On Delays in Project Completion With Cost Reduction: An Experiment.

Shubhro Sarkar[*] [†] Anthony M. Kwasnica[‡]

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Abstract

We examine the voluntary provision of a public project via binary contributions when contributions may be made over multiple periods. In many situations, early contributors are likely to pay a higher cost than those who wait. We show that in such circumstances the provision of the project always involves delay. Since this game involves coordination on complex, dynamic strategies in the face of asymmetries in payoffs, we examine behavior in the laboratory.

Keywords: Public goods provisioning, cost reduction, coordination games, subgame perfection, experiment.

JEL codes: H41, C91, C92, C72.

1 Introduction

The focus of this paper is on the effects of externalities on delays in completion of a public project. It is often the case that the individual cost of contribution for

[*]Indira Gandhi Institute of Development Research, Mumbai, 400065, India. Email: shubhro@igidr.ac.in

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[‡]The Pennsylvania State University, Smeal College of Business Administration, University Park, PA, 16802, US. Email: kwasnica@psu.edu

a public good decreases as the number of contributions already made increases. Allegations of corruption against public officials can be viewed as a public project with these features. If the corrupt official can be identified and removed, everyone receives some benefit, but this can only happen if a sufficient number of individuals are willing to implicate the official. The person bringing the first allegation not only faces the social stigma that such allegations could bring, but potentially, could also have to deal with retaliation from the person or parties against whom such allegations have been made. As more allegations are brought forward, the private cost of bringing similar allegations is reduced since these allegations become more credible. Thus, individuals have an incentive to free ride on the contributions made by others. Individuals with access to information that might bring the official to justice face a dilemma: they could contribute now with the hope that the official is brought to justice sooner rather than later, or they could choose to wait, hoping others contribute first. This process of *whistleblowing* is only one example of a public project with cost reduction; another example includes early adoption of a new technology standard.

We construct a multi-period voluntary contributions public project model designed to capture the vital features of the problem described above. Agents can choose to make an irrevocable, binary contribution at any point of time before a contribution deadline. The cost of contribution decreases as the number of prior contributors increases. If a sufficient number of contributions is received, the project is completed and all agents get a benefit. The benefit of the project decreases over time. If the project is not completed before the contribution deadline, none of the agents receive any benefit, but agents who chose to contribute still incur their cost of contribution.

When there is no cost reduction, there is a Pareto dominant, subgame perfect equilibrium where the project is completed without delay. We show that as long as cost reduction is sufficiently large, there is no pure-strategy subgame perfect equilibrium that does not involve delay. While all equilibria must result in completion of the project, the effect of cost reduction is to lead to excessive delay in project provision and, since benefits decline over time, inefficient outcomes. Both with and without cost reduction, there exists multiple pure-strategy subgame perfect Nash equilibria. We design an experiment based on the same theoretical framework, where we consider two treatments, one with and one without cost reduction. The objective of the experiment was to determine whether the actions of human participants are consistent with the theoretical predictions of the model. And, since there are many possible equilibria, the experiment might provide insights into which outcomes are more likely. Specifically, we designed the experiment in the hope of answering the following questions:

1. Does cost reduction result in significantly more delay?
2. Is the project completed under both conditions?
3. In both treatments, do the players manage to coordinate on Pareto superior equilibria?

We find that the project is completed in the treatment with cost reduction with more delay than it is in the treatment without cost reduction. We also find that the Pareto-dominant subgame perfect outcome is played frequently in both treatments. However, the players do not appear to completely overcome the significant coordination problems prevalent in this setup. For example, the actual project completion rates are significantly below what might be expected. We hypothesize that coordination problems are exacerbated in this model due to the highly asymmetric payoffs in pure-strategy equilibria.

Since choices in laboratory experiments appear inherently mixed, we solve for the symmetric mixed-strategy subgame perfect Nash equilibria for both the games with and without cost reduction and find that observed choice frequencies appear to be similar to those predicted by the *purely* mixed-strategy subgame perfect Nash equilibrium in the case with cost reduction, such that it is possible that mixed-strategies were used by the players in that game. Most players were also observed to follow a strategy of rotation, according to which each player chose to contribute about 60% of the time. While analyzing individual behavior, we find that while contribution rates did not vary significantly over the two treatments, there is evidence which suggests that players chose to contribute with more delay and to contribute more frequently in histories where one or two prior contributions were already made in the treatment with cost reduction than without cost reduction. Three contributions was the modal choice in the data. How groups managed to coordinate on three contributions is a fundamental question. We find that such coordination rates varied widely across the groups and discuss features which account for such (un)successful coordination.

The rest of the paper is organized as follows. In section 2 we discuss some related literature. In section 3 we present the model and our theoretical results. The design of the experiment is described in section 4. We present the experiment results in section 5 and conclude in section 6.

2 Related Literature

There is a substantial theoretical and experimental literature on public projects with binary contributions. A review of the extensive experimental literature on public goods provision is provided by Ledyard (1995).

A series of papers by Palfrey and Rosenthal (1984, 1988, 1991, 1994) examine a model of public project completion with binary contributions. They examine the model under complete and incomplete information and examine human participants' behavior in the laboratory under a number of treatments. Their models differ from ours in several key aspects. First, contributions are made simultaneously so dynamics are not considered, and, second, in most cases, each agent's cost of contribution is private information.

Seminal works by Schelling (1978) and Olson (1982) recognized that dynamics may play a vital role in problems of collective action. Bliss and Nalebuff (1984) develop a model where the public good is provided if one individual makes a contribution. With a finite population, equilibrium involves inefficient waiting, but as the population size approaches infinity, the inefficiency vanishes in the sense that the public good is provided almost immediately and by the lowest cost contributor. Our model differs from Bliss and Nalebuff in that multiple contributions may be required for completion allowing for cost reduction. We also examine the situation under the assumption of complete information. With complete information, the Bliss and Nalebuff model is a special case of our model without cost reduction, and we show that there exists an equilibrium without delay.

Gradstein (1992) examines a binary contribution model where the public benefit is strictly increasing in the number of contributions. Gradstein finds that when two contribution periods are allowed, inefficiency in the form of delay and underprovision may persist even for infinite populations. Marx and Matthews (2000) on the other hand show that in an environment where players can make multiple contributions before a contribution horizon is reached but have incomplete information about the actions of the other players, perfect Bayesian equilibria exist which essentially complete the project. They do this by constructing an equilibria involving punishment strategies where future contributions depend upon the observed level of previous contributions. Duffy et al. (2004) experimentally examine the Marx and Matthews model, and find that sequential play not only increases average contributions, but also increases the probability that groups reach the threshold level of the public good. While Duffy et al. focus on the potential benefits of sequential giving, our experiment highlights the potential coordination pitfalls that sequential contributions might create.

Our approach differs most substantially from the literature mentioned above on two key dimensions: First, our model has the twin features of cost reduction as other players make contributions and benefit reduction as players fail to complete the project sooner rather than later. These features are both likely to be prevalent in many public project settings and can make the efficiency issues of public project provision more salient. Second, while almost all of these models utilize an incomplete information setting, we assume complete information. Under these other models, cost differences are determined *exogenously* by nature. While this has the advantage of allowing one to identify a single, unique equilibrium, they potentially abstract from important coordination issues. In our model with complete information, the actual costs of each player is determined *endogenously* by the order of contribution. This creates a complex coordination problem that we feel is likely to be prevalent in many real-world public project applications and, since it involves potential coordination between different equilibria, is ideally suited to experimental examination.

3 The Model

We begin the theoretical analysis by describing a generalized version of the discrete time, finite horizon model with n players. We assume that each player $i \in \{1,...,n\}$, must choose whether and when to contribute for a public goods project during a contribution horizon lasting T periods. In each period t, player i must make an irreversible decision to either contribute (C) or not to contribute (NC). Player i's action in period t, is denoted by $g_i(t) \in \{C, NC\}$ provided $g_i(\tau) = NC \; \forall \tau = 1,..,t-1$ and $g_i(\tau) = NC$ for all $\tau = t+1,\ldots,T$ if $g_i(t) = C$. Let $G(t)$ be the number of players who chose to contribute up to period t. The project is completed in period t if $G(t) \geq \overline{G}$, where it is assumed that $\overline{G} < n$.

The common, public benefit from the completion of the project depends on the period in which the project is completed. Each player receives the benefit $b(r)$ where r is the first period where the project is completed, or $G(r) \geq \overline{G}$. Formally, let $r = \min\left\{\left\{1 \leq t \leq T : G(t) \geq \overline{G}\right\}, T+1\right\}$ where $r = T+1$ indicates that the project was not completed. The benefit from project completion decreases over time, or $b(t) < b(t-1)$. If sufficient contributions are not made before the contribution deadline, the project remains incomplete and none of the agents receive any benefit, or $b(T+1) = 0$.

The cost of contribution for player i in period t, $c_i(m)$ depends only on the number of players who have already chosen to contribute, denoted by m, where $m = G(t-1)$. The agent incurs the cost of contribution, even if the project remains incomplete at the end of T periods. We assume that either $c_i(m) = c_i(m')$ for all possible m and we call this the *no cost reduction* case, or $c_i(m) < c_i(m')$ for all $m > m'$ and we call this the *cost reduction* case. Notice that while cost incurred by a player by making a contribution in period t depends on when the player makes the contribution (and the number of prior contributions), benefit derived from project completion depends on when the project is completed and thus cannot be directly controlled by an individual player. Payoff to player i, u_i is then a function of both player i's contribution decisions (g_i) and the total contributions made (G):

$$u_i(g_i, G) = \begin{cases} b(r) - c_i(G(t-1)) & \text{if } g_i(t) = C \\ b(r) & \text{otherwise.} \end{cases} \tag{1}$$

Benefits and costs are assumed to vary in such a way to ensure that it is socially optimal for the project to be completed in period $t = 1$.

We assume that this is a game of complete information; each player knows her own cost and the cost of contribution of the others at each and every subgame. Players are only informed of the total number of contributions from the previous periods. Player i's personal history at the start of period t is $h_i^{t-1} = (g_i(\tau), G(\tau))_{\tau=1}^{t-1}$, and a player's strategy $s_i : h_i^{t-1} \longrightarrow g_i(t)$. A *pure-strategy subgame perfect Nash Equilibrium* (SPNE) of this game consists of a strategy profile, $s = (s_1, ..., s_n)$ that induces a Nash equilibrium in every subgame.

For the case without cost reduction, $b(1) > b(2)$ is a sufficient and necessary condition for the existence of a SPNE outcome where $\overline{G}$ of n players contribute in period 1 and the project is completed without delay. On the other hand, for the case with cost reduction, if there exists at least $n - (\overline{G} - 1)$ players such that

$$\frac{b(1) - b(2)}{c_i(0) - c_i(\overline{G} - 1)} < 1 \tag{2}$$

then there does not exist a SPNE outcome in which the project is completed in the first period. Given that $\overline{G} - 1$ players contribute in period 1, condition (2) ensures that all other players would rather delay completion of the project than pay the high initial contribution costs. Therefore, in equilibrium, the project is completed with delay.

Consider the following example that matches cost reduction environment from the experiments. Let $n = 5, T = 3$ and $\overline{G} = 3$. The project completion benefit is given by $b(r) = 1000 - (r-1)200$ for $r \leq 3$ and $b(r) = 0$ for $r > 3$ and the common contribution costs are given by $c(0) = 400$ and $c(m) = 400/(2m)$ for $m = 1, 2$.

The Pareto-dominant SPNE outcome of the game with cost reduction involves one player contributing in period 1, two of the remaining four players contributing in period 2 and the final two players not contributing. To see why project completion in the first period is not subgame perfect for this example, consider the following feasible strategy profile that does not involve delay: players 1, 2 and 3 contribute in period 1 and players 4 and 5 choose not to contribute. The payoff for players 1, 2 and 3 is 600, while the payoff for players 4 and 5 is 1000. However, players 1, 2, and 3 all find it profitable to unilaterally deviate by contributing in period 2 rather than period 1. The payoff from such a deviation is 700, which is better than the payoff under the outcome without delay. Thus, project completion in period 1 for the game with cost reduction is not subgame perfect. The total surplus generated by the SPNE outcome is 3,200 in this example, whereas the efficient allocation would prescribe contribution by exactly three players in period 1 for a surplus of 3,800.

In order to compare the effects of cost reduction on delays in project completion, we modify the previous example by making cost of contribution constant. Let $c_i(m) = 400$ for all m. Thus cost incurred by a player i in period t is independent of the number of prior contributions made. The Pareto-dominant SPNE outcome of the game without cost reduction involves three of five players contributing in period 1 and the remaining two players not contributing. Thus, the project is completed without delay and the efficient surplus is obtained.

In both cases, there are multiple SPNE involving pure strategies. The contribution patterns that are consistent with a SPNE under both with cost reduction (WCR) and without cost reduction (WOCR) are listed in Table 1. The total surplus of the SPNE outcomes varies considerably. Each contribution pattern is actually consistent with multiple SPNE outcomes where the identity of the contributing players varies amongst the five players. In addition to coordinating on a contribution pattern, players must coordinate on who is going to contribute and when they do so. The strategy (without mixing) of all players not contributing in any of the three periods is a Nash equilibrium for the treatment without cost reduction, but it is not subgame perfect. Once any player chooses to contribute in period 1, it is a best response for two of the remaining four players to contribute over the remaining two periods and complete the project. Thus, any player should be willing to deviate from the no completion strategy.

[Place table 1 here.]

While all players face (ex ante) symmetric costs of contributions, in equilibrium involving pure strategies, the payoffs are asymmetric. This asymmetry takes two forms. First, in both the with and without cost reduction cases, there are differential payoffs due to the lack of contribution by some players. In only the cost reduction case, differential payoffs are also generated by the timing decisions of those who decide to contribute. Both these asymmetries suggest that this situation will result in substantial coordination difficulties. Even if the players recognize the various SPNE of the game, they must find a way to arrive at a particular selection from the set. However, obvious equity issues are likely to complicate this choice. In the extreme case, players can guarantee an equitable payoff by refusing to contribute. As mentioned earlier, while this *no provision* outcome is a Nash equilibrium, it is not subgame perfect (in pure strategies) and is highly inefficient. As in all games of coordination with Pareto-ranked equilibria, coordination failure might be of two possible types (i) none of the equilibria might be achieved and (ii) players while successful in coordinating on some equilibrium, do not coordinate on the Pareto-optimal equilibrium. Further, in games with multiple equilibria, it is difficult to predict which of these is more likely to occur. This is an empirical question that we address by examining behavior in the laboratory.

Since equity is clearly an issue in the experimental laboratory, we examine SPNE involving mixed strategies which are (ex ante) symmetric in payoffs. In the game with cost reduction, there are two mixed-strategy SPNE, which are qualitatively similar. Table 2a presents the equilibrium probabilities of an individual contribution in the first mixed-strategy SPNE, given that the game has reached a particular period with a particular number of contributions in the previous periods.

In this equilibrium, if the players reach the third period and no previous contributions have been made, then the only symmetric equilibrium involves no contribution. The probability that the project is completed in each successive period is 0.0251 (Period 1), 0.2594 (Period 2) and 0.3355 (Period 3) for a total completion percentage of 0.62. Conditional on completion, the proportion of time the project is completed in the successive periods is .0405, .4183, and .5412 yielding an expected completion period of 2.50.

In the first equilibrium, players were assumed to play the *purely* mixed-strategy Nash equilibrium in the event they arrive at period three with one previous contribution, with a probability of contribution of 0.5509. However, in this situation, it is also clearly a Nash equilibrium (that is also ex-ante symmetric) for no player to contribute. Assuming this Nash equilibrium occurs, the corresponding SPNE is described in table 2b.

[Place table 2 here.]

In this SPNE, the probability that the project is completed in each successive period is .0034 (Period 1), .3504 (Period 2), and .2829 (Period 3) for a total completion percentage of .64. Conditional on completion, the proportion of time the project is completed in the successive periods is .0053, .5504, and .4443 yielding an expected completion period of 2.44.

In the game where cost reduction is not available, we find substantially different results. The outcome of this equilibrium is for there to be no contributions and obviously no project completion; the only history with a positive contribution percentage is when there have been two previous contributions, which is never reached in equilibrium. The high (initial) cost of contribution deters contributions in later stages, such that at histories where one contribution has already been made by period 2 or 3, the probabilities of making a contribution are lower than the corresponding probabilities at the same histories in the case with cost reduction. This, in turn, deters early contributions leaving the project incomplete. The mixed-strategy subgame perfect Nash outcome is in contrast to the pure-strategy SPNE finding, when it was assumed that players select only from the set of pure strategy equilibria, since contribution by one player in period 1 is preferred to not making any contribution in any period as it results in two additional eventual contributions. In order to verify whether the project was completed with more delay in the cost reduction treatment, whether players chose to play subgame perfect, Pareto-dominant outcomes and whether equity considerations drove players to use symmetric mixed strategies in preference to pure strategies, we turn to experimental evidence.

4 Experimental Design

For the experiment, we use the same parameterized game as in the example described above, with five players and three periods. The experiment consisted of two treatments, one with cost reduction (WCR) and one without cost reduction (WOCR), each repeated for a fixed number of rounds. In all there were three sessions. In session 1, the WOCR treatment was conducted first for 25 rounds, followed by the WCR for 25 rounds.[1] In session 2, the order of treatments was reversed. In session 3, the treatment WOCR preceded the treatment WCR, but this time the treatments involved 35 repetitions. This was done to check if increasing the number of times the game is played had any effect on the outcomes of each treatment in the last five rounds.

Each session involved 15 inexperienced subjects divided into three groups of five. Each subject was matched with the same four subjects for the entire session. We did this to enable learning over the rounds, since we were interested in studying coordination. At the conclusion of the second treatment, earnings from the both treatments plus a $5 show-up payment were paid to each subject in cash. Participants could earn a maximum of $10 in each treatment. Participants' earnings averaged $3.95 (standard deviation of $1.98, maximum of $8.88 and minimum of $1.15) for WOCR and $4.14 (standard deviation of $0.83, maximum of $5.96 and minimum of $2.68) for WCR.

All sessions of the experiment were computerized and were conducted in the Laboratory for Economic Management and Auctions (LEMA) at Pennsylvania State University. Participants were recruited from the student population of Pennsylvania State University. The experiment was programmed and conducted with the z-Tree software (Fischbacher 2007). Instructions used for the treatments are available upon request from the authors.

[1] Data from the last round in the WOCR treatment of the session 1 was lost. As a result, the reported results are based on 24 rounds.

5 Results

First, we present our primary results considering all the rounds for the two treatments. Next we examine the effects of learning by studying the first and last five rounds of each treatment. Then we look at individual behavior, whether players chose to play symmetric mixed-strategy SPNE for equity considerations and how players' behavior changed over the two treatments. Finally, we analyze coordination successes and failures and discuss extensions. We report our primary results using two logit models: (1) conditional logit model (CLM, also known as fixed-effects logit for panel data) and (2) rank-ordered logit model (ROLM). In the conditional logit model, we took a group's decision whether or not to complete the project in a round as the dependent variable, while controlling for group fixed-effects. In the rank-ordered logit model, the dependent variable is the period in which the group completed the project, in a particular round.[2] We coded non-completion as four in the first rank-ordered logit model (ROLM1) and dropped the same observations in the second (ROLM2). Our independent variables were:

- Round, which took values from one to 25 (sessions 1 and 2) or 35 (session 3).
- WCR Dummy, dummy variable which took value 1 if the treatment was with cost reduction, 0 otherwise.
- Second Treatment Dummy, dummy variable which took value 1 if the treatment was run second, 0 otherwise.

All pure-strategy SPNE under both treatments result in project completion and exactly three contributions. Therefore, we expect the project to be completed irrespective of the treatment and for the number of contributions to approach a degenerate distribution at three. We do not expect the numbers to be any different across the two treatments. If there are differences, we would infer that the added complexity and timing considerations of the WCR treatment resulted in greater coordination difficulties that manifest themselves with lack of project completion. At this level, there appears to be little discernible difference between the treatments. Since the order of treatments was varied over the experimental sessions, we also consider potential treatment order effects. The results from the regressions are summarized in table 3.

[Place table 3 here.]

[2] While the rank-ordered logit model is usually used for data where the individuals rank all available alternatives, it can also be used where only the most preferred alternative is observed.

Conclusion 1 *Cost reduction does not effect the rate of project completion or the number of contributions.*

Support: The average project completion rates for the treatments WOCR and WCR are 75% and 78% respectively. As is evident from the results from the CLM in table 3, the coefficient for the WCR dummy is not significant. In both treatments, three of five players chose to contribute most frequently. In figure 1 the distribution of contribution totals for the two treatments is displayed. Three of five contributions is the modal choice in the data. The average number of contributions is 2.77 and 2.87 for the treatments WOCR and WCR respectively. Using the Wilcoxon signed ranks test, we find that the difference in contribution levels between the two treatments is statistically not significant (at the $\alpha = 0.05$ level, $T^+ = 23$, for $N = 9$).

[Place figure 1 here.]

It is possible that the order in which the treatments were played might have had some effect on project completion rates; as the session progresses, participants learn that it is better to complete the project than to leave it incomplete. To check whether such order effects are significant, we reversed the order of treatments in the second session and found that project completion rates were nearly identical across the two treatments (81% (WCR) versus 84% (WOCR)). The coefficient for the second treatment dummy is not significant in the CLM as reported in table 3. There is thus little evidence of order effects on project completion rates. Increasing the number of rounds also had little effect on completion rates (74% (WCR) versus 80% (WOCR)).

The previous result indicates that, as expected, there is little difference between the two treatments in terms of coordination on project completion. However, we expect there to be substantial difference in the dynamics of project completion under the two treatments.

Conclusion 2 *Cost reduction results in more delay in project completion.*

Support: The project was completed in period 1 only 4% of the time on average under WCR, but completed in period 1 46% on average under WOCR. On the other hand, the project was completed in period 2 50% and 34% of the time under WCR and WOCR respectively. This results in an average project completion period under WOCR of 1.74 versus 2.41 for WCR. As reported in table 3, the coefficient for the WCR dummy is significant and positive, in both the rank-ordered logit models. The effect of cost reduction on project completion becomes even more apparent in the final five rounds of each treatment; the project was never completed in period 1 in any session for the treatment WCR.

While this result tells us that coordination with respect to timing is largely consistent with theory, there was still a substantial amount of unexpected delay under WOCR. There are a number of factors that might have caused such delay. First, there may be coordination failure amongst players. Second, players may be playing a mixed strategy. Finally, the order of treatments in each session suggests that experience may be determining the frequency of delays in WOCR. The project was completed more often without delay in the three groups where WOCR was played last (session 2). Notably, the coefficient for the second treatment dummy is significant and negative in both the rank-ordered logit models as shown in table 3.

The previous two results indicate that behavior under the two treatments is at least qualitatively similar to the behavior predicted by the theory. However, project completion and delay can also be consistent with non-equilibrium play. Therefore, we examine whether play was regularly consistent with SPNE, and, if so, which SPNE outcome was most common.

Conclusion 3 *The outcome of the game is frequently consistent with SPNE. The most frequent SPNE outcome is the Pareto-dominant outcome.*

Support: Contribution choices were consistent with a SPNE 30% of the time under WOCR and 24% of the time under WCR. Further, players chose strategies consistent with the Pareto-dominant SPNE outcome 26% and 17% of the time for WOCR and WCR respectively.

Theoretically, we expect no differences in the frequencies with which players choose to play subgame perfect outcomes or the Pareto-dominant subgame perfect outcome across the two treatments. Given the complex coordination problems the players face, these numbers could be considered as fairly large. However, players were not always successful in playing the subgame perfect outcome. But there is evidence that players learn to play the Pareto-dominant subgame perfect outcome more frequently over the duration of a session, in the sense that the Pareto-dominant subgame perfect outcome for the respective treatments were played more often in sessions where they were played second. For example, given that three contributions were made, the Pareto-dominant subgame perfect outcome for the treatment WOCR was played 35% of the time when the treatment was played first as opposed to 69% when it was played second. Similarly, for the treatment WCR, the Pareto-dominant subgame perfect outcome was played 29% of the time when the treatment was played first compared to 37% of the time when the treatment was played second. The frequency of outcomes that involve exactly three contributions over the three periods under the WCR treatment is shown in figure 2b. The outcomes with an asterisk correspond to outcomes consistent with SPNE, of which the one where one player contributes in period 1 and two of the remaining four players contribute in period 2 Pareto-dominates the others. The Pareto-dominant SPNE outcome was played most often.

Figure 2a reports the same information for the WOCR treatment. Once again, the Pareto-dominant SPNE outcome was played most often. This implies that the subjects were able to coordinate amongst themselves at both levels (i.e., playing an outcome where three of the five participants chose to contribute and selecting the Pareto-dominant subgame perfect outcome). The outcome which was played most frequently after the Pareto-dominant one in both the treatments, involved two players contributing in period 1 and one of the remaining three players contributing in period 2.[3] While this outcome is *not* subgame perfect, it is *sequentially rational*; if players ever arrived at a subgame where two players have already contributed, it would be a Nash equilibrium of this subgame for one more player to contribute immediately. So, while this play may look inconsistent with equilibrium play, it suggests that some players may be playing in a rational manner. Zero contributions, which is consistent with Nash equilibrium, was the third most frequently observed, in the treatment WCR.

[Place figures 2a and 2b here.]

While groups were "reasonably successful" in coordinating on three contributions and on the Pareto-dominant subgame perfect outcome, the success rates varied across groups. We analyze the reasons for coordination successes and failures in subsection 5.3.

5.1 Learning

Participants in each group were matched with the same four participants for the entire duration of each treatment. This was done to facilitate learning over the different rounds of the treatment. If there was learning, we would expect results from the last five rounds to be closer to the theoretical predictions than the first five rounds.

We found limited evidence in favor of learning. The coefficient for round in the CLM is not significant (table 3 and table 7). The project completion rates were found to decrease in the last five rounds as compared to the first five rounds. This result is similar to prior, well-known experimental findings which showed that participants in voluntary contribution games contribute less frequently over time. Such a decrease in contribution rates is supposed to be more pronounced in cases where participants are matched with the same partners for all the repetitions (Andreoni,

[3] It was the modal choice of all the non subgame perfect outcomes.

1988), as is true in our case. However, project completion rates went up in the second treatment for all the sessions in the last five rounds when compared to the first treatment.

[Place table 4 here.]

Though the average number of contributions dropped in the last five rounds under both treatments, the differences are not significant according to the Wilcoxon signed ranks test ($T^{+} = 24.5$ and 29.5 for WOCR and WCR respectively, $N = 9$). With regard to project completion delay, the results are mixed. Though the project was completed without delay for the treatment WOCR for the first five rounds, it was completed more frequently with delay in the last five rounds in sessions 1 and 3, which is contrary to our theoretical predictions. On the other hand, the project was completed with delay for the treatment WCR both for the first and last five rounds. More importantly, it was never completed in the first period in any of the last five rounds in any of the sessions. There is also little evidence in favor of the players learning to play either the subgame perfect outcomes or the Pareto-dominant subgame perfect outcome in either treatment.

5.2 Individual Behavior

We begin by looking at individual behavior of the players at two levels: (1) the percentage of times each player chose to contribute and (2) the percentage of times each player chose to contribute in period 1. Three of the five players in a group need to contribute for the project to be completed in both the treatments, but there are many ways such a contribution pattern could be realized. In one extreme, the same subset of players could volunteer to make contributions all the time while the others 'free-ride'. While this is easy to implement it would lead to highly asymmetric payoffs. In the other extreme, players could choose a *strategy of rotation*, according to which each player chooses to contribute only 60% of the time and free-rides on the contributions of others for the remaining rounds. While this outcome is equitable, it is hard to envision how the players, given the lack of direct communication, would coordinate on this rotation scheme.

For the treatment WCR, choosing to contribute however, is not enough. Deciding when to contribute has important consequences. This is because the first person to contribute does not enjoy the benefits of cost reduction. By choosing to contribute first, a participant provides an incentive for the others to contribute, by reducing their costs. The Pareto-dominant outcome requires only one person to contribute in period 1. Once again we could either have the same player contributing in period 1 in all the rounds (the inequitable outcome) or each player contributing in period 1 only 20% of the time (the equitable outcome). A player who chooses to contribute almost all the time and frequently always chooses to contribute in the first period for the treatment WCR could be thought of as an *altruistic leader*; she sacrifices some personal earnings in the interest of completion of the project. On the other hand, a participant who chooses never to contribute in period 1 could be labeled as a *selfish follower*; she is unwilling to accept a greater burden of the public project.

As is evident in figure 3a, most of the participants chose to contribute between 51–70% and 71–90% of the time for both the treatments. Many subjects chose contribution rates very close to the equitable option; the number of participants who chose to contribute between 55–65% of the time for the treatments WOCR and WCR were 8 (out of 45) and 10 (out of 45) respectively. The average frequency of contributions are 55 and 58 for the treatments WOCR and WCR respectively (t-statistic values were -1.3 and -0.6 for $n = 45$, $df = 44$, not significant). Using $n = 45$ we bootstrapped the mean of the observed contribution frequencies and found that the null hypothesis cannot be rejected for either treatment (table 5).

[Place figure 3 here.]

That most participants again chose a strategy of rotation for the role of leader is apparent from figure 3b. Most of the subjects contributed in period 1, 11 to 30% of the time for the treatment WCR. However, a significant fraction chose to contribute only 0–10% of the time, preferring to "wait and watch", letting someone else to make a contribution in period 1, thereby enabling themselves to enjoy a lower cost. In the WCR treatment, 10 participants (out of 45) chose never to contribute in period 1 versus 4 (out of 45) under WOCR. For the treatment WOCR, most participants chose to contribute between 51–70% of the time in period 1 as is required for efficient completion of the project and for play consistent with the Pareto-dominant SPNE. The average percentage of contributions in period 1 was found to be 40 and 18 for the treatments WOCR and WCR respectively (t-statistic for the latter with $n = 45, df = 44$ was -0.9, not significant. Corresponding variances were 6.5 and 2.4 respectively). We also calculated the correlation coefficient between the percentage of times players chose to contribute and percentage of times contributions were made by the same players in period 1 for the two treatments and found them to be 0.897 (WOCR) and 0.42 (WCR). This suggests that participants who chose to contribute for the treatment WOCR also chose to contribute early, while this was not true for WCR. Results from bootstrapping the mean of contribution frequencies in period 1 (using $n = 45$) are reported in table 5.

Another conceivable strategy which could have been used by players, given that the game was repeated a finite number of times, is a *tit-for-tat* type of strategy. To check whether players played any strategy similar to tit-for-tat, we looked at the following four proportions for each player:

CCC: Proportion of times player chose to contribute in round t given that in round $t-1$, she chose to contribute and project was completed.[4]

CNN: Proportion of times player chose not to contribute in round t given that in round $t-1$, she chose to contribute and project was not completed.

NCC: Proportion of times player chose to contribute in round t given that in round $t-1$, she chose not to contribute and project was completed.

NNN: Proportion of times player chose not to contribute in round t given that in round $t-1$, she chose not to contribute and project was not completed.

Thus contribution from other players which lead to project completion is considered as "cooperation", while non-completion is regarded as "defection". The proportion CNN best represents the tit-for-tat strategy and can also be interpreted to be a measure of *spitefulness* of a particular player. We found considerable variation in this proportion across the participants. The four proportions for the treatment WCR are displayed in figure 4. If players used such strategies, we would expect these proportions to be close to one. Results from bootstrapping the mean of these proportions show that there is little evidence to support such a hypothesis (table 5).

[Place figure 4 here.]
[Place table 5 here.]

Since players appeared to follow a strategy of rotation which yields more equitable payoffs over the rounds in both cases, it is possible that they chose to play the symmetric mixed-strategy SPNE which generates symmetric payoffs ex-ante. To corroborate this, we compared the predicted probabilities of contribution from the *purely* mixed-strategy SPNE (table 2a) with the observed choice frequencies for the different histories and found that the observed frequencies were fairly similar to the *purely* mixed-strategy SPNE prediction of the WCR treatment (figure 5). Using $n = 45$, we bootstrapped the mean of the observed frequency of contributions for the different histories, and found that the null hypothesis is rejected at the 5% level of significance in only two of the seven possible histories (table 6). We use the following terms to describe the different possible histories. *Null* refers to the beginning of the first period, when all five players simultaneously decide for the first time whether or not to contribute. In period 2, *Zero* denotes the history when no prior contributions were made in the first period, while *One* and *Two* represents histories where one or two prior contributions were made in period 1. Similarly,

[4] If a player chose to contribute while the project was completed in the same round 15 times, and she chose to contribute ten times in the following round, the proportion CCC for that player is $10/15 = 0.67$.

P3/0P denotes the history at the beginning of the third period, when no prior contributions were made in the first two periods, while *P3/1P (P3/2P)* refers to one (two) prior contribution(s) in the same situation.

[Place table 6 here.]
[Place figure 5 here.]

However, no such similarities were found in the treatment WOCR as shown in figure 6. The observed choice frequency was found to be highest at the beginning of the game, which provides a partial explanation as to why the Pareto-dominant pure-strategy SPNE was found to be played most often. Since we didn't solve for the asymmetric mixed-strategy SPNE, we cannot rule out players playing those equilibria.

[Place Figure 6 here.]

Finally, we examine how individual participants changed their behavior over the two treatments. We report conditional and rank-ordered logit model regression results similar to the ones used in analyzing group level decisions. In the conditional logit model, we took each individual's decision whether or not to contribute in a round as the dependent variable, and controlled for fixed-effects of individuals. In the rank-ordered logit model, we took the period in which the individual chose to contribute in a particular round as the dependent variable. Similar to the group-level regressions, we coded non-contribution as four in the first rank-ordered logit model and dropped these observations in the second. Regression results are reported in table 7.

Panel A in figure 7 reports the contribution rates for each of the 45 participants, while the corresponding average contribution periods are displayed in panel B. Almost all the participants chose on average, to contribute later in the treatment WCR than WOCR, with the noted exception of subject number 37 who chose to contribute 97% of the time in the WOCR treatment but switched to be a *complete free-rider* (player who chooses never to contribute) in the WCR treatment. The mean average contribution period was found to be 1.45 and 1.95 for the treatments WOCR and WCR respectively. That players contributed with more delay in the WCR treatment, is also supported by the positive and significant coefficient for the WCR dummy in both the rank-ordered logit regressions. The coefficient for the same dummy, however, was not significant for the CLM, which indicates that there were no significant differences in the contribution rates.

[Place table 7 here.]
[Place figure 7 here.]

Cost reduction is also expected to change the contribution frequencies (CF) across the different histories. While we can expect subjects to contribute more frequently in the history *Null* for the treatment WOCR, we can similarly expect the same subjects to contribute more frequently in histories *One*, *Two*, *P3/1P* and *P3/2P* in the WCR treatment. Taking

$$\begin{array}{c}\textit{Difference in CF}\\ \textit{for subject i history j}\end{array} = \begin{array}{c}\textit{CF for i,j}\\ \textit{in WOCR}\end{array} - \begin{array}{c}\textit{CF for i,j}\\ \textit{in WCR}.\end{array}$$

where $j \in \{Null, Zero, One, Two, P3/0P, P3/1P, P3/2P\}$, we can reject the null hypothesis that the mean difference in contribution frequencies (WOCR-WCR) is zero for four of the seven possible histories (table 8).

[Place table 8 here.]
[Place figure 8 here.]

5.3 Analyzing Coordination Successes and Failures

While players were successful in coordinating on the timing of their contributions to the extent that most of the time three of the five players chose to contribute for the public project and that given three contributions were made, the Pareto-dominant outcome was played most often in both the treatments, there were coordination failures. These failures were manifested in several ways. First, the project was not always completed in either treatment. Second, the project was completed with delay in several rounds under WOCR. Finally, non-equilibrium outcomes were played more often than equilibrium outcomes.

Non-equilibrium outcomes involving three contributions have already been discussed while presenting the support for conclusion 3. While three contributions was the modal choice in both treatments, four contributions was the second most frequently observed outcome. There were a few rounds in which five contributions were also made. Since contributions made beyond the required threshold are "wasted", we examine the contribution patterns associated with these contribution levels to understand the nature of such coordination failures. Figure 9 reports the frequency of the three most observed contribution patterns for the treatments WOCR and WCR, given that four contributions were made. The high frequency associated with $4\backslash0\backslash0$ could be explained as a coordination failure while attempting to achieve a contribution pattern of $3\backslash0\backslash0$ for the WOCR treatment; the corresponding high frequency associated with $1\backslash1\backslash2$ for the WCR treatment could be attributed to the high probability of making a contribution in the purely mixed strategy equilibrium for the history *P3/2P* ($p_{32} = 0.5918$).[5] Amongst the instances in which the project remained incomplete, two contributions was observed most frequently. In the WOCR treatment $2\backslash 0\backslash 0$ was the modal outcome, given that two contributions were made, even though the corresponding frequency is small when compared to the frequency with which the project was completed in rounds in which two contributions were made in the first period. The corresponding modal outcome for the WCR treatment was $0\backslash 1\backslash 1$.

[Place figure 9 here.]

The results based on all the sessions indicate that participants were moderately successful in alleviating the complex coordination problems they faced, to the extent that three contributions was the modal outcome in both treatments. To analyze how such problems were solved, we took a closer look at the performance of the different groups in terms of (i) frequency of project completion (ii) frequency with which three contributions were made and (iii) frequency of SPNE play, and found that there were variations in the success rates across the groups (figure 10). Since the frequency with which three contributions were made could be interpreted as (un)successful coordination, we provide the following analysis to explain the same.

[Place figure 10 here.]

5.3.1 WOCR Treatment

In the WOCR treatment, the average frequency of three contributions was 0.58. Groups 4, 6, 7, 8 and 9 had frequencies higher than average, group 5 had a below average frequency, followed by groups 1, 2, and 3 who did poorly. What distinguished the groups to account for this disparity? Successful groups had the following features (1) at least two players were either *incomplete leaders* (players who chose to contribute between $70-90\%$ of the time in the history Null) or *rotational leaders* (players with contribution frequency between $50-70\%$ in the history Null) and (2) exactly one player was an *incomplete free rider* (player with a contribution frequency above zero but below 20%).

Group 4, which played the WOCR treatment second, was particularly successful in not only coordinating on three contributions, but also on the Pareto-dominant subgame perfect outcome. While player 3 of this group chose to be an incomplete free rider, it seems that the other players tried different contribution patterns over

[5] Of the cases in which five contributions were made in the WCR treatment, $1\backslash 1\backslash 3$ was the most frequently observed pattern, accounting for six of the observed 12 instances. The high frequency of occurrence of such a contribution pattern can be explained by the high p_{32}.

the duration of the treatment, until they all chose the pattern of making contributions in three consecutive rounds, and to free ride in the next round (C-C-C-D), as shown in table 9.

[Place table 9 here.]

While Player 4 chose contribute-contribute-don't contribute (C-C-D) in rounds 1 – 3, all the while making contributions in period 1, she chose the same pattern in rounds 9 – 11, only to find that the project had not been completed in period 1 of round 11. She then chose to contribute in period 2 of the same round. [6] Player 3 contributed five times, each time in period 1, and every time this coincided with the project being completed with four or five contributions in the first period. She then chose to contribute for the last time in round 13. With one player choosing to free-ride, three of the remaining four players needed to contribute to complete the project. If players followed a rotation strategy, they would need to contribute 75% of the time. The contribution pattern C-C-C-D enabled them to achieve this, which resulted in the project being completed with three contributions from rounds 14 – 25. It seems that players in this group went through a learning process, in which they groped for the correct contribution pattern. With all five players contributing, the C-C-D pattern would have been closest to the equitable rotation strategy, but with one player choosing to free ride, C-C-C-D became the optimum pattern. No such contribution patterns were observed in the same group for the WCR treatment.

Group 8 was equally successful in coordinating on three contributions, but was not able to play the Pareto-dominant subgame perfect outcome as often as group 4. Contribution patterns of the type mentioned above, were not observed in this group. While $3\backslash0\backslash0$ was the modal outcome, being played in 13 rounds (out of 35), the outcomes $2\backslash1\backslash0$ and $2\backslash0\backslash1$ together, were played for another 12 rounds. In this group, player 4 chose to be the incomplete free rider, while players 1 and 3 were rotational leaders. Player 2 chose to contribute in all but one round, and did so frequently in period 1. The lack of successful coordination on the Pareto-dominant subgame perfect outcome can be attributed to player 5's strategy of contributing often in periods 2 and 3. She chose to contribute either in period 2 or 3, when two contributions had already been made in period 1, in 11 rounds. Had she contributed in period 1 instead, the project would have been completed in period 1 and brought the frequency of Pareto-dominant subgame perfect outcome play at par with that of group 4. Similarly, the frequency of SPNE play in group 9 could have improved to 37% had player 3 contributed in period 1 instead of period 2, in eight rounds. These players thus chose to "wait and watch", letting others contribute first, even though they did not enjoy any additional benefits from waiting.

[6] Player 5 had the same experience over rounds 6 – 8.

The first feature was missing in each of the groups which did poorly, which suggests the importance of leaders, either of incomplete or of rotational type, in successful coordination on three contributions in the WOCR treatment. For example, group 2 had only one rotational leader, while groups 1 and 3 had none. Having an incomplete free rider in the group also helped in the coordination process, since it would be easier for four players to efficiently complete the project rather than five.

5.3.2 WCR Treatment

While theory predicts that the frequency with which three contributions are made should remain unchanged across the two treatments, we found a lower average frequency of three contributions in the WCR treatment of 0.49, even though the variation in the success rate across the groups was smaller than under WOCR. Groups 3 and 7 were most successful, while groups 1 and 8 were least successful. There were no altruistic leaders; the highest contribution frequency in the history Null was 0.52.

Group 3 was the most successful at both levels. Players in this group seem to have played specific roles which helped the group achieve high coordination rates. Two players played the role of *incomplete leaders* (having contribution frequency above 30% in the history Null): one as a *weak free rider* (with contribution frequency between $20-50\%$), the other as an *incomplete contributor* (contribution frequency between $70-90\%$). Two other players chose to be *followers*, making 70% or more of their contributions in periods 2 or 3, of which one was a *selfish follower*. Group 7 had the second highest success rate and had its players playing similar roles.

Group 1 on the other hand, had as many as four players playing the role of follower. This meant that while the project completion rate of the group was at par with those of the other groups, there were far too many rounds in which four or five contributions were made. This could be due to the fact that the group had the lowest project completion rate in the WOCR treatment and that players wanted to "make up" for the low completion rate in the first treatment. Group 8 failed mainly because, one of its players who had chosen to be a *complete contributor* (contribution frequency above 90%) and an incomplete leader in the WOCR treatment[7] switched to be a complete free rider in the WCR treatment.

The disparity in the performance of the different groups can thus be accounted for by the roles players chose to play at the beginning of each treatment. Some chose to be contributors, others, free riders. At the same time, players decided ei-

[7] This player was closest to an altruistic leader.

ther to be leaders or followers. Kragt et al. (1983) while studying the effects of pre-play communication on the percentage of cooperative behavior, found that in each of the groups in which pre-play communication was allowed, subjects used the discussion to make a distributional decision about who would, and who would not make contributions. This resulted almost always in the public good being provided in an optimal manner. In our setup, where pre-play communication was not allowed, groups which successfully coordinated on three contributions, had the "optimal" distribution of number of contributors and free riders, as well as leaders and followers.

A number of extensions may provide insights into behavior. First, we could allow nonbinding pre-play communication between the players and check what kind of outcomes are played more frequently. Second, we could increase the number of players in a group, as well as the required threshold number of contributions in the public good project model described above, and check how changing the number of players affects the outcome(s) from the corresponding models. We would expect that allowing pre-play communication would obviate coordination failures while increasing the number of players would make coordination more difficult.[8]

6 Discussion and conclusion

We constructed a multi-period voluntary contributions model designed to capture features of a public goods provisioning problem where the cost of contribution reduces with the number of prior contributions. Our main results are as follows. The project was completed with more delay in the WCR treatment. While the project completion rates were 75% and 78% for the treatments WOCR and WCR respectively, the differences in the completion rates as well as in the contribution levels between the two treatments were not statistically significant. Three contributions was the modal outcome (58% and 49% for treatments WOCR and WCR respectively) and the Pareto-dominant outcome was played most often. Given the asymmetric nature of the payoffs derived from project completion and the complicated nature of the game, it is noteworthy that most of the time participants successfully coordinated amongst themselves at all levels to ensure that the project was completed.

Since the present study involves a threshold-type public goods framework with non-refundable binary contributions, it is appropriate to compare our results with those of previous studies which used a similar setup. Rapoport and Eshed-Levy (1989, REL) used a public goods model with parameters similar to the ones used

[8] Our hypothesis that increasing the number of players would lead to a lower project completion rate is backed by conclusions from Dixit and Olson (2000).

by us, with three of five players required to contribute for the provision of the public good. They report an average project completion rate of 33.7% along with a mean proportion of contributions of 0.365. Kragt et al. (1983) reported an average project completion rate of 65% and an optimal project completion rate of 29.4% in the treatment where no pre-play communication was allowed. Dawes et al. (1986) while studying the effects of a money-back guarantee device and an enforced contribution device in a public goods contribution game, report project completion rates of 70% and 40% and optimal project completion rates of 30% and 20% in treatments with seven subjects, of which, three and five subjects needed to contribute to complete the project respectively. All three studies involved subjects being endowed with an initial endowment, all or none of which had to be contributed to the public project. REL used a multiple-round design, whereas both Kragt et al. and Dawes et al. used a single-round design, where in each round, players chose simultaneously whether or not to contribute, once. Our design differs in the sense that each round of our experiment (potentially) consists of several periods, in each of which players choose simultaneously whether or not to make binary contributions. This same difference in design distinguishes our framework from those of other coordination games which involve Pareto-ranked equilibria, where inefficient outcomes get played more often (Van Huyck et al. 1990, VBB).

While the Pareto-dominant subgame perfect outcome was played most often in both treatments, non-equilibrium outcomes together were played more often than equilibrium outcomes over all rounds. Even in the treatment WOCR, where the Pareto-dominant subgame perfect outcome required three players to contribute in period 1, players often chose to "wait and watch", letting others contribute first, even though there was no apparent benefit from waiting. This could be due to the dual effects of the "incentive to free ride" and the "incentive to coordinate to ensure exactly three contributions were made". This is corroborated by the reasonably high frequency with which the outcomes $2\backslash1\backslash0$ and $2\backslash0\backslash1$ were played in the WOCR treatment.

Individual players were often found to play a strategy of rotation over the rounds, when faced with the decision as to whether or not to contribute and when to contribute, which generated more equitable payoffs. However, there was no evidence that symmetric mixed strategies were used in the treatment WOCR, though they could not be rejected in the WCR treatment. While there was no significant difference in the contribution rates across the treatments, there was evidence in favor of players choosing to contribute more often in periods 2 or 3 when 1 or 2 prior contributions had been made.

While analyzing the differential success rates of coordination on three contributions across groups, we found that groups which were most successful had an optimal distribution of leaders and free riders in the WOCR treatment, and leaders and followers in the WCR treatment. There was also evidence which suggests that players in one group tried different coordination devices over the duration of the WOCR treatment, which enabled them to efficiently complete the project.

Our main goal in this paper was to address the following question: does a cost reduction feature induce more delay in completion of a public good project than one without it? We attempted to answer this question in the framework of coordination games with Pareto-ranked multiple equilibria, where we predicted that the Pareto-dominant subgame perfect outcome would be played most frequently, such that, the project would be completed without delay in the case where there is no cost reduction and would be completed with delay in the model with cost reduction. Experimental evidence collected supports our hypothesis that cost reduction induces more delay and that the Pareto-dominant subgame perfect outcome is played most often in both cases. While analyzing the results we suggest that the nature of the game where a sequence of simultaneous games are played (as opposed to one shot nature as seen in VBB and REL) could have helped players to coordinate their actions.

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Tables

Table 1. SPNE Outcomes.

	Contributions in $Pd1\backslash Pd2\backslash Pd3$	Total Surplus
WOCR	3\0\0	3,800
	1\2\0	2,800
	0\3\0	2,800
	0\0\3	1,800
WCR	1\2\0	3,200
	0\1\2	2,200
	1\0\2	2,200

Contribution patterns and surplus for all SPNE outcomes of the example game described in section 3 with and without cost reduction.

Table 2. Mixed Strategy SPNE.

(a)

	Contributions		
Period	0	1	2
1	.1469	–	–
2	.0655	.3211	.4226
3	.0000	.5509	.5918

(b)

	Contributions		
Period	0	1	2
1	.0722	–	–
2	.3331	.4731	.4226
3	.0000	.0000	.5918

Probability of contribution in a period, given number of prior contributions in WCR mixed-strategy equilibria. Panel (a) reports the purely mixed-strategy equilibrium.

Table 3. Conditional and Rank-ordered Logit Regression Results for Group Level Decisions.

	Group		
	Conditional	Rank-Ordered	
	Logit	Logit 1	Logit 2
Round	-0.001 (0.012)	0.011^{*} (0.006)	0.018^{**} (0.008)
WCR dummy	0.070 (0.248)	1.012^{***} (0.134)	1.558^{***} (0.171)
Second Trt dummy	0.255 (0.248)	-0.422^{***} (0.134)	-0.432^{**} (0.171)
observations	507	507	389
log-likelihood	-247.470	-576.196	-307.223

Coefficients from Conditional and Rank-ordered Logit Regressions for group level decisions. Standard errors are in parenthesis.

* Significant at 0.10 level.

** Significant at 0.05 level.

*** significant at 0.01 level.

Table 4. First Five vs Last Five Rounds.

Completion rate	First 5	Last 5	
WOCR	84%	73%	
WCR	82%	71%	
Average # of Contributors	First 5	Last 5	p-value
WOCR	2.9	2.6	0.4610
WCR	3.1	2.7	0.1484

Completion rates and average number of contributors in the first and last five rounds for the treatments WOCR and WCR.

Table 5. Bootstrap Results.

	Obs Coeff	Bias	Bootstrap Std. Err.	95% CI (Percentile)	
Rotation					
Overall frequency					
WOCR	0.554	0.002	0.040	0.479	0.634
WCR	0.575	0.001	0.034	0.508	0.643
Period 1 frequency					
WOCR	0.405	0.002	0.038	0.328	0.479*
WCR	0.176	0.001	0.022	0.134	0.222
Tit-for-Tat					
CCC	0.667	−0.000	0.022	0.621	0.709
CNN	0.364	0.003	0.075	0.216	0.521
NCC	0.352	0.005	0.050	0.268	0.470
NNN	0.432	−0.003	0.055	0.320	0.536

Bootstrap results with $n = 45$ and number of repetitions = 1000. * indicates that the null hypothesis is rejected at 5% level of significance.

Table 6. Bootstrap Results.

	History	Obs. Coeff.	Bootstrap Std. Err.	95% CI (Percentile)		Pred. Coeff. (H_0)
1.	Null	0.176	0.022	0.134	0.219	0.147
2.	Zero	0.172	0.030	0.113	0.232	0.066*
3.	One	0.396	0.046	0.305	0.486	0.321
4.	Two	0.37	0.066	0.248	0.505	0.42
5.	P3/0P	0.041	0.014	0.013	0.07	0.00*
6.	P3/1P	0.497	0.06	0.381	0.614	0.551
7.	P3/2P	0.523	0.055	0.415	0.632	0.592

Bootstrap results with $n = 45$ and number of repetitions = 1000. * indicates that the null hypothesis is rejected at 5% level of significance. The H_0 is obtained from the purely Mixed Strategy Equilibrium for the WCR treatment described in table 2a.

Table 7. Conditional and Rank-ordered Logit Regression Results for Individual Level Decisions.

	Individual		
	Conditional	Rank-Ordered	
	Logit	Logit 1	Logit 2
Round	-0.006	0.005^{*}	0.007
	(0.005)	(0.003)	(0.005)
WCR dummy	0.034	0.507^{***}	1.694^{***}
	(0.096)	(0.059)	(0.125)
Second Trt dummy	0.127	-0.191^{***}	-0.597^{***}
	(0.096)	(0.059)	(0.125)
observations	2535	2535	1430
log-likelihood	-1430.726	-2521.273	-994.227

Coefficients from Conditional and Rank-ordered Logit Regressions for individual level decisions. Standard errors are in parenthesis.
* Significant at 0.10 level.
** Significant at 0.05 level.
*** significant at 0.01 level.

Table 8. T-test Results.

	History	$N\ (df)$	Mean	St. Error	H_A	t stat (p-value)
1.	Null	45 (44)	0.212	0.037	$\mu > 0$	5.71 (0.00)
2.	One	40 (39)	−0.111	0.06	$\mu < 0$	−1.91 (0.03)
3.	Two	40 (39)	−0.113	0.075	$\mu < 0$	−1.50 (0.07)
4.	P3/1P	31 (30)	−0.462	0.062	$\mu < 0$	−7.45 (0.00)
5.	P3/2P	44 (43)	−0.333	0.071	$\mu < 0$	−4.68 (0.00)

One sample t-test results which reject the H_0 that the mean difference (WOCR-WCR) in the observed contribution frequencies over the two treatments is zero for four histories.

Table 9. Contribution patterns for players of group 4 in WOCR treatment.

Pattern	Players	Rounds
C-C-C-C-D	$1,2,4,5$	$2-6, 3-7, 4-8$ and $1-5$ respectively
C-C-D	4	$1-3, 9-11(?)$
C-C-C-D	$1,2,4,5$	$7-25, 8-23, 13-24$ and $10-21$ respectively

Figures.

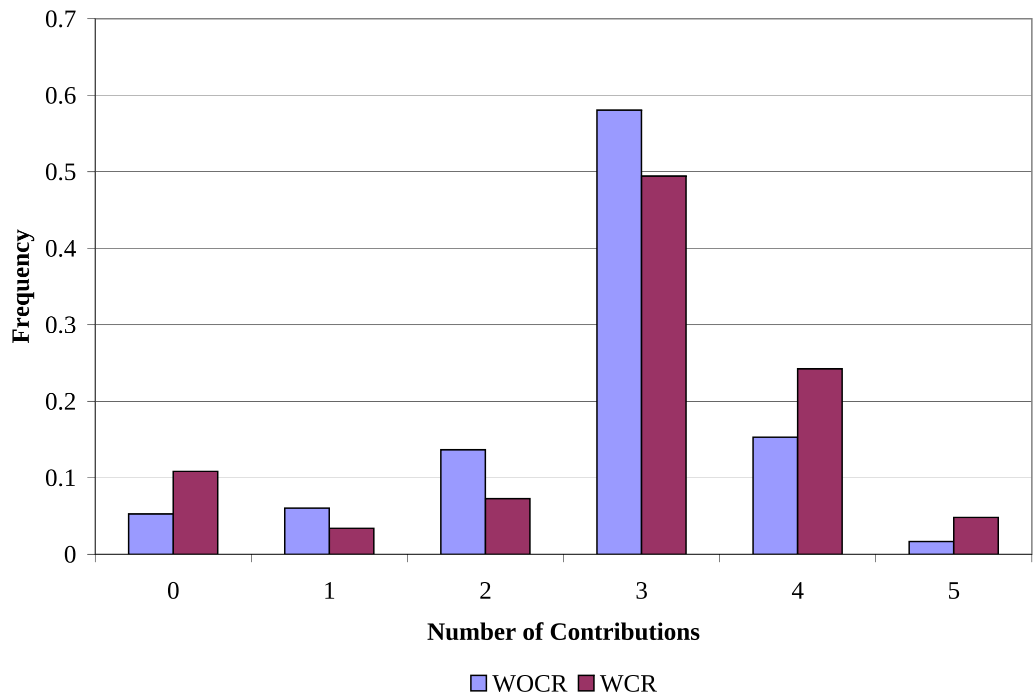
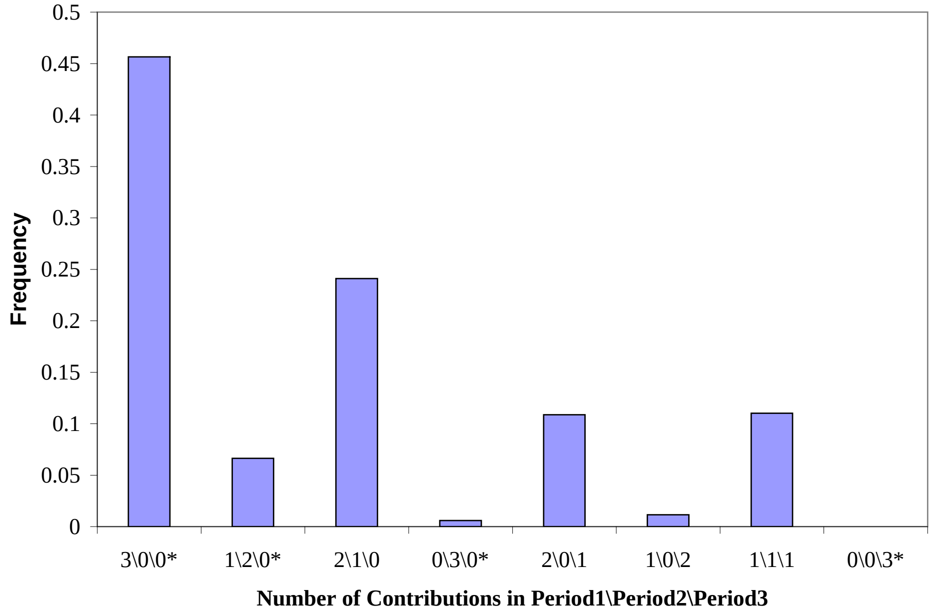
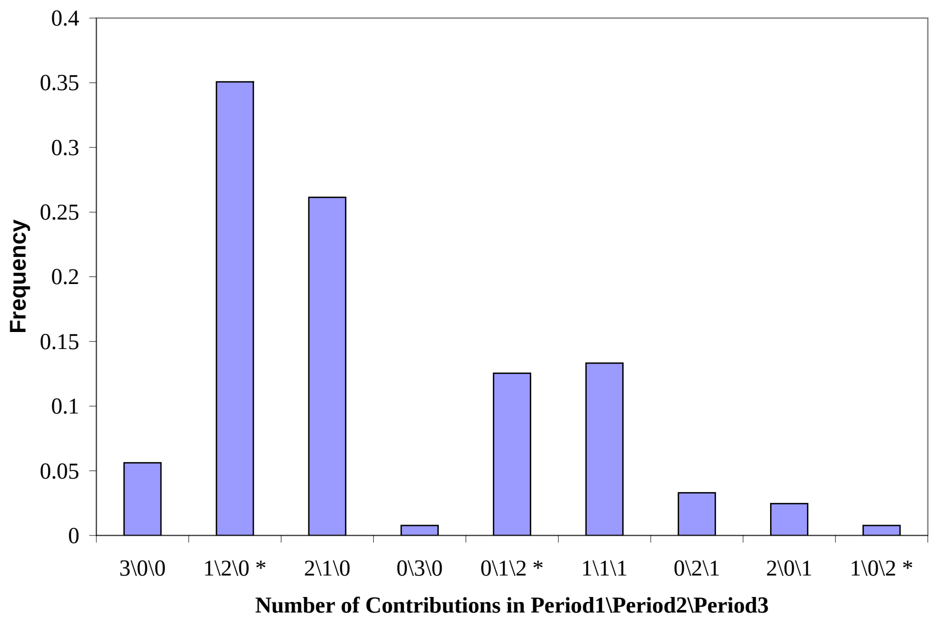


Figure 1. Distribution of number of contributions for treatments WOCR and WCR.

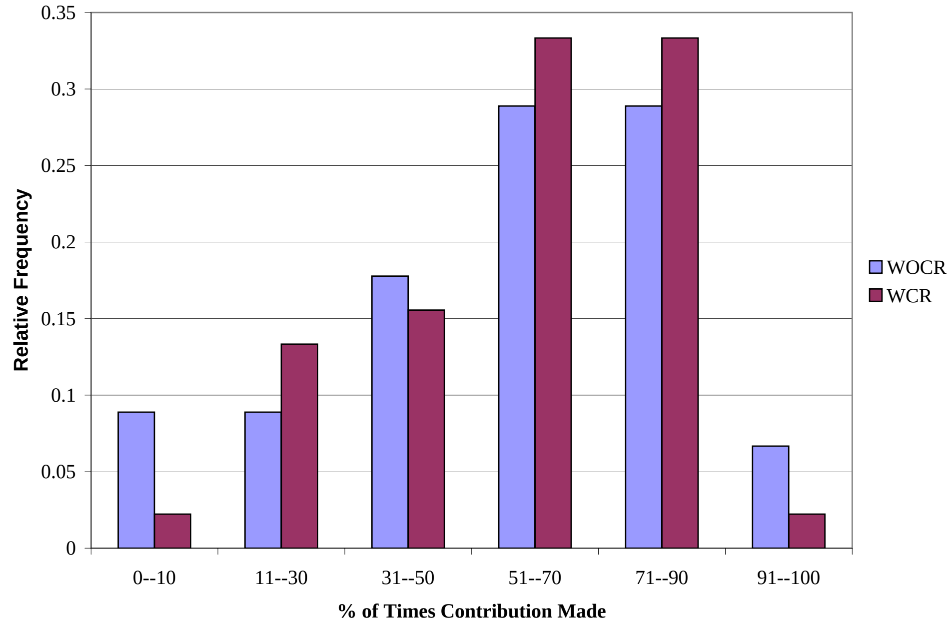


(a) WOCR

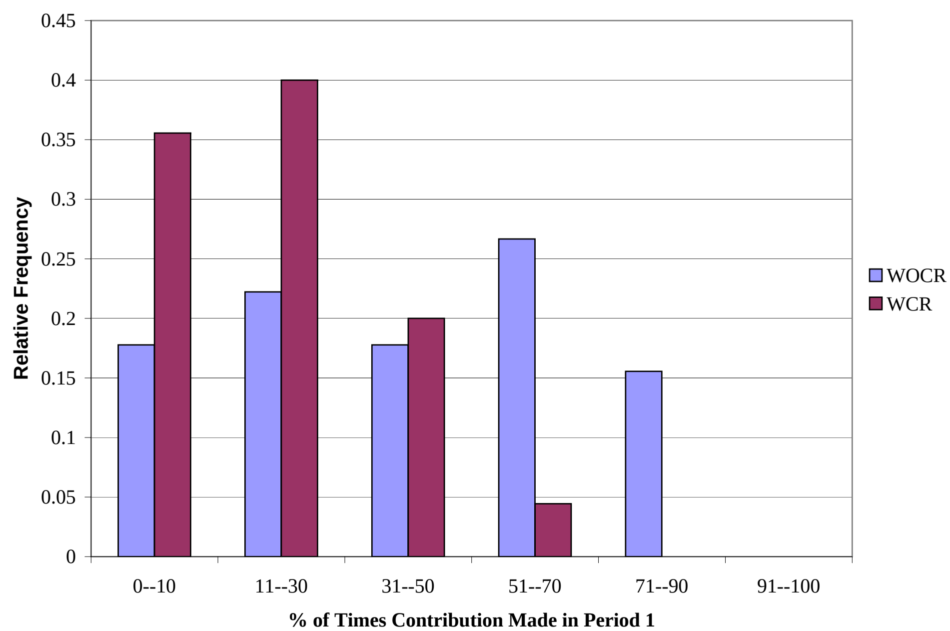


(b) WCR

Figure 2. Frequency of outcomes involving three contributions for treatments WOCR and WCR. Outcomes with $*$ are subgame perfect. The Pareto-dominant subgame perfect outcomes for the WOCR and WCR treatments are $3\backslash 0\backslash 0$ and $1\backslash 2\backslash 0$ respectively.



(a) Overall



(b) Period 1

Figure 3. Relative Frequency Distribution of % of times contribution made for treatments WOCR and WCR.

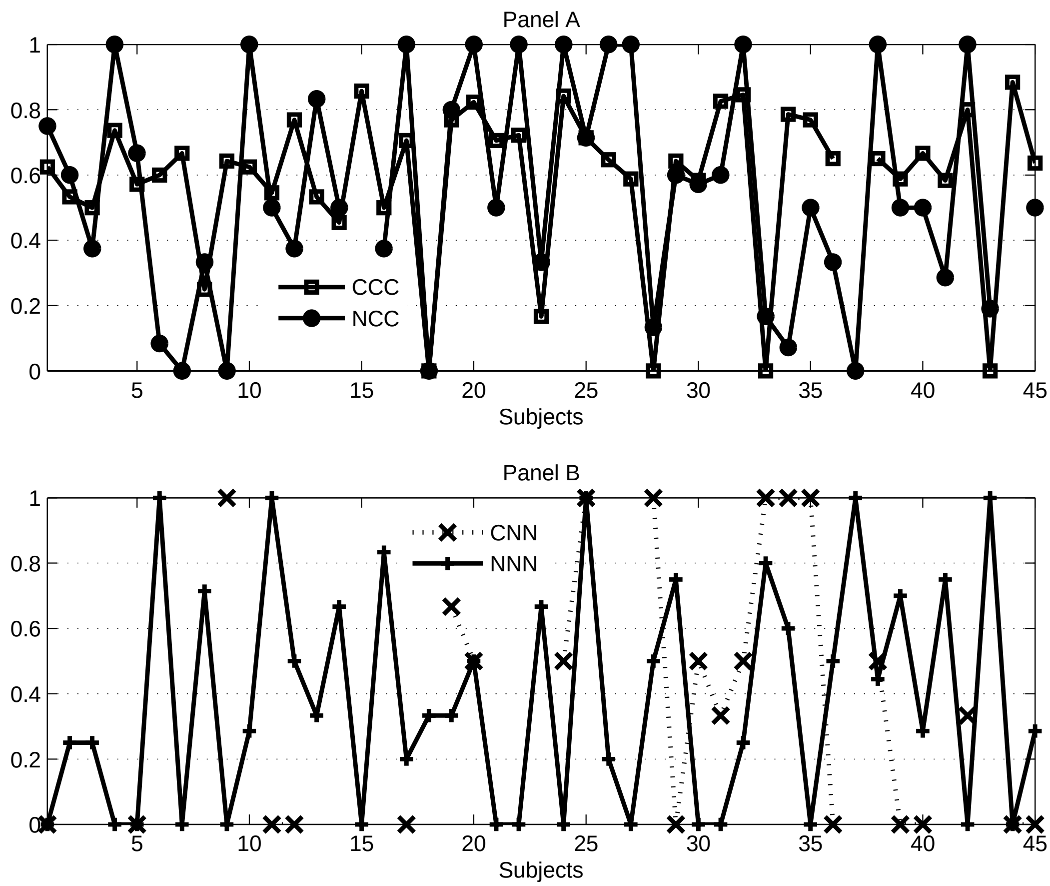


Figure 4. The proportions CCC, NCC, CNN and NNN for 45 subjects in WCR treatment.

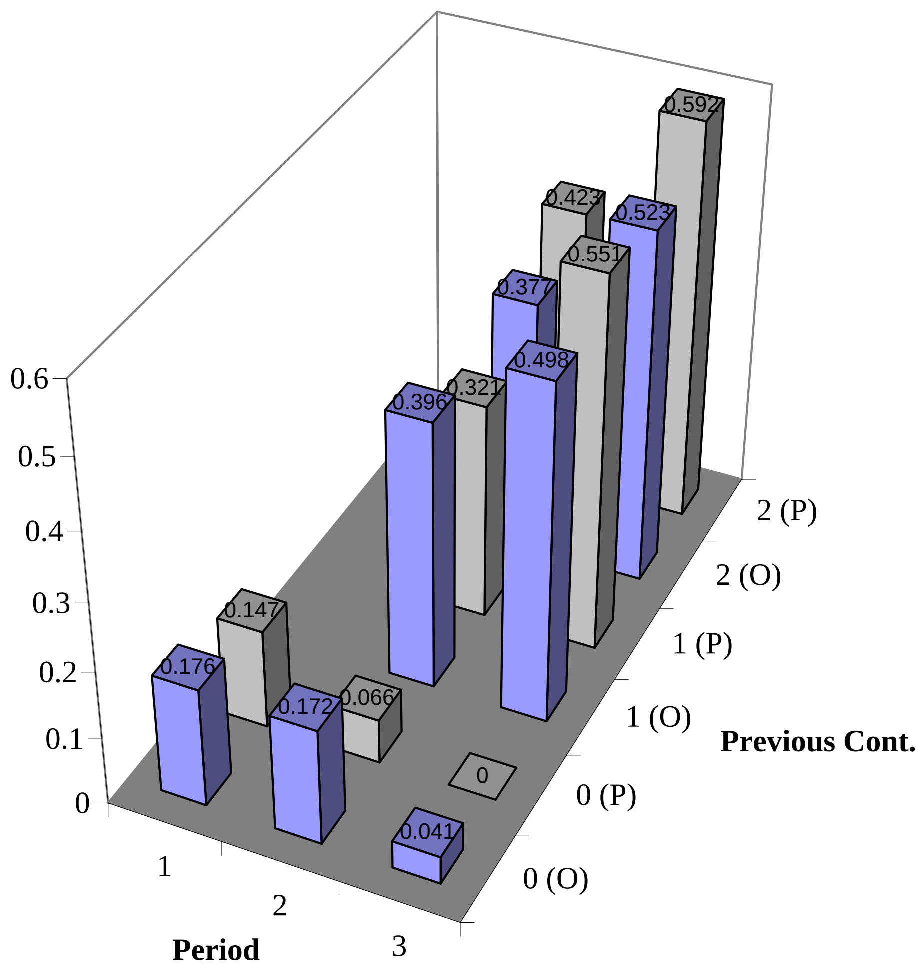


Figure 5. The purely mixed strategy SPNE probabilities (table 2a) are compared with the observed frequency of contribution (O) for each history in the WCR treatment.

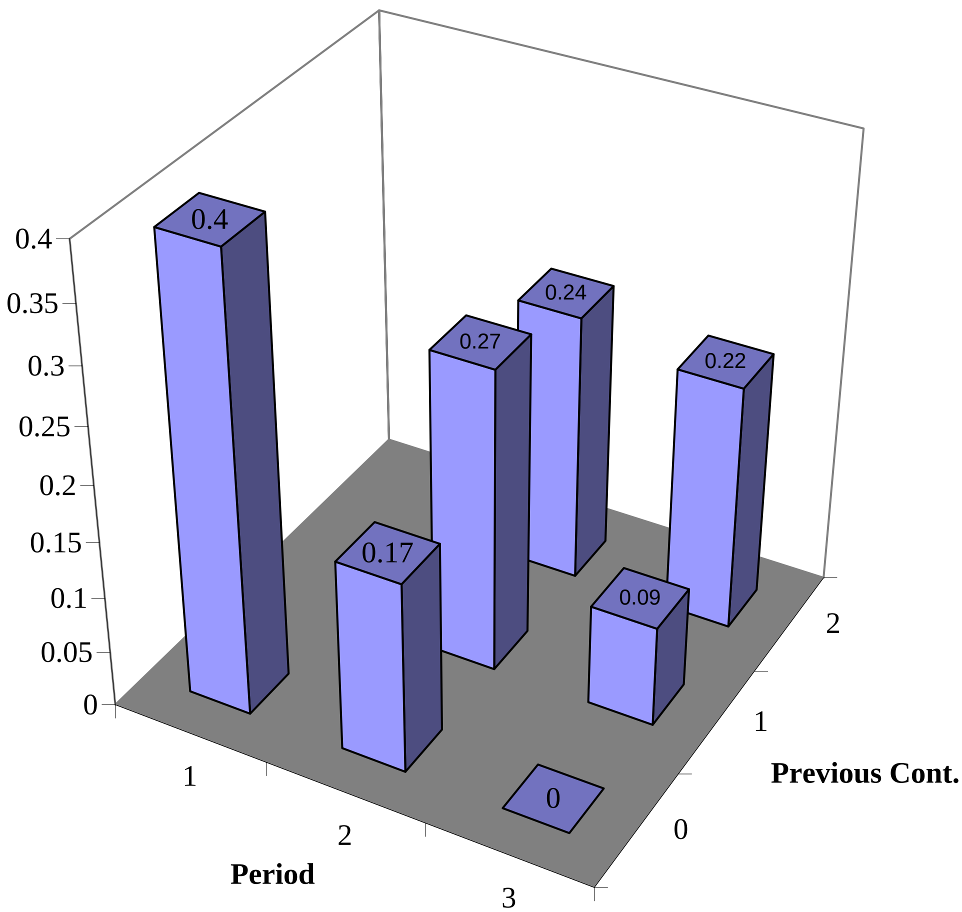


Figure 6. Observed frequency of contribution for different histories in WOCR treatment.

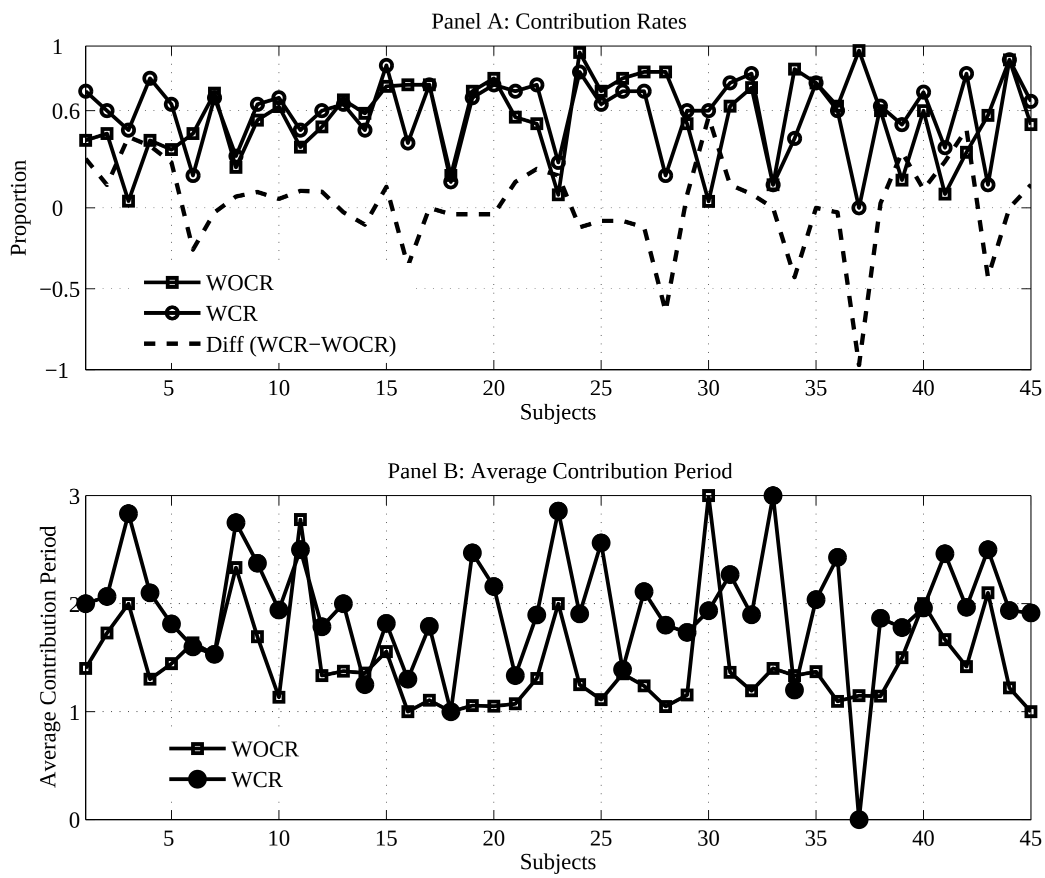


Figure 7. Contribution rates (panel A) and average contribution period (panel B) for the 45 subjects in WOCR and WCR treatment. Participants belonging to the same group are juxtaposed, with participants 1 – 5 belonging to group 1, 6 – 10 belonging to group 2 and so on.

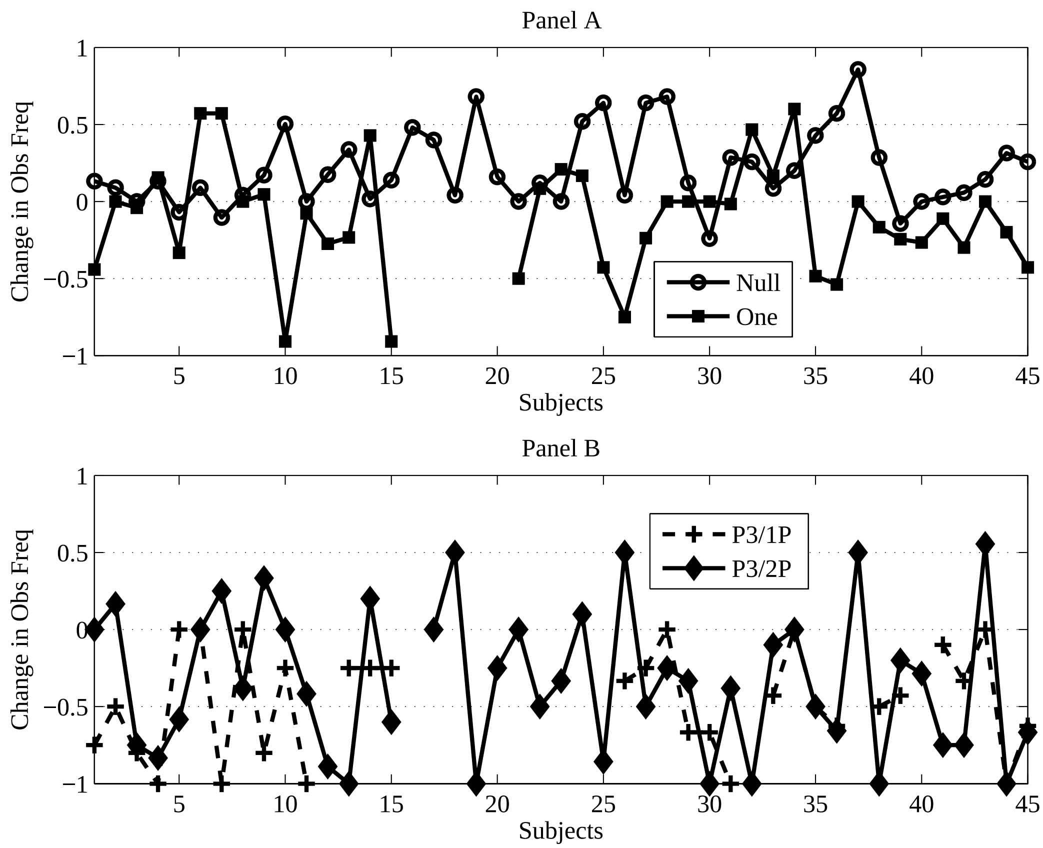


Figure 8. Differences ($WOCR - WCR$) in contribution frequencies for different histories for 45 subjects.

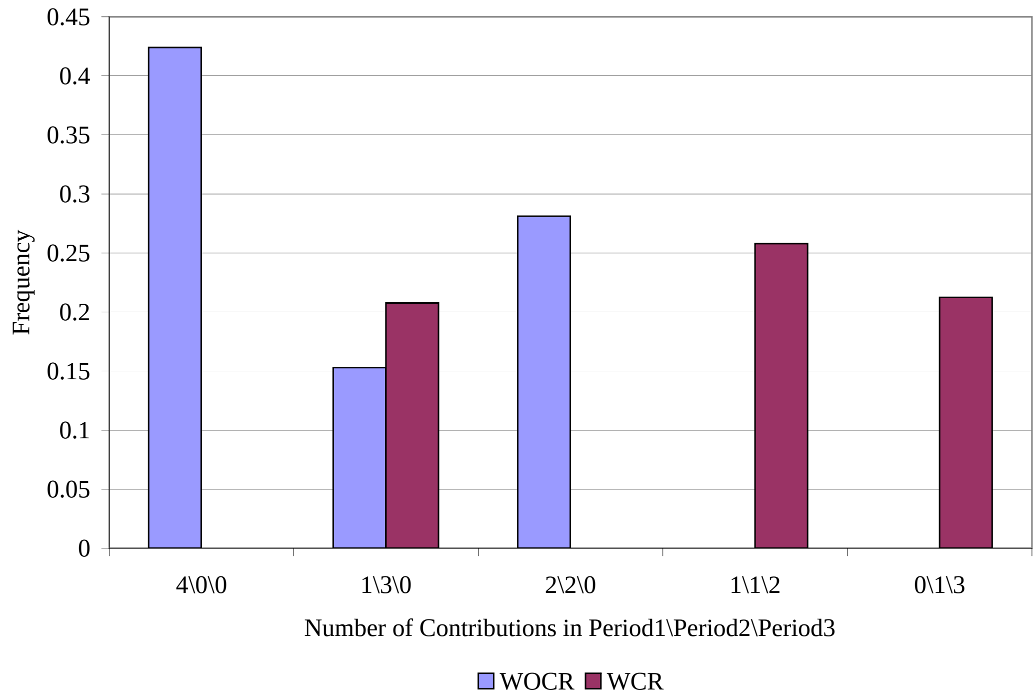


Figure 9. Frequency of outcomes involving four contributions for the treatments WOCR and WCR. Only the outcomes with highest three frequencies are reported.

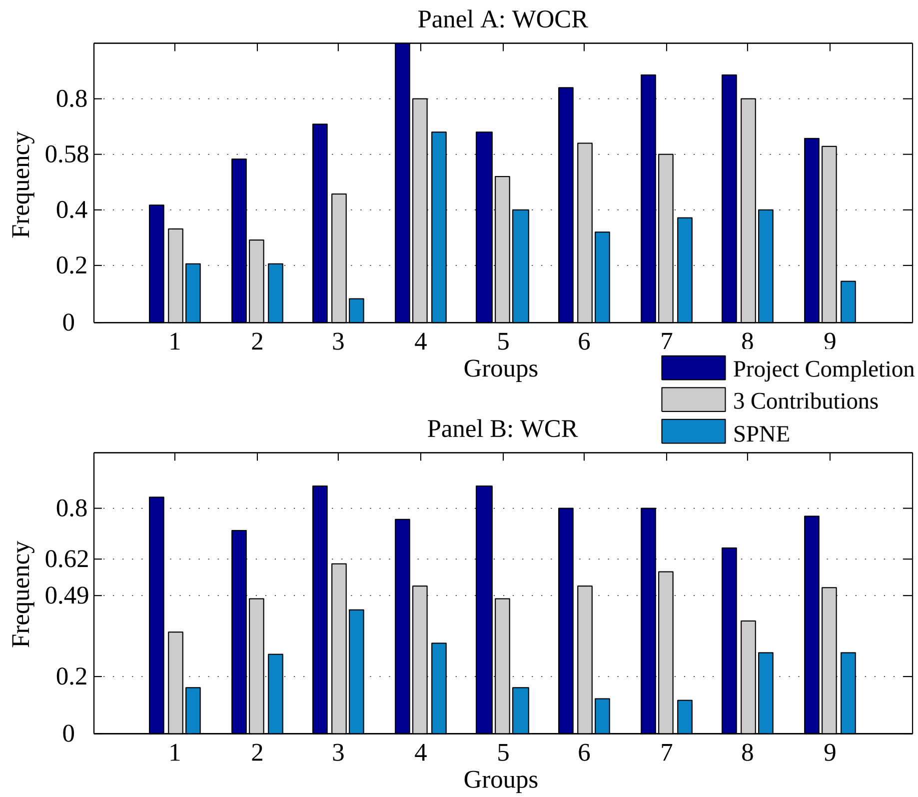


Figure 10. Frequency of (i) project completion (ii) three contributions and (iii) SPNE play for the treatments WOCR (panel A) and WCR (panel B) for the different groups. The purely mixed strategy SPNE predicts that the project completion rate in the WCR treatment will be 0.62.