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Referee report

Resilient cooperators stabilize long-run cooperation in the finitely repeated Prisoner's Dilemma

In this paper, the authors focus on the research question:

"What happens to cooperation in finitely repeated games when individuals within the same population repeatedly play these games over long intervals of time?"

The research question has been formulated well: it is crisp, framed without ambiguity and is neither too broad nor too narrow. Although previous studies have explored repeated iterations of repeated games, this research question sheds new light about the evolution of learning over longer periods of time.

The hypothesis developed in the paper is drawn from the well-established theory of 'rational cooperation'. Although the authors make no novel contributions in their theoretical proposition, they have cited relevant previous works that have lent their hypotheses to the paper. There are two main hypotheses that are used in the paper. The first is the 'unraveling' theory which states that rational players tend to defect towards the end rounds of each game to maximize their payoffs, and each rational player, expecting their rational opponent to defect tend to defect on earlier rounds. Over time this would result in all players defecting on all rounds if the population consists of only rational players. The second hypothesis deals with the case when the population contains a significant share of cooperative participants (these are the participants who do not defect first). In this situation, the cooperative players prevent the game from entirely unraveling and contribute to the overall benefit of all players sometimes at significant cost to themselves.

The authors have done a thorough study of the effect and give good evidence supporting both their hypotheses. The empirical evidence clearly shows two stages of the game as per the developed hypotheses: the first is the learning stage when players start out as highly cooperative but unravel over time, the second is the stabilization stage when the cooperation rates asymptotically approach a constant value greater than zero. This partially supports the 'unraveling' hypothesis for the first few rounds and then supports the 'cooperation' hypothesis. There is also conclusive evidence supporting the 'end game effect' (that rational players are more likely to defect the later the round) and the 'restart effect' (that cooperation rates are high at the start of every new game).

Further, a very interesting methodology to identify cooperative players is also presented. Triangulation using statistical, graphical, and qualitative tests is performed to show all

the tests identify the same set of ‘cooperative’ players. The extension of the study using simulation is also very interesting. It is able to extrapolate and show the results in extreme cases when the population contain 100% of either rational or cooperative players, and these results correspond to the expected outcomes of the study. The experiment is linked to the simulation by showing that the behavior of the agents modeled in the simulation represents an overwhelming majority of the decisions observed in the experiment. The experiment’s asymptotic values also correspond to a point on the graph generated by the simulation which further establishes the validity of the simulation. Thus the results are able to conclusively provide evidence to answer the research question.

One of the highlights of this paper is its unique experiment design that exploits the advantages of the virtual economy to feasibly collect empirical evidence. It is commendable that the authors solved the logistic hurdles of consistently collecting data over a long time from the same subjects by transferring the experiment to an online space. The data volume of 3,720 average individual decisions for 94 people totaling to 374,251 decisions is sufficient for the analysis of this research question. The researchers should also be lauded for making not just the experiment data but also a demo version of the experiment available open source.

Other parts of the experiment framework are also logical and well-thought-out. The incentive structure and the recruitment strategy have been designed aptly to motivate participants to commit to the lengthy timeline of the experiment. The population is reasonably representative of the location, gender, and age of participants. However, geography and nationality of the participant could play a significant role in cooperation, hence a more representative population could have been considered. The authors also do extensive analysis to show that attrition did not significantly affect the participant population parameters.

It is worthwhile to note that the experiment has been designed to enhance cooperation among players. The authors note that first, MTurk participants are more collaborative than the general population. Second, the value of g and l, both of which are representative of the incentive to defect (larger the value, more the incentive), are set to relatively low numbers. Third, the number of rounds per game is also very long making collaboration more likely. And finally, the expectation of repeated interactions incentivizes players to be more cooperative. Thus, although the study makes a conclusive case for the presented hypothesis, only the qualitative aspect (and not the quantitative values) of the results can be taken at face value. The research study could have performed experiments with environments differently conducive for cooperative play.

The authors have employed multiple strategies to analyze their results, including statistical methods, graphical method, qualitative study, and simulation. In the section ‘identification of steady state’ in the ‘methods’ part of the paper, it is given that the two-sample Kolmogorov-Smirnov test was used to test if cooperation varied day-by-day. It is also pointed out that K-S is not suitable for a discrete distribution. An alternate test suitable for a discrete distribution that the authors could have considered is the Chi-Square Goodness-of-Fit Test to see if both the samples (for the two days) were drawn

from the same population [1, 2]. The rest of the tests and models are rigorous and a sensitivity analysis is also performed for the player behavior simulation.

The authors have made the right amount of citation to support their work. Considering that this is an empirical paper, there is a need for the authors to extensively cite to support their hypothesis and explain their results. Their empirical evidence makes an important addition to the literature body of finitely repeated games. However, the authors could cite a few more articles to make their arguments more coherent according to the criticisms provided in this report. First, it has been found that altruistic tendencies vary from culture to culture and country to country (citation [3]), the authors can cite this paper to support more representation from countries other than US and Canada. Second, as mentioned before, the Chi-Square Goodness-of-Fit Test could replace the Kolmogorov-Smirnov test (citation [2]). Third, the authors could also consider and account for the factors and parameters that influence cooperation (citation [4]) because the existing set-up heavily favors cooperation.

Grammatical errors that need correction in the paper:

1. Abstract: "here, we report **the** results of a virtual lab experiment…" (missing 'the')
2. First section, paragraph 2: "…increasingly anticipating other rational players, begin to defect on ever**-**earlier rounds." "(that is, other**-**regarding)…" (missing hyphens)
3. First section, paragraph 3: "Empirical work has also failed to answer these questions conclusively**,** but has generally leaned toward…" "largely to different choices of parameters and experimental conditions**,** and attempts to resolve them" (two commas to be removed)
4. First section, paragraph 4: "Analysing results from a Prisoner's Dilemma experiment that ran for nearly a month of real**-**time, we find that a majority of players do indeed seek to exploit one another**,** and that as…" (addition of hyphen and removal of comma)
5. Experimental design, paragraph 1: "randomly paired to play a series of ten-round repeated games of PD, where**,** in each round each player…" "which are toward**s** the low end of the normal range for **the** previous studies." (addition of comma, 's' and 'the')
6. Initial cooperation and unraveling section, last line: "reset' themselves at the start of the next session such that there was little change from day**-**to**-**day" (addition of hyphens)
7. Resilient cooperators permanently stabilize cooperation section, paragraph 2: "… suggesting that in fact**,** the entire distribution of…" (addition of comma)
8. Discussion section, paragraph 1: "…instead **of** playing CC for the duration **of** the experiment even as they are…" (addition of two 'of's)

As mentioned before, this study design is very conducive to cooperation. Thus a logical extension of this study could be to understand how the threshold for cooperation varies with various parameters. Then the research question would be: "how does cooperation thresholds vary with various parameters for players in a finitely repeated Prisoner's Dilemma?" The same experimental setup could be used, but with one modification: different games would have different incentive structure (varying values of g and l) and

different length of rounds. This would help in capturing the variation in the resilience of players with different circumstances. The results from this study and the original study could be combined to understand the extent to which we can count on cooperative behavior to prevent unraveling.

References:

1. https://www.itl.nist.gov/div898/handbook/eda/section3/eda35f.htm
2. Snedecor, George W. Cochran, and G. William. "Statistical Methods" No. QA276. 12. S6313 (1989).
3. Charities Aid Foundation. "World Giving Index." (2015).
4. Dal Bó, Pedro, and Guillaume R. Fréchette. "On the determinants of cooperation in infinitely repeated games: A survey." *Journal of Economic Literature* 56, no. 1 (2018): 60-114.