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VOLUNTARY PARTICIPATION GAME EXPERIMENTS WITH A NON-EXCLUDABLE PUBLIC GOOD: IS SPITEFULNESS A SOURCE OF COOPERATION?

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Voluntary Participation Game Experiments with a Non-Excludable Public Good: Is Spitefulness a Source of Cooperation?[1]

by

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Abstract

Economic theory predicts that it is impossible to have cooperation in finitely repeated games such as a prisoners' dilemma game without communication. Yet experimental results follow a contradicting pattern: for example, cooperation is generally observed in public-goods experiments, at least in early rounds. This cooperation is often interpreted as kindness or fairness. In an experiment on a voluntary participation game with a non-excludable public good that is a version of a Hawk-Dove game, we observed that evolutionary stable strategies did not appear, but cooperation emerged through a transmutation from the Hawk-Dove game to a game where a dominant strategy outcome is Pareto efficient. We found that this transmutation is not due to kindness, but to *spitefulness* among subjects.

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1. Introduction

Economic theory usually predicts that it is impossible to have cooperation in finitely repeated games such as a prisoners' dilemma game without communication.[2] Yet experimental results follow a contradicting pattern: some cooperation is generally observed in public-goods experiments, for example, particularly in early rounds (see Ledyard, 1995). This cooperation is often interpreted as kindness or fairness. Andreoni (1995) confirmed that it comes from kindness or altruism of subjects. Most previous public goods experiments employ the voluntary contribution mechanism, in which each subject contributes some money to provide a public good so as to maximize her payoff or utility. A well-established theoretical result is that the Nash equilibrium outcomes of the voluntary contribution mechanism are not Pareto efficient.

Another line of experimental research in public goods is to investigate performance of mechanisms achieving Pareto efficient outcomes such as the Groves-Ledyard mechanism (1977). As Chen and Plott (1993) showed, the Groves-Ledyard mechanism works very well under some suitable punishment parameters.

Recently, Saijo and Yamato (1997, 1999) shed a new light on the meaning of voluntary participation in public goods provision mechanisms. Agents may have a choice not to participate in the mechanism proposed and hence some of them can free-ride on the benefit from a public good provided by others. In other words, most of the mechanisms designed so far -- including the voluntary contribution mechanism -- implicitly ignore non-excludability, which is one of the important features of a public good. Instead, designers assume that all agents must participate in the mechanism. Saijo and Yamato

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[2] Many theorists have been trying to explain cooperation with finitely repeated games. A basic idea is to introduce some irrationality with or without complete information. See Radner (1980), Kreps, Milgrom and Wilson (1982), Benoit and Krishna (1985), and Conlon (1996).

(1997) proved an impossibility theorem demonstrating that no mechanism satisfying voluntary participation exists in very reasonable environments.[3]

This participation problem is important in many practical circumstances, such as for international treaties. For example, it took 24 years to reach agreement on the disposition of chemical weapons in the chemical weapons treaty, and the number of signatories was more than 160 by the end of 1995. The treaty is a mechanism creating a public good, i.e., a greater likelihood of world peace. The treaty requires that at least 65 signatories must ratify it in order to make it effective. In October 1996, Hungary was the 65th country to ratify it, and the treaty was effective after a half year. However, China and Russia have the most chemical weapons have not ratified this treaty. This could limit the treaty's effectiveness. Another example is the League of Nations. Following World War I President Woodrow Wilson strongly supported the League, but the U.S. Congress never ratified the Treaty of Versailles. Another more contemporary example is the Kyoto Protocol on climate change in 1997 to reduce greenhouse gas emissions. A large number of countries appear unwilling to participate in the provision of this obviously non-excludable public good.

Voluntary public goods provision by individuals -- such as for public broadcasting -- also faces this participation problem. For example, part of public broadcasting in Japan is supported by the public broadcasting fee. Every family must pay the fee by law, but many choose not to since enforcement is practically non-existent. A natural question to ask is what would happen if we allow voluntary participation in the voluntary contribution mechanism.

We conducted an experiment to study the voluntary contribution mechanism with voluntary participation in a two-stage game. In the first stage, two subjects choose

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[3] See also Dixit and Olson (1997) for the voluntary participation problem in the context of the Coase theorem.

simultaneously whether or not they participate in the voluntary contribution mechanism. In the second stage, knowing the other subject's participation decision, subjects who selected participation in the first stage choose contributions to the public good. Subjects receive payoffs based on a Cobb-Douglas transformation of their consumption of the public good and their private good. The normal form game representation of the first stage participation decision is a Hawk-Dove game rather than the Prisoners' Dilemma game that represents the typical voluntary contributions mechanism with mandatory participation. As usual, this Hawk-Dove game has two pure strategy Nash equilibria and one mixed strategy Nash equilibrium which is the unique evolutionarily stable strategy (ESS) equilibrium.

We conducted two treatments. Both subjects were required to participate in the voluntary contribution mechanism in the control Treatment A. Each subject could choose her participation decision before her contribution decision in Treatment B. Thus, Treatment A only included the second stage, while Treatment B included both stages. Each treatment had twenty subjects and each subject was randomly paired with each other subject one at a time – a so-called "strangers" design. The same game was repeated 19 rounds, 4 for practice and 15 for monetary reward, so as not to pair the same two subjects more than once.

In Treatment A, subjects on average contributed (or "invested") close to the Nash equilibrium level, although some subjects exhibited *spiteful* behavior. A spiteful subject explicitly stated on her record sheet that she chose an investment number less than the Nash equilibrium investment so as to reduce her opponent's payoff more than her own payoff reduction.[4]

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[4] Saijo and Nakamura (1995) observed spiteful behavior in a traditional voluntary contribution mechanism experiment. See also Ito, Saijo, and Une (1995). Spiteful behavior is also observed in biology. Iwasa,

In Treatment B, the participation rate rose as rounds advanced, and the average investment in the final rounds in Treatment B was very close to that in Treatment A. Consequently, in the final two-thirds of Treatment B, subjects' participation rate nearly always exceeded the ESS participation rate. A typical subject behaved as follows: at the beginning she did not participate in the mechanism, expecting high payoff with free-riding. However, her opponent who decided to participate in the mechanism did not invest the number that maximized his own payoff. Rather, he invested a smaller amount so as to reduce his opponent's payoff more than his own payoff reduction. The non-participating subject thus learned that non-participation was not beneficial to her and hence she began regularly participating in the mechanism. That is, it seemed that the source of cooperation was not altruism or kindness but was a payoff-maximizing response to the *spiteful* behavior of other subjects. What we call cooperation here means that both subjects participate in the mechanism.

The remainder of the paper is organized as follows. In Section 2 we explain the voluntary contribution mechanisms with and without voluntary participation. Section 3 describes the experimental design. We present the results on the experiment of the voluntary contribution mechanism without voluntary participation in Section 4 and those on the experiment of the voluntary contribution mechanism with voluntary participation in Section 5. Section 6 concludes.

2. The Voluntary Contribution Mechanism

We employ the voluntary contribution mechanism with or without voluntary participation as our model.

Nakamaru, and Levin (1998) set up a model explaining spiteful behavior of colicin-producing bacteria against colicin-sensitive bacteria.

There are two subjects, *a* and *b*, and subject *i* (=*a,b*) has w_i units of initial endowment of a private good. Each subject faces a decision of splitting w_i between her own consumption of the private good (x_i) and investment (y_i). From the investment, each subject receives $y = y_a + y_b + w_y$, where w_y is the initial level of the pubic good. That is, the level of the public good is the sum of the investments of two subjects and the initial level of the public good. Therefore, each subject's decision problem is

$$\max u_i(x_i, y) \text{ subject to } x_i + y_i = w_i,$$

where $u_i(x_i, y)$ is subject *i*'s payoff function. We use a Cobb-Douglas type payoff function to transform contributions and the private good into subject payoffs, and all subjects have the same payoff function. That is, $u_i(x_i, y) = x_i^{\alpha} y^{1-\alpha}$, where $\alpha \in (0,1)$. Using a monotonic transformation, we specify the payoff function as follows:

$$(1) \qquad u_i(x_i, y) = \frac{\{x_i^{\alpha} y^{1-\alpha}\}^{\beta}}{50} + 500.$$

In our experiment we set $(w_a, w_b, w_y) = (24, 24, 3)$, $\alpha = 0.47$, and $\beta = 4.45$. With these parameters the Nash equilibrium investment pair of the voluntary contribution mechanism is $(\hat{y}_a, \hat{y}_b) = (7.69,\ 7.69)$ and the payoff is $u_i(\hat{x}_i, \hat{y}) = 7089$, where $\hat{x}_i = 24 - 7.69 = 16.31$ and $\hat{y} = \hat{y}_a + \hat{y}_b + w_y = 18.38$. The Pareto efficient level of the public good is determined uniquely by the Samuelson condition and the feasibility condition. Its symmetric contribution level is 12.02. Therefore, the Pareto efficient level of the public good is 27.04=12.02+12.02+3. Clearly, the level of the public good with the voluntary contribution mechanism is less than the Pareto efficient level of the public good.

So far we have assumed implicitly that subjects must participate in the voluntary contribution mechanism. Saijo and Yamato (1997) found that there is a wide class of mechanisms with public goods where subjects have incentives not to participate. The voluntary contribution mechanism is one of them. That is, the voluntary contribution mechanism is not *voluntary* from the viewpoint of participation incentives.

Consider now a two-stage game (see Figure 1). In the first stage, each subject simultaneously decides whether or not she should participate in the voluntary contribution mechanism without knowing the other subject's decision. In the second stage, each subject decides how many units of her initial endowment she should invest after knowing the other subject's participation decision.

Figure 1 is around here

Notice that non-participation is different from zero investment with participation. Once subject *a* decides to participate in the mechanism, subject *b* must take account of this fact when she chooses her investment number *without* knowing subject *a*'s investment number. On the other hand, if subject *a* chooses non-participation, then subject *b* knows that subject *a* invests nothing.

In our experiment, subjects choose integer investment numbers only. If both subjects decide to participate in the mechanism, then the Nash equilibrium of that subgame is for each subject to contribute 8 and obtain a payoff of 7345. No other Nash equilibria sneak into our model due to the discrete strategy choice set. If one subject participates in the mechanism and the other does not, then the participant maximizes her payoff at $y_i = 11$ and obtains a payoff of 2658, and the non-participant clearly invests nothing and obtains a payoff of 8278. If both choose not to participate in the mechanism, both subjects end up with a payoff of 706. These payoffs are summarized in the normal form game payoff table shown in Table 1.

Table 1 is around here

The game in Table 1 is a well-known Hawk-Dove game. Although the usual simplification of the public good problem is a Prisoners' Dilemma game, we find that the proper simplification is a Hawk-Dove game when we allow participation in the mechanism as a choice variable. There are two pure strategy Nash equilibria: either one of subjects participates in the mechanism. One more Nash equilibrium is a mixed strategy equilibrium: each subject *i* chooses 0.68 as her participation probability p_i. Among these three equilibria, the mixed strategy equilibrium is a unique ESS equilibrium.[5]

3. Experimental Design

Our experiment consisted of three treatments, A, B, and B′. Treatment A corresponded to the voluntary contribution mechanism without voluntary participation and Treatments B and B′ corresponded to the voluntary contribution mechanism with voluntary participation. We will explain the difference between Treatment B and Treatment B′ below.

We conducted one session in Treatment A and one session in Treatment B at the University of Tsukuba during December of 1995, and one session in Treatment B and one session in Treatment B′ at the Tokyo Metropolitan University during December of 1997. We recruited twenty students for each session by campus-wide advertisement. These students were told that there would be an opportunity to earn money in a research

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[5] See Maynard Smith (1982).

experiment. None of them had prior experience in a public good provision experiment. No subject attended in more than one session. The Treatment A session required approximately 90 minutes and the Treatment B and B′ sessions required approximately two hours to complete. The mean payoff per subject was $26.31 ($1=100 yen). The maximum payoff among the eighty subjects was $36.25, and the minimum payoff was $17.28.

Let us describe Treatment A first. Twenty subjects seated at desks in a relatively large room had identification numbers between one to twenty randomly. These identification numbers were not publicly displayed, however, so subjects could not determine who had which number. We made ten pairs out of twenty subjects. In each round, ten pairs played the game without the participation decision as described in the previous section. The pairings were determined in advance by experimenters so as not to pair the same two subjects more than once. The first four rounds were for practice and the remaining fifteen determined the subjects' monetary payoffs. Each subject received an experimental procedure sheet, a record sheet, payoff tables, 15 investment sheets, and 4 practice investment sheets.[6] Instructions were given by tape recorder to minimize the interaction between subjects and experimenters. Each subject determined her investment from an integer number between 0 and 24 by using payoff tables and then marked a number on an investment sheet. Experimenters collected these investment sheets and then redistributed them to the paired subjects. During the redistribution, subjects were asked to fill out the reasons why they chose these numbers. After the redistribution, subjects calculated their payoffs from the payoff tables. Then the next round started.

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[6] The use of practice periods permits subjects to send signals costlessly prior to the paid rounds. However, subjects interacted with each other in only one period and there was no public information after the instructions were completed and data collection began. Therefore, the impact of these signals is somewhat limited. Nevertheless, see footnote 14 for some minor evidence of spillover from the practice periods.

Treatment B had one additional step. Before choosing investment numbers, subjects decided whether or not they would participate in the voluntary contribution mechanism. These decisions were collected by experimenters and then redistributed to their paired subjects. After this procedure, subjects who decided to participate in the mechanism chose their investment numbers.

Treatment B′ is exactly the same as Treatment B except what term was used to describe the person that each subject is matched with at each period. The term "your opponent" was employed in the instructions, record sheets and payoff tables for both Treatment A and Treatment B. The phrase "the person you are paired with" replaced "your opponent" in all materials of Treatment B′. One might say that the term "opponent" forces subjects to think in relative terms. However, there was no essential difference between the results for Treatment B and those for Treatment B′, as we document below.

Every subject had the same payoff function and every subject knew this fact. We distributed three kinds of payoff tables to avoid any possible misunderstanding. The payoff tables used in Treatments A and B are Tables 2, 3, and 4. Table 2 is a detailed payoff table: the rows are for the subject's own investment numbers and the columns are for the other subject's investment numbers. Table 3 is a rough payoff table and Table 4 has an iso-payoff map. The payoff tables distributed in Treatment B′ are the same as Tables 2, 3, and 4 except that the term "your opponent" is replaced by the term "the person you are paired with".

We allowed subjects three minutes to examine the three payoff tables before the practice rounds and ten minutes to examine the three new payoff tables before the real rounds. The tables used for practice and real rounds were different.

Tables 2, 3 and 4 are around here

We declared that the experiment would be stopped if communication among the subjects was observed. This never happened.

4. Experimental Results for Treatment A

Treatment A was a control treatment intended to permit a comparison between mandatory participation and voluntary participation.

The Nash equilibrium investment pair was (8, 8) from Table 2, and no other Nash equilibrium exists. Since each round had 10 pairs and 15 rounds were conducted, we have 150 pairs of data. The order of investment numbers does not matter, so we rearranged each pair (x,y) with $x \geq y$. Figure 2 shows the frequency distribution of investment data. The maximum frequency pair was (8, 8) with 36 pairs, the second was (8, 7) with 35 pairs, the third was (8,6) with 14 pairs, and the fourth was (7, 7) with 11 pairs. The average investment across all subjects was 7.24.

Figure 2 is around here

Figure 3 shows the average investment pattern from round 1 to 15. The average investment was less than the Nash equilibrium level of investment (8) in all but one round. In order to understand why this happened, we checked the record sheets and questionnaire sheets of subjects. The record sheet was not only for keeping the investment record but also for specifying the reasons why a subject chose her investment numbers. We found four subjects who explicitly stated the following reasoning: they estimated that their opponent would chose 8, and then they chose 6 or 7 explicitly because this would make their opponent's payoff much lower than their own payoff. For example, consider the case that subject *a* chooses 7 and subject *b* chooses 8. Then subject *a* obtains 7340, and subject *b* obtains 6526. At the Nash equilibrium (8, 8), both subjects obtain 7345. From the viewpoint of subject *a*, the reduction of 5 units of payoff is minor, but subject *a* can make the reduction of subject *b*'s payoff (819) much greater than his own reduction.[7, 8] We label these subjects as *spiteful* subjects, and Figure 3 also presents mean investments after excluding those subjects.

Figure 3 is around here

We tested the hypothesis that mean investment equals the Nash equilibrium investment (8) first by pooling investments across rounds. Because each subject made 15 investment choices the data are clearly not independent. Therefore, we accounted for the panel nature of the data using a random effects error specification $v_{it} = e_i + \varepsilon_{it}$, where e_i is a subject-specific error term and ε_{it} is an iid error. The pooled data strongly reject the Nash equilibrium (t=3.28), and also reject the Nash equilibrium when spiteful subjects are excluded (t=4.45) and when spiteful subjects and their opponents' data are excluded (t=3.75). We then focused on round by round tests of the Nash equilibrium. Without excluding any data, a nonparametric Wilcoxon signed rank test rejects the Nash equilibrium hypothesis in ten out of fifteen rounds at the five percent significance level. Excluding spiteful subjects' data, this test rejects the Nash equilibrium hypothesis in five out of fifteen rounds. Finally, excluding spiteful subjects' and their opponents' data, this test rejects the Nash equilibrium hypothesis in four out of fifteen rounds. Nevertheless,

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[7] Akerlof and Yellen (1985a, 1985b) observed similar phenomena in Keynesian business cycles and industrial organization theory. A small amount of nonmaximizing behavior may cause some amount of changes at equilibrium that is larger in its magnitude than the losses due to nonmaximizing agents.

[8] Note that this spiteful (non-maximizing) behavior would not be observed in a usual two-by-two game. In our experimental setting, subjects can choose a slight deviation from an optimal investment strategy. That is, the two-by-two game approach is not rich enough to capture economic implications in public goods environments.

the fact that many subjects chose the Nash equilibrium investment indicates that at least economically the Nash equilibrium has attracting power for the data.[9]

These Treatment A results lead to the following observation.

Observation 1:

The mean investment across all rounds is significantly less than the Nash equilibrium investment, regardless of whether spiteful subjects' data are excluded. Overall, mean investments were approximately ten percent below the Nash equilibrium.

5. Experimental Results for Treatments B and B′

The session in Treatment B conducted at the University of Tsukuba, the session in Treatment B at the Tokyo Metropolitan University, and the session in Treatment B′ at the Tokyo Metropolitan University are called the Tsukuba B session, Tokyo B session, and Tokyo B' session, respectively. As shown in the appendix, the data from these three sessions are statistically indistinguishable in virtually all cases. This provides strong evidence that neither the experiment site (Tokyo versus Tsukuba) nor the experiment wording ("your opponent" versus "the person you are paired with") affect choices. Therefore, in the subsequent analysis we pool the data across the three Treatment B sessions, i.e., Tsukuba B, Tokyo B, and Tokyo B' sessions.

5.1 Investment Data

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[9] This result is similar to Andreoni (1993) and Chan et al. (1998), who study the crowding out hypothesis in public good experiments with an interior Nash equilibrium and minimum contribution "taxes" in some treatments. In both of these previous experiments contributions were close to but slightly below the Nash equilibrium prediction when no tax was imposed.

Figure 4 shows that the distribution of investment pairs in Treatment B are very different from that of Treatment A (Figure 2). The maximum frequency pair was (8,7) with 57 pairs, the second was (11,0) with 44 pairs, followed by (8,8) and (0,0) with 37 pairs each.

Figure 4 is around here

Also unlike Treatment A, the average investment (including the investments of zero by nonparticipants) changed across rounds in Treatment B. Figure 5 illustrates that the average investment in Treatment B was clearly less than in Treatment A, but the average investment in Treatment B ascended across rounds. In the late rounds the average investments in the two Treatments were very similar; for example, in the final round the average investments in Treatments A and B were 7.0 and 6.47 respectively. The average investments were not significantly different by round between Treatments A and B after round 4, according to the nonparametric two-sample Wilcoxon rank sum test.

Figure 5 is around here

Using a random-effects panel data model that is the same as that for Treatment A, we tested the hypothesis that mean investment equals the Nash equilibrium investment (8) in the case of both participating. The mean investment in this case was too low (7.26), and we rejected the hypothesis (t=4.21).[10] However, like the result for Treatment A, a substantial number of subjects selected the Nash equilibrium, so the Nash equilibrium is meaningful at least economically in the case of both participating.

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[10] For those who prefer nonparametric tests, we also conducted Wilcoxon signed rank tests separately for each of the 15 periods. This test rejects the null hypothesis that average investment equals 8 at the five percent level in 12 of the 15 periods.

5.2 Participation Data

We next examined whether the participation data in Treatment B were compatible with the mixed strategy equilibrium of the Hawk-Dove game described in Table 1. The null hypothesis is the ESS participation probability of 0.68. We first conducted a binomial test separately by round in order to avoid pooling dependent participation decisions made by the same subject in the same test. Under the ESS null hypothesis, the probability of observing 10 non-participation decisions or less out of 60 is less than one percent, and the probability of observing 12 non-participation decisions or less out of 60 is less than five percent. As Figure 6 shows, the participation rate rose as rounds advanced (although a brief decline was observed in rounds 8 and 9). The smooth curve is a simple log-linear regression. More to the point for this binomial test, the low non-participation rate permits the binomial test to reject the ESS null hypothesis in 9 rounds of the 15 total rounds (in rounds 5, 6, 7, 10, 11, 12, 13, 14, and 15) at the five percent (usually one percent) significance level.

Figure 6 is around here

We also examined the overall participation rates for each of 60 subjects separately. The mean participation rate was 80% (12 of 15 decisions), and the median participation rate was 86.7% (13 of 15 decisions). Note that the ESS rate of 0.68 implies on average slightly more than 10 participation decisions. Only 14 of the 60 subjects (23.3%) participated 10 times or less, while the other 46 subjects (76.6%) participated 11 times or more. 15 of the 60 subjects (25%) were apparently using a pure strategy, as they participated in 15 out of 15 periods. Using the 60 separate subject observations, the data reject the ESS prediction of 0.68 at better than the 0.0001 significance level using the non-parametric Wilcoxon signed-rank test.

Furthermore, we conducted a binomial test of the mixed strategy of $p = 0.68$ separately for each subject. Under the null hypothesis that subjects play this mixed strategy, participation decisions--even for an individual subject--are statistically independent. At the five percent significance threshold, 23 of 60 subjects (38.3%) participated too much (either 14 or 15 times), rejecting $p = 0.68$; 6 of 60 subjects (10%) participated too little (7 times or less), rejecting $p = 0.68$ in the other direction. At the ten percent significance threshold, 32 of 60 subjects (53.3%) participated too much (13, 14 or 15 times), rejecting $p = 0.68$; 9 of 60 subjects (15%) participated too little (8 times or less), rejecting $p = 0.68$ in the other direction.

5.3 Why were Participation Ratios High?

In order to understand these rather high participation ratios, consider the case in which only one subject in a pair participated in the voluntary contribution mechanism. When a subject did not participate in the mechanism, the other could obtain her maximum units of payoff by investing 11 (see Table 2). There were 139 observations with exactly one participant. In these cases the participant invested eleven 43 times, invested less than eleven 95 times (zero 17 times, invested one 3 times, invested two 7 times, invested three 8 times, invested four 7 times, invested five 1 times, invested six 16 times, invested seven 19 times, invested eight 9 times, invested nine 6 times, and invested ten 2 times), and invested more than eleven (twenty-four) only 1 time. In fact, the mean investment (6.90) was lower than when both subjects participated! Using a random effects model, we soundly reject the hypothesis that mean investment equals 11 in the case of one participant (*t*=8.14).[11]

As shown in Table 2, by investing 11 in response to the other not participating, the non-participating subject earns 8278 while the participating subject earns 2658. On the other hand, by investing 7 in this situation, the non-participating subject earns 4018 while the participating subject earns 2210. That is, the reduction of the participant's payoff (448=2658-2210) was relatively small, while the reduction of the non-participant's payoff (4269=8278-4018) was relatively large. This appears to be stronger evidence of spiteful-like behavior than we observed in Treatment A. The "spite rate", which is the ratio of the number of participants investing less than 11 to the number of observations with a single participant, is equal to 95/139 = 68%.

One might say that in the two-stage game of Treatment B, the low investment by the single participant could be interpreted as belonging to a tit-for-tat strategy to "teach" others to cooperate. Because subjects were re-paired with a new opponent each period and never interacted with the same subject in more than one period, however, such a strategy is not subgame perfect. Furthermore, although there is no need to take a tit-for-tat strategy at the final period of the experiment, the spite rate of the final period is equal to 6/9 = 67 percent.[12]

Our interpretation that this behavior is spiteful hinges on the low contributions made by subjects when they are the only participant. An alternative interpretation of altruism is also consistent with our finding that the participation rate exceeds the ESS prediction; altruistic subjects should always participate. Altruists, however, should also

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[11] The nonparametric Wilcoxon test rejects the null hypothesis that average investment equals 11 at the five percent level in 9 of the 15 periods, even though the average sample size per period is only about 9 because of the high participation rate.

[12] The full distribution of the 9 final period observations with exactly one participant is as follows: one participant invested two, one participant invested seven, three participants invested eight, one participant invested nine, and three participants invested eleven.

invest as least as much as the level that maximizes their own earnings—which is 11 in the case of a single participant—if not more, since the non-participant's earnings strictly increase in the participant's investment (see Table 2). Therefore, choices below 11 are inconsistent with pure altruism. These choices could, however, be consistent with notions of "inequality aversion" or reciprocal altruism advanced recently by some researchers (for example, see Fehr and Schmidt (1999) and Levine (1998)). What we refer to as spite in this context is a response to the nonparticipation of one's opponent, so it is a form of (negative) reciprocity.[13]

Figure 7 is around here

Figure 7 shows average payoffs by round depending on participation. Curve α denotes the average payoffs when both subjects participated in the mechanism. As Table 1 shows, the payoff should be 7345 according to the Nash equilibrium prediction, but actual data showed that average payoffs were less than 7000 units in all 15 rounds. Curve β denotes the average payoffs when only the other participated in the mechanism. According to the Nash equilibrium, this should lead to 8278 units of payoff, but actual payoffs were less than 6000 in 12 of 15 rounds. According to Table 1, curve β should be above curve α, but Figure 9 shows that curve α was above curve β in all but round 9. That is, participation became a dominant strategy even in early rounds, as illustrated in Table 5.

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[13] This is different from simple rivalistic behavior in which a subject seeks merely to earn more than his opponent earns. The data are inconsistent with such rivalistic motivations, because such motivations are more likely to lead to *less* participation than the ESS prediction since nonparticipation guarantees payoffs greater than or equal to those of the opponent. It is also unlikely that rivalistic choices would be so close to the Nash equilibrium when both subjects participate because rivalistic subjects have a strong incentive to reduce their public good investment.

Table 5 is around here

Our interpretation of this conversion to the dominant strategy game is based on subject learning and proceeds roughly as follows. After inspection of the payoff tables, some subjects initially do not participate in the mechanism hoping the other will participate and invest 11. They therefore expect (perhaps with the ESS probability of 0.68) to receive a payoff of 8278. However, since their participating opponent invested less than 11, the subject realized that her earnings in this subgame fell below 6000 on average. After learning this, she chose to participate in the mechanism in later rounds and frequently earned more than 6000.[14]

5.4 Learning Processes for Participation

Essentially, subjects learn (contrary to the ESS equilibrium) that expected profits from participation tend to exceed those from non-participation. In this final subsection we provide a simple model of this learning process. Many alternative approaches to learning have been advanced recently in the literature, including reinforcement learning (e.g., Erev and Roth, 1998), belief-based learning, and creative hybrid approaches (e.g., Camerer and Ho, 1999). Rather than provide an exhaustive evaluation of the various learning models

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[14] As Figure 9 in the appendix shows, the average participation rates at early rounds in the Tokyo B session were relatively high. To see why this happened, we looked at the record sheets for the four practice periods, since the experiences of subjects in the practice periods might affect their participation decisions in the actual experiment. We found that spiteful behavior during the practice periods would lead to high participation rates in early periods. First of all, we counted the number of subjects who explicitly wrote that they realized that non-participation was not beneficial because the participant would act spitefully in the practice periods. This number in the Tokyo B session (8) was much larger than both that in the Tokyo B′ session (1) and that in the Tsukuba B session (1). We also calculated the number of subjects who had no chance to experience spiteful behavior in the practice periods. Consider a subject who experienced the following: (a) no cases in which only one subject participated, or (b) if only one subject participated (either himself or his opponent), the payoff-maximizing (non-spiteful) investment was selected. Call such a subject a "spite-free" subject. The number of spite-free subjects in the Tokyo B session was 5, the number in the Tokyo B' session was 8, and at the number in the Tsukuba B session was 11. As the number of spite-free subjects was larger, the participation rate at period 1 was smaller.

using our data, we simply report results of an adaptive, reinforcement-based learning model. In particular, we estimate a probit model in which the probability of participation depends on the ratio of expected participation earnings (EPE) to expected non-participation earnings (ENE):

$$\text{(2)} \qquad \text{Probability(Participation)} = f(\text{EPE}/\text{ENE})$$

The next step is to specify the process underlying subjects' expectations. We use two polar cases for this simple model: (1) Cournot (or myopic) expectations and (2) Fictitious Play expectations (e.g., Cheung and Friedman, 1997; Cox and Walker, 1998).

According to Cournot, EPE are simply the realized earnings the last time the subject participated; and ENE are simply the realized earnings the last time the subject did not participate. In other words, subjects maintain a very short (myopic) memory length--of one observation for each (participate or not) decision. By contrast, according to Fictitious Play, subjects have a long memory, and each observation updates the expectation with a declining weight. For example, if a subject has participated N times up to this round, and they participated in this round, they update EPE as follows:

$$\text{(3)} \qquad \text{EPE}=((N^*\text{previous EPE})+\text{current participation earnings})/(N+1).$$

In other words, as subjects accumulate evidence they simply include it in their running average of the payoffs from participation for EPE. ENE is, of course, analogous.[15]

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[15] For both Cournot and Fictitious Play, we need the expectations to start somewhere when no evidence has yet accumulated. For these initial expectations we employ the ESS expected payoffs, which are 5829 for both EPE and ENE. Therefore, the EPE/ENE ratio is 1 in round 1.

The empirical model is probit maximum likelihood, with a random subject effect. Table 6 presents the estimation results separately and pooled for the three Treatment B sessions. For Fictitious Play, the expected payoff ratio is insignificantly different from zero except in the Tokyo B session, where the coefficient estimate has the wrong sign. For the Cournot specification, the ratio is significantly positive except in the Tokyo B session. The positive coefficient on the ratio implies that as the relative profitability of participation increases, the likelihood of participation increases. So, we can conclude that (1) subjects' participation decisions respond to their experience, and (2) subjects appear to update their expectations in this environment using a short (Cournot) memory length.

Table 6 is around here

Summarizing the above observations, we have the following.

Observation 2:

(*a*)*The ESS prediction regarding the participation ratio is rejected.*

(*b*) *The participation ratio rises as rounds advanced and the average investment in the final two-thirds of Treatment B is not significantly different from that in Treatment A.*

(*c*) *It seems that the source of cooperation is not altruism or kindness but is spiteful behavior of subjects. Subjects learn that non-participation will invoke a spiteful response, which reduces the payoff of non-participation below the payoff of participation. This converts participation into a dominant strategy.*

6. Concluding Remarks

We found that the ESS prediction in a Hawk-Dove game was rejected and some cooperation among subjects emerged across time. Furthermore, this cooperation did not come from altruism or kindness among subjects, but from an optimal response to other subjects' *spiteful* behavior. Acting spitefully in this way is costly, and this kind of spiteful or negative reciprocal behavior has also been observed recently by independent research on public goods (Fehr and Gachter, 1998) and in the ultimatum game (Ochs and Roth, 1989 and Prasnikar and Roth, 1992).

In neo-classical economic theory, it is assumed that each agent cares only about himself and maximizes his own payoff subject to some constraints. If people care about how they are doing relative to others (for example, see Hume, 1739),[16] however, then it is natural to think that they might often take *spiteful* actions in an attempt to decrease the happiness of others. One would think that such spiteful behavior might result in outcomes that are socially inferior to outcomes arising from the interaction of purely selfish individuals. We find that the opposite may occur: spitefulness leads to greater cooperation. This finding suggests a need to rethink our fundamental assumptions of human nature underlying our models.

In our experiment, each subject knew that every subject had the same payoff table. This might trigger spiteful behavior since every subject could understand opponent's payoff structure. In future experiments we plan to conduct a systematic exploration of this information effect. It is also possible that spiteful behavior is more likely in two-person games such as this because it encourages relative payoff comparison. Future experiments can test this conjecture using larger groups. We also leave for future research a comparison of American subjects to these Japanese subjects in the present environment. If the propensity for spiteful behavior differs across cultures, outcomes could be

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[16] “Now as we seldom judge of objects from their intrinsic value, but form our notions of them from a comparison with other objects; it follows, that according as we observe a greater or less share of happiness or misery in others, we must make an estimate of our own, and feel a consequent pain or pleasure. The misery of another gives us a more lively idea of our happiness, and his happiness of our misery. The former, therefore, produces delight; and the latter uneasiness.” (David Hume, 1739)

substantially different for these two subject pools. Finally, the ESS participation rate in the present experiment was 0.68. We are currently conducting experiments in which the ratio is less than 0.5.

APPENDIX: Comparisons of Tsukuba B, Tokyo B, and Tokyo B′ Sessions

First of all, we compare investments conditional on participation across the three B and B′ sessions. Figure 8 illustrates how the average investment conditional on participation, which equals the sum of investment numbers for participants divided by the number of participants, changed from round 1 to 15 for each of the three B and B′ sessions. The average investments conditional on participation were different in only a handful of periods according to the nonparametric Wilcoxon rank sum test. In 14 of the 15 periods there is no statistical difference between the Tokyo B and Tokyo B′ sessions at the five percent significance level, which indicates that the "opponent" wording did not affect investments conditional on participation.[17] Likewise, the Tokyo B and Tsukuba B sessions are not statistically different in 12 of the 15 periods, indicating that investments conditional on participation differed very little across sites.[18]

Figure 8 is around here

Figure 9 illustrates the average participation rate patterns from round 1 to 15 in Tsukuba B session, Tokyo B session, and Tokyo B′ session. There are some statistically significant differences in the participation rates between the Tsukuba B and Tokyo B

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[17] In period 8 the average investment in the Tokyo B′ session was significantly higher than in the Tokyo B session.

[18] The average investment was significantly higher in the Tsukuba B session in periods 1, 9 and 13.

sessions in periods 1 and 2.[19] After period 2, there are basically no systematic differences among the participation rates across sessions.[20]

Figure 9 is around here

Overall, we conclude that there are virtually no statistically significant differences in the data based on the experiment site or the experiment wording.

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[19] Fisher's exact test *p*-values for the Tokyo B versus Tsukuba B comparison are 0.022 in period 1 and 0.020 in period 2. We discuss the reasons for these differences in footnote 12. Fisher's exact test uses the hypergeometric probability distribution to calculate the exact probability of observing the distribution of participation rates (and those more unequally distributed) under the null hypothesis of no differences in rates across treatments.

[20] In period 5 the participation rate is significantly higher in the Tokyo B′ session than in the Tokyo B session, but in period 10 the participation rate is significantly lower in the Tokyo B′ session than in the Tokyo B session.

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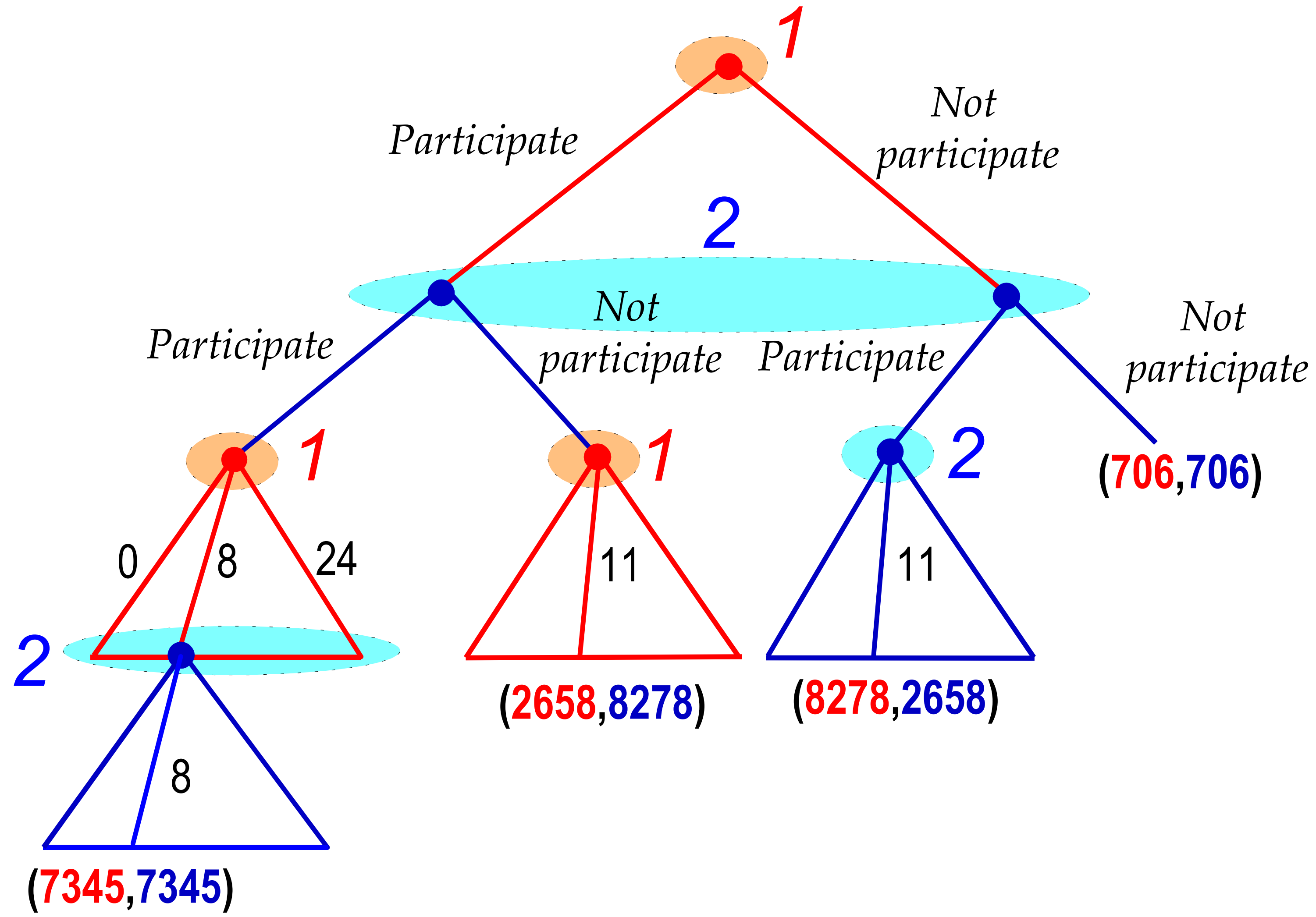
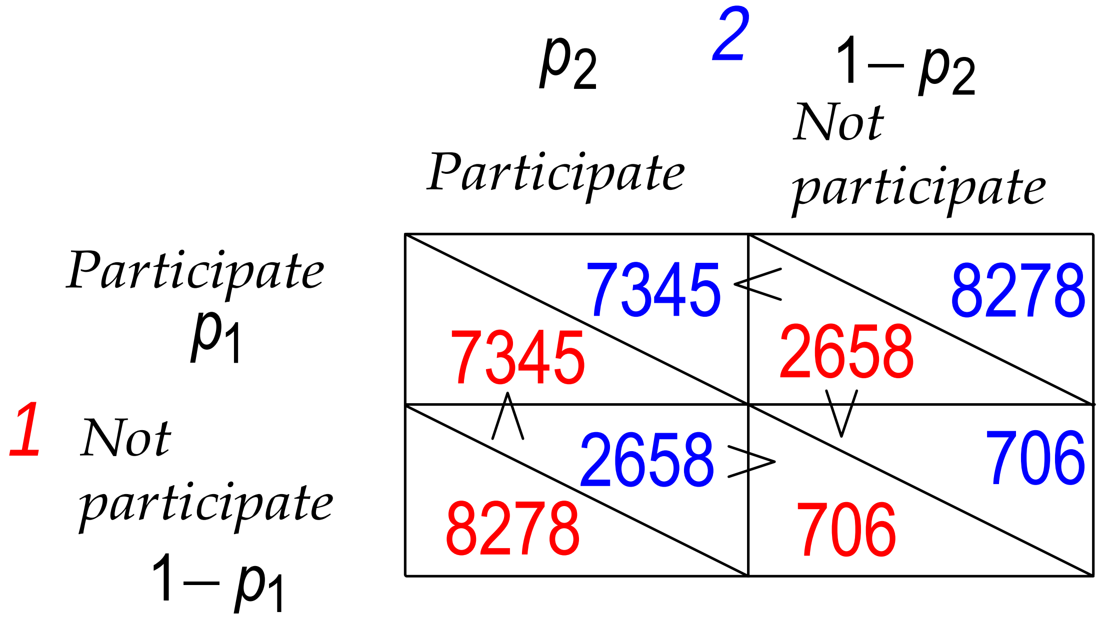


Figure 1. The game tree when subjects can choose their participation in the voluntary contribution mechanism.



1 \ 2	p_2 Participate	$1-p_2$ Not participate
Participate p_1	7345 7345	8278 2658
Not participate $1-p_1$	2658 8278	706 706

Nash equilbrium:

$$(p_1, p_2) = (1,0),(0,1),(0.68,0.68)$$

Evolutionarily stable strategy, ESS:

$$p_i = 0.68$$

Table 1. The payoff table becomes a Hawk-Dove game.

Your Investment Number

Your Opponent's Investment Number

Your Payoff	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
0	706	871	1072	1297	1536	1775	2003	2210	2386	2523	2615	2658	2648	2585	2470	2309	2106	1871	1614	1349	1091	858	669	543	500
1	905	1127	1379	1647	1919	2183	2427	2641	2816	2944	3019	3039	3001	2905	2755	2555	2313	2038	1743	1443	1154	894	685	548	500
2	1186	1465	1764	2072	2374	2658	2913	3129	3297	3411	3465	3456	3385	3252	3061	2819	2534	2217	1881	1543	1220	933	703	552	500
3	1554	1888	2232	2575	2902	3202	3463	3675	3831	3925	3952	3911	3801	3626	3391	3102	2770	2406	2027	1648	1290	973	721	556	500
4	2017	2401	2787	3160	3508	3817	4078	4281	4420	4488	4483	4403	4250	4028	3743	3404	3020	2608	2181	1759	1363	1015	740	561	500
5	2578	3010	3432	3831	4193	4507	4762	4950	5064	5101	5057	4934	4733	4459	4119	3725	3287	2821	2344	1877	1441	1060	760	566	500
6	3244	3718	4171	4590	4960	5272	5515	5681	5766	5765	5677	5504	5249	4918	4519	4065	3568	3045	2516	2000	1522	1106	781	571	500
7	4018	4529	5008	5440	5812	6115	6339	6478	6526	6481	6343	6114	5800	5406	4944	4425	3866	3282	2696	2129	1607	1155	802	576	500
8	4904	5447	5944	6383	6751	7038	7237	7340	7345	7250	7056	6765	6385	5924	5393	4806	4179	3532	2886	2265	1696	1206	825	582	500
9	5907	6475	6984	7422	7779	8043	8209	8271	8225	8073	7816	7458	7007	6472	5867	5207	4508	3793	3084	2407	1789	1259	849	588	500
10	7031	7616	8130	8561	8897	9132	9257	9270	9168	8951	8624	8193	7664	7051	6367	5628	4854	4067	3292	2555	1886	1315	874	594	500
11	8278	8873	9384	9800	10109	10306	10384	10339	10173	9886	9482	8970	8359	7661	6892	6070	5217	4354	3509	2710	1987	1372	899	600	500
12	9653	10250	10750	11142	11416	11567	11589	11480	11242	10877	10390	9791	9090	8302	7444	6534	5596	4654	3736	2871	2092	1432	926	606	500
13	11158	11749	12229	12589	12820	12916	12875	12694	12376	11925	11349	10656	9860	8976	8022	7019	5992	4967	3972	3039	2201	1494	953	613	500
14	12796	13372	13824	14144	14323	14356	14243	13982	13576	13033	12358	11565	10667	9681	8627	7526	6406	5292	4217	3213	2315	1559	982	620	500
15	14570	15123	15538	15808	15925	15888	15694	15344	14844	14199	13420	12520	11514	10419	9258	8055	6836	5631	4473	3394	2433	1626	1012	627	500
16	16484	17003	17372	17583	17630	17513	17229	16783	16179	15426	14535	13521	12399	11191	9918	8606	7285	5984	4738	3582	2555	1695	1042	635	500
17	18539	19016	19328	19471	19439	19232	18850	18299	17583	16714	15704	14568	13324	11995	10605	9180	7751	6350	5013	3777	2681	1767	1074	642	500
18	20739	21163	21409	21474	21353	21047	20559	19893	19057	18064	16926	15661	14290	12834	11320	9776	8235	6730	5298	3978	2812	1841	1107	650	500
19	23086	23447	23617	23594	23374	22960	22355	21566	20602	19476	18203	16803	15296	13706	12063	10395	8737	7123	5593	4187	2947	1917	1141	659	500
20	25583	25870	25954	25832	25504	24972	24241	23319	22218	20951	19536	17992	16342	14614	12835	11038	9257	7531	5899	4403	3087	1996	1176	667	500
21	28231	28433	28420	28190	27743	27083	26217	25154	23907	22491	20924	19230	17431	15556	13636	11704	9796	7953	6214	4625	3231	2078	1212	676	500
22	31034	31141	31020	30670	30094	29296	28285	27071	25669	24095	22370	20516	18561	16533	14465	12393	10354	8388	6540	4855	3380	2162	1249	685	500
23	33993	33993	33753	33273	32557	31611	30445	29071	27505	25764	23872	21852	19733	17546	15325	13106	10930	8838	6877	5092	3533	2248	1287	694	500
24	37111	36993	36622	36001	35135	34030	32699	31155	29416	27500	25432	23239	20949	18595	16214	13843	11525	9303	7224	5337	3691	2337	1326	703	500

Table 2. Detailed Payoff Table

Your Investment Number

Your Opponent's Investment Number

Your Payoff	0 1 2 3		4 5 6		7 8 9		10 11 12		13 14 15		16 17 18		19 20 21		22 23 24
0 1 2 3	1484	<	2446	<	3066	<	3246	>	2902	>	2127	>	1200	>	581
	∧		∧		∧		∧		∧		∧		∧		∧
4 5 6	3245	<	4512	<	5057	>	4921	>	4109	>	2821	>	1460	>	609
	∧		∧		∧		∧		∧		∧		∧		∧
7 8 9	5705	<	7036	<	7332	>	6749	>	5383	>	3536	>	1724	>	636
	∧		∧		∧		∧		∧		∧		∧		∧
10 11 12	9122	<	10295	>	10154	>	8952	>	6883	>	4364	>	2024	>	667
	∧		∧		∧		∧		∧		∧		∧		∧
13 14 15	13575	<	14338	>	13553	>	11545	>	8620	>	5310	>	2364	>	701
	∧		∧		∧		∧		∧		∧		∧		∧
16 17 18	19132	<	19206	>	17555	>	14548	>	10603	>	6376	>	2743	>	739
	∧		∧		∧		∧		∧		∧		∧		∧
19 20 21	25855	>	24939	>	22187	>	17973	>	12838	>	7567	>	3163	>	781
	∧		∧		∧		∧		∧		∧		∧		∧
22 23 24	33800	>	31573	>	27472	>	21836	>	15336	>	8887	>	3626	>	827

Table 3. Rough Payoff Table

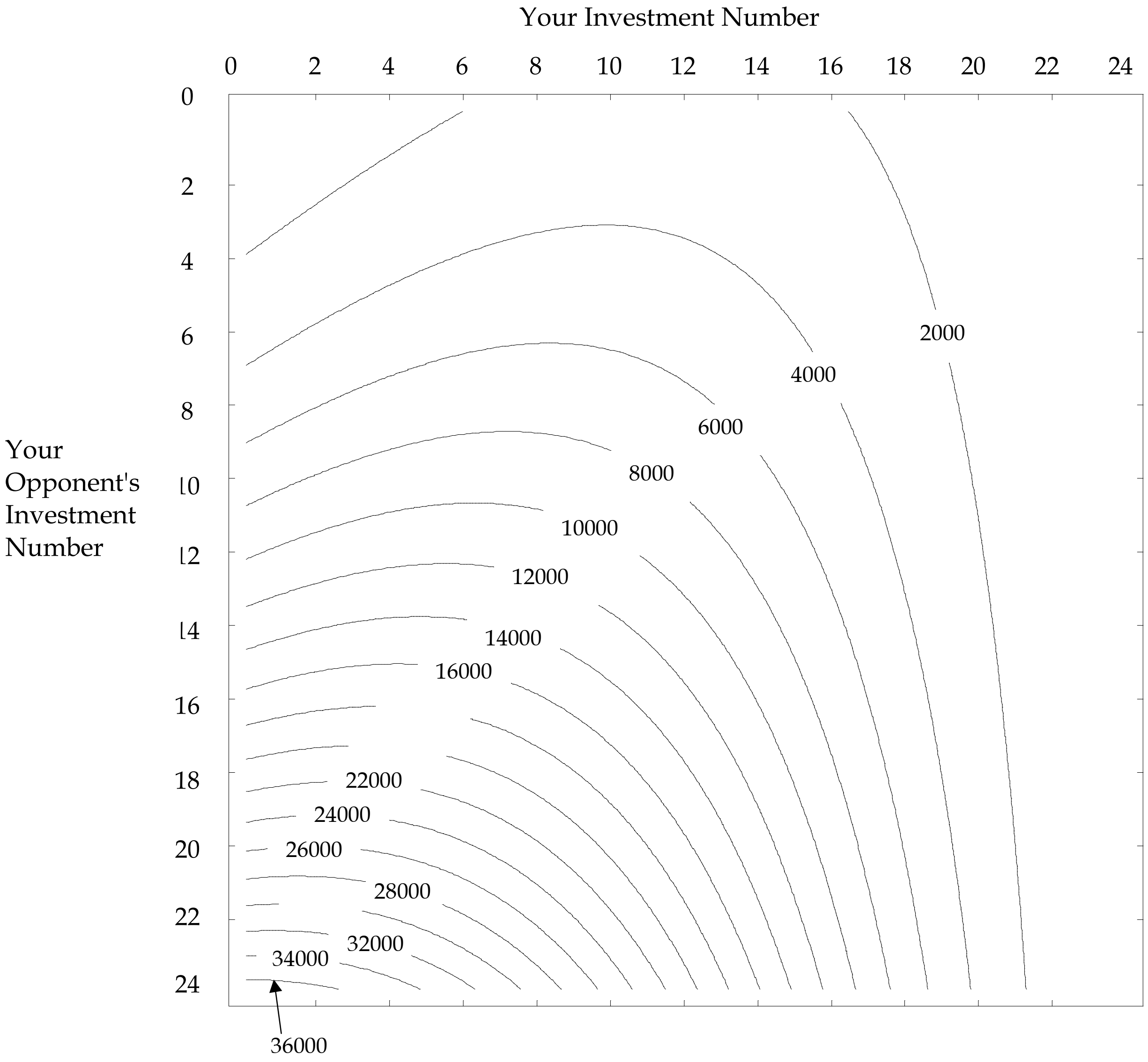


Table 4. Iso-Payoff Map

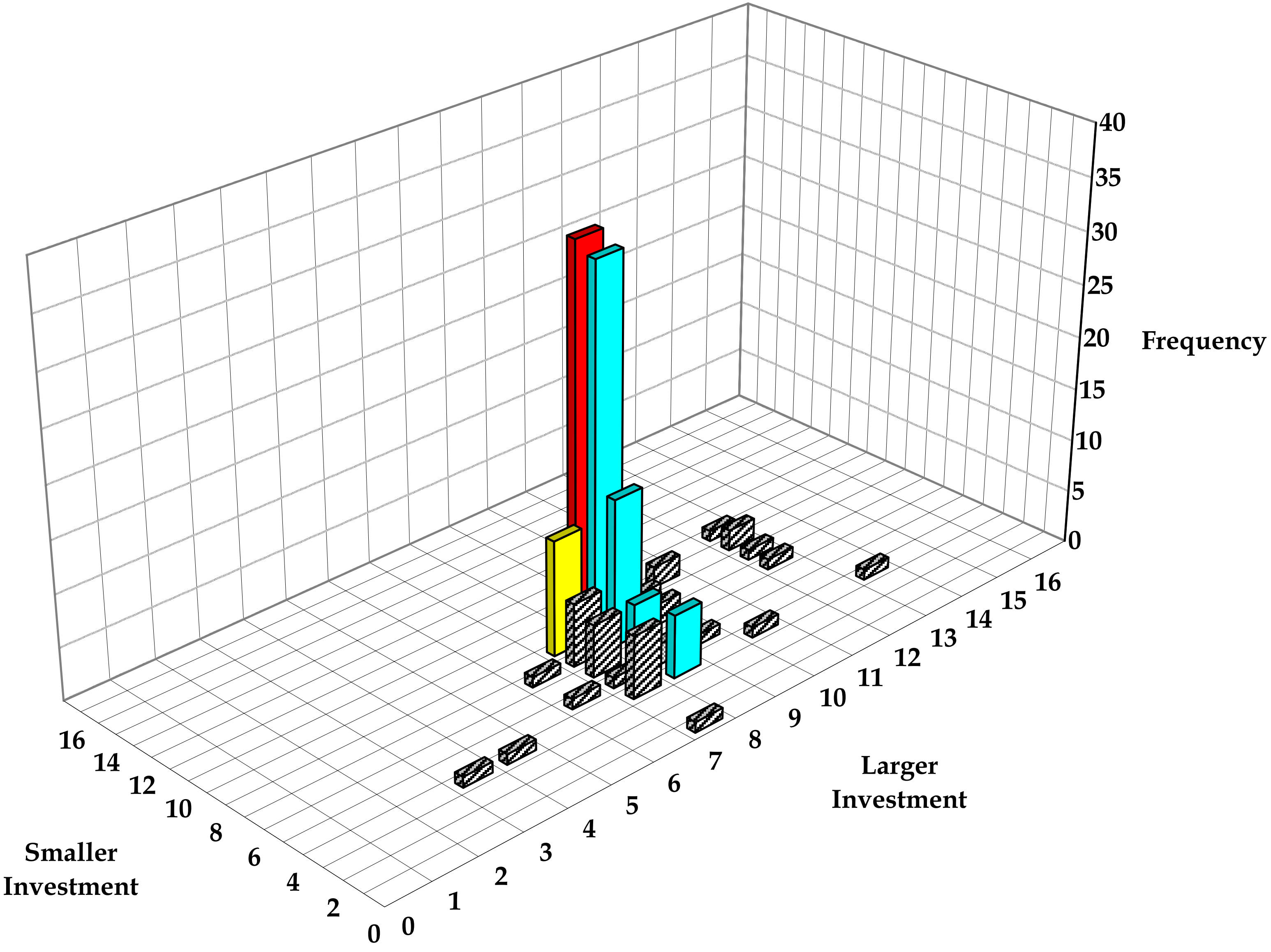


Figure 2. Investment Pattern in Treatment A

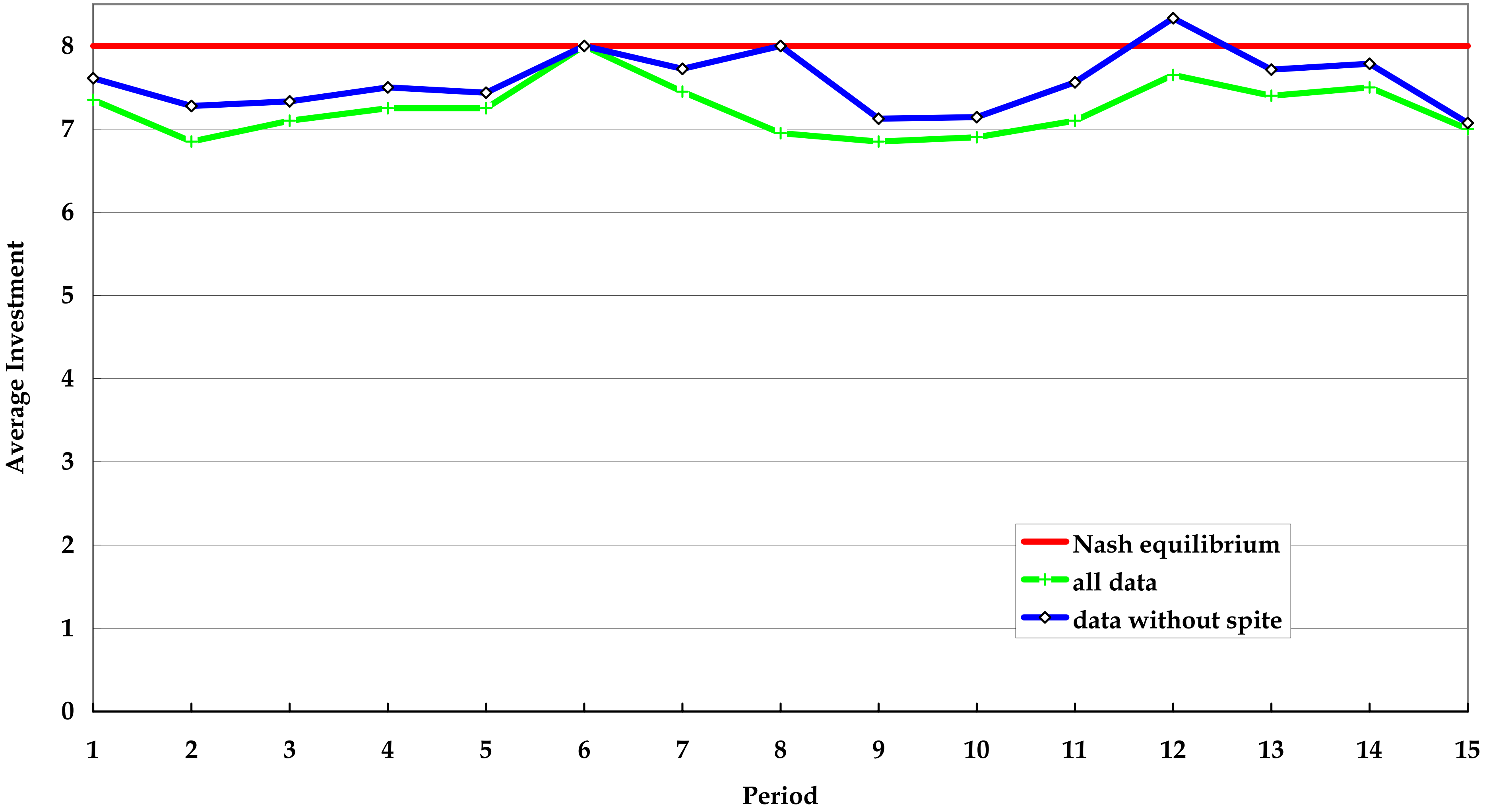


Figure 3. Average Investments in Treatment A.

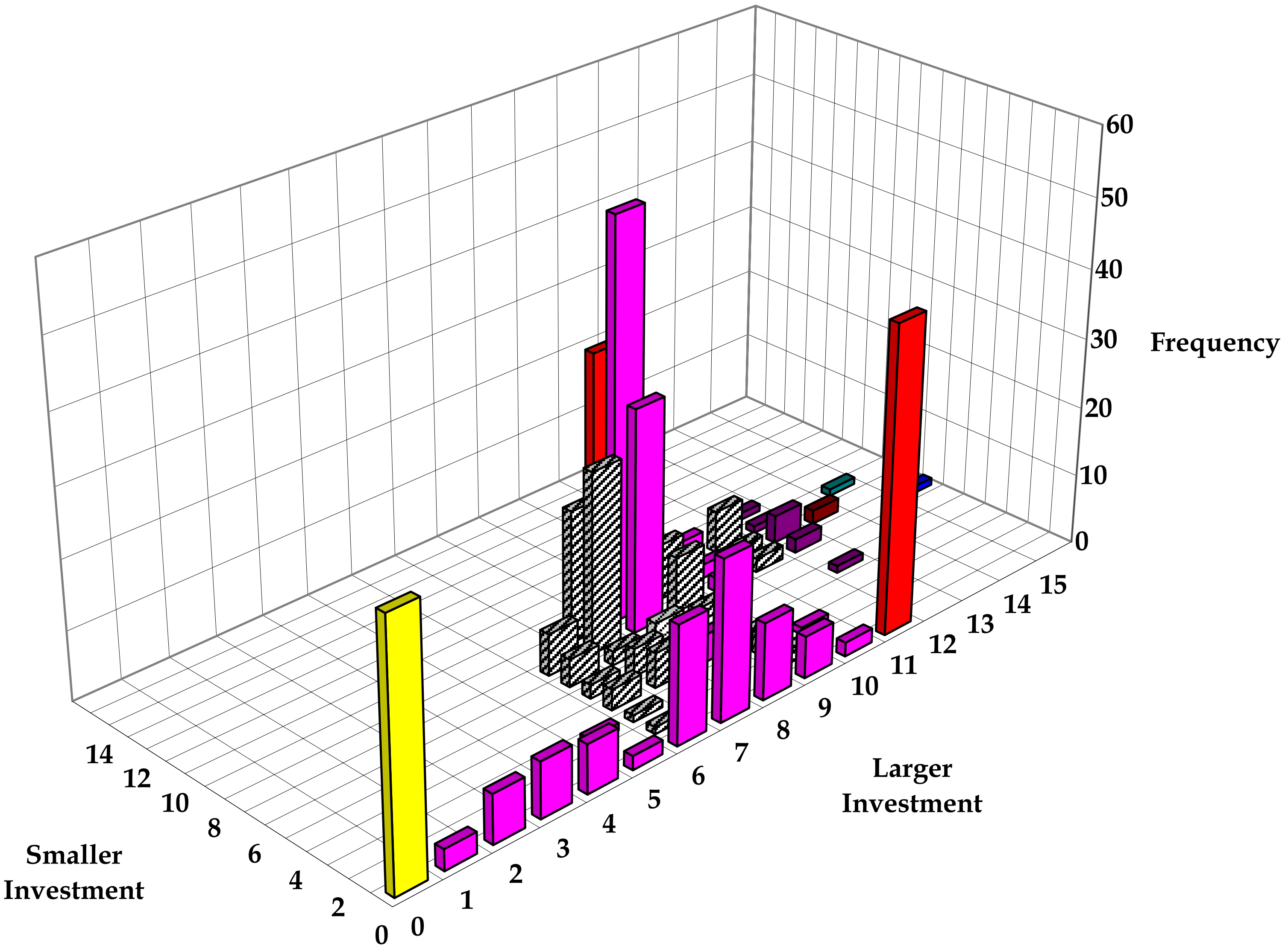


Figure 4. Investment Pattern in the Three Treatment B Sessions.

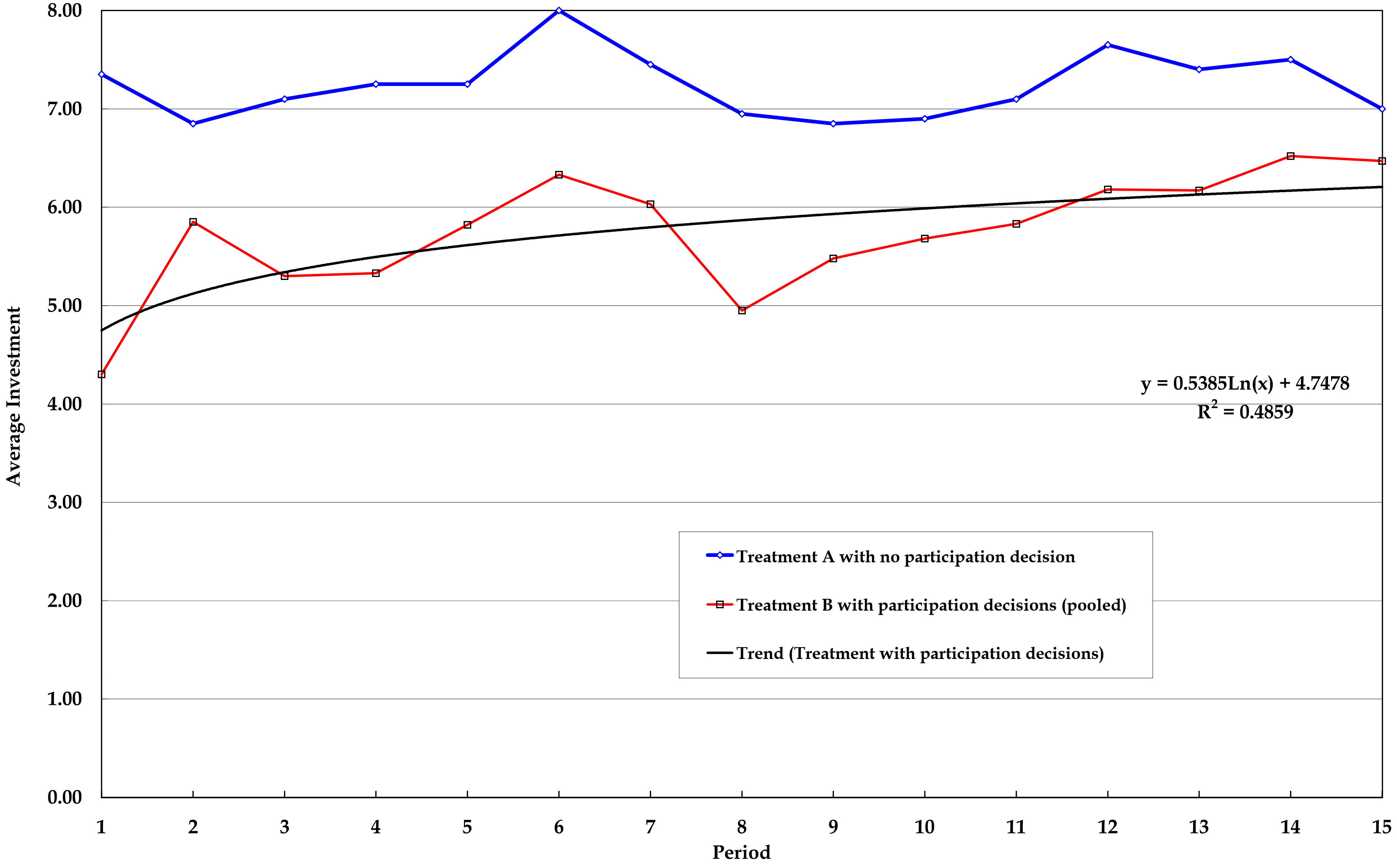


Figure 5. Comparison of Average Investment Patterns:
Treatment A versus Treatment B.

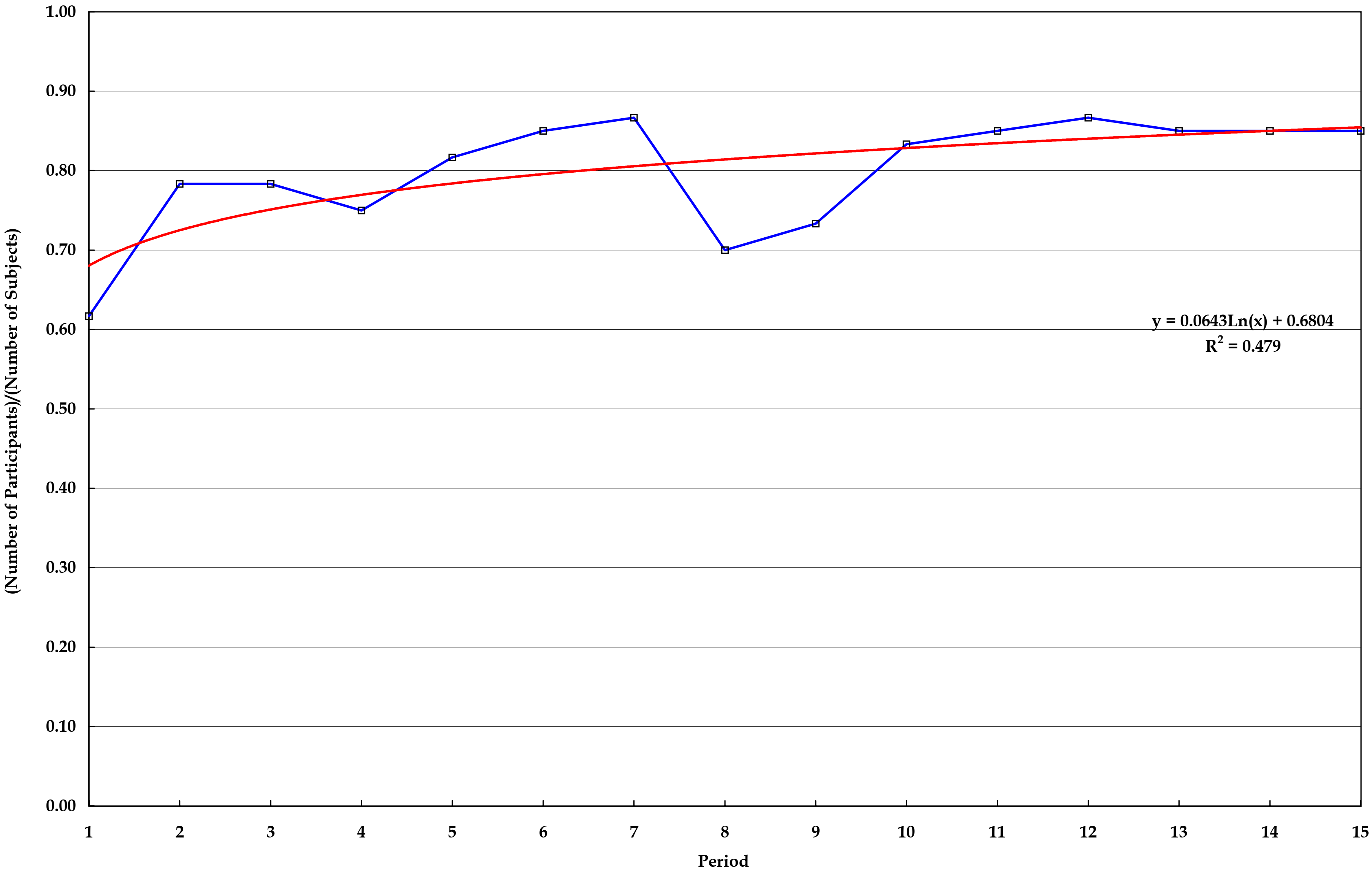


Figure 6. Participation Rate Pattern.

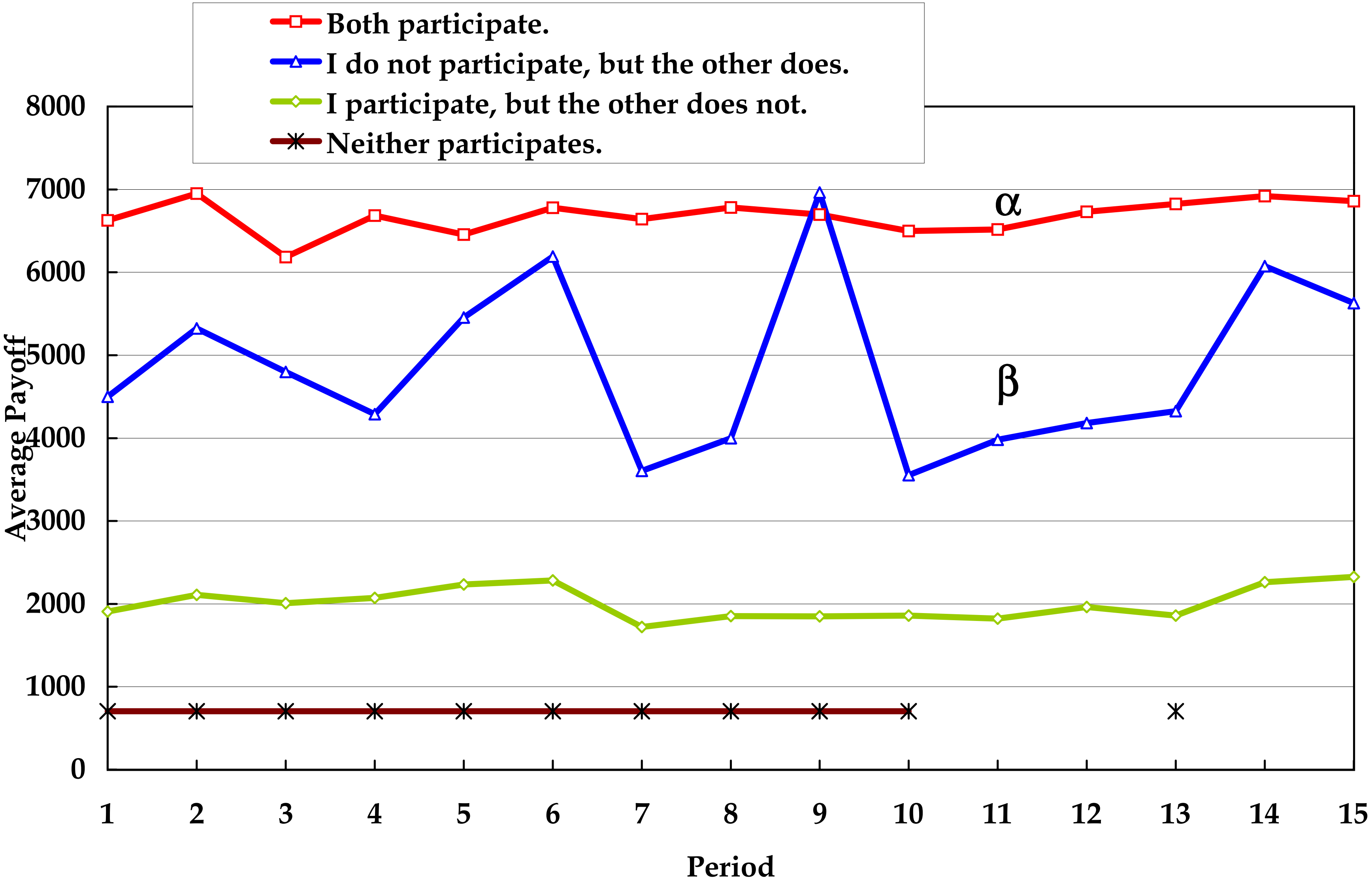
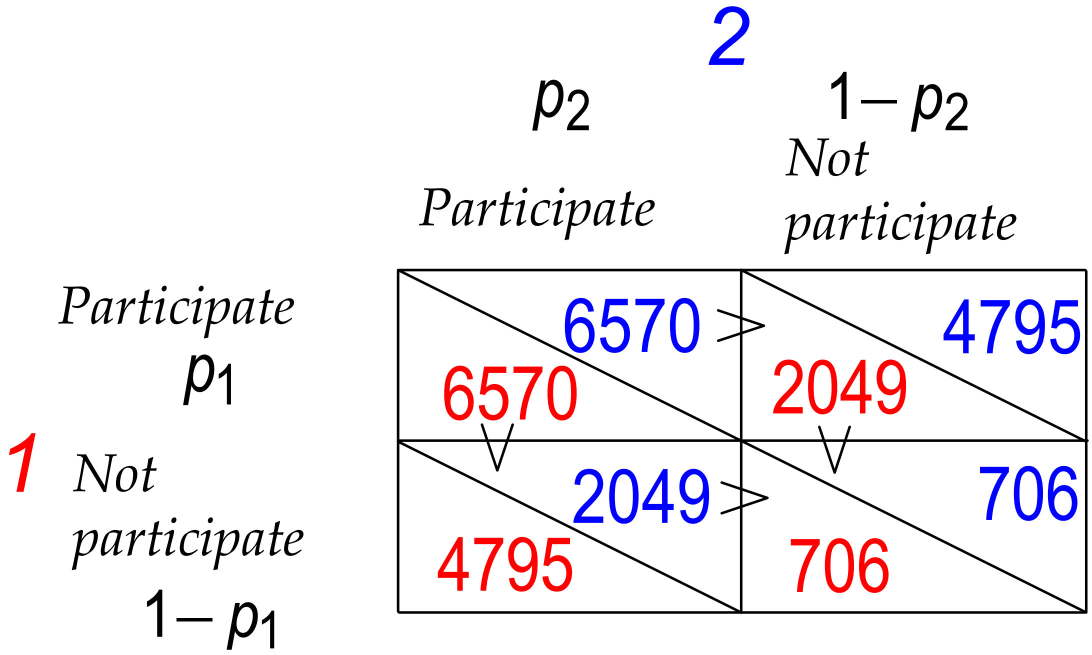


Figure 7. Average Payoffs by Participation Decision.



		2	
		p_2 Participate	$1-p_2$ Not participate
1	Participate p_1	6570 6570	2049 4795
	Not participate $1-p_1$	4795 2049	706 706

Table 5. The average values of payoff data up to round 5 for the three treatment B sessions.

Dependent Variable = 1 if Participate
0 if Not Participate

Probit Model with random subject effect

	Model (1): Cournot Expectations				Model (2): Fictitious Play Expectations			
Variable or Statistic	Tsukuba B	Tokyo B	Tokyo B′	B and B′ Pooled	Tsukuba B	Tokyo B	Tokyo B′	B and B′ Pooled
Expected Participation Earnings/ Expected Non-Participation Earnings	0.051* (0.022)	-0.044 (0.043)	0.086** (0.031)	0.028* (0.015)	-0.013 (0.054)	-0.132* (0.064)	0.131 (0.193)	-0.002 (0.025)
Intercept	0.618** (0.187)	1.279** (0.224)	1.126** (0.241)	1.010** (0.115)	0.915** (0.211)	1.312** (0.240)	0.935** (0.222)	1.073** (0.120)
Rho[a]	0.382* (0.165)	0.339 (0.221)	0.447* (0.191)	0.344** (0.100)	0.280* (0.137)	0.371* (0.176)	0.382* (0.193)	0.333** (0.094)
Number of Observations	300	300	300	900	300	300	300	900
Estimated Log-likelihood	-147.3	-123.7	-129.8	-405.6	-149.0	-122.7	-130.0	-406.7
Restricted (slopes=0) Log-likelihood	-161.6	-136.5	-145.8	-450.1	-161.6	-136.5	-145.8	-450.1

Standard errors in parentheses.
* denotes significantly different from zero at the 5-percent level; ** denotes significantly different from zero at the 1-percent level (all two-tailed tests except for Expected Participation Earnings/Expected Non-Participation Earnings).
[a] Rho is a standard Hausman test statistic for the presence of random effects.

Table 6. Results of Probit Participation Model

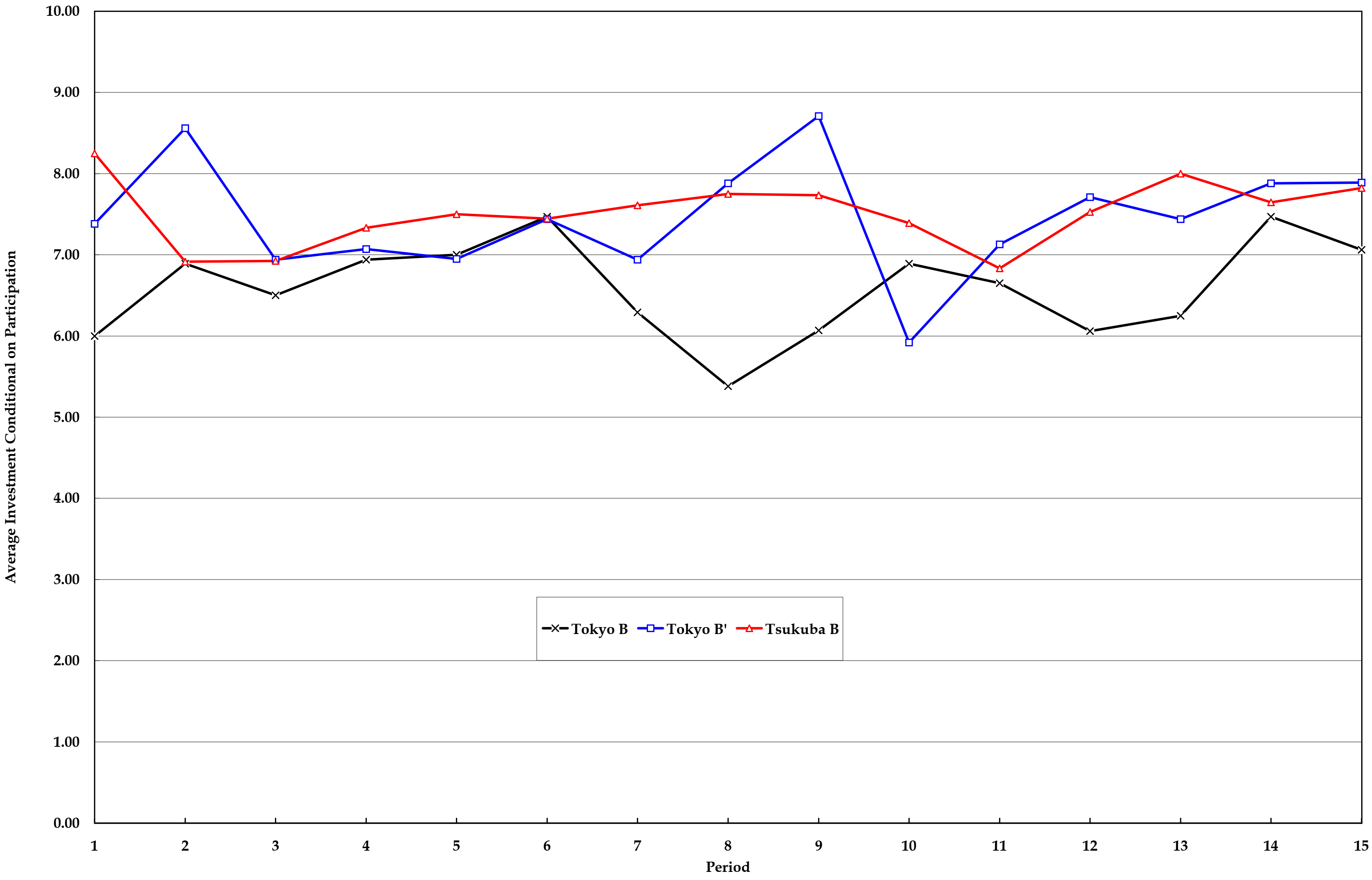


Figure 8. The Average Investment Patterns Conditional on Participation in Tsukuba B, Tokyo B, and Tokyo B' Sessions.

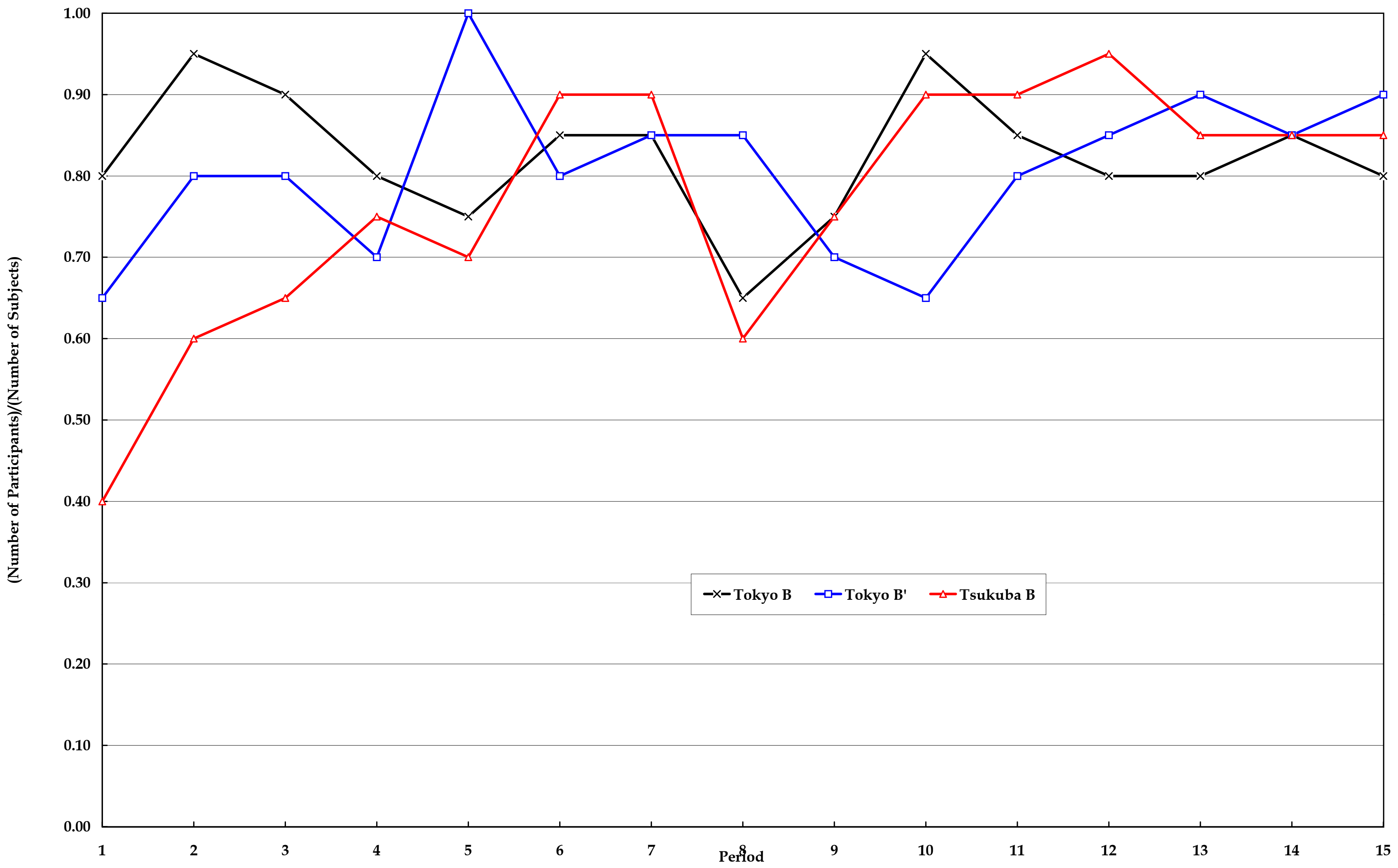


Figure 9. The Average Participation Rate Patterns
in Tsukuba B, Tokyo B, and Tokyo B' Sessions.