CIRJE-F-795

Monitoring Accuracy and Retaliation in Infinitely Repeated Games with Imperfect Private Monitoring: Theory and Experiments

Hitoshi Matsushima
University of Tokyo

Tomohisa Toyama
Kogakuin University

April 2011

Monitoring Accuracy and Retaliation in Infinitely Repeated Games with Imperfect Private Monitoring: Theory and Experiments[1]

Hitoshi Matsushima
Department of Economics, University of Tokyo[2]

Tomohisa Toyama
Faculty of Engineering, Kogakuin University

April 2, 2011

Abstract

This paper experimentally examines infinitely repeated prisoners' dilemma games with imperfect private monitoring and random termination where the probability of termination is very low. Laboratory subjects make the cooperative action choices quite often, and make the cooperative action choice when monitoring is accurate more often than when it is inaccurate. Our experimental results, however, indicate that they make the cooperative action choice much less often than the game theory predicts. The subjects' naïveté and social preferences concerning reciprocity prevent the device of regime shift between the reward and punishment phases from functioning in implicit collusion.

JEL Classification Numbers: C70, C71, C72, C73, D03.
Keywords: Infinitely Repeated Prisoners' Dilemma, Imperfect Private Monitoring, Experimental Economics, Monitoring Accuracy, Social Preference, Generous Tit-for-Tat.

---

[1]This paper is a revised version of a part of our earlier unpublished paper (jointly authored with Mr. Nobuyoki Yagi) entitled "Repeated Games with Imperfect Monitoring: An Experimental Approach" (2007). The abstract of the main findings of the present paper was introduced in a Japanese article written by Hitoshi Matsushima entitled "Introduction to Experimental Economics: The New Research and Education Scene"("Jikken Keizaigaku Kotohajime"), published as the first chapter of a book edited by Professor Tatsuyoshi Saijo entitled *An Invitation to Experimental Economics* (*Jikken Keizaigaku eno Shoutai*) (2007, NTT Press). Research for the present paper was supported by a Grant-in-Aid for Scientific Research (Kakenhi 21330043) from the Japan Society for the Promotion of Science (JSPS) and the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of the Japanese government and a grant from the 21st Century Culture, Arts, and Sciences Foundation. We thank all the participants of the conference for experimental economics held at the University of Tokyo (December 2, 2006). All errors are ours.
[2] Department of Economics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan. E-mail: hitoshi at mark e.u-tokyo.ac.jp.

1. Introduction

This paper examines infinitely repeated prisoners' dilemma games that are modeled as being randomly terminated at the end of every round with a fixed probability. We assume *imperfect monitoring*: neither player can directly observe whether his (or her) partner selects the cooperative action or the defective action. Instead, he can, indirectly and imperfectly, monitor his partner's action choice through the observation of a noisy signal that is contingent on this choice: either the good signal or the bad signal. We assume that this monitoring is *private*; whether the signal for a player's action is good or bad is not observable to this player. We also assume that the probability of termination is so low as to provide a rational and self-interested player with the incentive to make the cooperative action choice from the viewpoint of long-term benefit, even if the monitoring technology is inaccurate.

Based on these assumptions, we experimentally investigate whether and how often laboratory subjects make the cooperative action choices, whether and how their behavior is influenced by monitoring accuracy, and whether and why they fail to behave as cooperatively as the standard game theory predicts. Our experimental results support some aspects of game-theoretical prediction based on rational and self-interested motives; irrespective of monitoring accuracy, laboratory subjects make the cooperative action choices quite often. They make the cooperative action choice when the monitoring technology is accurate more often than when it is inaccurate.

Our experimental results, however, indicate that laboratory subjects make the cooperative action choice *much less often* than the standard game theory predicts. This paper argues that with imperfect private monitoring and low probability of termination, the subjects' naïveté and social preference concerning reciprocity might prevent the device of regime shift between the reward and punishment phases from functioning in implicit collusion.

It is a well-accepted view in the literature on repeated games with perfect monitoring that the device of regime shift functions in implicit collusion. When a player deviates from the collusive relationship with his partner by selecting the defective action, his partner will retaliate by selecting the defective action more often in the future, i.e., by shifting the regime from the reward phase to the punishment phase. Hence, implicit collusion can be sustained as a subgame perfect equilibrium if the deviant's instantaneous gain is exceeded by future loss caused by his partner's retaliation. For examples, see Fudenberg and Tirole (1993, Chapter 5), Osborne and Rubinstein (1994, Chapter 8), and Mailath and Samuelson (2006). This view is supported by experimental research (such as Dal Bó, 2005).

The device of regime shift can be applied to the case of imperfect monitoring, but with a limit. Since a player cannot directly respond to his partner's action choice, he instead makes his action choices contingent on the observed signal; when the player observes the bad signal, he will retaliate against his partner by selecting the defective action more often than when he observes the good signal.

Since monitoring is imperfect, however, it is inevitable that a player will observe the bad signal even if the partner makes the cooperative action choice. This causes *welfare loss peculiar to imperfect monitoring* to occur: the player will retaliate against the partner even when the partner actually selects the cooperative action because the bad signal for his action occurs. Hence, it is important to determine whether and how equilibrium can be constructed to decrease welfare loss and make the players as collusive as possible. For related works on imperfect public monitoring (i.e., signals are observable by all players), see Green and Porter (1984), Abreu, Pearce, and Stacchetti (1990), and Fudenberg, Levine, and Maskin (1994). For related works on imperfect private monitoring, see Sekiguchi (1997), Ely and Välimäki (2002), Piccione (2002), and Matsushima (2004).

Improvement in monitoring accuracy makes it easier to decrease this welfare loss without contradicting the incentive constraints: if monitoring technology becomes more accurate, a player can incentivize his partner to make the cooperative action choice while being less sensitive to whether the signal is good or bad and using a milder future punishment. Hence, it could be an effective way to decrease welfare loss since a player becomes less likely to retaliate against his partner as monitoring technology becomes more accurate; this should be regarded as a game-theoretical prediction about the influence of improvement in monitoring accuracy on subjects' behavioral mode.

Our experimental results, however, do not support this prediction: laboratory subjects are not so rational and self-interested as standard game theory expects. In this respect, the main contribution of this paper is that it explicitly takes into account *boundedly rational* aspects in laboratories: a subject tends to act in a naïve manner such that, disregarding complicated strategic aspects, he is simply more convinced that his partner selected the cooperative action whenever he observes the good signal rather than the bad signal. The degree of his conviction in this manner is reinforced as monitoring accuracy improves.

More importantly, it is anticipated that a subject will be motivated by *social preference concerning reciprocity*: the more he is convinced that his partner selected the defective action, the more severely he retaliates. Hence, the more accurate the monitoring technology is, the more severely the player tends to retaliate. This prediction of reciprocal retaliation is, however, diametrically opposite to the prediction based on rational and self-interested motives.

Our experimental results do support the boundedly rational prediction rather than the standard game-theoretical prediction. The difference in signal-contingent frequency of a subject's cooperative action choice between the good signal and the bad signal could be regarded as an appropriate substitute for the intensity with which he retaliates against his partner. Our experimental results imply that this difference tends to increase, i.e., the subject tends to retaliate more severely, as monitoring accuracy improves. This tendency makes the achievement of implicit collusion much less satisfactory than standard game theory predicts.

In order to further clarify this point, this paper will compare laboratory performance with that theoretically induced by a simple form of Nash equilibrium, *symmetric generous tit-for-tat Nash equilibrium*. This assumes that a player at all times responds only to the signal given during the previous round. The basic concept of the generous tit-for-tat Nash equilibrium was explored by Nowak and Sigmund (1992), Takahashi (1997), Matsushima (2010), and others. This equilibrium has a simple device for saving welfare loss by making the cooperative and defective action choices indifferent at all times. The difference in the signal-contingent probability of making the cooperative action choice is uniquely determined and is *decreasing* in monitoring accuracy. We further specify that the symmetric generous tit-for-tat Nash equilibrium is as compatible as possible with our experimental results.

Our experimental results show that irrespective of monitoring accuracy, subjects tend to make the cooperative action choice much less often than the symmetric generous tit-for-tat Nash equilibrium predicts. When the monitoring technology is accurate, laboratory subjects tend to retaliate much more severely than this equilibrium predicts. When the monitoring technology is inaccurate, the subjects tend to retaliate much less severely than this equilibrium predicts. From these observations, it could be concluded that when monitoring is accurate, the reason subjects are not very successful in implicit collusion is that they fail to decrease welfare loss because they are too sensitive about whether the signal is good or bad. When monitoring is inaccurate, the reason they are not very successful is that they fail to incentivize their partners to make cooperative action choices because their reciprocal retaliation is too weak.

Experimental research on various multi-stage models such as the ultimatum game, trust game, and gift exchange showed that social preference-based motives encourage subjects to cooperate with each other in a one-shot game framework. Here, subjects are motivated by social preference concerning reciprocity in ways that a player's friendly or hostile activity at an early stage induces the partner's altruistic or retaliatory response, respectively, at a later stage. For examples, see Güth, Schmittberger, and Schwarze (1982), Berg, Dickhaut, and McCabe (1995), Fehr and Gächter (2000), and Camerer (2003, Chapter 2).

Based on these experimental findings, it could be possible to anticipate that social preference-based motives occasionally facilitate collusion even in the repeated game framework. Duffy and Muñoz-García (2010) demonstrated that social preference helps the achievement of implicit collusion in infinitely repeated games and operates as a substitute for time discounting. In contrast with Duffy and Muñoz-García, this paper assumes that the discount factor, replicated by the probability of continuation, is very high, which substantially restricts the functioning of social preference in implicit collusion in the manner that Duffy and Muñoz-García pointed out.

There exists a large number of experimental studies on infinitely repeated games with perfect monitoring. See Roth and Murnighan (1978), Murnighan and Roth (1983), Dal Bó (2005), Dal Bó and Fréchette (2010), and others.[3] Roth and Murnighan (1978)

[3] See also the references listed in Dal Bó and Fréchette (2010).

and Murnighan and Roth (1983) explored the basic concept of experimental design for infinitely repeated games with random termination such that time discounting is replicated by a fixed probability that the game continues at the end of each round. Dal Bó (2005) reported that subjects are more successful in implicit collusion in infinitely repeated games with random termination than in finitely repeated games with a known terminal round. The present paper uses a random termination device as a proper replication of time discounting that is similar to Murnighan, Roth, and Dal Bó.

Aoyagi and Fréchette’s 2009 paper relates closely to the present paper, but up to a point. They studied infinitely repeated prisoners’ dilemma games with imperfect monitoring by varying the noise in monitoring. Their findings show that laboratory subjects are sophisticated enough to increase their level of cooperation as monitoring accuracy improves. Our substantial departure from Aoyagi and Fréchette is to shed light on the bounded rationality of laboratory subjects and the conflict between regime shift and social preference. Aoyagi and Fréchette assumed that monitoring is public and that the publicly observable signal is a single-dimensional real variable; from this signal, it is impossible to identify which player is more likely to deviate. In contrast, the present paper assumes that monitoring is private and that the players’ action choices are monitored through the observation of their respective private signals.[4]

The organization of this paper is as follows. Section 2 shows the model, where we define the component game as a prisoners’ dilemma with symmetry and with an additively separable form of payoff functions. Section 3 introduces the concept of symmetric generous tit-for-tat Nash equilibrium. Section 4 shows the theorem that characterizes the class of symmetric generous tit-for-tat Nash equilibrium and provides conjectures on subjects’ behavioral mode in laboratories both from the rational and self-interested viewpoint and from the boundedly rational viewpoint. Section 5 shows the experimental design where we demonstrate the device to help subjects to understand the possibility of random termination at the end of each round. Section 6 shows our experimental results. Section 7 compares our experimental results with the performance induced by the specified symmetric generous tit-for-tat Nash equilibrium. Section 8 gives further remarks.

[4]There are experimental studies, such as Holcomb and Nelson (1997) and Feinberg and Snyder (2002), where subjects do not necessarily observe the same signals.

2. The Model

We investigate a *repeated game* played by Players 1 and 2 in a discrete time horizon. The game has a finite number of rounds, but the terminal round is randomly determined and unknown to the players. The *component game* of this repeated game is denoted by $(S_i, u_i)_{i\in\{1,2\}}$, where S_i denotes the set of all actions for Player $i \in \{1,2\}$, $s_i \in S_i$, $S \equiv S_1 \times S_2$, $s \equiv (s_1, s_2) \in S$, $u_i : S \to R$, and $u_i(s)$ denotes the payoff for Player i induced by action profile $s \in S$. We assume that each Player $i's$ payoff has an *additively separable* form,

$$u_i(s) = v_i(s_i) + w_i(s_j) \text{ for all } s \in S \text{, where } j \neq i.$$

Two random signals, $\omega_1 \in \Omega_1$ and $\omega_2 \in \Omega_2$, occur after action choices are made, where Ω_i denotes the set of possible ω_i, $\omega = (\omega_1, \omega_2)$, and $\Omega = \Omega_1 \times \Omega_2$. A signal profile $\omega \in \Omega$ is randomly determined according to the conditional probability function $f(\cdot \mid s) : \Omega \to R_+$. Let $f_i(\omega_i \mid s) \equiv \sum_{\omega_j \in \Omega_j} f(\omega \mid s)$. We assume that $f_i(\omega_i \mid s)$ is independent of s_j; we denote $f_i(\omega_i \mid s_i)$ instead of $f_i(\omega_i \mid s)$ and use $\omega_i \in \Omega_i$ to denote *the signal for Player $i's$ action.*

We assume that monitoring is *imperfect*: at every round $t \in \{1,2,...\}$, no Player i can directly observe either the action $a_j(t) \in A_j$ that his partner $j \neq i$ selected or even the realized payoff profile $u(s(t)) = (u_1(s(t)), u_2(s(t)))$. Instead, he can observe the signal for his partner's action $\omega_j(t) \in \Omega_j$, through which he can imperfectly monitor him. We assume that monitoring is *private*; each Player i cannot observe the signal for his own action $\omega_i(t) \in \Omega_i$.

Let $h(t) = (s(\tau), \omega(\tau))_{\tau=1}^{t}$ denote the *history up to round* t. Let us denote by $H = \{h(t) \mid t = 0,1,...\}$ the set of possible histories, where $h(0)$ implies the null history. *The payoff for Player i per round when the history $h(t) \in H$ up to round t* occurs is defined as

$$U_i(h(t)) \equiv \frac{\sum_{\tau=1}^{t} u_i(s(\tau))}{t}.$$

Let us specify the component game as a *prisoners' dilemma with symmetry and additive separability*; for each $i \in \{1,2\}$,

$$S_i = \{A, B\},\ v_i(A) = -Y,\ v_i(B) = 0,\ w_i(A) = X + Y, \text{ and}$$

$$w_i(B) = X + Y - Z,$$

where $f_i(\omega_i \mid s) \equiv \sum_{\omega_j \in \Omega_j} f(\omega \mid s)$, X, Y, and Z are positive integers, and

$$Z > Y > 0.$$

Let us call A the *cooperative* action and B the *defective* action. It costs each player Y for his cooperative action choice, but this choice gives the partner a benefit Z, which is greater than the cost Y. The payoff vector (X, X) induced by the cooperative action profile (A, A) is efficient, and is better than the payoff vector $(X + Y - Z, X + Y - Z)$ induced by the defective action profile (B, B), which is a dominant strategy profile and the unique Nash equilibrium in the component game.

Let us specify

$$\Omega_i = \{a, b\} \text{ and } f_i(a \mid A) = f_i(b \mid B) = p, \text{ where } 1/2 < p < 1.$$

Let us call a the *good* signal and b the *bad* signal. The probability index p implies the *degree of monitoring accuracy*: the greater p is, the more accurately each player can monitor his partner's action choice. The inequality $p > 1/2$ implies that the probability of the good signal occurring is greater when Player i selects the cooperative action A than when he selects the defective action B.

For each history $h(t) \in H$ up to round t, let us denote the frequency of cooperative action choice A by

$$\rho(h(t)) \equiv \frac{|\{\tau \in \{1,...,t\} \mid S_1(\tau) = A\}| + |\{\tau \in \{1,...,t\} \mid S_2(\tau) = A\}|}{2t}.$$

Note from additive separability that the sum of the payoffs per round when the history $h(t) \in H$ up to round t occurs is given by

$$U_1(h(t)) + U_2(h(t)) = 2[X + \{1 - \rho(h(t))\}(Y - Z)],$$

which implies that the *frequency of cooperative action choice* $\rho(h(t))$ *uniquely determines the sum of the payoffs per round* $U_1(h(t)) + U_2(h(t))$.

Let $\delta \in (0,1)$ denote the probability of the repeated game continuing at the end of each round when this game continued up to the previous round $t-1$; the game is terminated at the end of each round $t \geq 1$ based on probability $\delta^{t-1}(1-\delta)$. Hence, the expected round length of the repeated game is given by

$$\sum_{t=1}^{\infty} \delta^{t-1}(1-\delta)t\,.$$

For our experiments, let us assume that

$$\delta = 0.967\,,$$

which implies that the probability of the repeated game continuing is *very high*. In this case, it might be possible for self-interested players to collude with each other to some extent, even if monitoring is inaccurate.

3. Symmetric Generous Tit-for-Tat Equilibrium

Let $\alpha_i \in [0,1]$ denote a mixed action for Player i, implying that the probability that he makes the cooperative action choice A is α_i. Player $i's$ strategy in the repeated game is defined as $\sigma_i : H \to [0,1]$; he selects A with probability $\sigma_i(h(t-1))$ in each round t when the history $h(t-1)$ up to round $t-1$ occurs. Let Σ_i denote the set of all strategies for Player i, $\sigma = (\sigma_1, \sigma_2)$, and $\Sigma = \Sigma_1 \times \Sigma_2$. The expected payoff per period for Player i induced by $\sigma \in \Sigma$ when the monitoring accuracy is given by $p \in (0,1)$ is defined as

$$U_i(\sigma; p) \equiv \frac{E[\sum_{t=1}^{\infty} \delta^{t-1}(1-\delta)\sum_{\tau=1}^{t} u_i(s(\tau)) \mid \sigma, p]}{\sum_{t=1}^{\infty} \delta^{t-1}(1-\delta)t}$$

$$= (1-\delta)E[\sum_{\tau=1}^{\infty} \delta^{\tau-1} u_i(s(\tau)) \mid \sigma, p],$$

where $E[\cdot \mid \sigma, p]$ denotes the expectation operator. The expected frequency of cooperative action choice A induced by $\sigma \in \Sigma$ when the monitoring accuracy is given by $p \in (0,1)$ is defined as

$$\rho(\sigma; p) \equiv \frac{E[\sum_{t=1}^{\infty} \delta^{t-1}(1-\delta)t\rho(h(t)) \mid \sigma, p]}{\sum_{t=1}^{\infty} \delta^{t-1}(1-\delta)t}.$$

From additive separability, it follows that

$$U_1(\sigma; p) + U_2(\sigma; p) = 2[X + \{1-\rho(\sigma; p)\}(Y-Z)],$$

which implies that *the expected frequency* $\rho(\sigma; p)$ *uniquely determines the sum of the expected payoffs per period* $U_1(\sigma; p) + U_2(\sigma; p)$.

A strategy profile $\sigma \in \Sigma$ is said to be a *Nash equilibrium* in the repeated game with monitoring accuracy $p \in (0,1)$ if

$$U_i(\sigma; p) \geq U_i(\sigma_i', \sigma_j; p) \text{ for all } i \in \{1,2\} \text{ and all } \sigma_i' \in \Sigma_i.$$

A strategy profile $\sigma \in \Sigma$ is said to be *symmetric generous tit-for-tat* if there exists

$(q, r(a), r(b)) \in [0,1]^3$ such that

$$r(a) > 0,$$

$$\sigma_1(h(0)) = \sigma_2(h(0)) = q,$$

and for each $i \in \{1,2\}$, every $t \geq 2$, and every $h(t-1) \in H$,

$$\sigma_i(h(t-1)) = r(a) \text{ if } \omega_j(t-1) = a,$$

$$\sigma_i(h(t-1)) = r(b) \text{ if } \omega_j(t-1) = b.$$

At round 1, each player makes the cooperative action choice A with probability q. At each round $t \geq 2$, each player i makes the cooperative action choice A with probability $r(\omega_j)$ when he observes the signal $\omega_j(t-1) = \omega_j$ for his partner's action at the previous round $t-1$. We will write $(q, r(a), r(b))$ instead of σ for any symmetric generous tit-for-tat strategy profile.

4. Theorem and Conjecture

Let us define

(1) $$w(p) \equiv \frac{Y}{\delta(2p-1)Z}.$$

Note that

$$0 < w(p) \leq 1 \text{ if and only if } \delta \geq \frac{Y}{(2p-1)Z}.$$

The following theorem shows that if a symmetric generous tit-for-tat strategy profile $(q, r(a), r(b))$ is a Nash equilibrium, then the difference in the signal-contingent probability of making the cooperative action choice between the good signal and the bad signal, i.e., $r(a)-r(b)$, must be equal to a fixed value given by $w(p)$.

The Theorem: *A symmetric generous tit-for-tat strategy profile* $(q, r(a), r(b))$ *is a Nash equilibrium in the repeated game with monitoring accuracy* p *if and only if*

(2) $$\delta \geq \frac{Y}{(2p-1)Z},$$

and for each $i \in \{1,2\}$,

(3) $$r(a) - r(b) = w(p).$$

Proof: Selecting $s_i = A$ instead of B costs Player i Y at the current round, whereas in the next round he can gain Z from his partner's response with a probability of $pr(a)+(1-p)r(b)$ instead of $(1-p)r(a)+pr(b)$. This holds irrespective of round and history because of additive separability. Since he is incentivized to select both A and B at all times, indifference to these action choices must be a necessary and sufficient condition,

$$-Y + \delta Z\{pr(a)+(1-p)r(b)\} = \delta Z\{(1-p)r(a) - pr(b)\},$$

which is equivalent to

$$r(a)-r(b) = \frac{Y}{\delta(2p-1)Z}, \text{ i.e., equality (3).}$$

Since $r(a) - r(b) \le 1$, $1 \ge \frac{Y}{\delta(2p-1)Z}$, i.e., inequality (2), must hold.

Q.E.D.

We will write $(\tilde{q}, \tilde{r}) \in [0,1]^2$ instead of $(q, r(a), r(b))$ for any symmetric generous tit-for-tat Nash equilibrium, where $(\tilde{q}, \tilde{r})$ was specified by

$$\tilde{q} \equiv q \quad \text{and} \quad \tilde{r} \equiv r(a).$$

Note from the theorem that

$$r(b) = \tilde{r} - w(p) = \tilde{r} - \frac{Y}{\delta(2p-1)Z}.$$

Since Player i is indifferent to the choice between A and B at all times, it follows from additive separability that the expected frequency of the cooperative action choice induced by $(\tilde{q}, \tilde{r})$ is given by

$$\rho(\tilde{q}, \tilde{r}; p) = \frac{1}{Z - Y}[\{(1-\delta)\tilde{q} + \delta\tilde{r}\}Z - \frac{p}{2p-1}Y],$$

and the expected payoff per round induced by $(\tilde{q}, \tilde{r})$ is given by

$$U_1(\tilde{q}, \tilde{r}; p) = U_2(\tilde{q}, \tilde{r}; p) = X + \{1 - \rho(\tilde{q}, \tilde{r}; p)\}(Y - Z).$$

This paper regards the intensity with which a subject retaliates against his partner as *the difference in the signal-contingent frequency of the cooperative action choice between the good signal and the bad signal*. If a subject is so rational and self-interested as to play a symmetric generous tit-for-tat Nash equilibrium, this difference can be approximated by the difference in the signal-contingent probability of making the cooperative action choice, i.e., $w(p)$. We can say that the greater $w(p)$ is, the more severely the player retaliates against his partner.

It is important to note that $w(p)$ is *decreasing in* p: the less accurate the monitoring technology is, the more severely a rational and self-interested player retaliates against his partner. In order to incentivize the player to make the cooperative action choice, it is necessary for the partner to select the defective action when observing the bad signal more often than when observing the good signal. When monitoring is less accurate, it is harder for a player to detect whether his partner selected the cooperative or defective action. In this case, an increase in intensity of the player's retaliation against his partner necessitates incentivizing the partner.

Since monitoring is imperfect, it is inevitable that a player will observe the bad signal even when his partner has made the cooperative action choice. This causes *welfare loss* to occur, and because the bad signal has occurred, the player must retaliate even when his partner has actually selected the cooperative action. If monitoring technology becomes more accurate, the player can incentivize his partner by being less sensitive to whether the observed signal is good or bad; this decreases the welfare loss caused by monitoring imperfection.

However, laboratory subjects are anticipated not to be either rational or self-interested. It might be that a subject tends to act in a naïve manner such that, disregarding complicated strategic aspects, he is simply more convinced that his partner selected the cooperative action whenever he observes the good signal, and the degree of his conviction is reinforced as monitoring accuracy improves.

More importantly, a laboratory subject is anticipated to be motivated not only by his self-interest but also by *social preference concerning reciprocity*; that is, the more he is convinced that his partner selected the defective action, the more severely and frequently he retaliates. This implies that *the more accurate the monitoring technology is, the more severely the player tends to retaliate against his partner*. The conjecture of reciprocal retaliation in this manner is diametrically opposite to the theoretical prediction based on rational and self-interested motives.

The following sections examine experimentally whether laboratory subjects' behavioral mode is, on average, based on either rational and self-interested motives or naïve and social preference-based motives.

5. Experimental Design

We conducted computerized experiments on October 5 and 6, 2006, at the University of Tokyo, where subjects were recruited from the undergraduate and graduate schools in all fields.[5] The subjects were well motivated; they had the opportunity to obtain points equal to their earned payoffs, which were converted into yen (0.6 yen per point). They received a participation fee of 1500 yen in addition to their earned payoffs.

We specify the prisoners’ dilemma with symmetry and additive separability as $(X,Y,Z)=(60,10,55)$. See Figure 1.

[Figure 1]

The probability of the repeated game continuing is given by $\delta=0.967$, which implies that the probability of the repeated game being terminated is so low as to incentivize rational and self-interested players to cooperate with each other to some extent, even if monitoring is inaccurate.

The experiments conducted for this paper are categorized into two types: type 0.9, where monitoring accuracy is given by $p=0.9$, and type 0.6, where monitoring accuracy is given by $p=0.6$. Type 0.9 obviously has greater monitoring accuracy than type 0.6.

On October 5, 2006, two experiments were conducted. In each, three games of type 0.6 were played, followed by three games of type 0.9. The first experiment featured 24, 40, and 25 rounds of repetition for type 0.6 and 28, 33, and 14 rounds of repetition for type 0.9; the second experiment used 20, 23, and 37 rounds of repetition for type 0.6 and 34, 34, and 19 rounds of repetition for type 0.9. Subjects were randomly paired at the beginning of each repeated game; the pairs remained unchanged throughout the repeated game. On October 6, 2006, other two experiments were conducted in which we first played three games of type 0.9, followed by three games of type 0.6. For further

[5]The experiment was programmed and conducted with the software z-Tree. See Fischbacher (2007).

details on our experimental design, see Appendix 1.

Each subject was given an experiment manual with instructions about game rules and printed computer screen images in Japanese.[6] These contents were explained by a voice recording. On the computer screen, each subject could always see the structure of the game, the history of his action choices, and the signals for his partner's action.

It is important to note that the subjects were *not* informed in advance about how many rounds each repeated game would include. They were only informed that the number of rounds was randomly determined according to the probability $1-\delta = 0.033$ of termination. In order to help the subjects understand this random termination, we showed them Figure 2 (1) or Figure 2 (2) on the computer screen at the end of each round. These show that one of 30 cells is selected at random, and the repeated game is terminated if and only if the 30th call is selected.

[Figure 2 (1)]

[Figure 2 (2)]

[6]See the supplement of this paper for the translation of the experiment manual and computer screen images into English.

6. Experimental Results

Appendix 2 shows the sample numbers used for our experimental analysis, such as the number of times cooperative action choice A was made in all rounds, which is denoted by $Num(A;p)$, and the number of cooperative action choices made in all rounds when the good signal a was observed in the previous round, which is denoted by $Num(A;a,p)$. We similarly defined $Num(B;p)$, $Num(B;b,p)$, and others. Appendix 2 also provides the relevant sample numbers by dividing the rounds into round 1, the range from round 2 to round 7 (the first range), the range from round 8 to round 13 (the second range), and the range from round 14 to the terminal round (the last range). By using these sample numbers, we can calculate all summary statistics used in this and the following sections.

Table 1 shows the frequency of cooperative action choice in all rounds, denoted by

$$\rho(p) \equiv \frac{Num(A;p)}{Num(A;p)+Num(B;p)}.$$

The experimental results imply that *subjects tend to make the cooperative action choice quite often* and that *they are more likely to make the cooperative action choice when monitoring is accurate, i.e., in type* $p=0.9$*, rather than when monitoring is inaccurate, i.e., in type* $p=0.6$. Improvement in monitoring accuracy enhances the possibility that players cooperate with each other.

[Table 1]

Table 1 also shows the frequencies of cooperative action choice in round 1, in the first range, in the second range, and in the last range. Irrespective of monitoring accuracy, there is a tendency for subjects to become less likely to select the cooperative action as time goes on. However, the extent to which this frequency tends to decrease is quite limited. It maybe that this stationary property across rounds is caused by the device of showing the subjects Figures 2 on the PC screen at the end of every round. Let us denote by $q(p) \in [0,1]$ the frequency of the cooperative action choice in round 1.[7]

Tables 2 and 3 show the signal-contingent frequencies of cooperative action choices; the frequency of the cooperative action choice in all rounds contingent on the occurrence of the good signal for the partner's action in the previous round is defined as

$$r(a;p) \equiv \frac{Num(A;a,p)}{Num(A;a,p)+Num(B;a,p)},$$

and $r(b;p)$ is similarly defined. The experimental results in these tables imply that irrespective of monitoring accuracy, the subject is more likely to select the cooperative action when the good signal occurs than when the bad signal occurs; *he tends to retaliate against the partner when he observes the bad signal instead of the good signal.* This experimental observation is consistent with the game-theoretical prediction that a player incentivizes his partner to make the cooperative action choice by retaliating against the partner when observing the bad signal for the partner's action.

[Table 2]

[Table 3]

Tables 2 and 3 also show the signal-contingent frequencies of the cooperative action choice in round 1, in the first range, in the second range, and in the last range; irrespective of monitoring accuracy and signal, there is a tendency for the subject to become less likely to select the cooperative action as time goes on. However, the extent to which this signal-contingent frequency tends to decrease is quite limited.

The highlight of our experimental results is shown in Table 4: the intensity with which the subject retaliates against the partner, defined as the difference in the signal-contingent frequency of the cooperative action choice, is greater in the case of type $p = 0.9$ than in the case of type $p = 0.6$. *The more accurate the monitoring technology is, the more severely the subject tends to retaliate against his partner.* This

[7] In Aoyagi and Fréchette (2009), when monitoring technology is accurate, subjects become even more likely to make the cooperative action choice as time goes on.

tendency is consistent with naïve and social preference-based motives, but is inconsistent with rational and self-interested motives.

[Table 4]

Table 4 also shows the differences in signal-contingent frequency in the first range, in the second range, and in the last range; irrespective of monitoring accuracy, there is no tendency for the subject to become less likely to retaliate against his partner as time goes on. On the contrary, in the case of type $p = 0.9$, where monitoring is accurate, there is a tendency for the subject to become even more likely to retaliate against his partner as time goes on.

7. Comparison to Symmetric Generous Tit-For-Tat Equilibrium

This section compares our experimental results with the theoretical prediction based on rational and self-interested motives; subjects play a symmetric generous tit-for-tat Nash equilibrium $(\tilde{q},\tilde{r}) = (\tilde{q}(p),\tilde{r}(p))$ specified as

$$(\tilde{q}(p),\tilde{r}(p)) = (q(p), r(a;p)) \quad \text{if} \quad w(p) \geq r(a;p),$$

and

$$(\tilde{q}(p),\tilde{r}(p)) = (0, w(p)) \qquad \text{otherwise.}$$

Note that $(\tilde{q}(p),\tilde{r}(p))$ was specified to be as compatible with our experimental results as possible; otherwise, it was specified as the *worst* symmetric generous tit-for-tat Nash equilibrium; i.e., $\tilde{q}(p) = 0$ and $\tilde{r}(p) = w(p)$.

From Section 4, we can calculate

$$w(0.9) \approx 0.235,$$

$$w(0.6) \approx 0.94,$$

$$\rho(\tilde{q},\tilde{r};0.9) = \frac{11(0.033\tilde{q} + 0.967\tilde{r})}{9} - \frac{1}{4},$$

and

$$\rho(\tilde{q},\tilde{r};0.6) = \frac{11(0.033\tilde{q} + 0.967\tilde{r})}{9} - \frac{2}{3}.$$

For the detailed specifications of symmetric generous tit-for-tat Nash equilibrium, see Table 5. Note that $(\tilde{q}(0.6),\tilde{r}(0.6))$ was specified as the worst symmetric generous tit-for-tat Nash equilibrium because $w(0.6) > r(a;0.6)$; i.e., our experimental results are not compatible with any symmetric generous tit-for-tat Nash equilibrium.

[Table 5]

From Tables 1 and 5, it follows that

$$\rho(0.9) < \rho(\tilde{q},\tilde{r};0.9) \quad \text{and} \quad \rho(0.6) < \rho(\tilde{q},\tilde{r};0.6),$$

which implies that, irrespective of monitoring accuracy, a subject is less likely to select the cooperative action than the specified symmetric generous tit-for-tat Nash equilibrium predicts. From Tables 4 and 5, it follows that

$$r(a;0.9) - r(b;0.9) > w(0.9) .$$

When $p = 0.9$, i.e., when the monitoring technology is accurate, the subject tends to retaliate against his partner more severely than this equilibrium predicts. It might be that this tendency increases the welfare loss caused by the monitoring imperfection. Hence, *when the monitoring technology is accurate, the enhancement in welfare loss caused by monitoring imperfection can be regarded as the reason why laboratory subjects are not as successful in implicit collusion as game theory predicts*.

From Tables 4 and 5, it follows also that

$$r(a;0.6) - r(b;0.6) < w(0.6) .$$

When $p = 0.6$, i.e., when the monitoring technology is inaccurate, the subject tends to retaliate against his partner less severely than the symmetric generous tit-for-tat Nash equilibrium predicts. It might be that this tendency fails to incentivize the partner to make the cooperative action choice. Hence, *when the monitoring technology is inaccurate, the failure to incentivize the partner caused by less severe retaliation can be regarded as the reason why laboratory subjects are not as successful in implicit collusion as game theory predicts*. This observation is diametrically opposite to that when the monitoring technology is accurate.

8. Further Remarks

Experimental research on the estimation of subjects' repeated game strategies has been conducted by Mason and Phillips (2006), Engle-Warnick and Slonim (2006), Aoyagi and Fréchette (2009), and Dal Bó and Fréchette (2010), among others, yet no definitive conclusion about the strategies that laboratory subjects use to achieve implicit collusion has been reached. The present paper does not investigate the detailed estimation of repeated game strategies; we do not claim that subjects tend to behave according to the symmetric generous tit-for-tat strategy specified as $(q, r(a), r(b)) = (q(p), r(a;p), r(b;p))$.[8]

Table 6 shows the experimental results derived from the supplementary sample numbers listed in Appendix 4,[9] where the frequency of a subject's selection of the cooperative action choice contingent on his choice of action A and the occurrence of the good signal for his partner's action in the previous round is defined as

$$r(A,a;p) \equiv \frac{Num(A;A,a,p)}{Num(A;A,a,p) + Num(B;A,a,p)}.$$

Similarly, $r(A,b;p)$, $r(B,a;p)$, and $r(B,b;p)$ are defined. The experimental results show that $r(A,a;p) - r(B,a;p) > 0$ and $r(A,a;p) - r(B,a;p) > 0$ irrespective of either $p = 0.9$ or $p = 0.6$; there is a non-negligible tendency of *inertia* in the sense that laboratory subjects are likely to select the same action they selected in the previous round, which is, however, excluded from symmetric generous tit-for-tat strategies by definition.

[Table 6]

[8] However, there are experimental reports, such as Aoyagi and Fréchette (2009), which assert that subjects' strategies do not heavily rely on what occurred two rounds earlier.

[9] In Appendix 4, $Num(A;A,a,p)$ denotes the number of times any subject selected cooperative action choice A in the case of type p when he selected action A and observed signal a in the previous round. The other sample numbers are similarly defined.

References

Abreu, D., D. Pearce, and E. Stacchetti (1990): “Toward a Theory of Discounted Repeated Games with Imperfect Monitoring,” *Econometrica* 58, 1041–1063.

Aoyagi, M. and G. Fréchette (2009): “Collusion as Public Monitoring Becomes Noisy: Experimental Evidence,” *Journal of Economic Theory* 114, 1135-1165.

Berg, J., J. Dickhaut, and K. McCabe (1995): “Trust, Reciprocity, and Social History,” *Games and Economic Behavior* 10, 122-142.

Camerer, C. (2003): *Behavioral Game Theory*, Princeton University Press.

Dal Bó, P. (2005): “Cooperation under the Shadow of the Future: Experimental Evidence from Infinitely Repeated Games,” *American Economic Review* 95, 1591–1604.

Dal Bó, P. and G. Fréchette (2010): “Strategy Choice in the Infinitely Repeated Prisoners Dilemma,” mimeo.

Duffy, J. and F. Muñoz-García(2010): “Patience or Fairness? Analyzing Social Preferences in Repeated Games,” Working Paper 83, University of Pittsburgh, Department of Economics.

Ely, J. and J. Välimäki (2002): “A Robust Folk Theorem for the Prisoner’s Dilemma,” *Journal of Economic Theory* 102, 84–105.

Engle-Warnick, J. and R. Slonim (2006): “Inferring Repeated-Game Strategies from Actions: Evidence from Repeated Trust Game Experiments,” *Economic Theory* 28, 603–632

Fehr, E. and S. Gächter (2000): “Fairness and Retaliation: The Economics of Reciprocity,” *Journal of Economic Perspectives* 14, 159-181.

Feinberg, R. and C. Snyder (2002): “Collusion with Secret Price Cuts: An Experimental Investigation,” *Economic Bulletin* 3, 1–11.

Fischbacher, U. (2007): “z-Tree: Zurich Toolbox for Ready-made Economic Experiments,” *Experimental Economics* 10(2), 171-178.

Green, E. and R. Porter (1984): “Noncooperative Collusion under Imperfect Price Information, *Econometrica* 52, 87–100.

Fudenberg, D. and J. Tirole (1993): *Game Theory*, MIT Press.

Güth, W., R. Schmittberger, and B. Schwarze (1982): "An Experimental Analysis of Ultimatum Bargaining," *Journal of Economic Behavior and Organization* 3, 367-88.

Holcomb, J. and P. Nelson (1997): "The Role of Monitoring in Duopoly Market Outcomes," *Journal of Socio-Economics* 26, 79–93.

Mailath, J. and L. Samuelson (2006): *Repeated Games and Reputations: Long-Run Relationships*, Oxford University Press.

Mason, C. and O. Phillips (2002): "In Support of Trigger Strategies: Experimental Evidence from Two-Person Noncooperative Games,"*Journal of Economics and Management Strategy* 11, 685–716.

Matsushima, H. (2004): "Repeated Games with Private Monitoring: Two Players," *Econometrica* 72, 823–852.

Matsushima, H. (2010): "Interlinkage and Generous Tit-For-Tat Strategy," mimeo.

Murnighan, J. and A. Roth (1983): "Expecting Continued Play in Prisoner's Dilemma Games." *Journal of Conflict Resolution* 27, 279–300.

Nowak, M. and K. Sigmund (1992): "Tit for Tat in Heterogeneous Populations," *Nature* 355, 250–253.

Osborne, M. and A. Rubinstein (1994): *A Course in Game Theory*, MIT Press.

Piccione, M. (2002): "The Repeated Prisoners' Dilemma with Imperfect Private Monitoring," *Journal of Economic Theory* 102, 70–83.

Roth, A. and J. Murnighan (1978): "Equilibrium Behavior and Repeated Play of the Prisoner's Dilemma, *Journal of Mathematical Psychology* 17, 189–198.

Sekiguchi, T. (1997): "Efficiency in Repeated Prisoners' Dilemma with Private Monitoring," *Journal of Economic Theory* 76, 345–361.

Takahashi, S. (2010): "Community Enforcement When Players Observe Partners' Past Play," *Journal of Economic Theory* 145, 42–64.

Figure 1:
Prisoners' dilemma with Symmetry and Additive Separability
$(X, Y, Z) = (60, 10, 55)$

	A	B
A	60 60	5 70
B	70 5	15 15

Figure 2 (1):
Random Termination Device

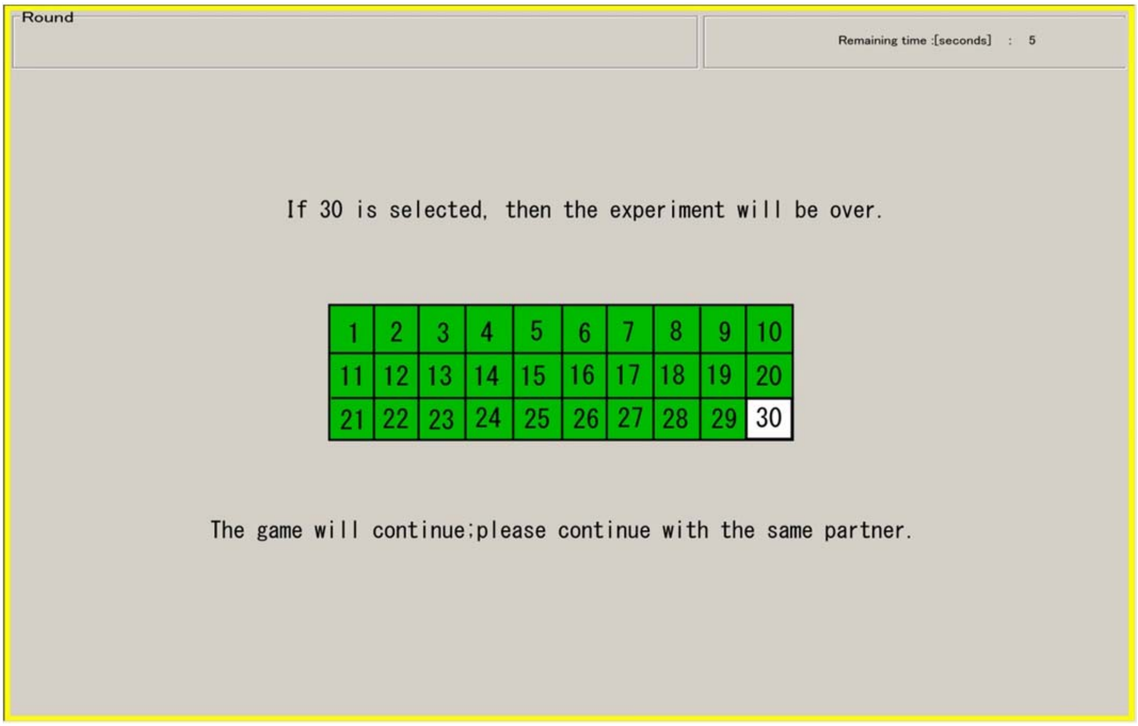


Figure 2 (2):
Random Termination Device

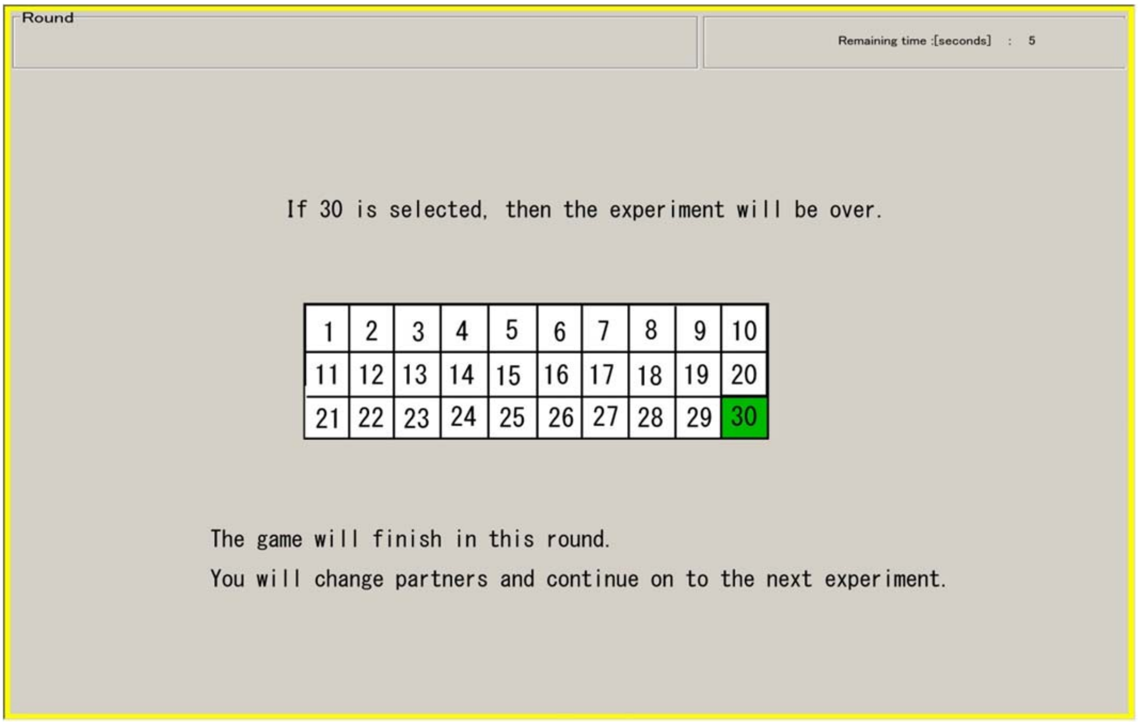


Table 1:
Frequencies of Cooperative Action Choice

	$p = 0.9$	$p = 0.6$
$\rho(p)$ (All Rounds)	0.672	0.355
$q(p)$ (Round 1)	0.781	0.438
Rounds 2~7	0.733	0.421
Rounds 8~13	0.685	0.369
Rounds 14~	0.634	0.316

Table 2:
Frequencies of Cooperative Action Choice Contingent on a Good Signal

	$p = 0.9$	$p = 0.6$
$r(a;p)$ (All Rounds)	0.852	0.437
Rounds 2~7	0.867	0.498
Rounds 8~13	0.85	0.459
Rounds 14~	0.846	0.402

Table 3:
Frequencies of Cooperative Action Choice Contingent on a Bad Signal

	$p = 0.9$	$p = 0.6$
$r(b;p)$ (All Rounds)	0.344	0.272
Rounds 2~7	0.431	0.347
Rounds 8~13	0.361	0.282
Rounds 14~	0.309	0.24

Table 4:
Differences in Signal-Contingent Frequency

	$p = 0.9$	$p = 0.6$
$r(a; p) - r(b; p)$ (All Rounds)	0.508	0.165
Rounds 2~7	0.433	0.151
Rounds 8~13	0.489	0.177
Rounds 14~	0.537	0.162

Table 5:
Symmetric Generous Tit-for-Tat Nash Equilibria $(\tilde{q}(p), \tilde{r}(p))$

	$p = 0.9$	$p = 0.6$
$\tilde{q}(p)$	0.781	0
$\tilde{r}(p)$	0.852	0.94
$w(p)$	0.235	0.94
$\rho(\tilde{q}(p), \tilde{r}(p); p)$	0.788	0.444

Table 6:
Frequencies of Cooperative Action Choice Contingent on Action and Signal

	$p = 0.9$	$P = 0.6$
$r(A, a; p)$	0.942	0.793
$r(A, b; p)$	0.59	0.559
$r(B, a; p)$	0.503	0.231
$r(B, b; p)$	0.134	0.12
$r(A, a; p) - r(B, a; p)$	0.439	0.562
$r(B, a; p) - r(B, b; p)$	0.456	0.447

Appendix 1: Features of Experimental Design

	Number of Subjects	Turn of Treatments (games)
October 5, 2006 (10:30 ~ 12:30)	28	0.6 (24, 40, 25), 0.9 (28, 33, 14)
October 5, 2006 (14:30 ~ 16:30)	24	0.6 (20, 23, 37), 0.9 (34, 34, 19)
October 6, 2006 (10:30 ~ 12:30)	28	0.9 (38, 21, 25), 0.6 (25, 28, 29)
October 6, 2006 (14:30 ~ 16:30)	28	0.9 (25, 35, 23), 0.6 (36, 30, 21)

Appendix 2: Sample Numbers

	$p = 0.9$	$p = 0.6$
$Num(A; p)$ (All Rounds)	5960	3245
Round 1	253	142
Rounds 2~7	1425	819
Rounds 8~13	1332	718
Rounds 14~	2950	1566
$Num(B; p)$ (All Rounds)	2904	5899
Round 1	71	182
Rounds 2~7	519	1125
Rounds 8~13	612	1226
Rounds 14~	1702	3366
$Num(A; a, p)$ (All Rounds)	4646	1863
Rounds 2~7	1167	474
Rounds 8~13	1096	440
Rounds 14~	2383	949
$Num(A; b, p)$ (All Rounds)	1061	1240
Rounds 2~7	258	345
Rounds 8~13	236	278
Rounds 14~	567	617
$Num(B; a, p)$ (All Rounds)	807	2402
Rounds 2~7	179	477
Rounds 8~13	194	518
Rounds 14~	434	1407
$Num(B; b, p)$ (All Rounds)	2026	3315
Rounds 2~7	340	648
Rounds 8~13	418	708
Rounds 14~	1268	1959

Appendix 3: Supplementary Sample Numbers

	$p = 0.9$	$P = 0.6$
$Num(A; A, a, p)$	4083	1239
$Num(A; A, b, p)$	838	881
$Num(B; A, a, p)$	251	323
$Num(B; A, b, p)$	581	694
$Num(A; B, a, p)$	563	624
$Num(A; B, a, p)$	223	359
$Num(B; B, a, p)$	556	2079
$Num(B; B, b, p)$	1445	2621

Monitoring Accuracy and Retaliation in Infinitely Repeated Games with Imperfect Private Monitoring: Theory and Experiments

Supplement

Hitoshi Matsushima
Department of Economics, University of Tokyo[1]

Tomohisa Toyama
Faculty of Engineering, Kogakuin University

April 2, 2011

1. Experiment Manual
(October 6, 2006, Translation from Japanese into English)

Please check the contents of the envelope and the items that have been distributed. The list of distributed items consists of:

1. Ballpoint pen - 1
2. Experimental manual – 1 copy
3. Booklet with printed computer screen images – 1 copy
4. Bank remittance form – 1 sheet
5. Memo paper – 1 sheet

If any of the distributed items are missing, please quietly raise your hand. The distributed items will be collected after the experiments, except for the memo paper, which you can take with you.

Please look at the experiment manual. Your will be asked to make selection on a computer terminal and depending on the results, you will be awarded “points”. These points will be converted into funds at the exchange rate of 0.6 yen per point, which will be paid to you as compensation, in addition to the participation fee of 1500 yen. Therefore, the amount of money you will receive from these experiments will be:

The number of points awarded × 0.6 yen + participation fee of 1500 yen

Please do not speak to or exchange signals with anyone during the experiments, or you may be asked to leave. Furthermore, you will not be allowed to leave during the experiments, except under unavoidable circumstances. Please turn off your cell phones during the experiments.

Summary of Experiments

We will conduct 6 experiments across 2 sessions, with 3 experiments in each session. The 6 experiments are independent of each other; the results of one experiment will have no effect on the results of the other experiments. The experiments will be conducted via computer, and all your interactions during the experiments will be conducted through the computer terminal.

All of you will be divided into pairs and asked to make decisions. The pairings will be

[1] Department of Economics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan. E-mail: hitoshi at mark e.u-tokyo.ac.jp.

randomly decided by the computer. In each experiment, you will be asked to make the selections described below multiple times. We refer to these frequencies as round 1, round 2, round 3, and so forth. Later, we will explain the number of rounds that will take place in each experiment.

Those who have any questions, please quietly raise your hand.

Decision Making

You will select either A or B in each round. Your partner will also select A or B. Please look at the table.

You \ Your partner	A	B
A	**60** 60	**5** 70
B	**70** 5	**15** 15

The table shows the selections of you and your partner and the resulting points that you and your partner will be awarded. The left column consists of your choices, A or B. In the top column are the choices of your partner, also A or B. The numbers in red on the left will show the points you will be awarded, and the numbers in light blue on the right will show the points your partner will be awarded.

If both you and your partner select A:

Both will be awarded 60 points.

If you select A and your partner selects B:

You will be awarded 5 points, and your partner, 70 points.

If you select B and your partner selects A:

You will be awarded 70 points, and your partner, 5 points.

If both you and your partner select B:

Both will be awarded 15 points.

Please look at the table carefully and ensure that you understand how the points will be allocated to you and your partner. Your selection alone will not decide how many points you will be awarded; it will also depend on your partner's selection. Similarly, the number of points that your partner will be awarded will not be decided by his/her selection alone but will also depend on your selection.

Those who have any questions, please quietly raise your hand.

Session 1

In session 1, experiments 1, 2, and 3 will be conducted. The three experiments are identical and will be conducted consecutively.

Observable Information

You will not know whether your partner selected A or B. However, you will be shown signal a or b, depending on your partner's selection. The computer will determine whether you will be shown signal a or signal b, in accordance to the following rules of probability. If your partner selects A, you will be shown:

Signal a at a probability of 90% and signal b at a probability of 10%.

If your partner selects B, you will be shown:

Signal b at a probability of 90% and signal a at a probability of 10%.

In the same way, your partner will not know whether you selected A or B. However, your partner will also be shown signal a or b, depending on your selection. The computer will determine whether your partner will be shown signal a or signal b, in accordance to the following rules of probability. If you select A, your partner will be shown:

Signal a at a probability of 90% and signal b at a probability of 10%.

If you select B, your partner will be shown:

Signal b at a probability of 90% and signal a at a probability of 10%.

The signal for your partner's selection and the signal for your selection are decided independently and have no correlation. Also, the computer determines the signals independently for each round. This method of determining the signal is called **signaling with 90% accuracy.**

Those who have any questions, please quietly raise your hand.

Number of Rounds

The number of rounds for each experiment will be randomly determined. At the end of each round, the computer will randomly select a number from 1 to 30, so there is a one-in-thirty chance of any number being selected by the computer. This probability is the same for everyone participating in the experiment.

The experiment will end when the number 30 is selected randomly.

The experiment will continue if any number other than 30 is selected. However, you will only know if a number other than 30 has been selected. You will move on to the next round and make the decisions again with the same partner.

The probability that the experiment will end in the current round will always remain constant (one-in-thirty), whether it is round 1, round 2, round 3, and so forth. The number of repeated rounds is set using a random number within the range of 98 or less. At the end of experiment 1, you will form a new pair with a different partner and start experiment 2. At the end of experiment 2, you will again form a new pair with a different partner and start experiment 3. Session 1 will be over once experiment 3 is completed.

Those who have any questions, please quietly raise your hand.

Description of Screen Displays and Operations for Computers

Please look at the booklet with printed computer screen images.

Please look at screens 1 and 2. Screen 1 is the selection screen that you will see. Screen 2 is the selection screen that your partner will see. Please look at the top left portion of each screen; you will see that the current round is round 4. The left portion of screen 1 displays the information available to you about the previous rounds. The left portion of screen 2 displays the information available to your partner about the previous rounds.

You will use the information and the table in the top right portion of the screen for reference and then select either "A" or "B" from the bottom right portion of the screen with your mouse and then confirm your selection by clicking the "OK" button in the bottom right portion of the screen.

Next, please look at screens 3 and 4. Screen 3 is the results screen that you will see; screen 4 is the results screen that your partner will see. In round 4, both of you chose A . The results screen that you will see indicates that signal (accuracy: 90%) is b. Conversely, the results screen that your partner will see indicates that signal (accuracy 90%) is a. Please remember that when you select A, there is a 90% probability that "signal a" will be sent to your partner and a 10% probability that "signal b" will be sent to your partner.

Next, we will explain the roulette screen. Please turn the page and look at screens 5 and 6, which show the roulette. A number from 1 to 30 will be randomly selected and the probability of any number being selected will be the same (one-in-thirty). The number chosen will be in green. If 30 is in green, it means that the current experiment is over, and you will then change partners.

In screen 5, any number between 1 and 29 has been chosen. All the numbers between 1 and 29 are in green, so you do not know the number that has been selected. However, as 30 has not been selected, you will continue on to the next round with the same partner. In screen 6, 30 has been selected. As 30 is in green, the current experiment is over in this case.

Finally, please look at screen 7. This screen shows the total number of points that you have been rewarded in that experiment, the average number of points per round that you have been rewarded, the total number of points that your partner has been rewarded, and the average number of points per round that your partner has been rewarded. You will then change partners and move on to the next experiment.

Those who have any questions, please quietly raise your hand.

Session 2

Please look at page 6 of your experiment manual. In session 2, you will participate in experiments 4, 5, and 6.

The three experiments are identical and will be conducted consecutively. However, the signal accuracy of session 2 is different compared with that of session 1. Apart from that, the two sessions are the same.

Observable Information

You will not know whether your partner selected A or B. However, you will be shown signal a or b, depending on your partner's selection. The computer will use the probability rules described below to determine whether you will be shown signal a or signal b. If your partner selects A, you will be shown:

Signal a at a probability of 60% and signal b at a probability of 40%.

If your partner selects B, you will be shown:

Signal b at a probability of 60% and signal a at a probability of 40%.

Similarly, your partner will not know whether you selected A or B. However, your partner will be shown signal a or b, depending your selection. The computer will use the probability rules described below to determine whether you will be shown signal a or signal b. If you select A, your partner will be shown:

Signal a at a probability of 60% and signal b at a probability of 40%.

If you select B, your partner will be shown:

Signal b at a probability of 60% and signal a at a probability of 40%.

The signal for the other person's selection and the signal for your selection are decided independently and have no correlation. The computer determines the signaling independently, and its selection is not affected by the selections in the previous rounds. This method of determining the signal is called **signaling with 60% accuracy.**

Those who have any questions, please quietly raise your hand.

Description of Screen Displays and Operations for Computers

Please look at the booklet with printed computer screen images.

Please look at screens 8 and 9. Screen 8 is the selection screen that you will see. The left portion of screen 8 displays the information available to you about the previous rounds. You will see the message "Signal accuracy for your partner's selection: 60%." The left portion of screen 9 displays the information available to your partner about the previous rounds.

Please look at screens 10 and 11 on page six. Screen 10 is the results screen that you will see; screen 11 is the results screen that your partner will see. In round 4, both of you chose A and from the results screen, you can see that you received signal b, and your partner received signal a. On the bottom right portion of screens 10 and 11, you can see the message "Signal accuracy of your partner's selection: 60%" and that you were shown signal b and your partner was shown signal a. By looking at the screens, you can see that only you will know your choice and the signal regarding your partner's choice.

The roulette screen is the same as that in session 1, which shows numbers from 1 to 30. Please refer back to screens 5 and 6; the results screens are also the same as those in session 1.

Those who have any questions, please quietly raise your hand.

At this time, all of the experiments have been completed and all the points awarded to everyone are recorded on the computer.

Please enter your details on a survey form that will now be distributed.

Furthermore, please take out the bank remittance form from the envelope and enter the details accurately. Please note that unless all the necessary details are provided, we will not be able to pay you for your awarded amounts.

Those who have any questions, please quietly raise your hand.

Please verify that all your details are provided on the survey form and on the bank remittance form.

Those who have any questions, please quietly raise your hand.

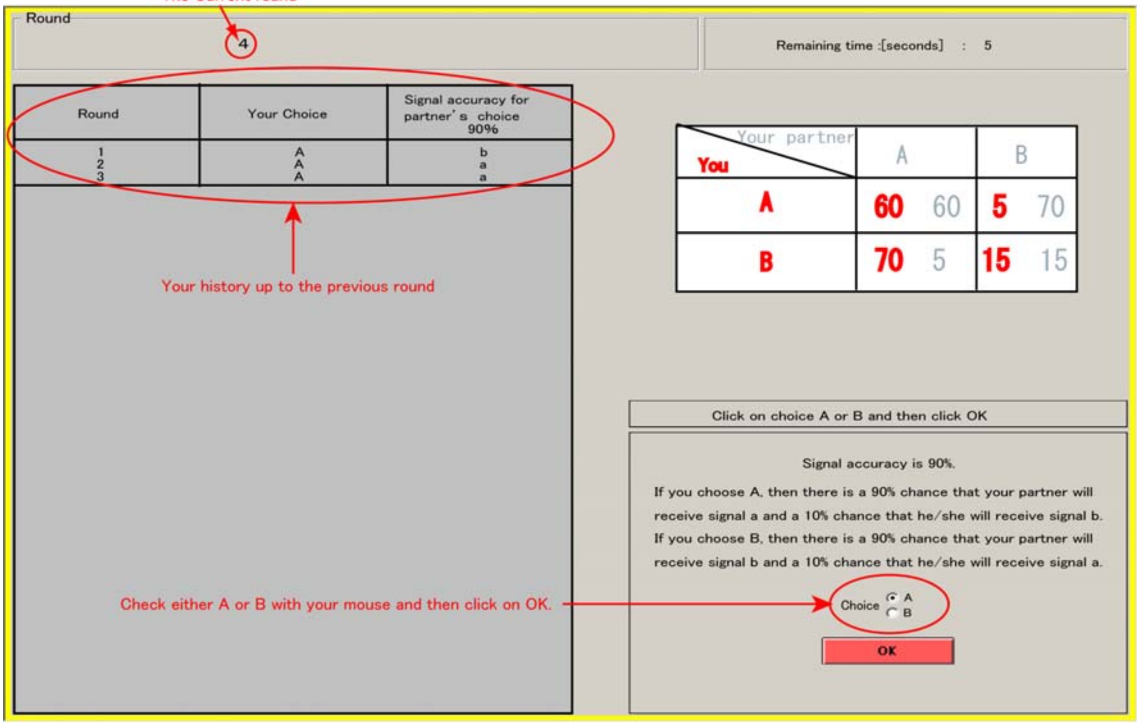
Please place all the documents inside the envelope. You are welcome to take the memo paper with you. Please leave the ball-pointed pen and ink pad on the desk. Also make sure you take all your belongings with you when you leave.

Please do not to talk about or divulge any details regarding today's experiments to anyone until Saturday. Thank you very much for your participation. We will now ask you to leave in an orderly manner.

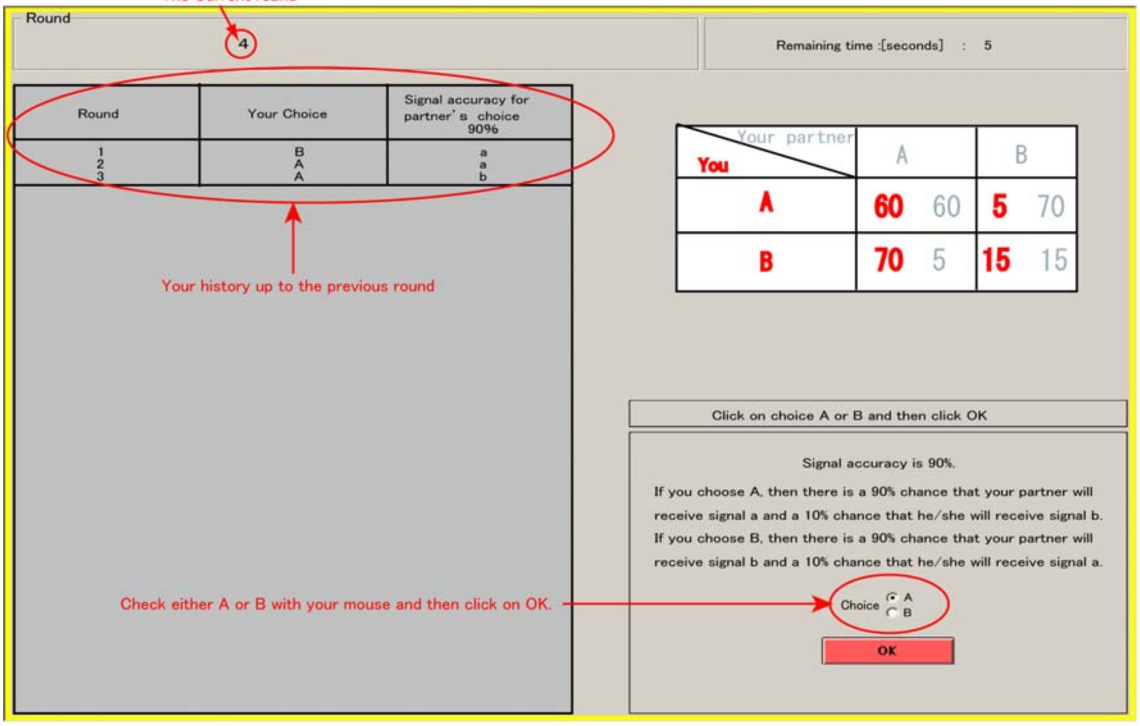
First, the people in the two rows along the corridor side of the room please leave the room and then the people in the two rows in the middle of the room. Finally, the people in the two rows on the window side of the room please leave the room.

2. Computer Screen Images
(October 6, 2006, Translation from Japanese into English)

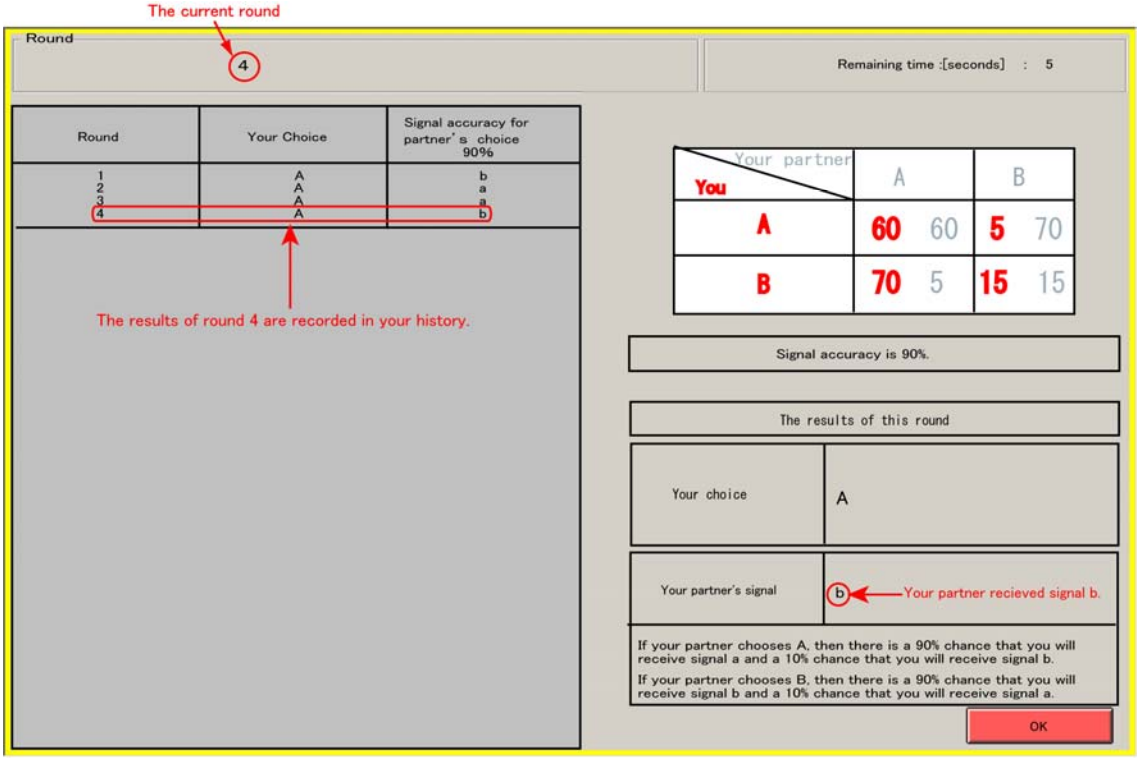
Screen 1: Your Selection Screen



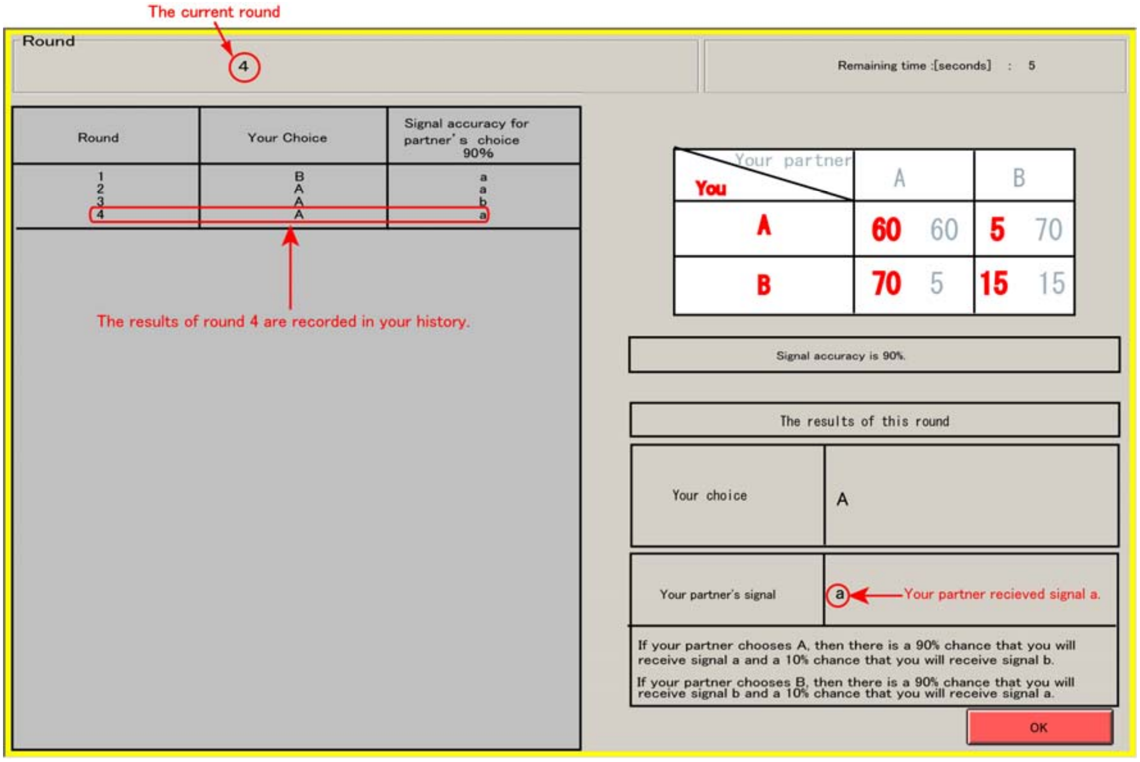
Screen 2: Your Partner's Screen



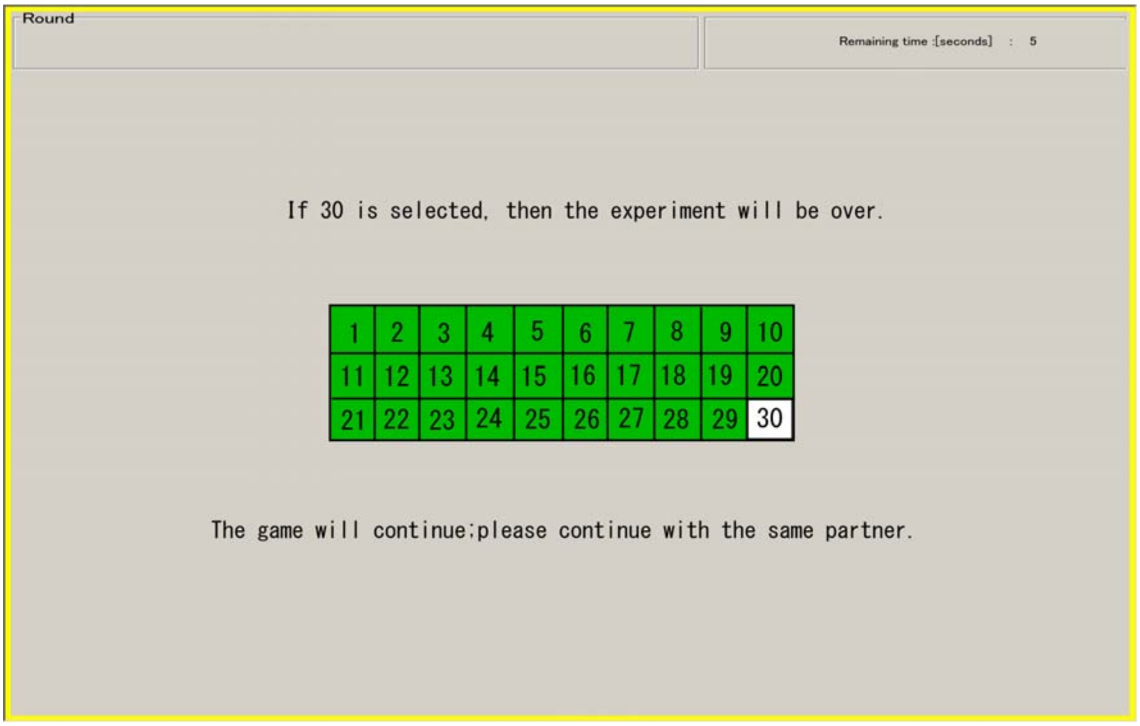
Screen 3: Your Results Screen



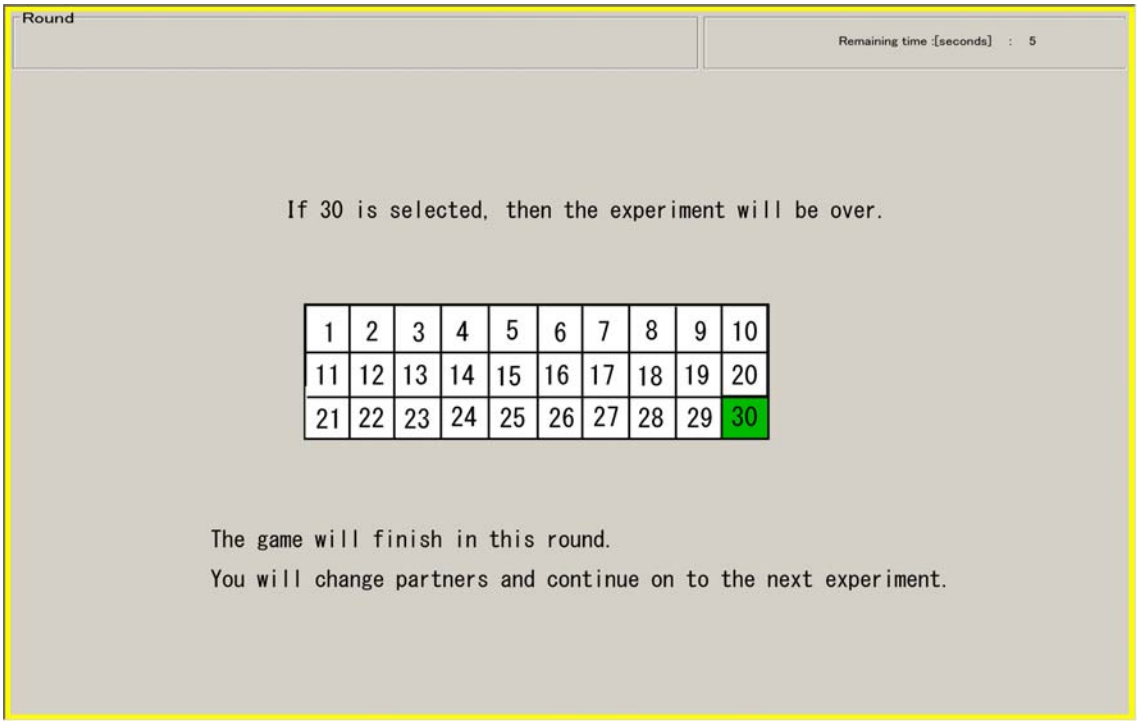
Screen 4: Your Partner's Results Screen



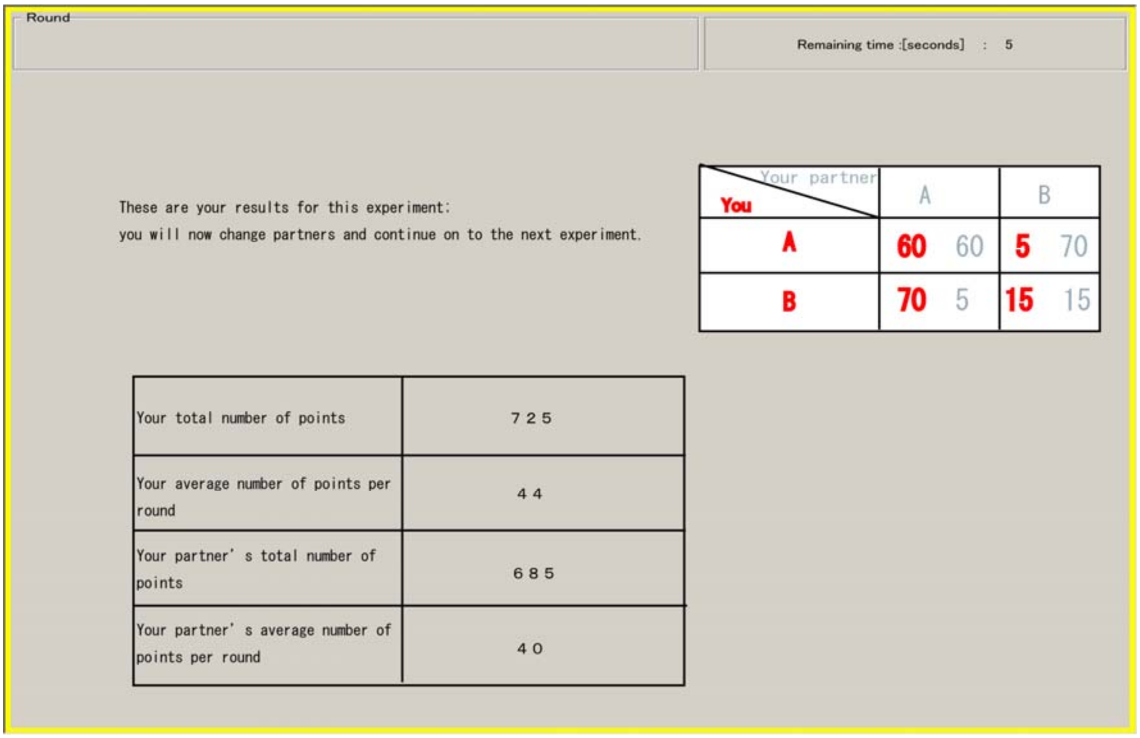
Screen 5: Roulette (experiment continues)



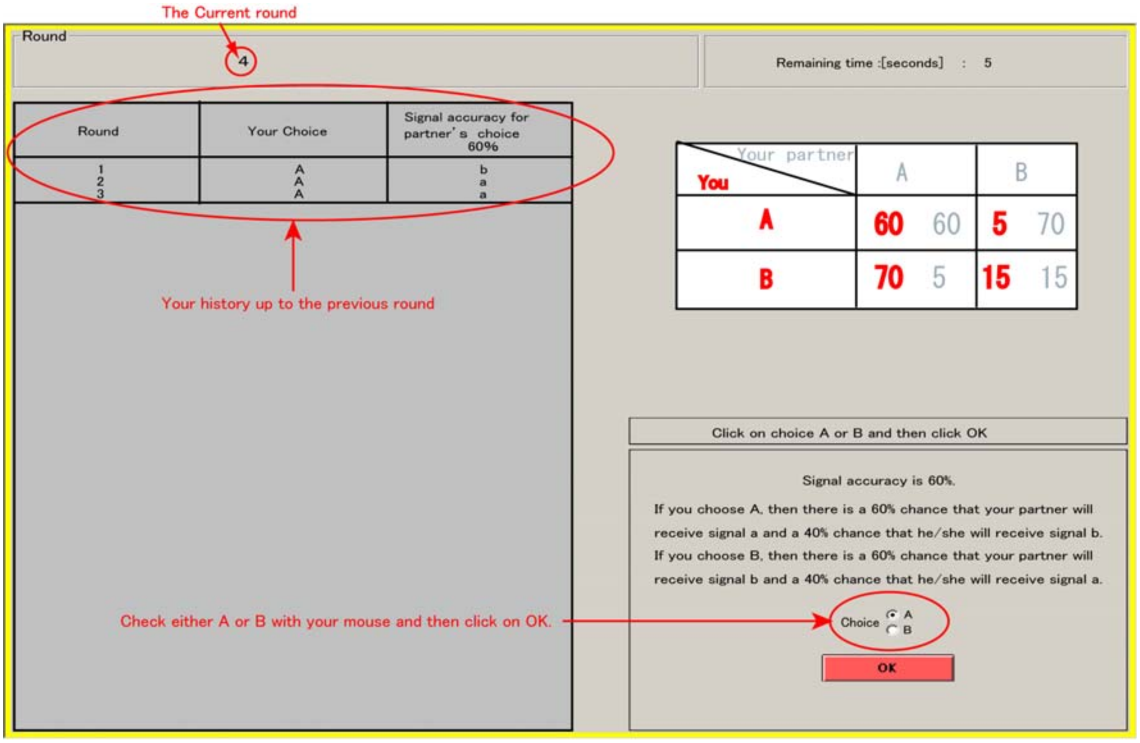
Screen 6: Roulette (experiment is over)



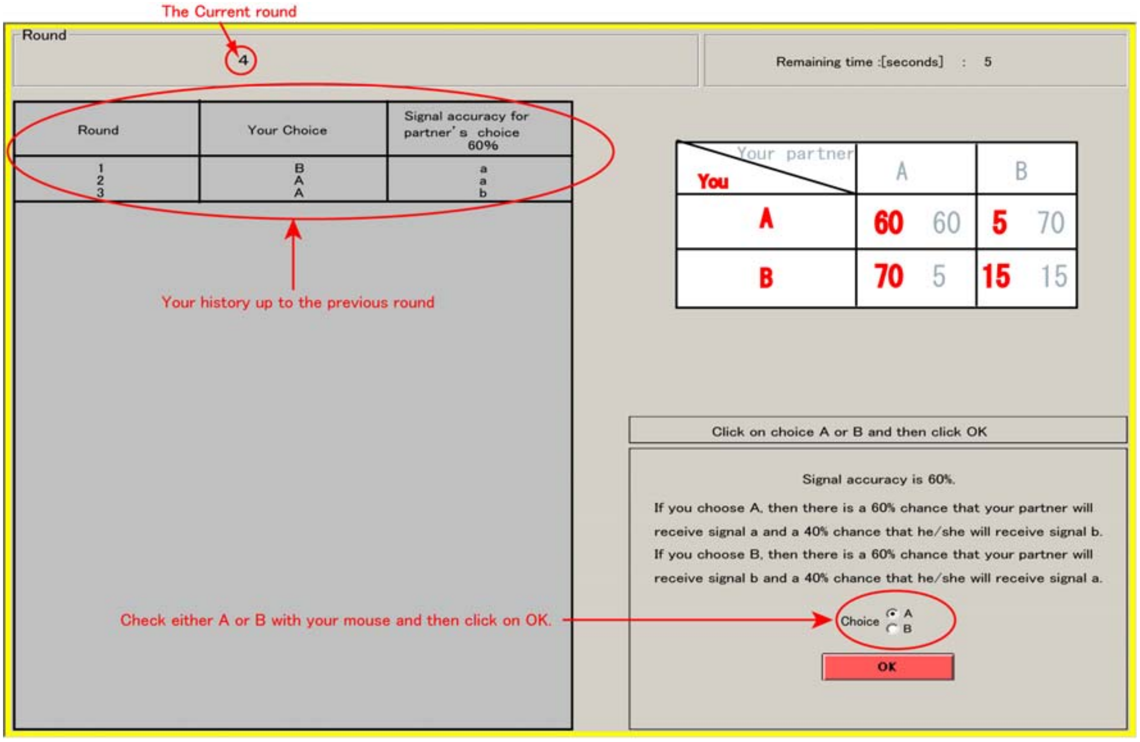
Screen 7: The Results Screen



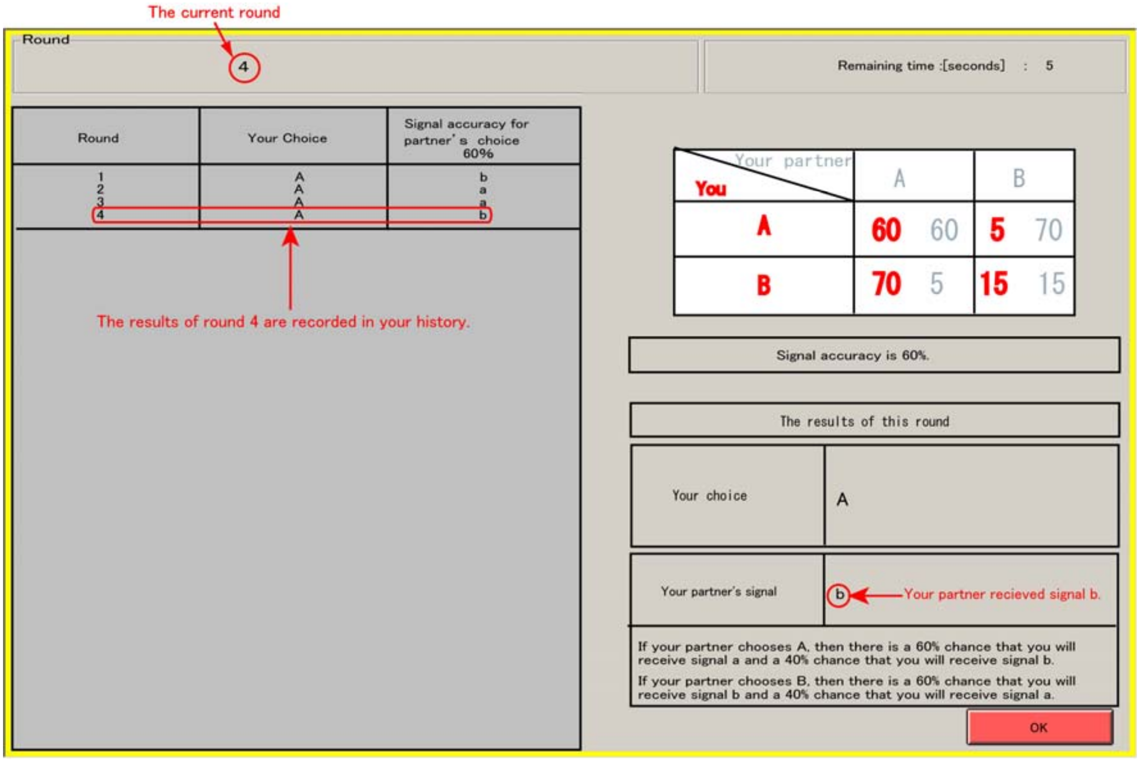
Screen 8: Your Selection Screen



Screen 9: Your Partner's Results Screen



Screen 10: Your Results Screen



Screen 11: Your Partner's Results Screen