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Abstract

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(A)symmetric Information Bubbles: Experimental Evidence*

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Abstract

Asymmetric information has explained the existence of a bubble in extant theoretical models. This study experimentally analyzes traders' choices, with and without asymmetric information, based on the riding-bubble model. We show that traders tend to hold a bubble asset for longer, thereby expanding the bubble in a market with symmetric, rather than asymmetric, information. However, when traders are more experienced, the size of the bubble decreases, in which case, bubbles do not arise with symmetric information. In contrast, the size of the bubble is stable in a market with asymmetric information.

Keywords: riding bubbles, crashes, asymmetric information, experiment, clock game

JEL Classification Numbers: C72, D82, D84, E58, G12, G18

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1 Introduction

History is rife with examples of bubbles and bursts (Kindleberger and Aliber, 2011). A prime example of a bubble bursting is the recent financial crisis that started in summer of 2007. However, we have limited knowledge of how bubbles arise, continue, and burst.

Previous theoretical studies have implemented various frameworks to explain the emergence of bubbles.[1] Among them, recent models have shown that investors hold a bubble asset because they believe they can sell it at a higher price in the future. These models focus on the microeconomic aspect of bubbles, which can be explained by asymmetric information.[2] Indeed, Brunnermeier (2001) states that "whereas almost all bubbles can be ruled out in symmetric information setting, this is not the case if different traders have different information and they do not know what the others know." (p. 59)

To test the statement, we ran a series of experiments designed to examine the behavioral validity of symmetric and asymmetric information. Most experimental studies on bubbles are developed based on the pioneering work of Smith, Suchanek, and Williams (1988; hereafter, SSW), who consider a double-auction market where all traders have symmetric information.[3]

[1] Classically, bubbles are described using rational bubble models within a rational expectations framework (Samuelson, 1958; Tirole, 1985). These models, which analyze the macro-implications of bubbles, often assume that bubbles, bursts, and coordination expectations are given exogenously. Therefore, these studies overlook the strategies of individuals.

[2] However, it is well known that asymmetric information alone cannot explain bubbles. The key theoretical basis of this is the no-trade theorem (see Brunnermeier, 2001): investors do not hold a bubble asset when they have common knowledge on a true model, because they can deduce the content of the asymmetric information (see also Allen, Morris, and Postlewaite, 1993; Morris, Postlewaite, and Shin, 1995). Therefore, several studies have explained bubbles by introducing noise or behavioral traders (De Long et al., 1990; Abreu and Brunnermeier, 2003), heterogeneous beliefs (Harrison and Kreps, 1978; Scheinkman and Xiong, 2003), or principal–agent problems between fund managers and investors (Allen and Gordon, 1993; Allen and Gale, 2000).

[3] Past studies show that bubbles also arise in call markets (Van Boening, Williams, and LaMaster, 1993) without speculation, where traders are prohibited from reselling an asset (Lei, Noussair, and Plott, 2001), with constant fundamental values (Noussair, Robin, and Ruffieux, 2001), and with lottery-like (i.e., riskier) assets (Ackert et al., 2006). In contrast, bubbles tend not to arise with the following conditions: traders receive dividends only once (Smith, Van Boening, and Wellford, 2000); subjects are knowledgeable about financial markets (Ackert and Church, 2001); some (although not all) traders are experienced (Dufwenberg,

They show that bubbles can arise in experiments even though bubbles theoretically never arise in equilibrium. In other words, they interpret bubbles as disequilibrium phenomena and a consequence of behavioral choices. Although their findings are important, it is equally important for us to take the theory of bubbles seriously and investigate a possibility for bubbles to occur as an equilibrium phenomenon and a consequence of rational choices.

Unlike the study of SSW and its extensions, the contribution of our study is in comparing the effects of two information types, symmetric or asymmetric, in a context where bubbles should theoretically occur in one of the two types of information. Moreover, we test whether asymmetric information is the necessary condition to explain bubbles. The context is based on the seminal and tractable "riding-bubble model" developed by Abreu and Brunnermeier (2003). In a riding-bubble model, a bubble is depicted as a situation in which the asset price is above its fundamental value. At some point during the bubble, investors become aware of its occurrence after a signal, but the timing for this to occur differs among investors, generating asymmetric information. Thus, although they notice that the bubble has already occurred, they do not know when it actually started. Therefore, an investor faces a trade-off by selling earlier: although he or she may be able to sell the asset before the bubble bursts, he or she forgoes the chance of selling it at a higher price. On the basis of such trade-off, investors have an incentive to keep the asset for a certain period after they receive a signal in equilibrium. In contrast, if all investors know the true starting point of the bubble, each of them has an incentive to move slightly earlier than the others to sell the asset at a high price for sure. As a result, they will all try to sell the asset before the others do, and this backward-induction argument excludes the existence of the bubble. Thus, the model predicts that investors have a higher incentive to ride a bubble after receiving an asymmetric-information signal than they do after receiving a symmetric information signal.

We find that, contrary to the theoretical predictions, traders have an incentive to hold a bubble asset for longer, thereby expanding the bubble in a market with symmetric rather than asymmetric information. The emergence of symmetric information bubbles may be

Lindqvist, and Moore, 2005), with low initial liquidity (Caginalp, Porter, and Smith, 2001); futures markets exist (Porter and Smith, 1995); short sales are allowed (Ackert et al., 2006; Haruvy and Noussair, 2006); and only one chance to sell is available (Ackert et al., 2009).

unsurprising given the study by SSW and its numerous extensions. However, our experiments show that bubble duration is lengthened by eliminating information asymmetry rather than by creating it, which is completely opposite to the findings of past theoretical studies.

Although symmetric information creates a larger bubble in the short run, as subjects are experienced, the bubble decreases in size and finally vanishes like in the study of SSW and its extensions. In contrast, the bubble duration does not change over time in the market with asymmetric information. These findings suggest that, on the one hand, symmetric information bubbles represent short-lived imbalance, which occurs in disequilibrium when traders are inexperienced. On the other hand, asymmetric information bubbles are long-lived bubbles, which occur in equilibrium even if traders are experienced. Our experiments produce these two types of bubble in a unified framework by changing just one parameter associated with information asymmetry.

The remainder of the paper proceeds as follows. The next subsection reviews related studies, after which Section 2 presents the theoretical hypothesis based on the riding-bubble model. Section 3 outlines the experimental design, and Section 4 describes the related results. Section 5 concludes the paper.

1.1 Related Literature

There are two major past studies about bubbles related to our study: SSW and Abreu and Brunnermeier (2003). Most past experiments on bubbles use the framework by SSW, but they are not based on a theory positing that bubbles occur as an equilibrium phenomenon. To develop a theory of bubbles, it is important to conduct experiments based on a theory that presents bubbles as an equilibrium outcome, similarly to that of Abreu and Brunnermeier (2003).

Brunnermeier and Morgan (2010) conduct experiments using the riding-bubble model (known as the clock game). The main difference of our study is that we consider the case of symmetric information. We compare two different information structures, symmetric and asymmetric, to test whether asymmetric information is the key to a bubble emergence.

There are two experimental studies that compared different cases similar to our study. First, Porter and Smith (1995), whose study is also based on SSW, consider the cases of random versus certain dividends. They show that bubbles can arise in both cases. However, as in SSW, bubbles should not arise in equilibrium in both cases. Furthermore, a difference is in whether dividends are certain or not; thus, both cases are with symmetric information.

Second, Moinas and Pouget (2013) propose "the bubble game," which is similar to the three-player centipede game. In this game, the players' timing of play is decided randomly. Players choose whether to buy an asset at a price above the true value to try to resell it to the next player. If a player is the last (third) player to buy, he or she is never able to resell, so he or she should not buy the asset. Players proposed the price for an asset as a private signal, and although the price proposed to the first player is random, the subsequent price path is exogenously given. Thus, in the presence of a price cap, a player has a chance of knowing that he or she is the last player, because he or she may receive the highest possible price. Without a price cap, no such chance exists. Moinas and Pouget (2013) consider both cases. Theoretically, bubbles never arise in equilibrium with a price cap but can do without it. Contrary to this prediction, they find that bubbles can arise in both cases. A difference from our study is that asymmetric information is present independently of the price cap because the three players receive different price signals in both cases. Moreover, the riding-bubble model derived from Abreu and Brunnermeier (2003) is clearly very different from their bubble-game model. For example, the former concerns players' decisions about when to sell their assets, whereas the latter relates to players' decisions about whether to buy an asset.[4]

2 Background

2.1 Model

This section summarizes the riding-bubble model based on Asako and Ueda (2014) and shows the theoretical predictions of its outcomes.[5] Time is continuous and infinite, with periods

[4] Moinas and Pouget (2013) provide a detailed discussion of the similarities and differences between the riding-bubble model and their bubble game (p. 1512).

[5] Asako and Ueda (2014) simplify the model of Abreu and Brunnermeier (2003) to consider two discrete types of rational investors who have different levels of information, instead of considering continuously

labeled $t \in \Re$. Figure 1 presents the asset price process. From $t = 0$ onwards, asset price p_t grows at a rate of $g > 0$; that is, the price evolves as $p_t = \exp(gt)$. Up to some random time t_0, the higher price is justified by the true (fundamental) value, but this is not the case after the bubble starts at t_0. The true value grows from t_0 at the rate of zero, and hence, the price justified by the true value stays constant at $\exp(gt_0)$, and the bubble component is given by $\exp(gt) - \exp(gt_0)$, where $t > t_0$.[6] Like Doblas-Madrid (2012), we assume that the starting point of bubble t_0 is discrete as is $t_0 = 0,\ \eta,\ 2\eta,\ 3\eta \cdots$, where $\eta > 0$ and that a geometric distribution with probability function exists given by $\phi(t_0) = (\exp(\lambda) - 1)\exp(-\lambda t_0)$, where $\lambda > 0$.

[Figure 1 Here]

There exists a continuum of investors of size one, who are risk-neutral and have a discount rate equal to zero. As long as investors hold an asset, they have two choices in each period (i.e., either sell the asset or keep it). They cannot buy their asset back. When $\alpha \in (0, 1)$ of the investors sell their assets, the bubble bursts (endogenous burst), and the asset price drops to the true value ($\exp(gt_0)$). If fewer than α of the investors sell their assets when time $\bar{\tau}$ passes after t_0, the bubble bursts automatically at $t_0 + \bar{\tau}$ (exogenous burst). If an investor can sell an asset at t, which is before the bubble bursts, he or she receives the price in the selling period ($\exp(gt)$). If not, he or she only receives the true value $\exp(gt_0)$, which is below the price at $t > t_0$.

The first case we consider is that with asymmetric information, where players receive different information; this case is studied by Abreu and Brunnermeier (2003). To be precise,

distributed rational investors.

[6] Price $\exp(gt)$ is kept above the true value after t_0 by behavioral (or irrational) investors. Abreu and Brunnermeier (2003) indicate that such behavioral investors "believe in a 'new economy paradigm' and think that the price will grow at a rate g in perpetuity" (p. 179). This is a controversial feature in that the price formation process is given exogenously, and behavioral investors play an important role in supporting such a high price. Doblas-Madrid (2012) uses a discrete-time model assuming fully rational investors and shows an implication similar to that of Abreu and Brunnermeier (2003). The other controversial feature is that to support such an investment strategy (i.e., riding a bubble), investors' endowments must grow rapidly and indefinitely. Doblas-Madrid (2016) uses a finite model without endowment growth and shows that a riding-bubble strategy can be sustained.

an *asymmetric signal* informs them that the true value is below the asset price (i.e., a bubble has occurred). The signal, however, does not completely reveal the true timing of the bubble occurrence t_0. Two types of investors exist. A proportion β of them are early-signal agents (type-E), whereas the rest, namely, $1-\beta$, are late-signal agents (type-L). We denote their types by $i = E, L$. Type-i investors receive an asymmetric signal at

$$t_i = \begin{cases} t_0 & \text{if } i = E \\ t_0 + \eta & \text{if } i = L, \end{cases}$$

where $\eta > 0$ as shown in Figure 1. These investors hold an asset in period 0. Once an investor receives her asymmetric signal at time t_i, he or she knows that t_0 equals either $t_i - \eta$ or t_i.[7] That is, after the investor receives a signal at t_i, he or she knows that the asset price is above the true value, but he or she does not know his or her type, type-E (and $t_0 = t_i$) or type-L (and $t_0 = t_i - \eta$). We simply assume that $\beta = \alpha$, so α has two indications: (i) the proportion of type-E investors and (ii) the proportion of investors that would cause the bubble to burst endogenously if they were to sell their asset.[8] Therefore, if all type-E investors sell their asset, the bubble bursts. Rational investors never sell an asset before they receive an asymmetric signal because the true value continues to increase until t_0.[9] The second case is a new feature in our model, which is that with symmetric information. All players receive a *symmetric signal*, which informs them of the true t_0. This signal informs the exact value of t_0 for all investors, so it provides common knowledge and perfect information for them.[10]

We denote the duration of holding an asset after receiving a signal (either symmetric or asymmetric) by $\tau \geq 0$; that is, investor i sells the asset at $t_i + \tau$. Rational investors never sell an asset until t_0.

[7] The exceptional case is $t_i = 0$, where an investor knows that he or she is a type-E investor.

[8] According to Asako and Ueda (2014), even if $\beta \neq \alpha$, our results hardly change when $\beta > \alpha$.

[9] The posterior belief that an investor is type-E after he or she receives an asymmetric signal differs from α, but only to a small extent. See Asako and Ueda (2014) for more details.

[10] In this study, we use the term symmetric/asymmetric signal, whereas Abreu and Brunnermeier (2003) call it private/public signal. It is because a "private signal" usually means that the information is dispersed even within the same group. Similar to Abreu and Brunnermeier (2003), Morris and Shin (2002) also consider the effects of public and private information on investors' choices. The authors demonstrate that agents overreact to public information and under-react to private information.

2.2 Model Predictions

This model yields the following prediction.

Hypothesis 1 *Investors hold an asset for a longer duration (τ is larger) with asymmetric information than with symmetric information.*

With a symmetric signal, the size of the bubble is zero because all players (investors) know t_0. Consequently, investors prefer to sell earlier than others to receive a higher price with higher probability; hence, they sell an asset as soon as possible after a symmetric signal is received. In other words, the backward-induction argument excludes the existence of the bubble. On the contrary, with an asymmetric signal, the size of the bubble can be large. In particular, investors may hold the asset even after both types of investors receive the asymmetric signal.

Investors' strategies are to sell the asset at $t_i + \tau$, where $\tau \geq \eta$. There is a risk of waiting until $t_i + \tau$ if $\tau \geq \eta$. If investors are type-E with probability α, they can sell at a high price $(\exp(g(t_i + \tau)))$; however, if they are type-L with probability $1 - \alpha$, the bubble bursts before they sell (corresponding to the price $\exp(g(t_i - \eta))$). Therefore, the expected payoff is $\alpha \exp(g(t_i + \tau)) + (1 - \alpha) \exp(g(t_i - \eta))$. In this case, there may be an advantage to selling earlier. Notably, if an investor sells η periods earlier than $t_i + \tau$, he or she may be able to sell before the bubble bursts at price $\exp(g(t_i - \eta + \tau))$. However, with this deviation, the investor needs to forgo the chance of selling the asset at a higher price $\exp(g(t_0 + \tau))$ with probability α. On the basis of such a trade-off, investors decide the duration of holding an asset τ.

The investor does not have an incentive to deviate from $t_i + \tau$ to $t_i - \eta + \tau$ if $\alpha \exp(g(t_i + \tau)) + (1 - \alpha) \exp(g(t_i - \eta)) \geq \exp(g(t_i - \eta + \tau))$. This condition is satisfied for any $\tau \leq \min\{\tau^*, \bar{\tau}\}$ where τ^* satisfies

$$\alpha = \frac{\exp(-g\eta) [\exp(g\tau^*) - 1]}{\exp(g\tau^*) - \exp(-g\eta)}. \tag{1}$$

As η decreases to zero, its right-hand side decreases to one, which means that τ^* must also decrease to zero to satisfy (1). Therefore, with a symmetric signal (i.e., $\eta = 0$), no player has an incentive to hold an asset. As η increases, investors have an incentive to hold an asset for longer periods.

Note that the price ($\exp(gt)$) is kept above the fundamental value after t_0 by behavioral (or irrational) investors in the model. As aforementioned, this is due to the behavioral investors' belief in "new economy paradigm"and their thinking that the "price will grow at a rate g in perpetuity"(Abreu and Brunnermeier, 2003, p. 179). The existence of such behavioral investors made the riding-bubble model a non-zero-sum game, which differs from the typical market experiments conducted by SSW.

It should be noted that our experimental environment is not exactly the same as that of Asako and Ueda (2014). In our experiment, time is discrete and the number of investors is finite. Although this modification complicates the solution of equilibrium, we will show in Section 3.3 that the main model predictions do not change. The result of the numerical calculation will be presented after we explain the experimental design in detail.

3 Experimental Design

3.1 Nature of the Experiment

Seven experimental sessions were conducted in Japan during fall 2015 and spring 2016 (Table 1). Thirty subjects participated in each session, and they appeared in only one session each. Subjects were divided into six groups, each consisting of five members. They played the same game for several rounds in succession. Members of the group were randomly matched at the beginning of each round, and thus, the composition of the groups changed in each round.

[Table 1 Here]

One session consists of several rounds. Each round includes several periods and represents the trading of one asset. At the beginning of each round, subjects are required to buy an asset at price 1, and they need to decide whether they sell it or not in each period (i.e., they decide the timing to sell). At the beginning of each round, the asset price begins at 1 point and increases by 5% in each period ($g \doteqdot 0.05$). The true value of the asset also increases and has the same value as the price until a certain period (t_0). Thereafter, the true value ceases to increase further and remains constant at the price in period t_0. A certain period t_0

is randomly chosen, and there is a 5% chance that the true value ceases to increase in each period ($\lambda \doteqdot 0.05$).

At one point, when or after the true value ceases to increase, subjects receive a signal that notifies them that the current price of the asset exceeds its true value. On the computer screen, the asset price changes from black to red after they receive a signal. To compare the symmetric and asymmetric information structures, we suppose the following two experimental conditions:

- *Asym* η: Among the five members of the group, three members receive a signal at $t_i = t_0$. They are type-E, and $\alpha = 3/5$. On the contrary, the remaining two members are type-L, who receive a signal at $t_i = t_0 + \eta$. We inform the subjects two possible true values: the true value if a subject is type-E (the price at t_i) and the true value if a subject is type-L (the price at $t_i - \eta$). Depending on the session, the value of η is either 2 or 5. We call a session *Asym 2* and *Asym 5* with $\eta = 2$ and $\eta = 5$, respectively.

- *Sym*: All subjects receive a signal at t_0, and we inform the subjects the true value.

In each round, the game ends when (i) 20 periods have passed after the true value ceases to increase ($\bar{\tau} = 20$: exogenous burst); or (ii) three members of the group decide to sell the asset before 20 periods have passed (endogenous burst). If subjects choose to sell the asset before the game ends, they receive the number of points equal to the price in the selling period (price point). Otherwise, subjects receive the number of points equal to the true value. Note that if subsequent members sell at the same time as when the third member sells, the members who receive the price point in the selling period are randomly chosen with an equal probability among members who sell at the latest. The probability is decided such that three members can receive the price point in the selling period, whereas the remaining two members receive the true value.

In summary, all subjects have common knowledge about an asset price, $\alpha = 3/5$, $\overline{\tau} = 20$, $g \fallingdotseq 0.05$, and $\lambda \fallingdotseq 0.05$. The value of η is also common knowledge in the case with an asymmetric signal. However, t_i is not common knowledge in the case with an asymmetric signal, and they do not know whether they are type-E or type-L. In the case with a symmetric signal, t_i is common knowledge.

3.2 Sessions

Subjects were 210 Japanese undergraduate students taking various majors in Waseda University. They were recruited through a website used exclusively by the students.

Upon arrival, subjects were randomly allocated to each computer. Each subject had a cubicle seat, so subjects were unable to see other computer screens. They also received a set of instructions (see Appendix A), and the computer read these out at the beginning of the experiment. The subjects faced difficulties understanding the game in our pilot experiments because the riding-bubble game is somewhat complicated. Therefore, to ensure they understood the game clearly, we prepared detailed examples. Moreover, we also asked them to answer some quizzes. The experiment did not begin until all participants had answered the quizzes correctly. The subjects understood the game very well after this process; thus, little variability is observed in their choices in the early rounds of each session. Hence, we used the results of all rounds for our analysis.

In each period, subjects decided whether to sell the asset by clicking the mouse. However, subjects may have used these sounds of mouse clicks to infer other subjects' choices, as Brunnermeier and Morgan (2010) indicate. To remedy this problem, we employed the following three designs. First, in each period, subjects needed to click "SELL" or "NOT SELL" on the computer screen. That is, they needed to click regardless of their choices. Second, even after subjects sold the asset or the game ended in one group, they were required to continue clicking "OK" until all groups ended that round. Third, in sessions 3–7, we used silent mice (i.e., the click sound is faint). Indeed, we found that click sounds disappeared because of the background noise of the air conditioners.[11]

Further, we restrict the time to make a decision. If the subjects did not click after a few seconds, the game moves to the next period automatically. If the game moves to the next period without any click, the computer interprets that this subject chose "NOT SELL." In

[11] There is no significant difference between sessions 1–2 and sessions 3–7. However, after the experiment, one subject inferred t_0 from the click sounds in session 1 (*Private 5*). The subject indicated that the click sounds came apart at t_0 because only type-E subjects received a signal and took the time to make a decision, whereas type-L subjects clicked immediately. This comment has prompted us to use silent mice.

sessions 6 and 7, it was 2 sec. In other sessions, it was 5 sec.[12]

After all the groups completed one round, the following four values were shown on the screen: the true value of the asset, the subject's earned points in that round, the earned points of all members of the group, and the subject's total earned points for all rounds. This feedback was designed to speed the learning process, which was also employed by Brunnermeier and Morgan (2010).

After the experiment, we asked survey questions related to the experiment. We also asked questions to measure subjects' attitudes toward risk (developed by Holt and Laury, 2002), subjective intellectual levels, and objective intellectual levels by using CRT (cognitive reflection test) questions (developed by Frederick, 2005). See Appendix B for more details.

There are two types of sessions: baseline and extended. Extended sessions include more rounds than baseline sessions to check subjects' choices after they learn and understand the game very well. In both baseline and extended sessions held, subjects were informed that they would receive a participation fee of 500 yen, in addition to any earnings they received in the asset market (conversion rate: 1 point = 50 yen). The baseline sessions (sessions 1–5) had 14 rounds and lasted approximately 2 h. The average profit made by each subject was 1,870 yen including a participation fee. On the contrary, sessions 6 and 7 (the extended sessions) had $14 + 24 = 38$ and $14 + 19 = 33$ rounds respectively, and lasted approximately 3 h. The average profit made by each subject was 3,235 yen including a participation fee. In the extended session, subjects took a break (about 10 min) between the first 14 rounds and the last 19 or 24 rounds, but we did not announce this break at the beginning of the experiment. Subjects were not allowed to communicate during the break. Note the following three points. First, the number of rounds was determined in advance, but we did not announce this to the subjects in either session (baseline or extended) because they may have changed their strategies if they expected the experiment to finish soon. Second, there was no refreshment effect; that is, subjects did not significantly change their strategies after the break. Third, to compare subjects' choices among sessions, we used the identical stream of the values of t_0 listed in Table 2 for all sessions and all six groups, but we did not announce them to the

[12] In sessions 1 and 2, even though we did not inform the subjects about this design feature, there was no significant effect from this treatment.

subjects.

[Table 2 Here]

In summary, there were three short treatments and two long treatments, in which the long treatments were divided into two subsamples. *Sym*, *Asym 2*, and *Asym 5* consist of short treatments and the first 14 rounds of long treatments, whereas *Sym extended* and *Asym 5 extended* consist of the last 19 and 24 rounds of the long treatments, respectively. Thus, the first 14 observations in the long treatments correspond to *Sym* (*Asym 5*), whereas the last 24 (19) do to *Sym extended* (*Asym 5 extended*). *Sym extended* has more rounds than *Asym 5 extended* because subjects made decisions more quickly in *Sym extended* and the long session had to end within three hours. Note also that *Asym 2* does not have an extended session because there is no robust and significant difference between *Asym 2* and *Asym 5*; hence, we predict that an extended session of *Asym 2* should have similar results to *Asym 5 extended*.

3.3 Differences from Theory

We have changed some of the settings from those of Asako and Ueda (2014) because of the constraints in our experimental environment, as discussed in Section 2. First, whereas Asako and Ueda (2014) consider continuous time periods, we consider discrete time in our experiments. Second, whereas Asako and Ueda (2014) consider an infinite number of investors, we consider a finite number of investors ($N = 5$). In addition, the theoretical model considers that the price evolves as $p_t = \exp(gt)$. However, to ensure subjects understood the game clearly, we supposed that the asset price increases by 5% in each period; that is, $\exp(gt)$ is approximated by $(1 + g)^t$. Similarly, the theoretical model considers that t_0 obeys the geometric distribution with a probability function given by $\phi(t_0) = (\exp(\lambda) - 1)\exp(-\lambda t_0)$. However, we supposed that there is a 5% chance that the true value ceases to increase in each period. The final two differences are just approximations which do not affect our theoretical predictions.

These differences change some of the theoretical results as follows. First, tiny bubbles can occur with a symmetric signal, but it never happens in Asako and Ueda (2014). Suppose that all investors sell assets at $t_0 + \tau$, where $\tau \geq 1$. Then, the expected payoff is $\alpha(1+g)^{t_0+\tau} + (1-\alpha)(1+g)^{t_0}$; in other words, an investor may be unable to sell an asset at a high price. On the contrary, if an investor deviates by selling an asset one period earlier, that is, at $t_0 + \tau - 1$, he or she can sell at price $(1+g)^{t_0+\tau-1}$. Thus, investors do not have an incentive to sell at $t_0 + \tau$ if

$$\alpha < \frac{(1+g)^{\tau-1} - 1}{(1+g)^{\tau} - 1}.$$

This condition does not hold when $\tau = 1$ because the right-hand side is 0, but it can hold when $\tau > 1$. Note that with continuous time, an investor can deviate by selling slightly before $t_0 + \tau$ and obtain (slightly lower than) the price at $t_0 + \tau$ for sure, so he or she deviates if $\tau > 0$. However, with discrete time, an investor cannot deviate to sell at an infinitesimally earlier period than $t_0 + \tau$ but at $t_0 + \tau - 1$, which decreases an incentive to deviate and sell early. Our experiments suppose $\alpha = 3/5$ and $g = 0.05$; therefore, according to the modified model, rational investors hold an asset at most for two periods ($\tau = 2$) because the right-hand side is about 0.65 when $\tau = 3$. Although tiny bubbles occur with a symmetric signal, two periods are still shorter than equilibrium with an asymmetric signal discussed in the following parts.[13]

In addition, under asymmetric information, the equilibrium comes with mixed strategies, and pure-strategy equilibrium does not exist with a finite number of investors. With an infinite number of investors, a deviation of one player does not change the timing of the bubble crash. However, if the number of investors is finite, one investor can change the timing of the bubble crash. Suppose an equilibrium exists with infinite investors where all investors sell at $t_i + \tau$; therefore, α of investors sell their assets, and the bubble crashes at $t_0 + \tau$. With finite investors, if an investor is type-E, the bubble duration can be extended from $t_0 + \tau$ because only $\alpha N - 1$ investors sell at $t_0 + \tau$ without this investor. Thus, an investor has an incentive to deviate by selling later in order to sell at a higher price, so no

[13] Note that Asako and Ueda (2014) assume that if more than α of the investors sell assets at the same time, all of them only receive the true value. Our experiments, which consider a finite number of investors, assume that if more than α of the investors sell assets at the same time, the randomly chosen investors receive the true value, whereas the others receive a price in the selling period. This feature also induces an occurrence of tiny bubbles with a symmetric signal.

pure strategy equilibrium exists.[14]

Meanwhile, there exist mixed-strategy equilibria because this game has finite strategy sets, and the characteristics of equilibrium differ depending on the value of η. A mixed strategy in a perfect Bayesian equilibrium may include three or more pure strategies that complicate the analysis. To simplify our discussions, we employ ϵ-equilibrium introduced by Radner (1980). With $\epsilon \geq 0$, an ϵ-equilibrium is "a combination of randomized strategies such that no player could expect to gain more than ϵ by switching to any of his feasible strategies, instead of following the randomized strategy specified for him" (Myerson, 1991, p.143). There are two possible interpretations of ϵ. First, ϵ is a certain cost to change the strategy. Second, players ignore profitable deviations when a profit from deviation is very small. We use ϵ-equilibrium because the following simplest mixed strategy can be equilibrium for any value of η:

$$T(t_i) = \begin{cases} t_i + \tau & \text{with prob } 1 - \sigma \\ t_i + \tau - \eta & \text{with prob } \sigma, \end{cases}$$

where $0 < \sigma < 1$. To be precise, this mixed strategy is a perfect Bayesian equilibrium when $\eta = 2$ or 3, whereas it is ϵ-equilibrium when $\eta \geq 2$. The details of the analysis are presented in Appendix C. In our experiments, we suppose $\alpha = 3/5$, $g = 0.05$, and the two values of η are 2 and 5. With these parameter values, Figure 2 shows the duration for which an investor waits until he or she sells the asset in equilibrium. Figure 2(a) shows the value of τ, and Figure 2(b) shows the expected value of this duration, that is, $\sigma(\tau - \eta) + (1 - \sigma)\tau$. Both values increase with η, and they are all higher than 2, which is the equilibrium value of τ with a symmetric signal.

[Figure 2 Here]

Therefore, a bubble duration is longer with an asymmetric signal than with a symmetric signal. Therefore, even with these changes, Hypothesis 1 holds, and thus, these changes do not severely affect the experimental results. The theoretically predicted (maximum) durations of holding an asset are about 4 and 12 with $\eta = 2$ and $\eta = 5$, respectively, as

[14] Note that it does not change the theoretical implications with a symmetric signal because all investors sell at the same period in equilibrium, and no one can change the timing of the bubble crash.

shown in Figure 2. These predicted values are the same as the predicted values of the model of Asako and Ueda (2014).

4 Experimental Results

4.1 Duration of the Bubble

In the theoretical analysis, we are mainly interested in the trader's duration of holding an asset after he or she receives a signal, either symmetric or asymmetric, τ. Therefore, in our experiments, we measure the variable *Delay*, which represents the duration for which a subject waits until he or she sells the asset. To be precise, we denote the time subject i receives a signal, either symmetric or asymmetric, and the time he or she decides to sell the asset by t_i and $t_i + \tau_i$, respectively. Then, $Delay_i$ for subject i equals τ_i. It is important to note that this $Delay_i$ is not necessarily observable because it is right censored at $t_{bc} - t_i$, where t_{bc} represents the bubble-crashing time. Table 3 shows the descriptive statistics of *Delay* and the number of observations for each subsample. We count the variable for only those subjects who actually sell the asset at or before the point of the bubble crashing, meaning that it is censored on the right-hand side. We count *Delay* in the first 14 rounds for *Sym*, *Asym 2*, and *Asym 5*, and we count it in the last 19 or 24 rounds for *Sym extended* and *Asym 5 extended*.

[Table 3 Here]

The average of *Delay* is longer in *Sym* than in both *Asym 2* and *Asym 5*. This result indicates that subjects tend to hold an asset longer with a symmetric signal than with an asymmetric signal in the first 14 rounds. However, this duration becomes shorter in *Sym extended* than in *Asym 5 extended*, implying that subjects sell an asset earlier with a symmetric signal than an asymmetric signal in the last 19 or 24 rounds. Furthermore, the average of *Delay* is shorter in *Sym extended* (i.e., in the last 24 rounds) than that in *Sym* (i.e., in the first 14 rounds).

From Table 3, we can compare the experimental results and theoretical predictions. The average values of *Delay* is about 4 in both *Asym 2* and *Asym 5* of our experiments, whereas the theoretically predicted *Delay* is about 4 and 12 in *Asym 2* and *Asym 5*, respectively (Section 3.3). Hence, *Delay* is almost the predicted duration in *Asym 2*, whereas subjects tend to sell earlier than the predicted duration in *Asym 5*.

We can only observe the variable *Delay* for only those subjects who sell the asset at or before the point of the bubble crashing; thus, we recover this censored *Delay* by using a Tobit model (the interval regression of Stata).[15] Table 4 shows the estimated average of *Delay*. In the following parts, we call this estimated value *Delay*. Table 4 confirms the findings shown in Table 3. The average value of *Delay* is longer in *Sym* than in both *Asym 2* and *Asym 5* in the first 14 rounds, whereas the former is shorter in the last 19 or 24 periods (*Asym 5 extended* and *Sym extended*).[16]

[Table 4 Here]

We next test the difference of *Delay* between the three treatments. The model of the interval regression for $Delay_{ir}$ for subject i at round r is

$$Delay_{ir} = \alpha + \beta_1 Sym + \beta_2 Asym\ 2 + \beta_3 X_{ir} + \varepsilon_{ir}, \quad (2)$$

where *Sym* and *Asym 2* are the dummy variables that take the value of 1 when a session is *Sym* and *Asym 2*, respectively. An error term is ε_{ir}, and the other variables are included in X_{ir}. Table 5 shows the empirical results. The first and third columns do not include other variables, and the second column includes the period in which the true value ceases to increase ($t_0(r)$), the round number (r), and its interactions with *Sym* and *Asym 2*.[17] For the

[15] Denote the observed variable of $Delay_i$ by $Delay_i^0$. Then, $Delay_i^0 = Delay_i$ if $Delay_i \leq t_{bc} - t_i$ and $Delay_i^0 = t_{bc} - t_i$ otherwise. Then, we estimate the mean of $Delay_{it}$ using pooled data for individual i and round t.

[16] Note that very few subjects sold the asset before receiving a signal. In this case, *Delay* is negative because τ measures how long, in periods, subjects hold an asset after they receive a signal. Such subjects may have sold the asset by mistake; therefore, it may be better to treat that $\tau = 0$ when subjects sold an asset before a signal. By using the interval regression with both lower and upper bounds, we confirm that doing so hardly changes our results.

[17] The values of t_0 are predetermined for all sessions (Table 2), so the value of t_0 is the same, given the number of round r in all sessions.

first 14 rounds, the estimated β_1 is 1.48 and significant at 5% level, and β_2 is not significant in the first column, suggesting that, on average, *Delay* is longer by 1.48 periods in *Sym* than in *Asym 5* and *Asym 2*. Meanwhile, in the second column, β_1 is 3.66 and β_2 is 1.5, and both are significant at 5% level, which means that *Delay* becomes longer as type-L receives an asymmetric signal earlier (η is small). However, for the last 19 or 24 rounds, this result is reversed: *Delay* is shorter by 1.41 periods in *Sym extended* than in *Asym 5 extended*.

[Table 5 Here]

Figure 3 shows the evolution of *Delay* over rounds. To draw this, we estimate the average duration by using the interval regression for each round. *Delay* decreases over rounds with a symmetric signal, and subjects hold assets for a shorter time with a symmetric signal than an asymmetric signal as rounds proceed. At the beginning of the session, *Delay* is about 10 periods, whereas it converges to 1–2 periods about round 25 (Figure 3).[18]

[Figure 3 Here]

4.2 Characteristics of Experiments and Subjects

To investigate the effects of characteristics of the experiments and the subjects on *Delay*, we conduct the interval regression of $Delay_{ir}$ by using a number of control variables (these variables are defined in Appendix D). Table 6 and the second column of Table 5 show the empirical results.

[Table 6 Here]

We obtain four implications. First and most importantly, a learning effect exists in the sessions with a symmetric signal, but not in the sessions with an asymmetric signal. As subjects play more rounds of the game (i.e., as r increases), *Delay* becomes shorter with a symmetric signal only. However, because the coefficients of squared r (round) are

[18] *Delay* fluctuates over rounds, reflecting changes in t_0 that are shown on the right axis. *Delay* tends to be shorter when t_0 is longer. In particular, at round 5, t_0 is the longest (50), and we can observe a dip in the duration of holding an asset. The path of t_0 is the same for the experiments of *Asym 5*, *Asym 2*, and *Sym*.

positive, the duration stops decreasing after about 12 periods (Figure 3). On the contrary, the round number is not significant for *Delay* with an asymmetric signal, which implies that subjects choose the optimal duration from the early rounds. The second column of Table 5 is consistent with this result. For *Asym 5*, the coefficient of r is not significant, whereas the interaction term of r with *Sym* is negative and significant, which suggests a learning effect with a symmetric signal. A learning effect is also present with *Asym 2*, but this effect is smaller than *Sym*.

As discussed, subjects answered practice questions before the experiment to ensure that they understood the game sufficiently well from the beginning. This fact contributes to the non-existence of learning effect with an asymmetric signal.[19]

Second, the coefficients of t_0 are negative, suggesting that when a bubble starts later (i.e., t_0 is larger), subjects tend to sell an asset earlier. In our model, the value of t_0 is irrelevant to *Delay*. However, in our experiments, subjects seemed to be more risk averse and preferred to finish the round earlier when the true value continued to increase and subjects did not receive a signal for a longer duration.

Third, the coefficients of lag Win are positive. If a subject succeeds in selling an asset before the bubble crashes and receives the price point in the previous round (i.e., lag Win is 1), this subject tends to hold an asset longer in the next round. The successful experience may induce subjects to be more confident and optimistic.

Lastly, the characteristics of the subjects do not seem to be important factors in determining *Delay*. Although some coefficients are significant, neither intelligence (both subjective and objective) nor risk attitude seems to significantly influence the duration in a robust manner. If anything, women tend to hold assets for a shorter duration than men, whereas those subjects who answered quizzes at the beginning of the session quickly (i.e., Test Time is higher) tended to hold an asset longer with an asymmetric signal.

[19] There may be a possibility that subjects sell early simply because they become bored. However, the fact that the decrease in *Delay* does not occur in the private signal excludes this possibility. Moreover, the individual decision to sell early does not directly mean that the round ends early, because the end depends on the decisions of other subjects.

4.3 Discussion

4.3.1 Questions

The immediate questions that arise from the aforementioned results are the following: (i) why, in the early rounds, did subjects have a greater incentive to hold an asset after a symmetric signal than they did after an asymmetric signal; and (ii) why did bubbles disappear only with a symmetric signal after subjects had played the game for several rounds.

Regarding question (ii), note that bubbles with asymmetric information are an equilibrium phenomenon in the riding-bubble model. Thus, bubbles are sustainable with asymmetric information, but not with symmetric information. Regarding question (i), it is pointed out that the bubble that arises with symmetric information in our experiments is similar to that in SSW and its extensions.

4.3.2 Strategic Uncertainty

Porter and Smith's (1995) interpretation of the findings of SSW's experiments convey that "common information on fundamental share value is not sufficient to induce common expectations" "because there is still behavioral or strategic uncertainty about how others will utilize the information" (p. 512). If other players do not understand the game, there is a possibility that an investor believes to be able to resell the asset to such an irrational investor with a higher price, so they have an incentive to ride on bubbles. Meanwhile, Lei, Noussair, and Plott (2001) indicate that bounded rationality (i.e., an investor rides on bubbles because he or she is irrational or confusing) is more important than strategic uncertainty. Akiyama, Hanaki, and Ishikawa (2017) show that both strategic uncertainty and bounded rationality contribute equally to the deviation from the fundamental values. Given strategic uncertainty, it is reasonable to consider that strategic uncertainty disappears after several rounds because subjects can reach common expectations with experience (Dufwenberg et al., 2005). Indeed, SSW and its extensions often show that the bubble disappears with experienced subjects.

In contrast, bubbles with asymmetric information do not disappear. One possible interpretation is that it occurs because it is an equilibrium phenomenon. At the same time, asymmetric information adds a source of strategic uncertainty because it becomes more difficult for subjects to expect what others think. Thus, it becomes more likely for them not to have common expectations. While Hirota and Sunder (2007) indicate bubbles are more likely to occur by adding the source of subjective uncertainty, Boun My, Cornand, and Dos Santos Ferreira (2018) indicate that speculation may be reduced by an increase in strategic uncertainty. Our experimental outcomes are the same line with the latter.[20]

4.3.3 Adaptive Beliefs

Furthermore, adaptive beliefs may eliminate bubbles with symmetric information. After bubbles with symmetric information occur (possibly because of strategic uncertainty), as subjects gain experience, investors respond to the timing of the bubble crash in previous rounds. Haruvy, Lahav, and Noussair (2007) determine that subjects' beliefs about prices are adaptive. This simple adaptive rule works because all subjects know about mispricing at the same time. That is, as subjects gain experience, they respond to the timing of the crash that occurred in previous rounds by selling earlier in the recent round, resulting in smaller bubbles over rounds.

In contrast, with asymmetric information, subjects do not know their own type at any given round, so experience does not help subjects learn about the validity of their pricing strategy, and therefore, subjects do not use a simple adaptive rule. As a result, a constant bubble occurs. Indeed, the number of rounds have significant effect on the variable *Delay* only with symmetric information, as shown in Table 6.

4.3.4 Policy Implication

Bubble prevention is clearly a very important policy challenge. Sometimes, the government authorities provide warnings and let investors know about overpricing. If asymmetric information creates bubbles as the past theoretical studies indicate, symmetric information (government warning) should be considered important to reduce the degree of asymmetric information, thereby eliminating the bubble. However, government authorities have been

[20]Note that these two studies and our study employ different settings. Hirota and Sunder (2007) use double auction markets (SSW), Boun My et al. (2017) use Keynes' beauty contest (Morris and Shin, 2002), and our paper uses the riding-bubble model.

unable to successfully stop bubbles by means of warnings. Kindleberger and Aliber (2011, p.19) state

> One question is whether manias can be halted by official warning—moral suasion or jawboning. The evidence suggests that they cannot, or at least that many crises followed warnings that were intended to head them off.

Then, the question is whether the government's warnings can prevent bubbles. According to our experimental results, the answer highly depends on how experienced actual traders are. If traders are experienced, bubbles should not arise with symmetric information. However, bubbles rarely occur, so there is a possibility that actual traders may not have sufficient experience of bubbles. If so, symmetric information may enlarge, rather than check, bubbles compared with the case without it. Asako and Ueda (2014) indicate "an important aspect with regard to a public warning is whether investors believe it" (p. 1146) to prevent bubbles. However, even if the investors believe a warning, it may not be able to stop bubbles if they are inexperienced.

5 Conclusion

According to game-theoretical analyses of bubbles, one necessary condition to explain why a bubble occurs is the existence of asymmetric information. Investors hold a bubble asset because the presence of asymmetric information allows them to believe they can sell it for a higher price, with a positive probability, in a future period. We investigate this claim experimentally by comparing traders' choices with and without asymmetric information, based on the riding-bubble model, in which players decide when to sell an asset.

We show that subjects tend to hold a bubble asset longer in the experiments with symmetric information than they do in those with asymmetric information, when traders are inexperienced (i.e., they tend to hold the asset in the early rounds of the game). However, as subjects continue to play the game with symmetric information, they tend to hold an asset for a shorter duration, implying a learning effect. In contrast, this learning effect is not observed with asymmetric information.

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A Instructions

Thank you for participating in this experiment.

You are participating in an experiment of investment decision making. After reading these instructions, you are required to make decisions to earn money. Your earnings will be shown as points during the experiment. At the end of this experiment, you will be paid in cash according to the following conversion rate.

1 point = 50 yen

You will also earn a participation fee of 500 yen. Other participants cannot know your ID, decisions, and earnings. Please refrain from talking to other participants during the experiment. If you have any questions, please raise your hand. Please also do not keep anything, including pens, on top of the desk. Please keep them in your bag.

There are 30 participants in this experiment. Participants are divided into six groups, and five members constitute a group. You are about to play the same game for several rounds in succession. In each round, you will play the game, which is explained later, with members of your group. Members of the group are randomly matched at the beginning of each round, and thus, the composition of members changes in each round. You will not know which other participants are playing the game with you. Note that your choices will affect your and other members' earning points in your group.

At the beginning of each round, you need to buy an asset at price 1. One round includes several periods, and it represents the trading of one asset. You need to decide the period in which to sell this asset.

[Figure A-1 Here]

Figure A-1 displays the computer screen at the beginning of each round. At the beginning of each round, the price of an asset begins with 1 point and increases by 5% in each period. The current price is displayed on the screen. This price is common for all participants.

Furthermore, the asset has a true value, which is common for all participants. The true value increases and has the same value as the price until a certain period. Thereafter, the true value ceases to increase further and remains constant at the price of the period. The timing in which the true value ceases to increase is randomly determined. In each period, the true value continues to increase with a probability of 95%. However, there is a 5% chance that the true value ceases to increase in each period.

Asym: At one point after the true value ceases to increase, you will receive a signal that notifies you that the current price of the asset exceeds its true value.

[Figures A-2 (a) and (b) Here]

Asym η (η is either 2 or 5): The screen changes to Figure A-2 (a) after you receive a signal, and the asset price changes from black to red. The screen also shows two possible true values (maximum and minimum). The true value must be one of them. Among the five members of the group, three members receive a signal in the period in which the true value ceases to increase. However, the remaining two members receive a signal at η periods later than the period in which the true value ceases to increase. If you are in the former, the maximum value is the true value. If you are in the latter, the minimum value is the true value.

Sym: When the true value ceases to increase, you receive a signal that notifies you that the current price of the asset has exceeded its true value. The screen changes to Figure A-2 (b) after you receive the signal, and the asset price changes from black to red. The screen also shows the true value.

How to Sell: In each period, click "SELL" or "NOT SELL" on the screen. You can sell the asset before or after you receive a signal.

Sessions 1–2: If all participants click, the game moves on to the next period. Note that you cannot buy back the asset.

Sessions 3–7 (Note that y = 5 in sessions 1–5, and y = 2 in sessions 6 and 7): Note that if y seconds have passed without any click, the game moves on to the next period automatically. If the game moves on to the next period without any click, the computer interprets that you choose "NOT SELL." If all participants click, or y seconds have passed, the game moves on to the next period. You cannot buy back the asset.

Even if the true value ceases to increase, the asset price continues to increase by 5% in each period until one of the following two conditions is satisfied:

- *The condition that the game ends in each round*

1. Twenty periods have passed after the true value ceases to increase (not the beginning of the game).

2. After the true value ceases to increase, three members of the group decide to sell the asset before 20 periods have passed.

If you choose to sell the asset before the game ends, you receive a point that is the same as the price in the selling period (price point). If you do not sell, you receive a point that is the same as the true value. You cannot know other participants' choices during the game.

You need to buy the asset at price 1 at the beginning of the game. Thus, to derive your final earned points, which will be exchanged for cash, you must deduct one point. Hence, if you choose to sell the asset in the first period, your earned points equal zero. Note that if subsequent members sell at the same period as when the third member sells, the members who receive the price point in the selling period are randomly chosen with an equal probability among members who sell at the latest. The probability is decided in the following way: three members among the five members of the group can receive the price point in the selling period (which is higher than or, at least, the same as the true value), and the remaining two members receive the true value.

[Figure A-3 Here]

Attention: The screen changes to Figure A-3 after you choose to sell the asset. The screen also changes to Figure A-3 if three members of the group sell the asset and one round is complete. On this screen, continue to click "OK." Because all groups must complete one round to move on to the next round, you must click on this screen.

[Figure A-4 Here]

In each round, the following four values are shown on the screen after all groups complete a round (see Figure A-4): the true value of the asset; your earned points in this round; the earned points of all five members of the group, including you; and your cumulative earned points for all rounds. An earned point shown on this screen is that earned after already deducting the point used to buy this asset at the beginning of each round. Click "OK" and move on to the next round. After all participants click, the next round begins. The new members of your group differ from those in the previous rounds.

To help you understand this game more clearly, we discuss the following example.

The asset price increases by 5% in each period. Consequently, the asset price and earned point (which is the asset price minus one point) change, as shown in Table A-1. Suppose that the true value of this asset ceases to increase in period 35.

[Table A-1 Here]

Asym 5: In this case, you receive a signal in period 35 or period 40.

Asym 2: In this case, you receive a signal in period 35 or period 37.

Sym: In this case, you receive a signal in period 35.

Moreover, this round of the game ends in period 55 (i.e., when 20 periods have passed from period 35).

Then, among the one group including you, suppose that A sells in period 35, B sells in period 45, C sells in period 50, and D sells in period 55.

- Case 1: Suppose that you choose to sell the asset in period 5, that is, before you receive a signal. Then, you are the only member who chose to sell by period 5. You receive the price point of the selling period, that is, 1.22, and your earned points are 0.22. This round ends in period 45 when B sells, and the other members receive the following earned points: A receives 4.25, B receives 7.56, and C and D receive 4.25, which is the true value minus one point.

- Case 2: Suppose that you choose to sell the asset in period 35. Then, two members, you and A, chose to sell by period 35. Hence, your price point is 5.25 and your earned points are 4.25. The period in which this round ends and the earned points of each member are the same as in Case 1.

- Case 3: Suppose that you choose to sell the asset in period 45. Then, three members, you, A, and B, chose to sell by period 45. Hence, your earned points are 7.56. The period in which this round ends and the earned points of each member are the same as in Case 1.

- Case 4: Suppose that you choose to sell the asset after period 51. Then, three members, A, B, and C, already chose to sell by period 50. Hence, this round ends in period 50.

You receive the true value 5.25, which is the same as the price in period 35, meaning that your earned points are 4.25. The other members receive the following earned points: A receives 4.25, B receives 7.56, C receives 9.92, and D receives 4.25.

Note that if you choose to sell in period 50, the timing to sell of the third member is the same as C's timing to sell. In this case, the probability that you receive 10.92, which is the price point in period 50, is one-half and the probability that you receive 5.25, which is the true value and the price in period 35, is one-half.

To test your understanding of the game, please answer the following quizzes. Note that the experiment will not begin until all participants have answered the quizzes correctly.

Asym: Please note that in the game after the quizzes, you cannot know the period in which the true value ceases to increase, other members' timings to sell, or whether you receive a signal earlier or later.

Sym: Please note that in the game after the quizzes, you cannot know other members' timings to sell.

If you have any questions during the experiment, please raise your hand.

A.1 Quizzes

Suppose that the true value of this asset ceases to increase in period 45. Then, among one group including you, suppose that A sells in period 45, B sells in period 50, C sells in period 55, and D sells in period 60. Answer the question by using the information provided in Table A-1.

- Q1: When do you receive a signal?

  Asym: There are two possible timings; so, fill in both blanks.

  Sym: Fill in the blank.

- Q2: Suppose that you choose to sell the asset in period 10 when the asset price is 1.55. When does this game end? What are your earned points?

- Q3: Suppose that you choose to sell the asset in period 50 when the asset price is 10.92. When does this game end? What are your earned points?

- Q4: Suppose that you choose to sell the asset in period 100 when the asset price is 125.24. When does this game end? What are your earned points?

B Questionnaires After the Experiment

1. First, write your seat number.

2. (Questions related to risk aversion developed by Holt and Laury, 2002)

   Which lottery do you prefer? Note that the following questions are not real. Your rewards will not be affected by your answers. There are 10 questions. Answer all the questions and then click "OK."

   (a) Lottery A gives 200 yen with probability 10% and 160 yen with probability 90%. Lottery B gives 385 yen with probability 10% and 10 yen with probability 90%.

   (b) Lottery A gives 200 yen with probability 20% and 160 yen with probability 80%. Lottery B gives 385 yen with probability 20% and 10 yen with probability 80%.

   (c) Lottery A gives 200 yen with probability 30% and 160 yen with probability 70%. Lottery B gives 385 yen with probability 30% and 10 yen with probability 70%.

   (d) Lottery A gives 200 yen with probability 40% and 160 yen with probability 60%. Lottery B gives 385 yen with probability 40% and 10 yen with probability 60%.

   (e) Lottery A gives 200 yen with probability 50% and 160 yen with probability 50%. Lottery B gives 385 yen with probability 50% and 10 yen with probability 50%.

   (f) Lottery A gives 200 yen with probability 60% and 160 yen with probability 40%. Lottery B gives 385 yen with probability 60% and 10 yen with probability 40%.

   (g) Lottery A gives 200 yen with probability 70% and 160 yen with probability 30%. Lottery B gives 385 yen with probability 70% and 10 yen with probability 30%.

   (h) Lottery A gives 200 yen with probability 80% and 160 yen with probability 20%. Lottery B gives 385 yen with probability 80% and 10 yen with probability 20%.

(i) Lottery A gives 200 yen with probability 90% and 160 yen with probability 10%. Lottery B gives 385 yen with probability 90% and 10 yen with probability 10%.

(j) Lottery A gives 200 yen with probability 100% and 160 yen with probability 0%. Lottery B gives 385 yen with probability 100% and 10 yen with probability 0%.

3. Do you think that your intellectual level is higher than that of the others? Choose one of the following choices:

   (a) Much higher than the others

   (b) Slightly higher than the others

   (c) Almost equivalent to the others

   (d) Slightly lower than the others

   (e) Much lower than the others

   (f) Unwilling to answer

4. (CRT developed by Frederick, 2005)

   (a) A bat and ball cost 110 yen. The bat costs 100 yen more than the ball. How much does the ball cost?

   (b) If it takes five machines 5 min to make five widgets, how long would it take 100 machines to make 100 widgets?

   (c) Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?

5. Questionnaires about the experiments

   (a) Did you understand the instructions for this experiment?

   (b) Was there anything unclear or any issues you noticed in the instructions of this experiment?

   (c) Did you understand how to make a decision on the computer screen?

(d) Please write freely any misleading aspects during the experiment if any.

(e) Explain your strategy during the experiment.

(f) **Asymmetric**: In the experiment, two types of participants received a signal earlier and later. Which type did you predict when you made a choice? How did you make that prediction?

(g) Did the choices made in previous rounds affect your strategy in the next round? If yes, explain how.

C Model with Five Players and Discrete Time

Time is discrete. There are 5 players, among which three are type-E and two are type-L, that is, $\alpha = 3/5$. The asset price at period t is $(1+g)^t$ similar to the setting of experiments. Denote $T(t_i)$ as a period that player i sells the asset given the timing to receive an asymmetric signal t_i.

Suppose all players choose the following mixed strategy:

$$T(t_i) = \begin{cases} t_i + \tau & \text{with prob } 1 - \sigma \\ t_i + \tau - \eta & \text{with prob } \sigma, \end{cases} \tag{3}$$

where $0 < \sigma < 1$. Define $\Pr(j, k, l|i)$ is the probability that the number of players who sell the asset at $t_0 + \tau - \eta$, $t_0 + \tau$, and $t_0 + \tau + \eta$, are j, k, and l, respectively, given the player's type i where $i = E$ or L. There are five players; hence, $j, k, l = 0, 1, \cdots, 4$, and $j + k + l = 4$ must be satisfied. Moreover, the timing to sell the asset should be $t_0 + \tau - \eta$, $t_0 + \tau$, or $t_0 + \tau + \eta$, given the mixed strategy (3). For example, $\Pr(0, 2, 2|E) = (1 - \sigma)^2(1 - \sigma)^2$ because, given that the player is type-E, there are other two type-E and two type-L players. The probability that other two type-E players sell at $t_0 + \tau$ equals $(1 - \sigma)^2$. Similarly, the probability that two type-L players sell at $t_0 + \tau + \eta$ equals $(1 - \sigma)^2$. When the player is type-E, there are $(2+1)\cdot(2+1) = 9$ possible cases as follows.

$$\Pr(0,2,2|E) = (1-\sigma)^2(1-\sigma)^2,$$
$$\Pr(0,3,1|E) = (1-\sigma)^2 2(1-\sigma)\sigma,$$
$$\Pr(0,4,0|E) = (1-\sigma)^2\sigma^2,$$
$$\Pr(1,1,2|E) = 2(1-\sigma)\sigma(1-\sigma)^2,$$
$$\Pr(1,2,1|E) = 2(1-\sigma)\sigma 2(1-\sigma)\sigma,$$
$$\Pr(1,3,0|E) = 2(1-\sigma)\sigma\sigma^2,$$
$$\Pr(2,0,2|E) = \sigma^2(1-\sigma)^2,$$
$$\Pr(2,1,1|E) = \sigma^2 2(1-\sigma)\sigma,$$
$$\Pr(2,2,0|E) = \sigma^2\sigma^2.$$

When the player is type-L, there are $(2+2)\cdot 2 = 8$ cases as follows.

$$\Pr(0,3,1|L) = (1-\sigma)^3(1-\sigma),$$
$$\Pr(0,4,0|L) = (1-\sigma)^3\sigma,$$
$$\Pr(1,2,1|L) = 3(1-\sigma)^2\sigma(1-\sigma),$$
$$\Pr(1,3,0|L) = 3(1-\sigma)^2\sigma\sigma,$$
$$\Pr(2,1,1|L) = 3(1-\sigma)\sigma^2(1-\sigma),$$
$$\Pr(2,2,0|L) = 3(1-\sigma)\sigma^2\sigma,$$
$$\Pr(3,0,1|L) = \sigma^3(1-\sigma),$$
$$\Pr(3,1,0|L) = \sigma^3\sigma.$$

Denote $E_{T(t_i)-t_i}$ the expected payoff when a player sells the asset at $T(t_i)$. There are nine possible cases. The first two cases are included in the mixed strategy (3).

(i) When the player sells it at $t_i + \tau$, the expected payoff equals

$$E_\tau = \alpha \left\{ \begin{array}{c} \Pr(0,2,2|E) \cdot 1 + \Pr(0,3,1|E) \cdot 3/4 + \Pr(0,4,0|E) \cdot 3/5 \\ + \Pr(1,1,2|E) \cdot 1 + \Pr(1,2,1|E) \cdot 2/3 + \Pr(1,3,0|E) \cdot 2/4 \\ + \Pr(2,0,2|E) \cdot 1 + \Pr(2,1,1|E) \cdot 1/2 + \Pr(2,2,0|E) \cdot 1/3 \end{array} \right\} (1+g)^{t_i+\tau}$$
$$+ \alpha \left\{ \begin{array}{c} \Pr(0,2,2|E) \cdot 0 + \Pr(0,3,1|E) \cdot 1/4 + \Pr(0,4,0|E) \cdot 2/5 \\ + \Pr(1,1,2|E) \cdot 0 + \Pr(1,2,1|E) \cdot 1/3 + \Pr(1,3,0|E) \cdot 2/4 \\ + \Pr(2,0,2|E) \cdot 0 + \Pr(2,1,1|E) \cdot 1/2 + \Pr(2,2,0|E) \cdot 2/3 \end{array} \right\} (1+g)^{t_i}$$
$$+ (1-\alpha)(1+g)^{t_i-\eta}.$$

(ii) When the player sells it at $t_i + \tau - \eta$, the expected payoff equals

$$E_{\tau-\eta} = \alpha(1+g)^{t_i+\tau-\eta}$$
$$+ (1-\alpha) \left\{ \begin{array}{c} \Pr(0,3,1|L) \cdot 3/4 + \Pr(0,4,0|L) \cdot 3/5 \\ + \Pr(1,2,1|L) \cdot 2/3 + \Pr(1,3,0|L) \cdot 2/4 \\ + \Pr(2,1,1|L) \cdot 1/2 + \Pr(2,2,0|L) \cdot 1/3 \\ + \Pr(3,0,1|L) \cdot 0 + \Pr(3,1,0|L) \cdot 0 \end{array} \right\} (1+g)^{t_i+\tau-\eta}$$
$$+ (1-\alpha) \left\{ \begin{array}{c} \Pr(0,3,1|L) \cdot 1/4 + \Pr(0,4,0|L) \cdot 2/5 \\ + \Pr(1,2,1|L) \cdot 1/3 + \Pr(1,3,0|L) \cdot 2/4 \\ + \Pr(2,1,1|L) \cdot 1/2 + \Pr(2,2,0|L) \cdot 2/3 \\ + \Pr(3,0,1|L) \cdot 1 + \Pr(3,1,0|L) \cdot 1 \end{array} \right\} (1+g)^{t_i-\eta}.$$

The remaining seven cases are possible deviations from the mixed strategy (3). Suppose that γ is an integer in the following parts.

(iii) When the player sells it at $t_i + \tau - 2\eta - \gamma$ where $\gamma > 0$, the expected payoff equals

$$E_{\tau-2\eta-\gamma} = (1+g)^{t_i+\tau-2\eta-\gamma},$$

and $\gamma = 1$ yields the highest payoff.

(iv) When the player sells it at $t_i + \tau - 2\eta$, the expected payoff equals

$$
\begin{aligned}
E_{\tau-2\eta} &= \alpha(1+g)^{t_i+\tau-2\eta} \\
&\quad + (1-\alpha)\left\{\begin{array}{c} \Pr(0,3,1|L)\cdot 1 + \Pr(0,4,0|L)\cdot 1 \\ +\Pr(1,2,1|L)\cdot 1 + \Pr(1,3,0|L)\cdot 1 \\ +\Pr(2,1,1|L)\cdot 1 + \Pr(2,2,0|L)\cdot 1 \\ +\Pr(3,0,1|L)\cdot 3/4 + \Pr(3,1,0|L)\cdot 3/4 \end{array}\right\}(1+g)^{t_i+\tau-2\eta} \\
&\quad + (1-\alpha)\left\{\begin{array}{c} \Pr(0,3,1|L)\cdot 0 + \Pr(0,4,0|L)\cdot 0 \\ +\Pr(1,2,1|L)\cdot 0 + \Pr(1,3,0|L)\cdot 0 \\ +\Pr(2,1,1|L)\cdot 0 + \Pr(2,2,0|L)\cdot 0 \\ +\Pr(3,0,1|L)\cdot 1/4 + \Pr(3,1,0|L)\cdot 1/4 \end{array}\right\}(1+g)^{t_i-\eta}.
\end{aligned}
$$

(v) When the player sells it at $t_i + \tau - \eta - \gamma$ where $0 < \gamma < \eta$, the expected payoff equals

$$
\begin{aligned}
E_{\tau-\eta-\gamma} &= \alpha(1+g)^{t_i+\tau-\eta-\gamma} \\
&\quad + (1-\alpha)\left\{\begin{array}{c} \Pr(0,3,1|L)\cdot 1 + \Pr(0,4,0|L)\cdot 1 \\ +\Pr(1,2,1|L)\cdot 1 + \Pr(1,3,0|L)\cdot 1 \\ +\Pr(2,1,1|L)\cdot 1 + \Pr(2,2,0|L)\cdot 1 \\ +\Pr(3,0,1|L)\cdot 0 + \Pr(3,1,0|L)\cdot 0 \end{array}\right\}(1+g)^{t_i+\tau-\eta-\gamma} \\
&\quad + (1-\alpha)\left\{\begin{array}{c} \Pr(0,3,1|L)\cdot 0 + \Pr(0,4,0|L)\cdot 0 \\ +\Pr(1,2,1|L)\cdot 0 + \Pr(1,3,0|L)\cdot 0 \\ +\Pr(2,1,1|L)\cdot 0 + \Pr(2,2,0|L)\cdot 0 \\ +\Pr(3,0,1|L)\cdot 1 + \Pr(3,1,0|L)\cdot 1 \end{array}\right\}(1+g)^{t_i-\eta},
\end{aligned}
$$

and $\gamma = 1$ yields the highest expected payoff.

(vi) When the player sells it at $t_i + \tau - \gamma$ where $0 < \gamma < \eta$, the expected payoff equals

$$
\begin{aligned}
E_{\tau-t_i+\tau-\gamma} &= \alpha(1+g)^{t_i+\tau-\gamma} \\
&\quad +(1-\alpha)(1+g)^{t_i-\eta},
\end{aligned}
$$

where $\gamma = 1$ yields the highest expected payoff.

(vii) When the player sells it at $t_i + \tau + \gamma$ where $0 < \gamma < \eta$, the expected payoff equals

$$E_{\tau+\gamma} = \alpha \left\{ \begin{array}{c} \Pr(0,2,2|E) \cdot 1 + \Pr(0,3,1|E) \cdot 0 + \Pr(0,4,0|E) \cdot 0 \\ + \Pr(1,1,2|E) \cdot 1 + \Pr(1,2,1|E) \cdot 0 + \Pr(1,3,0|E) \cdot 0 \\ + \Pr(2,0,2|E) \cdot 1 + \Pr(2,1,1|E) \cdot 0 + \Pr(2,2,0|E) \cdot 0 \end{array} \right\} (1+g)^{t_i+\tau+\gamma}$$
$$+\alpha \left\{ \begin{array}{c} \Pr(0,2,2|E) \cdot 0 + \Pr(0,3,1|E) \cdot 1 + \Pr(0,4,0|E) \cdot 1 \\ + \Pr(1,1,2|E) \cdot 0 + \Pr(1,2,1|E) \cdot 1 + \Pr(1,3,0|E) \cdot 1 \\ + \Pr(2,0,2|E) \cdot 0 + \Pr(2,1,1|E) \cdot 1 + \Pr(2,2,0|E) \cdot 1 \end{array} \right\} (1+g)^{t_i}$$
$$+(1-\alpha)(1+g)^{t_i-\eta},$$

and $\gamma = \eta - 1$ yields the highest expected payoff.

(viii) When the player sells it at $t_i + \tau + \eta$, the expected payoff equals

$$E_{\tau+\eta} = \alpha \left\{ \begin{array}{c} \Pr(0,2,2|E) \cdot 1/3 + \Pr(0,3,1|E) \cdot 0 + \Pr(0,4,0|E) \cdot 0 \\ + \Pr(1,1,2|E) \cdot 1/3 + \Pr(1,2,1|E) \cdot 0 + \Pr(1,3,0|E) \cdot 0 \\ + \Pr(2,0,2|E) \cdot 1/3 + \Pr(2,1,1|E) \cdot 0 + \Pr(2,2,0|E) \cdot 0 \end{array} \right\} (1+g)^{t_i+\tau+\eta}$$
$$+\alpha \left\{ \begin{array}{c} \Pr(0,2,2|E) \cdot 2/3 + \Pr(0,3,1|E) \cdot 1 + \Pr(0,4,0|E) \cdot 1 \\ + \Pr(1,1,2|E) \cdot 2/3 + \Pr(1,2,1|E) \cdot 1 + \Pr(1,3,0|E) \cdot 1 \\ + \Pr(2,0,2|E) \cdot 2/3 + \Pr(2,1,1|E) \cdot 1 + \Pr(2,2,0|E) \cdot 1 \end{array} \right\} (1+g)^{t_i}$$
$$+(1-\alpha)(1+g)^{t_i-\eta}.$$

(ix) When the player sells it at $t_i + \tau + \eta + \gamma$ where $\gamma > 0$, the expected payoff equals

$$E_{\tau+\eta+\gamma} = \alpha(1+g)^{t_i} + (1-\alpha)(1+g)^{t_i-\eta}.$$

It is clear that $E_{\tau+\eta+\gamma} < E_{\tau+\eta}$, so case (ix) does not bind.

In order to be a perfect Bayesian equilibrium, the following conditions must be satisfied.

$$\begin{aligned} E_\tau &= E_{\tau-\eta}, \\ &\geq \max\left[E_{\tau-2\eta-\gamma}, E_{\tau-2\eta}, E_{\tau-\eta-\gamma}, E_{\tau-\gamma}, E_{\tau+\gamma}, E_{\tau+\eta}, E_{\tau+\eta+\gamma}\right]. \end{aligned}$$

However, in order to be an ϵ- (perfect Bayesian) equilibrium, the conditions can be relaxed as follows: For $\epsilon > 0$,

$$\begin{aligned} E_\tau &= E_{\tau-\eta}, \\ &\geq \max\left[E_{\tau-2\eta-\gamma}, E_{\tau-2\eta}, E_{\tau-\eta-\gamma}, E_{\tau-\gamma}, E_{\tau+\gamma}, E_{\tau+\eta}, E_{\tau+\eta+\gamma}\right] - \epsilon, \end{aligned}$$

If ϵ converges to zero, ϵ-equilibrium becomes a perfect Bayesian equilibrium. To grasp an intuition about the degree of ϵ, we normalize ϵ by dividing it by $E_\tau - E_{\tau=0}$ in Figure 2. This term shows how much agents expect to increase their payoff by choosing their mixed strategy, compared with the strategy that agents sell their stock immediately after they receive an asymmetric signal at t_i. If $\epsilon = 0.05$, this implies that agents should pay 5% of this increase in their expected payoff by a deviation.

Figure 2 shows the numerical computations by supposing $g = 0.05$. The mixed strategy (3) is a perfect Bayesian equilibrium when $\eta = 2$ or 3, whereas it is ϵ-equilibrium with $\epsilon = 0.05$ when $\eta = 2$ to 4 and $\epsilon = 0.1$ when $\eta = 2$ to 6.

D Definitions of the Variables

- *Asym 5*: Dummy variable that takes the value of 1 when the session has an asymmetric signal and type-L receives a signal five periods later than the period in which the true value ceases to increase. This includes both the baseline sessions and the first 14 rounds of the extended sessions.

- *Asym 2*: Dummy variable that takes the value of 1 when the session has an asymmetric signal and type-L receives a signal two periods later than the period in which the true value ceases to increase.

- *Sym*: Dummy variable that takes the value of 1 when the session has a symmetric signal. This includes both the baseline sessions and the first 14 rounds of the extended sessions.

- *Asym 5 extended*: Dummy variable that takes the value of 1 when the session has an asymmetric signal and type-L receives a signal five periods later than the period in which the true value ceases to increase. This includes only the last 19 rounds of the extended session.

- *Sym extended*: Dummy variable that takes the value of 1 when the session has a symmetric signal. This includes only the last 24 rounds of the extended session.
- t_0: The period in which the true value ceases to increase.
- *Round*: The round number.
- *Intelligence*: Answer for Q3 of the questionnaires. Higher values indicate that subjective intellectual level is lower (1 to 5).
- *CRT*: Answer for Q4 of the questionnaires. Higher values indicate that the score on the CRT test is higher (0 to 3).
- *Risk Attitude*: Answer for Q2 of the questionnaires. Higher values indicate that subjects are more risk averse.
- *Test Time*: The length, in time, that a subject spends solving the practice questions before the experiment. Higher values indicate that subjects spent less time on the practice questions.
- *lag Win*: Dummy variable that takes the value of 1 when a subject sold before the bubble crashed in the previous round.

Table 1: Summary of Experimental Sessions

Session	1	2	3	4	5	6	7
Date	2015/11/20	2015/11/20	2016/1/22	2016/1/27	2016/1/29	2016/3/2	2016/4/27
Signal	Asymmetric	Symmetric	Asymmetric	Asymmetric	Symmetric	Symmetric	Asymmetric
η	5		2	5			5
Group members	5	5	5	5	5	5	5
Rounds (r)	14	14	14	14	14	14+24	14+19
Age (average)	20.67	20.96	20.83	21.3	20.8	20.53	19.5
Female	11	9	13	7	10	9	14
Silent mouse	No	No	Yes	Yes	Yes	Yes	Yes
Time limit (sec)	5	5	5	5	5	2	2
Profit (average)	¥1,896	¥1,924	¥1,851	¥1,862	¥1,930	¥3,376	¥3,094

Table 2: Stream of the Values of t_0

First 14 rounds

Round		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
t_0		11	17	12	7	50	23	19	10	11	20	39	36	29	7

Last 19 or 24 rounds (used in sessions 6 and 7)

Round	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
t_0	7	6	2	32	17	20	10	13	15	10	29	37	14	9

Round	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
t_0	13	22	5	14	10	23	15	3	11	15

Table 3: Descriptive Statistics of *Delay*

	Mean	Std. Dev.	Min.	Max.	Obs.
Asym 5	3.5	5.8	–47	16	789
Asym 2	3.8	3.6	–18	15	283
Sym	4.9	4.2	–42	19	856
Asym 5 extended	3.5	2.3	–8	10	354
Sym extended	2.0	1.2	–12	7	554

Note: *Delay* represents the duration for which a subject waits until he or she sells an asset. The variable is counted only for subjects who actually sell the asset at or before the point of the bubble crashing. A unit of time is a period.

Table 4: Interval Regression of *Delay*

	Mean	Std. Err.	Obs.
Asym 5	6.02	0.21	1260
Asym 2	5.64	0.24	420
Sym	7.14	0.16	1260
Asym 5 extended	4.17	0.12	570
Sym extended	2.57	0.07	720

Table 5: Test for Differences with Upper Bounds

	First 14 rounds (a)	First 14 rounds (b)	Last 19 or 24 rounds
Sym	1.48**	3.66**	–1.41**
	(0.24)	(0.46)	(0.13)
Asym 2	0.20	1.50**	
	(0.34)	(0.64)	
t_0		–0.15**	
		(0.01)	
Round (*r*)		–0.03	
		(0.04)	
r ×*Sym*		–0.28**	
		(0.05)	
r ×*Asym 2*		–0.17**	
		(0.08)	
c	5.78**	8,81**	4.06**
	(0.18)	(0.35)	(0.10)

Note: Standard errors are in parentheses. ** indicates significance at 5% level.
The dependent variable is the duration of holding an asset. The independent variables, *Sym* and *Asym 2*, take the value of 1 when a session is *Sym* and *Asym 2,* respectively.

Table 6: Interval Regression

	Asym 5	*Asym 2*	*Sym*	*Asym 5 extended*	*Sym extended*
t_0	0.03	–0.21**	–0.14**	–0.25**	–0.09**
	(0.06)	(0.06)	(0.05)	(0.05)	(0.02)
Round (r)	–0.05	0.06	–0.69**	0.05	–0.18**
	(0.224)	(0.25)	(0.18)	(0.11)	(0.03)
t_0^2	–0.004**	0.002	0.001	0.004**	0.0010**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.0005)
r^2	0.003	–0.015	0.023**	–0.002	0.002
	(0.014)	(0.015)	(0.011)	(0.005)	(0.001)
Female	–0.62	–0.43	–0.92**	–0.86**	–0.07
	(0.38)	(0.42)	(0.31)	(0.28)	(0.12)
Age	0.45**	0.37**	0.02	0.10	–0.00
	(0.11)	(0.12)	(0.08)	(0.10)	(0.03)
Intelligence	–0.50**	0.51**	–0.19	–0.24	–0.02
	(0.17)	(0.24)	(0.15)	(0.13)	(0.06)
CRT	0.15	0.13	–0.03	–0.26**	–0.10
	(0.19)	(0.19)	(0.14)	(0.10)	(0.05)

Table 6 continued

	Asym 5	*Asym 2*	*Sym*	*Asym 5 extended*	*Sym extended*
Risk attitude	0.03	–0.07	–0.01	0.05	–0.09**
	(0.07)	(0.07)	(0.06)	(0.05)	(0.02)
Test time	0.0048**	0.0048**	0.0000	–0.0001	–0.0003
	(0.0015)	(0.0014)	(0.0010)	(0.0011)	(0.0004)
Lag Win	0.72**	–0.12	0.66**	0.55**	–0.12
	(0.33)	(0.37)	(0.26)	(0.21)	0.10
c	0.14	1.38	13.10**	5.34**	6.07**
	(2.45)	(2.78)	(2.01)	(2.08)	(0.82)

Note: Standard errors are in parentheses. ** denotes 5% significance.
The dependent variable is the duration of holding an asset.
See Appendix C for detailed variable definitions.

Table A-1: Change in the Asset Price

Period	1	2	3	4	5	10	15	20	25
Asset price	1.00	1.05	1.10	1.16	1.22	1.55	1.98	2.53	3.23
Earned points	0.00	0.05	0.10	0.16	0.22	0.55	0.98	1.53	2.23

Period	30	35	40	45	50	55	60	100	200
Asset price	4.12	5.25	6.70	8.56	10.92	13.94	17.80	125.24	16469.12
Earned points	3.12	4.25	5.70	7.56	9.92	12.94	16.80	124.24	16468.12

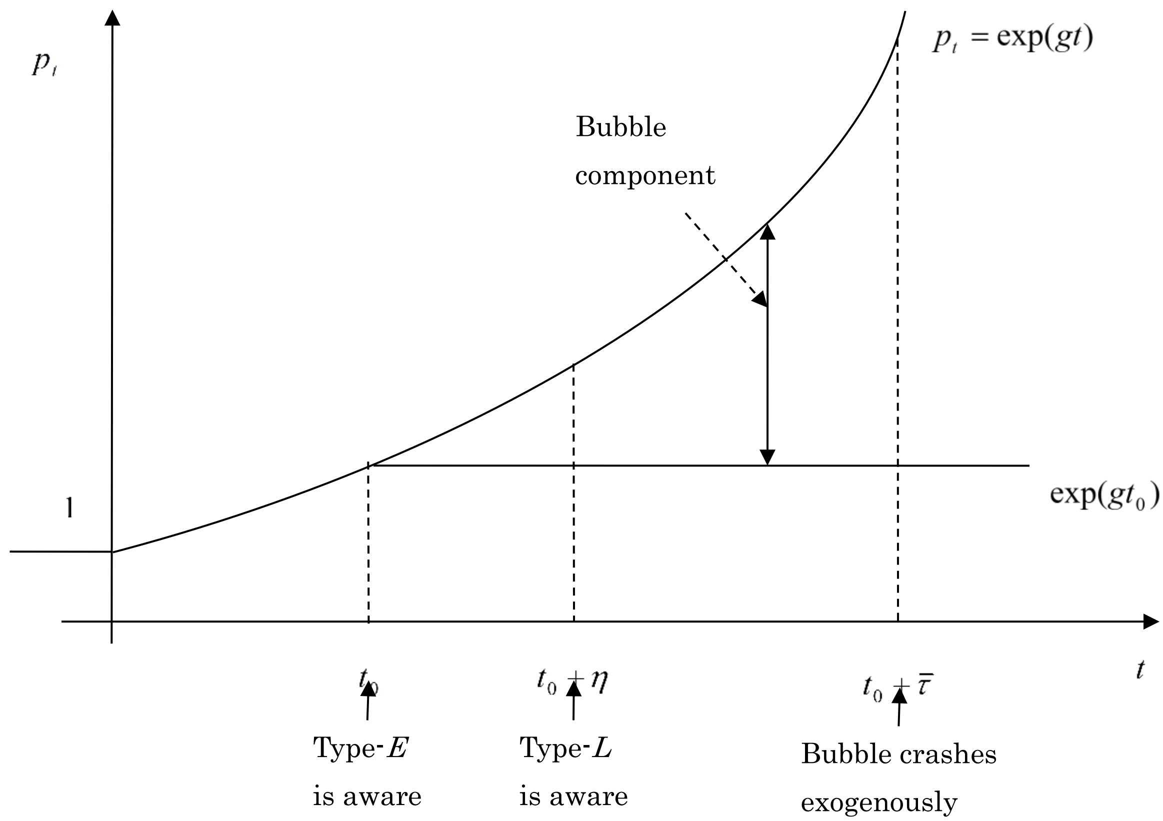
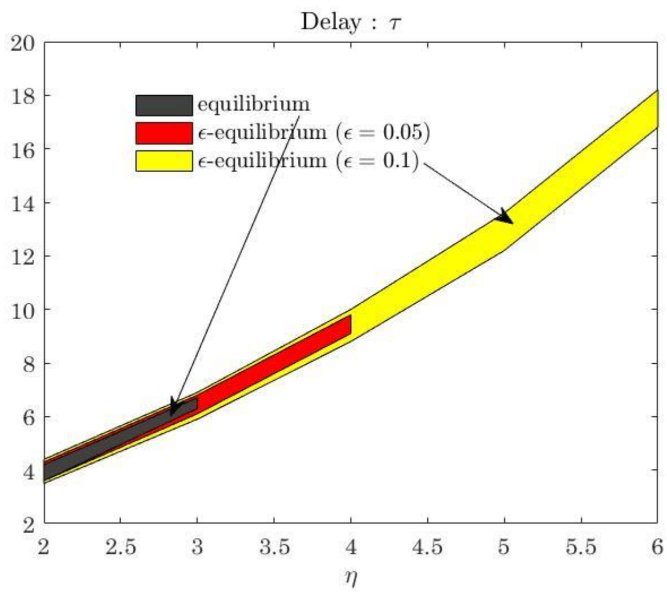
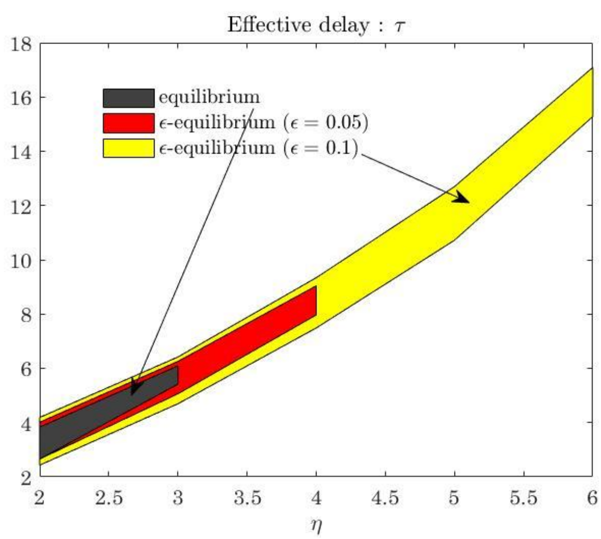


Figure 1: Riding-bubble Model



(a) The Value of τ



(b) The Expected Value: $(\sigma(\tau - \eta) + (1 - \sigma)\tau)$

Figure 2 The Duration of Holding an Asset in a Mixed-strategy Equilibrium

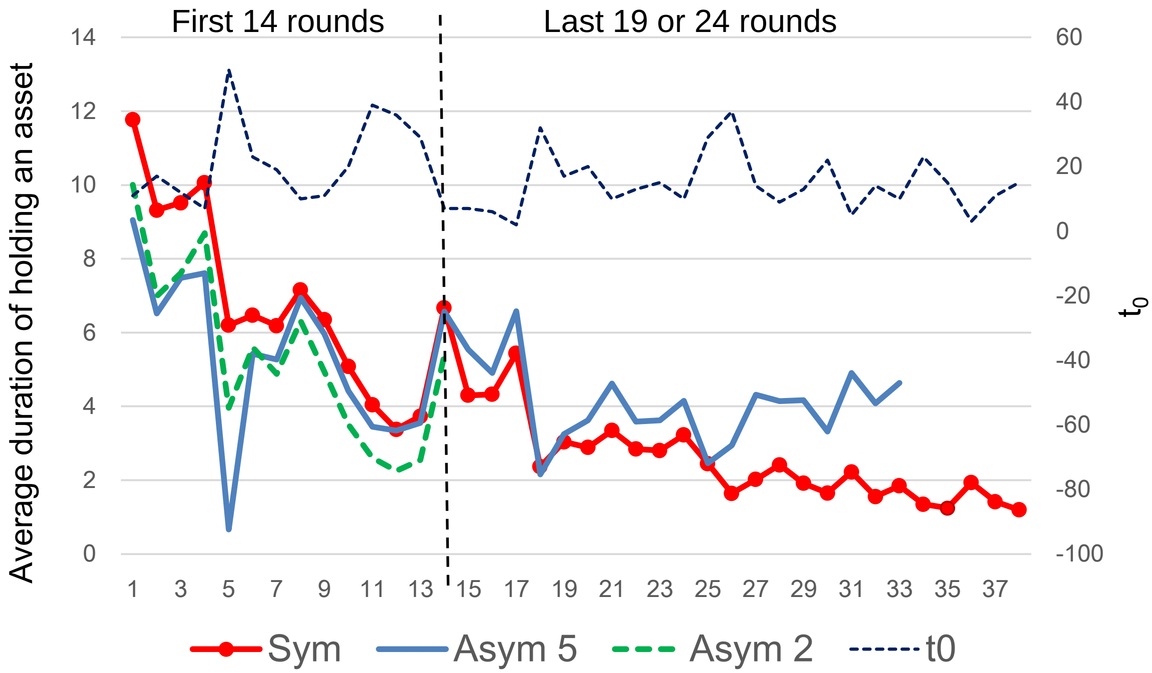


Figure 3: Average Duration of Holding an Asset after a Signal (τ)

Figure A-1: At the Beginning of Each Round

The current period is ***.
The asset price is 1.0000.

Your earned points are those earned after deducting the point you paid to buy this asset.

Figure A-2 (a): After You Receive an Asymmetric Signal

The current period is ***.
The asset price is 5.0000.
The possible minimum true value is 4.8769.
The possible maximum true value is 5.0000.

Your earned points are those earned after deducting the point you paid to buy this asset.

Figure A-2 (b): After You Receive a Symmetric Signal

The current period is ***.
The asset price is 5.0000.
The true value is 5.0000.

Your earned points are those earned after deducting the point you paid to buy this asset.

Figure A-3: After You Choose to Sell or One Round is Complete

The current period is ***.
The asset price is 1.0000.
Please click OK.

Figure A-4: After All Groups Complete One Round

This round is finished.
The true value was 1.0000.
You sell the asset at price 1.0000.
Your earned points in this round are 0.0000.
Your cumulative earned points for all rounds are 0.0000.
The earned points of all five group members, including you, are as follows.
0.0000…
We move into the next round after the group members are randomly re-matched.
Please click OK.