with each game consisting of 10 sequences (supergames) of decision rounds, except for ALT, which consists of 4 sequences. Due to the higher continuation probability in ALT, fewer sequences are considered to complete within the allotted session time. After each sequence, subjects are randomly rematched. It is an across-subject design, so each subject participates in only one treatment. Note that the control group for PD1 and PD2 can be obtained in the first game of the treatments; thus, there is only ALT control group.

Treatment	1st game	2nd game	Number of sessions	Subjects per session
PD1-PD2	PD1	PD2	2	8
PD2-PD1	PD2	PD1	2	8
PD1-ALT	PD1	ALT	2	8

Table 4: Summary of treatments

Control	Number of sessions	Subjects per session
ALT	2	8

Table 5: Summary of control

We introduce infinitely repeated game in the lab by using a random continuation probability. We consider $\delta = 0.75$ for PD games and $\delta = 0.9$ for alternation games. The number of rounds in sequences depends on the continuation probability. For example, a continuation probability of 0.75 means games have a 75% chance to continue to the next round.

At the end of the experiment, subjects will receive $5 for show up fee and an amount that depends on the subjects performance in the experiment. The experiment lasts around one hour. Earnings for this experiment fall between $15 and $20 with an average of $18.

4 Hypothesis

We can normalize any Prisoner's Dilemma (PD) game using Table 6 and Table 7. The normalized matrix consists of g, the gain from defection when the other player cooperates, and l, the loss from cooperation when the other player defects.

		Player 2	
		C	D
Player 1	C	R	S
	D	T	P

Table 6: Original PD matrix

		Player 2	
		C	D
Player 1	C	$\frac{R-P}{R-P} = 1$	$\frac{S-P}{R-P} = -l$
	D	$\frac{T-P}{R-P} = 1 + g$	$\frac{R-P}{R-P} = 0$

Table 7: Normalized PD matrix

According to Dal Bó and Fréchette (2018), the critical value to support mutual cooperation is

$$\delta^{SPE} = \frac{g}{1+g}$$

and the critical value for cooperation to be a risk-dominant equilibrium is

$$\delta^{RD} = \frac{g+l}{1+g+l}$$

Thus, we can conclude that as $\delta = 0.75$, cooperation is the subgame perfect Nash equilibrium and the risk-dominant action in PD1, while it is only the subgame perfect Nash equilibrium in PD2. Furthermore, if cooperation can be supported in equilibrium, the $SizeBAD$ (the size of the basin of attraction of Always Defect) can be calculated as the maximum probability of the other player following the grim strategy such that playing always defect is optimal. In PD1, $SizeBAD = 0.1625$, while in PD2, $SizeBAD = 0.8125$. A larger $SizeBAD$ indicates weaker cooperation in response to strategic uncertainty.

Dal Bó and Fréchette (2018) find that experience leads to optimal decisions in infinitely repeated PD1, while it is not the case in infinitely repeated PD2 as cooperation is not risk dominant and $SizeBAD$ is large. As they do not let subjects play two games to discover potential spillover effects, we proceed by offering hypotheses based on previous studies.

Hypothesis 1: ***positive spillover effects from PD1 to PD2***

Comparing the cooperation rates in the first round and all rounds of every supergame of PD2 in treatment PD1-**PD2** with the baseline PD2, which is PD2 in treatment **PD2**-PD1, allows for the identification of the existence and persistence of positive spillovers effects.

Bednar et al. (2012), Liu et al. (2019), and Savikhin and Sheremeta (2013) show that the causes of spillovers can be strategic uncertainty, from low to high strategic uncertainty. Since PD2 has larger $SizeBAD$ than PD1, it suggests weaker cooperation and higher levels of strategic uncertainty in the game. Therefore, we hypothesize that cooperative behaviors observed in PD1 will spill over to PD2, resulting in higher average cooperation rates in PD2 compared to the baseline where PD2 is played alone. Additionally, these positive spillover effects may persist over sequences as subjects learn from PD1 that being more cooperative can be beneficial.

Hypothesis 2: ***no negative spillover effects from PD2 to PD1***

Comparing the cooperation rates in the first round and all rounds of every supergame of PD1 in treatment PD2-**PD1** with the baseline PD1, which is PD1 in treatment **PD1**-PD2, allows for the identification of the existence of negative spillover effects.

Conversely, since PD1 has smaller $SizeBAD$ compared to PD2, it indicates that strategic uncertainty decreases from high to low. Therefore, we hypothesize that cooperative behaviors observed in PD1 may not be influenced by PD2. In PD1, the incentives to cooperate are strong and subjects are certain about cooperating, so the experience in playing PD2 is unlikely to affect their behaviors in PD1.

Cason et al. (2013) find that learning and teaching help adopt turn-taking in the common-pool resources (CPR) assignment game. Table 8 shows the CPR assignment game. In the game, two fishermen decide to go to one of two fishing spots. The good spot has a value of h fish , and the bad spot has a value of l fish, where $h > l > 0$ and $h > 2l$.

They select the parameters to represent a low and a high conflict assignment game as Table 9 and Table 10. In the low conflict assignment game, the ratio of the value of the good spot to the value of the bad spot, which represents the degree of conflict, is $\frac{7}{3}$. In the high conflict assignment game, this ratio is 6. They set the continuation probability as 0.9, and find that for matches (sequences) that continued for more than 4 periods, the turn-taking rate is 40% for the low conflict treatment.

		Player 2	
		Good spot (Tough)	Bad spot (Soft)
Player 1	Good spot (Tough)	$(0.5h, 0.5h)$	$(h, l))$
	Bad spot (Soft)	(l, h)	$(0.5l, 0.5l)$

Table 8: CPR assignment game

		Player 2	
		Good spot (Tough)	Bad spot (Soft)
Player 1	Good spot (Tough)	$(49, 49)$	$(98, 42)$
	Bad spot (Soft)	$(42, 98)$	$(21, 21)$

Table 9: Low conflict assignment game

		Player 2	
		Good spot (Tough)	Bad spot (Soft)
Player 1	Good spot (Tough)	$(60, 60)$	$(120, 20))$
	Bad spot (Soft)	$(20, 120)$	$(10, 10)$

Table 10: High conflict assignment game

Inspired by their work, we modify the low conflict assignment game to the alternation game as Table 10. While the dominant strategy differs from the low conflict assignment game, the joint payoff to alternate between two actions remains the same. Moreover, the punishment for not alternating is less than in the low conflict assignment game, so we may expect a higher alternation rate. Previous research has shown that turn-taking is not easy to achieve, as it requires a player to act as a teacher and sacrifice herself first to teach the other player how to take turns. In our experiment, we first let subjects play PD1, and then the alternation game. We aim to investigate whether learning in the first PD game leads to the optimal decision and a higher alternation rate in the alternation game.

		Player 2	
		C	D
Player 1	C	$(49, 49)$	$(42, 98)$
	D	$(98, 42)$	$(43, 43)$

Table 11: Alternation game

Hypothesis 3: ***negative and positive spillover effects from PD1 to ALT***

Comparing the alternation rates in every supergame of ALT in treatment PD1-**ALT** with the baseline ALT, which is ALT in control, allows for the identification of the existence and persistence of negative and positive spillover effects. Note that Cason et al. (2013) find that when subjects accomplish turn taking, they rarely deviate from the turn-taking path.

Cason and Gangadharan (2013) discover that behavioral stickiness leads to negative spillovers. Initially, during the transition from PD1 to ALT, subjects may adhere to cooperation in ALT, similar to the findings in Bednar et al. (2012) and Liu et al. (2019). However, with past cooperative experiences, the negative spillover effects may not last long, and subjects may eventually achieve higher alternation rates or attain the alternation faster, indicating positive spillover effects, similar to what Cason et al. (2013) show regarding how experience aids in achieving turn-taking. The hypothesis demonstrates that subjects learn to achieve efficient outcomes after being immersed in cooperative environments.

5 Discussion

This paper experimentally investigates spillover effects in infinitely repeated PD games and infinitely repeated alternation games. The results show that when subjects previously learn to cooperate, they tend to cooperate in the later environment where cooperation is difficult to sustain, demonstrating spillover effects. Additionally, subjects who have experiences of cooperation are able to achieve the efficient outcomes in the later alternation game. On the other hand, after subjects interact in the environment where cooperation is difficult to sustain, the spillover effects do not occur and past experience does not prevent subjects from cooperating. The reason is that the direction of spillover effects tends to be from games with low strategic uncertainty to games with high strategic uncertainty. Since there is higher strategic uncertainty in PD2 than in PD1, when subjects transition from PD2 to PD1, there is no spillover effect.

The parameters used in the PD games in this paper are consistent with past literature. Building on the results of the evolution of cooperation in infinitely repeated PD games, we are able to create two different environments. However, this limits our choice of parameters. Future studies should consider using more general parameters to further explore the repeated games.

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Appendix

Instructions

Welcome

This is a computerized experiment on decision-making. What you will earn is the show-up fee of $5 together with the money you accumulate in the experiment. The experiment lasts about 60 minutes. At the end of the experiment, you will be paid in cash for your participation.

Please turn off your cell phones and remain silent. Looking at others' screens is not allowed. If you have any question, please raise your hand and an experiment administrator will come to you. We are interested in individual choices so please remember that there are no right or wrong answers.

Payment

In this experiment you will earn points through the decisions that you make. At the end of the experiment, these points will be converted into dollars. 1 point equals 0.005 dollars. In addition to any money you earn from your decisions you will also receive a $5 show-up fee.

Experiment Overview

- The experiment will be split into two parts, Part 1 and Part 2. The choices you make in Part 1 won't influence what happens in Part 2. Your final earnings will be the total sum of the points you accumulate in both Part 1 and Part 2.

- Part 1 and Part 2 will consist of many individual sub-sections called supergames. At the beginning of each supergame, you will be paired with another individual in the room. You will then play a random number of rounds with this individual.

- Once a supergame ends, you will be randomly paired with someone for a new supergame. You will not be able to identify who you've interacted with in previous or future supergames.

Description of a Supergame

- In each round, you will be presented with two options: C and D
- You are Player 1. The person you are paired with is Player 2.
- The payoff matrix in each round in Part 1 is as follows:

		Player 2	
		C	D
2*Player 1	C	$(48, 48)$	$(12, 50)$
	D	$(50, 12)$	$(25, 25)$

  and the payoff matrix in each round in Part 2 is as follows:

		Player 2	
		C	D
2*Player 1	C	$(32, 32)$	$(12, 50)$
	D	$(50, 12)$	$(25, 25)$

  Notice that the left entry in each cell is your payoff for each round, and the right one is the payoff of the person you are paired with. For example, in Part 1,

  - If you (Player 1) choose C and the other person chooses C, you will both get 48 points.
  - If you (Player 1) choose C and the other person (Player 2) chooses D, you will get 12 points and the other person gets 50 points.
  - If you (Player 1) choose D and the other person (Player 2) chooses C, you will get 50 points and the other person gets 12 points.
  - If you (Player 1) choose D and the other person (Player 2) chooses D, you will both get 25 points.

- Your payoff for each round will be calculated and presented to you on your computer screen. The exchange rate is 1 point = \$0.005.

- After each round, there is a 0.75 probability of another round, and 0.25 probability that the supergame will end. This probability does not depend on how many rounds you have already played. Once the supergame ends, you will be randomly re-matched with a different person in the room for another supergame. Choices that you make will not influence either the number of supergames you have or the number of rounds in any supergame.

You will now take a very short quiz to make sure you understand the setup. The quiz won't affect your final payoff.

Quiz

This is the payoff matrix in Part 2.

		Player 2	
		C	D
2*Player 1	C	$(32, 32)$	$(12, 50)$
	D	$(50, 12)$	$(25, 25)$

1. If you choose C and the other person chooses D, you will receive...

   (a) 32 (b) 12 (c) 50 (d) 25 points

2. If you choose D and the other person choose C, you will receive...

   (a) 32 (b) 12 (c) 50 (d) 25 points

3. The number of rounds in a supergame depends on your actions in that supergame or other supergames.

   (a) True (b) False

4. If you have already played 2 rounds, the probability that there will be another round in your supergame is...

   (a) 0 (b) 0.25 (c) 0.75 (d) 1