A Replication and Robustness Check of the Centipede Game*

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Abstract

We replicate the classical centipede game of McKelvey and Palfrey (1992) and examine the effects of feedback regarding aggregate behavior. Our subjects exhibit Nash behaviour significantly more frequently than subjects in the original experiment, and aggregate feedback concerning opponent behavior induces stronger convergence to Nash equilibrium. However, following a slight modification to the payoff structure of final decision node, the treatment effects of aggregate information often shift in the opposite direction.

Keywords: Centipede Game, Replication, Self-Confirming Equilibrium

JEL Codes: C71, C73, C91

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1 Introduction

Experimental behaviour in the centipede game has been intriguing for researchers. In the two-player centipede game, two players share a monetary amount split into a large and a small pile. At each decision node, the player who moves can either 'Take' the large pile of money and the game ends, or 'Pass' to the other player and let the total amount multiply in size. In its finite version with selfish payoffs, the centipede game has a unique Nash equilibrium, whereby the first mover selects 'Take' in the initial node with probability one. However, the results from previous centipede game experiments have been among the most famous examples of deviations from game-theoretic predictions. Following the seminal experiment of McKelvey and Palfrey (1992) (henceforth MP), which demonstrated that only a small fraction of participants 'Take' immediately, subsequent experimental studies based on MP's design found limited support for the Nash prediction, restricted to specific conditions.[1] It is thus of great interest to replicate and explore the robustness of MP, as we do in this study.

First, we have a 'No Information Revelation' condition, which is simply a replication of MP. Moreover, Fudenberg and Levine (1997) argue that heterogeneous self-confirming beliefs account for behavior in extensive-form games. Hence, aggregate information may have strong effects on behavior. Following Fudenberg and Levine (1997), in our robustness check of MP, we modify the information structure, using two forms of information feedback. At each decision node under the 'Full Information Revelation' condition, subjects observe the aggregate proportions of 'Pass' and 'Take' at that node from the immediately preceding round.[2] In the 'Partial Information Revelation' condition, subjects observe these proportions only for decision nodes where the 'opponent' group moves (subjects were divided evenly into two groups and matched with members of the other group). The latter condition is

[1]Let EP denote the percentage of matches in which the equilibrium outcome is observed. In MP, subjects' EP was around 8%. Fey et al. (1996) used a game with constant social payoffs, and the EP varied considerably, ranging from 22% among Pasadena City College subjects to 77% among University of Iowa subjects. Nagel and Tang (1998), using the normal form of a 12-move centipede game, found EP not exceeding 0.5%. In Rapoport et al. (2003), EP was between 30% and 40%, in an experiment where each 'inning' of choices involved three players, rather than two. Murphy et al. (2006) used a continuous-time, symmetric version of the centipede game, and observed high EP, especially for large groups of players. In Palacios-Huerta and Volij (2009), student subjects exhibited low EP (3%), while subjects comprising chess players frequently demonstrated Nash equilibrium play (EP = 72.5%). Pulford et al. (2016) introduce "cooperative" and "competitive" reminders in the instructions, finding that EP smaller than 2%. Crosetto and Mantovani (2018) conducted a 12-move centipede game with different representations of identical payoffs, and across all treatments, EP was less than 5%. One treatment in Gamba and Regner (2019) is similar to ours in manipulating the feedback players received, yielding low EP rates (less than 1% according to the reported graph). Wang (2023) demonstrates that in a three-move centipede game with increasing-sum payoffs as in MP, the EP is approximately 30%. However, when the payoff structure shifts to constant-sum, the EP increases to 70%.

[2]Of course, since not all nodes were reached in each match, subjects saw information only about those matches that reached each particular node in the previous round.

introduced to test whether information from players' own group affects their behavior or whether only information about opponents' behavior matters. Two payoff structures are used. In the "initial payoff" condition, we use the same payoff structure as in MP, where the total pot is divided into a large pile (80% of the pot) and a small pile (20% of the pot), and whenever the active player opts to pass, both piles are doubled.[3] In the "modified payoff" condition, we introduce a small but salient change in the payoff structure: the cost for player 2 of selecting 'Pass' at the final decision node is reduced (see underlined payoffs in the last terminal node in Figure 1).

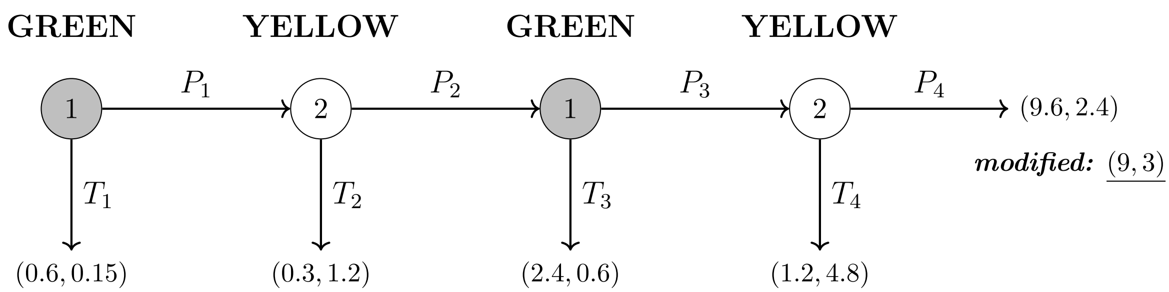

Figure 1: The Two-Player Centipede Game with Geometrically Increasing Payoffs

With no aggregate feedback, our subjects reached the Nash equilibrium outcome more often than in MP. With aggregate information, even stronger convergence to the Nash equilibrium outcome took place, especially for the 'Partial Information Revelation' condition. Our results indicate that frequent Nash play can be observed even using game structure of MP. Moreover, a small alteration in payoffs changed the effects of aggregate information. In the "modified payoff" treatments, subjects with aggregate information exhibited greater willingness to pass at early nodes.

2 The experiments

The experiments were conducted at CASSEL lab at UCLA, between March and October of 2007 and in November of 2011, with UCLA students (mostly undergraduates). For each session, subjects were assigned to two equally-sized groups, labeled GREEN and YELLOW, with group composition remaining fixed throughout the session. A rotating matching scheme was used and each participant was matched with each member of the other group exactly once, resulting in $n/2$ real rounds for a session with n participants, and there were three

[3]Despite having the same payoff structure with MP, our dollar payoffs were 50% higher in each terminal node, in order to account for the differences in purchasing power, due to the temporal distance between our experiments and the original study.

practice rounds before the real rounds. Members of the GREEN group always played the role of player 1 in the game, while members of the YELLOW group always played the role of player 2 (See Figure 1). Information about the structure of the game and matching details was made public. Subjects were paid the amount that they accumulated in all real rounds, plus a $5 participation fee. Average payoffs were $25.47, while each session lasted for approximately 50 minutes.

We conducted 16 sessions in total, and Table 1 presents descriptions of all sessions. In the eleven sessions with the original payoff structure of MP, the game was as described in Figure 1 (the amounts correspond to US dollars). Sessions NIR1 - NIR4 constitute the "No Information Revelation" (NIR) treatment, which replicated the four-move games of MP. Sessions FIR1 - FIR4 constitute the "Full Information Revelation" (FIR) treatment, in which both groups received information about decisions in the previous round. Specifically, at each decision node, both groups observed the group proportions of 'Pass' and 'Take' choices at that particular node from the immediately preceding round. For example, in round 10, at the first decision node, all subjects observed the choice proportions of the GREEN group at this node in round 9. Sessions PIR1 - PIR3 constitute the treatment "Partial Information Revelation" (PIR). Subjects received information as in FIR, but only regarding the opposite group. For example, in round 10, at the first decision node, GREEN subjects observed no information, while YELLOW subjects (inactive at this node), observed the choice proportions of GREEN subjects at this node in round 9. Treatment PIR examines whether information about one's own population is irrelevant for behavior, as a model with purely selfish players would predict.

In the remaining five sessions, participants played the game in Figure 1, but with the payoffs at the last terminal node having been modified to the underlined values. We implemented two modified-payoff treatments: NIR-M and FIR-M. The two sessions of treatment NIR-M provided no aggregate feedback, while the three sessions of treatment FIR-M revealed full aggregate information.[4]

3 Results

Relative to the original experiment of MP, involving 10 rounds, our sessions include more subjects and allow for more rounds. For comparability with MP, we therefore restrict our

[4]The modified-payoff treatments were introduced to test the hypothesis that, with aggregate feedback, initial behavior may serve as a communication selection device. See the model in the full working paper of Maniadis (2012).

Session	Sample Size	Total Rounds	Aggregate Information	Payoff Structure
NIR1	30	15	No	MP
NIR2	28	14	No	MP
NIR3	30	15	No	MP
NIR4	26	13	No	MP
FIR1	30	15	Full	MP
FIR2	30	15	Full	MP
FIR3	30	15	Full	MP
FIR4	30	15	Full	MP
PIR1	30	15	Other Group Only	MP
PIR2	28	14	Other Group Only	MP
PIR3	30	15	Other Group Only	MP
NIR1-M	30	15	No	Modified
NIR2-M	26	13	No	Modified
FIR1-M	30	15	Full	Modified
FIR2-M	30	15	Full	Modified
FIR3-M	30	15	Full	Modified

Table 1: Summary of the Experimental Sessions

analysis to rounds 6 through 10.[5] For the game of Figure 1, there are 5 terminal nodes, which we denote as $T1$ - $T4$ and $P4$. Figure 2 displays the distributions of game termination points in MP and in our treatments with MP-like payoff structures (NIR, FIR, and PIR). Across all our treatments, the proportion of players selecting 'Take' at the initial decision node substantially exceeds the corresponding proportion observed in MP, and aggregate feedback causes even stronger convergence to Nash equilibrium.[6] Figure 3 presents the distributions of game termination points in MP and in our modified-payoff treatments (NIR-M and FIR-M). In the modified-payoff treatments, the proportion of equilibrium play decreases substantially to levels comparable to MP. Moreover, subjects exhibited a greater propensity to select 'Pass' across the board, leading to a higher frequency of games reaching the final decision node and, consequently, terminal nodes $T4$ and $P4$.

In our primary replication test, we compare the distribution of matches terminating across the five terminal nodes in our NIR treatment during rounds 6-10 ($N = 285$) with the corresponding rounds of the four-move centipede games in MP ($N = 136$). These

[5]The relevant information is drawn from Table IIIA and Table IIIB in page 810 of MP. Note that there seems to be a typo in Table IIIB of MP. The value of p_2 in the row "Four Move, 6-10" should be 0.449 (or 0.45 if rounded to two decimals) rather than 0.49. Otherwise, the table is not self-contained.

[6]Note that Figure 2 focuses on rounds 6-10 for comparison with MP, indicating that the proportion of Nash equilibrium plays is marginally lower in FIR relative to NIR. However, if we focus on rounds 11-15, the Nash play rate reaches 33.3% in FIR and 40.8% in PIR, compared to 27.8% in NIR.

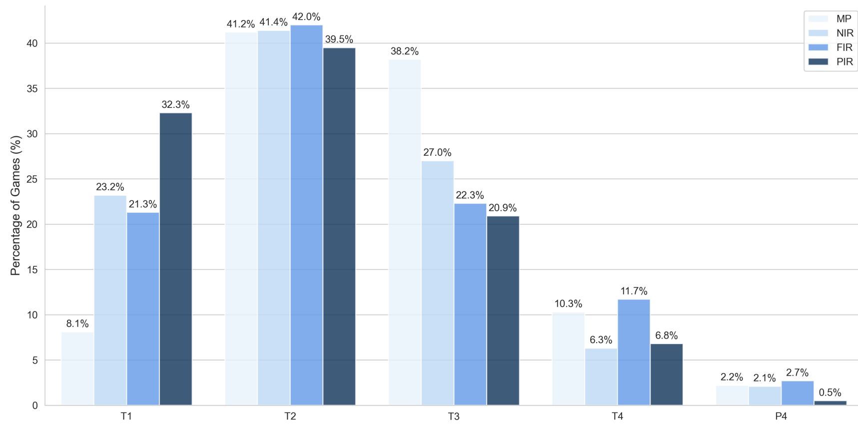

Figure 2: Distributions of Termination Points (MP, NIR, FIR, PIR)

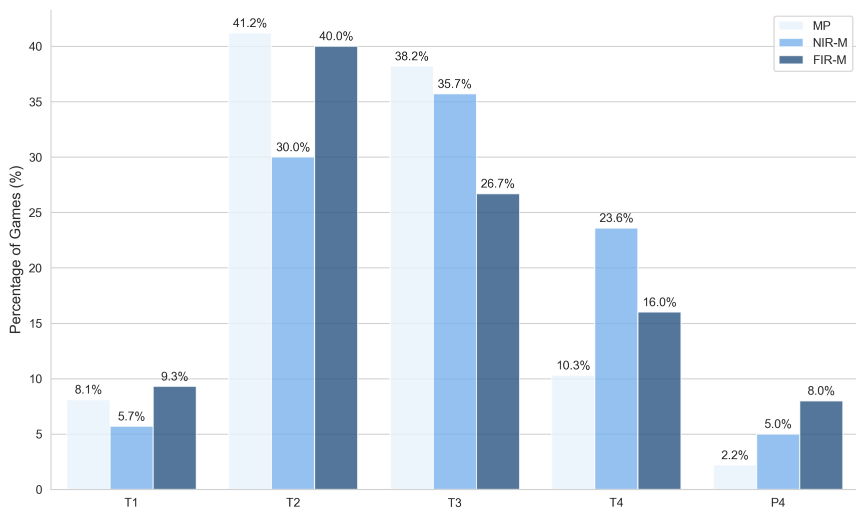

Figure 3: Distributions of Termination Points (MP, NIR-M, FIR-M)

distributions differ significantly ($\chi^2 = 17.1$, $p = 0.0018$),[7] and we therefore conclude that behavior in our experiments differs significantly from that documented in MP.[8]

Consistent with findings from prior experiments, the Conditional Take Fractions (CTF)[9] increase across decision nodes in all treatments as shown in Figure 4. Examining behavior at the final decision node is particularly interesting because it involves a dominated choice, namely 'Take'. Overall, our findings for this node align closely with MP, with CTF being

[7] A test comparing the relevant proportions of equilibrium play (matches terminating at $T1$) is also statistically significant ($\chi^2 = 13.0$, $p = 0.0003$).

[8] There are several factors that may account for this difference. Firstly, it should be noted that our UCLA subjects are part of a much larger subject pool relative to MP's Caltech subjects. In addition, several years elapsed, and our absolute payoffs are different.

[9] The Conditional Take Fraction at a given decision node is defined as the number of matches in which Take was chosen at that node divided by the total number of matches reaching that node.

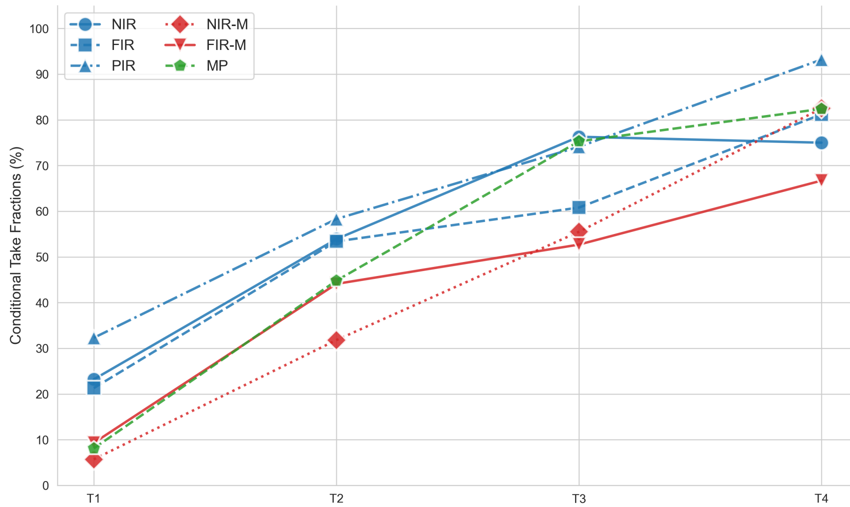

Figure 4: Conditional Take Fractions in All Treatments

approximately 80% across treatments. However, there are two exceptions: treatment PIR shows a high CTF at 93.2%, whereas treatment FIR-M exhibits a relatively low CTF (66.7%).

4 Conclusion

In our replication and extension of the prolific study of McKelvey and Palfrey (1992), we found significant differences in participants' behaviour. In the benchmark replication treatment, a much higher fraction of matches reached Nash equilibrium play, and this fraction increased further when extension treatments - with aggregate information about the previous round - were introduced.

Showcasing the 'cutting edge' nature of equilibrium behaviour in this game, we also introduced treatments modifying payoffs at the terminal decision node (far off the equilibrium path) and found that most sessions exhibited substantial passing behavior across all nodes, yielding high payoffs for participants (for NIR, FIR, and PIR, the average payoffs in real rounds are \$18.76, \$18.01, and \$15.72 respectively, and for NIR-M and FIR-M, the corresponding average payoffs are \$24.85 and \$27.83). The reason is that even a small fraction of subjects' passing in the last decision node makes it worthwhile to pass in the previous node, in turn making it profitable to pass in the node previous to that, and so on. In other words, with some other-regarding behaviour in the last decision node, the optimal behaviour changes radically for the whole game. Our modified-payoff treatments 'lower the demands' for such other-regarding behaviour, making it easier to reach the state where it is worthwhile for player 1 to always choose 'Pass'.

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A Instructions for Treatment FIR

INSTRUCTIONS

Introduction

Welcome to CASSEL. The policy in this lab is never to deceive participants. This is an experiment in group decision making, and you will be paid for your participation in cash, at the end of the experiment. Different participants may earn different amounts. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance. Please turn off all pagers and cell phones now.

The entire experiment will take place through computer terminals, and all interaction between you will take place through the computers. It is important that you do not talk, or in any way try to communicate with others during the experiment.

We will start with a brief instruction period. During the instruction period you will be given a description of the main features of the experiment and will be shown how to use the computers. If you have any questions during the instruction period, please raise your hand and your question will be answered so anyone can hear. If you have any difficulties after the experiment has begun, please raise your hand and an experimenter will come and assist you.

You will be divided into two groups, each containing __ people. The groups will be labeled the GREEN and the YELLOW group. The computer you are using will assign you to one of the two groups. If you are assigned to be GREEN you will be GREEN throughout the experiment. If you are assigned to be YELLOW you will be YELLOW throughout the experiment.

A Decision Problem

In this experiment, you will be participating in the following interaction, for real money.

In each round you will be matched with a person of the other color. During each move of a particular round, either you or the person you are matched with makes an action. The payoffs for you, and for the person you are matched with, depend on the moves you both make.

In pages 6 and 7 of the instructions you see an illustration of a specific round based on the experiment screen.

There are two piles of money: a Large Pile and a Small Pile. At the beginning of the round, the Large Pile has 60 cents and the Small Pile has 15 cents.

GREEN has the first move and can either pass or take the pile. If GREEN chooses "Take", GREEN gets the Large Pile of 60 cents, YELLOW gets the Small Pile of 15 cents, and the round is over. If GREEN chooses "Pass", both piles double and it is YELLOW's turn.

The Large Pile now contains 1.20 dollars and the Small Pile 30 cents. Now YELLOW can take or pass the pile. If YELLOW takes, YELLOW ends up with the Large Pile of 1.20 dollars and GREEN gets the Small Pile of 30 cents and the round is over. If YELLOW passes, both piles double and it is GREEN's turn again.

The Large Pile now contains 2.40 dollars and the Small Pile 60 cents. GREEN can again take or pass the pile. If GREEN takes, GREEN ends up with the Large Pile of 2.40 dollars and YELLOW ends up with the Small Pile of 60 cents and the round is over. If GREEN passes, both piles double and it is YELLOW's turn again.

The Large Pile now contains 4.80 dollars and the Small Pile 1.20 dollars. This is the last move, and it is YELLOW's second choice. If YELLOW takes the pile, YELLOW ends up with the Large Pile of 4.80 dollars and GREEN gets the Small Pile of 1.20 dollars and the round is over. If YELLOW passes, then the piles double again. GREEN then gets the Large Pile of 9.60 dollars and YELLOW gets the Small Pile of 2.40 dollars. Note that this is not an actual move, since GREEN has only one choice.

After the end of the first round, you will have the opportunity to get information about what all the YELLOW people and all the GREEN people chose in the previous round. In particular, for each of the moves, you will see the fraction of the people who chose "Take" and the fraction that chose "Pass" in the previous round. For example, during the third round, you will see information that refers to the behavior of participants in the second round.

In the first box, the GREEN people move. The numbers under the word "History" represent the fractions of GREEN people who chose "Take" and the fraction of the GREEN people who chose "Pass", in this move, in the previous round. Similarly, in the second box, the YELLOW people move. In the second box, the numbers under the word "History" represent the fractions of the YELLOW people who chose "Take" and the fraction of the YELLOW people who chose "Pass", in this particular move, in the previous round.

Note that not all the YELLOW people need have moved in this box in the previous round. Remember that all boxes, except the first one, are reached only if the other player chooses "Pass" in the previous box. The numbers under "History" have the same meaning in the other boxes. If a box does not have "History", this implies that this box was never reached in the previous round.

The experiment consists of __ rounds. In each round you will interact with a person of the different color. So this person will be GREEN if you are YELLOW and YELLOW if you are GREEN. You will not be matched with the same person twice, as there are __ people of the other color. So you will be matched with each person of the other color exactly once.

Practice Session

We will now start the instruction session. During the instruction session, we will teach you how to use the computers by going through three practice rounds. During the instruction period please do not hit any key unless you are instructed to. You will not be paid for the practice rounds. Please wait until we set up the experiment.

Please double click on the small red icon labeled "MC". When the computer prompts for you name, please type the number of the computer you are in, for example if you are at computer 14, type "SSEL 14". Then, please hit the "SUBMIT" key.

Now you should all have a window saying: "Please Wait. Connecting to Server". Please do not close any windows.

Now all of you should be able to see the experiment screen. The experiment screen should display five boxes. Remember that the last box does not describe a real move since GREEN can only choose “Take”. You see that the first match has begun. The box with the red color represents the current move, in which, one of the two participants has to make a choice. If it is your turn to move, you are given a description of the choices available to you.

If you are told in the first box that this is your move, and you have the choice menu, you are a GREEN participant. If you are told to wait for your partner to make his/her decision, you are a YELLOW participant. You will have the same color throughout the experiment. Please record your color and computer number in your record sheet. You need to record your computer number since you will be paid according to this number.

We will now start the first practice round. Will all the GREEN participants please choose PASS from your menu now?

GREEN participants now receive a message that they have passed, and now the other person (YELLOW) will get the opportunity to take or pass the pile. YELLOW participants now receive a message that the person they are matched with (GREEN) has passed the pile, and now they will have the move. Please do not forget to click “OK” on your information icons each time.

Since GREEN chose PASS, the second box now has the red color, and the YELLOW person now has the choice menu, indicating that it is YELLOW’S move. The GREEN participants are told that it is the other person’s turn to choose. Notice that there is now a large pile of 1.2 dollars and a small pile of 30 cents.

Will all the YELLOW participants please choose TAKE from you menu now?

Since YELLOW chose TAKE, the round has ended. A message informs that you or the other participant, depending on your color, has taken the pile, and tells you your payoffs. Please record your payoffs to the record sheet provided. You must do so after every round in order to double-check your payoffs are correct.

You are not being paid for the practice session, but if this was the real experiment, then the payoffs you have recorded would be money you have earned from the first round, and you would be paid this amount for that round at the end of the experiment. The total you earn over all the __ real rounds, plus your guaranteed show up fee of five dollars, is what you will be paid for your participation in the experiment.

We will now proceed to the second practice round. You now see that you have been matched with a new person of the opposite color and that the second round has begun. Does everyone see this?

The rules for the second round are exactly like the first, but now you can observe the way participants played in the first practice round. The numbers at the lower part of the boxes, under the word “History”, represent the fractions of “Take” and “Pass” decisions of participant the previous match. In the first box, you are being informed that that all the GREEN persons have chosen “Pass” in their first decision in the previous round.

Similarly, in the second box, which corresponds to the second move of the round, but only to the first decision of the YELLOW participants, you are informed that all the YELLOW people who moved chose “Take” in their first decision. The other boxes do not have numbers because there were no decisions at all to be revealed: no GREEN or YELLOW participants reached their second move. Remember that the fractions under “History” refer only to the preceding round, not all the previous rounds completed.

Now you are free to choose whatever you want in the next two practice rounds. Please stop after you have completed the third practice round. Please record your payoffs to the record sheet provided, but remember you are not paid for the practice rounds. Please remember to record your payoffs after each real round.

This concludes the practice session. In the actual experiment there will be __ rounds instead of three, and of course, it will be up to you to make your own decisions. You will not see any history in the first round. Remember that you will meet each person of the other color exactly once. At the end of round __, the experiment ends and we will pay each of you privately in cash, the total amount you have accumulated during all real rounds, plus your guaranteed five dollar participation fee. No other person will be told how much cash you earned in the experiment. You need not tell any other participants how much you earned.

We will now begin with the actual experiment. If there are any problems from this point on, please raise you hand and an experimenter will come and assist you.