Costly Strategy Adjustment Lowers Cooperation Rate In the Indefinitely Repeated Prisoner’s Dilemma

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Abstract

We study cooperation in the indefinitely repeated prisoner’s dilemma when it is costly for players to change their strategies. In contrast to standard repeated games experiments, in which players directly choose an action each period, subjects in our experiment design a comprehensive strategy, which then selects actions for them. Subjects are also able to adjust their strategies continuously during the supergames. We find that cooperation rates are significantly lower when strategy adjustment is costly than when it is not.

Keywords: Repeated Prisoners’ Dilemma, Experiments, Cooperation, Strategies

1 Introduction

In a strategic setting, it is often assumed that agents costlessly direct-respond to each other’s actions. However, in many situations, strategies have to be decided ahead of time and are costly to change at the action stage. For example, to set a plan of action, or strategy, a firm requires an executive board meeting, shareholder vote, consultants’ advice, etc. The plan of action, then, specifies the state- or history-contingent actions to be taken in the future, and, while it is costless to follow this plan, revisions are costly.

In this paper, we investigate the cooperation in an indefinitely repeated prisoner’s dilemma when changing strategy is costly. Specifically, the experiment uses two treatments - one in which it is costly and one in which costless to modify the strategy during the game. The two setups are otherwise identical and include costless strategy creation and a modification stage before each game begins. Thus, because the strategy is set ahead of time, from a game-theoretic perspective, the addition of costs during the supergame should not affect behavior.

We use the experimental interface of Romero and Rosokha (2015), which combines elements of near-continuous-time experiments (Friedman and Oprea, 2012) and the strategy method (Selten, 1967). The strategy method has been commonly used in experimental economics, and much work has been undertaken to understand its similarities to and the differences from the game method,
also known as the direct-response method (Brandts and Charness, 2011). Unlike the literature reviewed by Brandts and Charness (2011), we do not aim to compare the strategy method to the game method. Rather, we focus on the strategy method and show that explicit costs placed on strategy adjustments decrease the cooperative behavior. This result contributes to the growing experimental literature that investigates conditions under which cooperation arises in repeated prisoner’s dilemma (Duffy and Ochs, 2009; Camera and Casari, 2009; Dal Bó and Fréchette, 2011; Friedman and Oprea, 2012; Fudenberg, Rand, and Dreber, 2012; Dal Bó and Fréchette, 2013; Peysakhovich and Rand, 2013; Dal Bó and Fréchette, 2014; Honhon and Hyndman, 2015; Bigoni, Casari, Skrzypacz, and Spagnolo, 2015).

What are the reasons for the significantly lower cooperation rate when there are costs to changing strategy? Our key observation is that in the presence of costs, subjects’ strategies are more likely to be opportunistic, with a significant fraction of subjects constructing strategies that have defection following a sequence of mutual cooperation. In this way, subjects’ strategies try to exploit the possibility the costs will deter a forgiving opponent from adjusting his strategy. This leads to fewer always-cooperate strategies and to more always-defect and tit-for-tat strategies. And, although this change is relatively small, the combination of the latter two strategies yields significantly less cooperation at the aggregate level.

2 Experimental Design and Administration

Seventy students were recruited for the experiment using ORSEE software (Greiner, 2004) on the campus of Purdue University. The experiment was conducted using the experimental interface of Romero and Rosokha (2015).\(^1\) Four sessions of the experiment were administered between May and July 2015, with the number of participants varying between 16 and 18. Each session consisted of fifteen supergames. At the beginning of each supergame, participants were randomly paired and remained in the same pairs until the end of the match. The number of periods in each match was determined using a binomial distribution. Specifically, the probability of continuation was set to \(\delta = .98\). To ensure a valid comparison, the same sequence of random numbers was used in every session. Since there were no participant identifiers within the game interface, participants remained anonymous throughout the experiment.

The first five supergames of the experiment were implemented through the game method to give participants an opportunity to familiarize themselves with the game, the payoffs, and the potential strategies to be used. The last ten supergames were implemented through the strategy method. In particular, subjects constructed strategies as a collection of if-then rules that automatically made choices for them. Play proceeded automatically with four seconds per period. See Appendix A for more details on the experimental instructions and the experimental interface.

Table 1 presents summaries of the two treatments. The only difference between the treatments is whether or not strategy adjustment during the supergame is costly. There are two types of

\(^1\)A demo of the interface is available at http://jnromero.com/StrategyChoice/game.html?viewType=demo
costs associated with the strategy adjustment: a) there is a fixed cost of 25 points associated with entering the construction stage; and b) there is cost of three points per second for remaining in the construction stage. Note that in both treatments, subjects had a chance to construct and modify strategies before the start of each supergame for free.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stage Game Payoff</th>
<th>Continuation Probability</th>
<th>Sessions</th>
<th>Subjects</th>
<th>Supergames 1-5</th>
<th>Supergames 6-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Costs</td>
<td></td>
<td>δ = .98</td>
<td>2</td>
<td>36</td>
<td>Game Method</td>
<td>Strategy Method</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td>δ = .98</td>
<td>2</td>
<td>34</td>
<td>Game Method</td>
<td>Strategy Method</td>
</tr>
</tbody>
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C  
| 38,38 | 12,50 |
| 50,12 | 25,25 |

Table 1: Treatments summary

3 Results

![Graph showing average cooperation over supergames]

Figure 1: Average Cooperation. Notes: The first five supergames were implemented through the game method for subjects to get familiar with the game. The last ten supergames were implemented through the strategy method. For the costs treatment, the costs were imposed in all fifteen supergames of the experiment.

Figure 1 presents the cooperation rates obtained in our experiment. The main result is that when strategy adjustment is costly, the cooperation rate is lower than when it is not costly. In particular, in the last five supergames, the median mutual cooperation rate in the Costs treatment is 0.49, with the bootstrapped standard deviation of 0.05; and the median mutual cooperation rate in the No-Costs treatment is 0.66, with the bootstrapped standard deviation of 0.07. This result is especially interesting given that the cooperation rates and the dynamics of the evolution of cooperation during the first five supergames are not different from each other.
3.1 Constructed Rules and Strategies

Figure 2 presents the most frequent rules that subjects kept in their rule sets at some point during the last five supergames. While, for the most part, results between the two treatment are quite similar, the main differences are among fractions of $DD \rightarrow D$, $CCCC \rightarrow D$, and $CC.CC \rightarrow D$ rules. We will refer to the last two rules jointly as $CtoD$ type rules. Thus, in the costs treatment, we observe exploitative rules and persistent defection rules, which are much less frequent in the no-costs treatment. Notably, these differences lead to lower cooperation rates.

Figure 2: Most common rules during last five supergames.

Looking at the rules, however, is not sufficient, as there can be multiple combinations of rules that yield the same overall strategy. Therefore, we use simulations and clustering to identify
similar strategies within the two treatments. Specifically, we run the *affinity propagation* cluster analysis (Frey and Dueck, 2007) on the vectors of actions obtained when participants’ strategies are simulated against the set of 500 sequences described in Romero and Rosokha (2015). Figure 3 presents the results for supergames 6, 9, 12, and 15. Strategies are taken at the beginning of each supergame and the domain is *persistence-in-cooperation* x *reciprocity-in-cooperation*. Persistence in cooperation is measured as the difference between the likelihood that the participant is cooperating after mutual cooperation and how likely the participant is to cooperate after a defection by the opponent; and reciprocity in cooperation is measured as the difference between the likelihood that the participant reciprocates cooperatively and the likelihood that the participant cooperates after mutual defection. Notice that, as described in Romero and Rosokha (2015), the five common memory-1 and memory-0 strategies are distinct on this domain, specifically: grim trigger strategy is at (0,0); always-defect is at (-1,0); always-cooperate is at (1,0); tit-for-tat is at (0,1); and, finally, win-stay-lose-shift is at (0,-1).

![Figure 3: Cluster Analysis. Notes: Persistence in C = P(C after CC)-Pr(D after CD). Reciprocity in C = Pr(C after DC)-Pr(C after DD). Circles are centered at exemplar locations. The circle radius - number of participants in the cluster. Black points mark individual participant’s strategies. Reference strategies: GRIM is at (0,0); ALLD is at (-1,0); ALLC is at (1,0); TFT is at (0,1); WSLS is at (0,-1); TF2T is at (.75,1); Grim2 is at (.75,0).](image-url)

At first glance, the clusters in the two treatments are similar. Specifically, there are three main clusters: i) always-defect at (-1,0); ii) always-cooperate at (1,0); and iii) tit-for-tat at (0,1). However, the relative proportions of strategies in the three clusters are somewhat different. In particular, the fraction of always-cooperate strategies is lower, and, instead, there are higher fractions...
of tit-for-tat and always-defect strategies in the costs treatment.

![Graph showing changes in strategies per period for Supergames 1-5, Supergames 6-10, and Supergames 11-15. The x-axis represents time in seconds, ranging from 0 to 80, and the y-axis represents the average number of changes per period, ranging from 0 to 0.2. The graph shows three distinct spikes, with the first spike occurring during the 20-second break prior to the start of the supergame, indicative of participants making changes to their rule sets prior to the start of the supergame. The second spike occurs after several periods of interaction, indicating a response to the opponent’s actions. The behavior is different with the strategy approach, as the second spike is absent and there are significantly fewer changes during the supergames. This makes intuitive sense: the strategy has already been specified and will respond without any adjustments by the participant. However, if the strategy is forgiving, then there could be some benefit from trying to exploit it through use of CtoD type rules.]

Figure 4: Average Number of Changes to Strategies Per Period. Notes: Time is in seconds. Each period lasts four seconds. Seconds [-20,0] is the time prior to start of a supergame, during which subjects can make changes to their rule sets for free.

Lastly, we take a look at the adjustment process. In the first part of the experiment, which was implemented through the game method, we find two main spikes regardless of the treatment. The first spike occurs during the 20-second break prior to the start of the supergame, and is indicative of participants making changes to their rule sets prior to the start of the supergame. The second spike occurs after several periods of interaction, indicating a response to the opponent’s actions. This response comes despite costs since there is no other means of interaction. The behavior is different with the strategy approach, as the second spike is absent and there are significantly fewer changes during the supergames. This makes intuitive sense: the strategy has already been specified and will respond without any adjustments by the participant. However, if the strategy is forgiving, then there could be some benefit from trying to exploit it through use of CtoD type rules.

4 Conclusions

We report results obtained from the indefinitely repeated Prisoner’s Dilemma with costly strategy adjustment. We find that cooperation is lower when there are costs associated with making strategy changes, even though subjects have the ability to completely specify the strategy before the start of the supergame for free.

We identify the source of this difference: in the costs treatment there are rules that are exploitative and these rules are virtually absent in the no-costs treatment. These rules vary by length, but all defect after a sequence of mutual cooperation. When taking a look at the strategies, we find support of this result in that the main difference between treatments is in the fraction of participants that are playing always-cooperate strategy. Instead this fraction seems to have switched to
tit-for-tat and always-defect strategies. The combination of the latter two strategies results in a significantly less mutual cooperation and more mutual defections.

References


Appendix A: Interface Screen-shot and Experimental Instructions

Interface Screen-shot

Full Instructions


Appendix B: Quiz