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Yasushi Asako
Waseda University

Yukihiko Funaki
Waseda University

Kozo Ueda
Waseda University and
Centre for Applied Macroeconomic Analysis, ANU

Nobuyuki Uto
Waseda University

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Keywords

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

JEL Classification

C72, D82, D84, E58, G12, G18

Address for correspondence:

(E) cama.admin@anu.edu.au

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Symmetric Information Bubbles: Experimental Evidence*

Yasushi Asako[†], Yukihiro Funaki[‡], Kozo Ueda[§], and Nobuyuki Uto[¶]

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This study experimentally analyzes traders' choices, with and without asymmetric information, based on the riding-bubble model. While asymmetric information has been necessary to explain a bubble in past theoretical models, our experiments show that traders have an incentive to hold a bubble asset for longer, thereby expanding the bubble in a market with symmetric, rather than asymmetric information. This finding implies a possibility that information symmetry promotes cooperation. However, when traders are more experienced, the size of the bubble decreases, in which case bubbles do not arise, even with symmetric information.

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[†]Waseda University (yasushi.asako@waseda.jp)

[‡]Waseda University (funaki@waseda.jp)

[§]Waseda University and Centre for Applied Macroeconomic Analysis (CAMA) (kozo.ueda@waseda.jp)

[¶]Waseda University (nobuyuki.uto@gmail.com)

1 Introduction

History is rife with examples of bubbles and bursts (see Kindleberger and Aliber [2011]). A prime example of a bubble bursting is the recent financial crisis that started in the 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. Classically, bubbles are explained 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 expectation are given exogenously. Therefore, these studies overlook individuals' strategies. Recently, however, several models have shown that investors hold a bubble asset because they believe they can sell it at a higher price in future. These models focus on the microeconomic aspect of bubbles, assuming asymmetric information. Therefore, according to these studies, the existence of asymmetric information is needed in order to explain bubbles.¹ Indeed, Brunnermeier (2001) states that “(w)hereas almost all bubbles can be ruled out in a 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)

This study experimentally analyzes traders' choices, with and without asymmetric information. In contrast to past theoretical predictions, we show that traders have an incentive to hold a bubble asset for longer, thereby expanding the bubble in a market with symmetric, rather than asymmetric information. Therefore, the elimination of asymmetric information can generate or expand a bubble.

Our experiments are based on the seminal and tractable “riding-bubble model” of Abreu

¹However, 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] and 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]).

and Brunnermeier (2003) and Asako and Ueda (2014), which shows that a bubble arises with asymmetric information. In this 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 private signal, but the timing of this differs among investors (i.e., some investors become aware of the bubble earlier than others), which is a source of asymmetric information. Thus, although they notice that the bubble has already occurred, they do not know its true starting point. Therefore, there exists a trade-off for an investor by selling earlier: while she may be able to sell before the bubble bursts, she forgoes the chance of selling the asset at a higher price. Based on such a trade-off, investors have an incentive to keep the asset for a certain period after they receive a private signal. In equilibrium, investors may keep their assets, even though they know that other investors are also aware of the bubble. In contrast, if all investors know the true starting point of the bubble, because of a public signal, they will all try to sell the asset before the others do. Thus, there is no longer an incentive to keep the asset after a public signal, in which case, the bubble bursts immediately. Thus, the model predicts that investors have a higher incentive to ride a bubble after receiving a private signal (asymmetric information) than they do after receiving a public signal (symmetric information).

To test the model, we run a series of experiments designed to examine the behavioral validity of asymmetric and symmetric information. To the best of our knowledge, this study is the first to compare these two information structures in a bubble experiment. In the experiment, we focus on the bubble duration, that is, how long subjects hold the asset after receiving either a private or a public signal.

We find that, contrary to the theoretical predictions, the duration of holding an asset is longer after a public signal than it is after a private signal, in the early rounds. However, after subjects play the game several times, the duration of holding an asset after a public signal becomes shorter than that after a private signal. In contrast, this duration does not change over time in the case of a private signal. These findings imply a possibility that subjects have an incentive to cooperate in the case of symmetric information, as is pointed out in the experiments of the centipede game by, for example, McKelvey and Palfrey (1992). On the other hand, subjects do not coordinate and rush to sell in the case of asymmetric information.

This is in line with the findings of experiments on an asymmetric prisoner’s dilemma by, for example, Ahn et al. (2007). In order to examine the importance of cooperation, we increase the number of players in a group in our experiments. We expect to see it becomes more difficult for subjects to cooperate as the number of players increases, which will shorten the bubble duration. Our experiments show that the duration of holding an asset after a public signal decreases dramatically after we increase the number of players.

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 experiment design, and Section 4 describes the results of those experiments. We interpret our findings in Section 5, before concluding the paper in Section 6.

1.1 Related Literature

Experimental studies of bubbles were pioneered by Smith, Suchanek, and Williams (1988), who considered a double-auction market in several periods for an asset with random dividends. Traders do not know the dividend amount in each period, but they know its probability distribution and, hence, face symmetric information. Most subsequent studies have been based on this experimental asset market.² These studies show that bubbles often arise, although they tend to disappear when subjects continue to play and learn about the game. In these settings, subjects do not have asymmetric information, which means that, theoretically, bubbles never arise in equilibrium.

Two experimental studies have compared different information structures in the same

²Past 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 Ruffleux [2001]), and with lottery-like (i.e., riskier) assets (Ackert et al. [2006]). In contrast, bubbles tend not to arise: when traders receive dividends only once (Smith, Van Boening, and Wellford [2000]), when subjects are knowledgeable about financial markets (Ackert and Church [2001]), when some (although not all) traders are experienced (Dufwenberg, Lindqvist, and Moore [2005]), with low initial liquidity (Caginalp, Porter, and Smith [2001]), when there are futures markets (Porter and Smith [1995]), when short sales are allowed (Ackert et al. [2006], Haruvy and Noussair [2006]), and when there is only one chance to sell (Ackert et al. [2009]).

way that we compare the symmetric and asymmetric information settings. First, Porter and Smith (1995), whose study is also based on that of Smith, Suchanek, and Williams (1988), consider the cases of random dividends and certain dividends (i.e., cases with risk and with certainty). They show that bubbles can arise in both information structures, even though they never arise in equilibrium in either case. Second, Moinas and Pouget (2013) propose “the bubble game,” which is similar to the three-player centipede game, in which players’ timing of play is decided randomly. In this game, players decide whether to buy an asset at a price above the true value in order to try to resell it to the next player. If a player is the last (third) player to buy, she is never able to resell. In this case, she should not buy the asset. Moinas and Pouget (2013) consider two cases: (i) players have a chance of knowing they are the last player; and (ii) there is no such chance. Theoretically, bubbles never arise in equilibrium in the first case, but can do so in the second case. Contrary to the theoretical predictions, they find that bubbles can arise in both cases. However, unlike our model, theirs introduces asymmetric information in both cases and, thus, they do not compare the consequences with and without asymmetric information.³

The riding-bubble model with asymmetric information is also supported by the experimental findings of Brunnermeier and Morgan (2010).⁴ We conduct experiments using the riding-bubble model, both with and without asymmetric information. Our experiments show that bubbles can arise in the riding-bubble model in both information structures. Moreover, we show that the size of bubbles is larger after a public signal than it is after a private signal. Brunnermeier and Morgan’s (2010) experiment does not include symmetric information.

Finally, our study is also related to that of Morris and Shin (2002). Using a model with strategic complementarity, the authors demonstrate that agents overreact to public information and underreact to private information. These differing reactions to public and private information are further studied in experiments by, for example, Ackert, Church, and Gillette (2004), Middeldorp and Rosenkranz (2011), Dale and Morgan (2012), and Cornand and Heinemann (2014).

³In their model, players receive a different price for the asset, which is the source of the asymmetric information. Moinas and Pouget (2013) provide a detailed discussion on the similarities and differences between the riding-bubble model and their bubble game (p.1952).

⁴Brunnermeier and Morgan (2010) call this game “the clock game.”

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 labeled $t \in \mathfrak{R}$. Figure 1 depicts 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 $t_0 = 0, \eta, 2\eta, 3\eta \dots$, where $\eta > 0$ and that it obeys the geometric distribution with a probability function 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 they hold an asset, investors 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

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

⁶Price $\exp(gt)$ 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.

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, she receives the price in the selling period ($\exp(gt)$). If not, she only receives 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 private information; this case is studied in Abreu and Brunnermeier (2003). To be precise, a private signal informs them that the true value is below the asset price (i.e., a bubble has occurred). The signal, however, does not provide any information about the true timing of bubble occurrence t_0 . Two types of investors exist. A proportion β of them are early-signal agents (type- E), while the rest, namely, $1 - \beta$, are late-signal agents (type- L). We denote their types by $i = E, L$. Type- i investors receive a private 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 Figure 1 shows. These investors hold an asset in period 0. Once an investor receives her private signal at time t_i , 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 , she knows that the asset price is above the true value, but she does not know 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 meanings: it indicates (i) the proportion of type- E investors and (ii) the proportion of investors that would cause the bubble to burst endogenously were they 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 a private signal since 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 public signal, which informs them of the true t_0 .

We denote the duration of holding an asset after receiving a (either public or private) signal by $\tau \geq 0$. That is, investor i sells it at $t_i + \tau$. Rational investors never sell an asset

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

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

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

until t_0 .

2.2 Model Predictions

This model yields the following prediction.

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

With a public signal, the size of the bubble is zero since all players know t_0 . Because t_0 is known by all investors, they prefer to sell earlier than others in order to receive a higher price with higher probability; hence, they sell an asset as soon as possible after a public signal is received. On the contrary, with a private signal, the size of the bubble can be large. In particular, investors may hold the asset even after both types of investors receive the private 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 $t_i + \tau$, she may be able to sell before the bubble bursts at price $\exp(g(t_i - \eta + \tau))$. However, with this deviation, she needs to forgo the chance of selling the asset at a higher price $\exp(g(t_0 + \tau))$ with probability α . Based on 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 satisfies for any $\tau \leq \min\{\tau^*, \bar{\tau}\}$ where τ^* satisfies

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

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 public 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.

In our experiments, we suppose $\alpha = 3/5$, $g = 0.05$, and two values of η , 2 and 5. With these parameter values, the theoretically predicted (maximum) durations of holding an asset τ^* are about 4 and 12 with $\eta = 2$ and $\eta = 5$, respectively.

3 Experimental Design

3.1 Nature of the Experiment

Eight experimental sessions were conducted at Waseda University in Japan during fall 2015 and spring 2016 (see Table 1). Thirty subjects participated in each session, and they appeared in only one session each. Subjects were divided into six groups constituted by five members in sessions 1–7. Session 8 is explained in Section 5. Subjects 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 members changed in each round.

[Table 1 Here]

One session consists of several rounds. Each round includes several periods, and it 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 the period in which to sell this asset (i.e., the timing to sell). At the beginning of each round, the *asset price* begins at 1 point and increases by 5% in each period ($g \doteq 0.05$). 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 ($\lambda \doteq 0.05$). To compare subjects' choices between the two types of information structures, we use the identical stream of the values of t_0 listed in Table 2 for all sessions and all six groups.

[Table 2 Here]

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 two experimental conditions:

- *Private η* : Among the five members of the group, three members receive a signal in the period in which the true value ceases to increase. They are type-*E*, and $\alpha = 3/5$. On the contrary, the remaining two members are type-*L*, who receive a signal at η periods later than the period in which the true value ceases to increase. We tell subjects two possible true values: the maximum value (i.e., the true value if a subject is type-*E*) and the minimum value (i.e., the true value if a subject is type-*L*). Depending on the session, the value of η is either 2 or 5. We call a session *Private 2* and *Private 5* with $\eta = 2$ and $\eta = 5$, respectively.
- *Public*: All subjects receive a signal at t_0 , and we tell 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 a point that is the same as the price in the selling period (*price point*). Otherwise, subjects receive a point that is the same as 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, while the remaining two members receive the true value.

3.2 Differences From Theory

Because of the constraints in our experimental environment, we change some of the settings from Asako and Ueda (2014) discussed in Section 2. First, while Asako and Ueda (2014) consider an infinite number of investors, we consider finite N investors. Moreover, 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. This extreme assumption is not critical in Asako and

Ueda (2014) since they consider an infinite number of investors, and a deviation of one player does not change the timing of the bubble crash. In our experiments, which consider a finite number of investors, however, we assume that if more than α of the investors sell assets at the same time, the randomly chosen investors receive the true value, while the others receive a price in the selling period. Second, while Asako and Ueda (2014) consider continuous time periods, we consider discrete time.

With these changes, tiny bubbles can occur even with a public signal. Suppose that all investors sell assets at $t_0 + \tau$ where $\tau \geq 1$. Then, if investors are risk neutral, the expected payoff is $\alpha \exp(g(t_0 + \tau)) + (1 - \alpha) \exp(g(t_0))$; 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 $t_0 + \tau - 1$, she can sell at price $\exp(g(t_0 + \tau - 1))$. Thus, investors do not have an incentive to sell at $t_0 + \tau$ if $\alpha < [\exp(\tau - 1) - 1]/[\exp(\tau) - 1]$. This condition does not hold when $\tau = 1$, but it can hold when $\tau > 1$. In our experiments, we suppose $\alpha = 3/5$, meaning that rational investors hold an asset at most for two periods. On the contrary, the equilibrium comes with mixed strategies, and the duration of holding an asset tends to be longer with a private signal. However, Hypothesis 1 does not change, and thus, these changes do not severely affect the experimental results.¹⁰

3.3 Sessions

Subjects were 240 Japanese undergraduate students from various majors in Waseda University. They were recruited through a website used exclusively by the students of Waseda University.

Upon arrival, subjects were randomly allocated to each computer. Each subject has 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 out at the beginning of the

¹⁰In 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.

experiment. As the riding-bubble game is somewhat complicated, subjects faced difficulties understanding the game in our pilot experiments. Therefore, to ensure subjects understood the game clearly, we prepared detailed examples. Moreover, we also asked subjects to answer some quizzes. The experiment did not begin until all participants had answered the quizzes correctly. Because subjects understood the game very well after this process, we observed little variability 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 sell the asset by clicking the mouse. However, subjects may have used these 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 must click "SELL" or "NOT SELL" on the computer screen. That is, they need to click regardless of their choices. Second, even after subjects sell the asset or the game ends in one group, they are required to continue clicking "OK" until all groups end this round. Third, in sessions 3–8, we used silent mice (i.e., the click sound is very small). Indeed, we found that click sounds disappear because of the background noise of the air conditioners.¹¹

Further, we restrict the time to make a decision. If some seconds have passed without any click, 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 sessions 6 and 7, it was two seconds. In other sessions, it was five seconds.¹²

After all 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 this round, the earned points of all members of the group, and the subject's total earned points for all rounds.

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

¹¹There is no significant difference between sessions 1–2 and sessions 3–8. However, one subject said after the experiment that he inferred t_0 from the click sounds in session 1 (*Private 5*). He indicated that the click sounds came apart at t_0 since only type- E subjects receive a signal and take time to make a decision, while type- L subjects click immediately. Because of this comment, we decided to use silent mice.

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

[2002]), subjective intellectual levels, and objective intellectual levels by using CRT questions (developed by Frederick [2005]). See Appendix B for more details.

In both baseline and extended sessions, 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 and 8) had 14 rounds and lasted approximately two hours. The average profit of each subject was 1,870 yen. On the contrary, the extended sessions (sessions 6 and 7) had 14 + 19 or 14 + 24 rounds and lasted approximately three hours. The average profit of each subject was 3,235 yen. In the extended session, subjects took a break (around 10 minutes) 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. Note that the number of rounds was preliminarily determined, but we also did not announce this to subjects in either session (baseline or extended) because they may have changed their strategies if they expected the experiment to finish soon. Note also that there is no refreshment effect, that is, subjects did not significantly change their strategies after the break.

In summary, there were three short treatments and two long treatments, the latter of which were divided into two subsamples, as Table 3 shows. While *Private 5* and *Public* constituted the two long treatments, their subsamples consisted of the first 14 rounds and the last 19 or 24 rounds in the extended sessions. In addition, the treatment *Public 10persons* is explained in Section 5. Note that the number of rounds was 24 in *Public extend* and 19 in *Private 5 extend* since subjects made a decision earlier in *Public extend*, and the number of rounds was decided to finish the session within three hours.

[Table 3 Here]

4 Experimental Results

In the theoretical analysis, we are mainly interested in the trader’s duration of holding an asset after she receives a signal, either private or public, τ . Therefore, in our experiments, we measure the variable *Delay*, which represents the duration that a subject waits until she sells the asset. To be precise, this equals the number of periods between the time she receives

a signal, either private or public, and the time she decides to sell the asset. Table 4 shows the descriptive statistics of *Delay* and the number of observations for each subsample. We count the variable for only the 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.

[Table 4 Here]

The average of *Delay* is longer in *Public* than in both *Private 2* and *Private 5*. This result means that subjects tend to hold an asset longer with a public signal than with a private signal in the first 14 rounds. However, this duration becomes shorter in *Public extend* than in *Private 5 extend*, implying that subjects sell an asset earlier with a public signal than a private signal in the last 19 or 24 rounds. Note that as discussed in Section 2, the theoretically predicted duration of holding an asset is about 4 and 12 in *Private 2* and *Private 5*, respectively. Hence, the duration of holding an asset is almost the predicted duration in *Private 2*, whereas subjects tend to sell earlier than the predicted duration in *Private 5*.

Because we can observe the variable *Delay* for only those subjects who sell the asset at or before the point of the bubble crashing, we next recover this censored *Delay* by using a Tobit model. Table 5 shows the estimated average duration of holding an asset that incorporates that for those subjects who cannot sell the asset before the bubble crashes by using the interval regression of Stata. In the following parts, we call this estimated value *Delay*. Table 5 confirms the findings shown in Table 4. The average of *Delay* is longer in *Public* than in both *Private 2* and *Private 5* in the first 14 rounds, while the former is shorter in the last 19 or 24 periods.¹³

[Table 5 Here]

¹³Note that very few subjects sold the asset before receiving a public or private signal. In this case, the duration of holding an asset is negative since τ measures how long, in periods, subjects hold an asset after they receive a signal. Because such subjects may have sold the asset by mistake, 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.

We next test the difference in the duration of holding an asset between the three treatments. The model of the interval regression is

$$\tau_{it} = \alpha + \beta_1 \textit{Public} + \beta_2 \textit{Private 2},$$

where *Public* and *Private 2* are the dummy variables that take one when a session is *Public* and *Private 2*, respectively. The dependent variable τ_{it} is the duration of holding an asset of subject i in round t . Table 6 shows the estimated results. For the first 14 rounds, the estimated β_1 is 1.48 and significant at the 5% level, suggesting that, on average, the duration of holding an asset is longer by 1.48 periods in *Public* than in *Private 5 (2)*. However, for the last 19 or 24 rounds, this result is reversed: the duration of holding an asset is shorter by 1.41 periods in *Public extend* than in *Private 5 extend*. On the contrary, the estimated β_2 is not significant, implying no significant difference between *Private 2* and *Private 5*.

[Table 6 Here]

Figure 2 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 public signal, while it stays almost constant with a private signal. As a result, subjects hold assets for a shorter time with a public signal than a private signal as rounds proceed. At the beginning of the game, the duration of holding an asset is around 10 periods, while it converges to 1–2 periods around round 25 (see Figure 2).¹⁴

[Figure 2 Here]

We now investigate the effects of experiments' and subjects' characteristics on the duration of holding an asset. We conduct the interval regression of *Delay* by using a number of control variables (these variables are defined in Appendix C). Table 7 shows the estimation results.

¹⁴The duration of holding an asset fluctuates over rounds, reflecting changes in t_0 that is shown on the right axis. The duration of holding an asset 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 *Private 5*, *Private 2*, and *Public*.

[Table 7 Here]

We obtain four implications. First and most importantly, a learning effect exists in the sessions with a public signal, but not in the sessions with a private signal. As subjects play more rounds of the game (i.e., as *Round* rises), the duration of holding an asset becomes shorter with a public signal only. However, because the coefficients of squared *Round* are positive, the duration stops decreasing around 1–2 periods (Figure 2). On the contrary, the round number is not significant for *Delay* with a private signal, which implies that subjects choose the optimal duration from the early rounds. 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 existence of no learning effect with a private signal.

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 seem to be more risk averse and prefer to finish the round earlier when the true value continues to increase and subjects do 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, subjects' characteristics do not seem to be important factors in determining the duration of holding an asset. 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, while those subjects who answered quizzes at the beginning of the session quickly (i.e., *Test Time* is higher) tend to hold an asset longer with a private signal.

5 Discussions

The immediate question that arises from the aforementioned results is why, in the early rounds, subjects have a greater incentive to hold an asset after a public signal than they do after a private signal.

Some studies argue that the situation of bubbles is similar to the centipede game (e.g., Brunnermeier and Morgan [2010], Moinas and Pouget [2013]). In the centipede game, the theoretical prediction is of no coordination among players. However, in experiments, many subjects prefer to coordinate (e.g., McKelvey and Palfrey [1992]). The same behavioral choices may occur in our experiments after a public signal, because both experiments suppose symmetric information. That is, players try to coordinate by waiting until an asset price becomes sufficiently high. On the other hand, when subjects have different (asymmetric) information, they may feel a sense of unfairness, which decreases the incentive to coordinate. Indeed, several past studies show that asymmetric payoffs reduce the rate of cooperation in the prisoner’s dilemma game (Sheposh and Gallo [1973], Ahn et al., [2007], Beckenkamp, Henning-Schmidt, and Maier-Rigaud [2007]). These studies consider asymmetric payoffs, not asymmetric information, but show that asymmetry among players induces less cooperation.

Cooperation may become difficult if the number of players increases. Indeed, Rapoport et al. (2003) show that there is less cooperation in a three-person centipede game than there is in a two-person game. Similarly, an increase in the number of players results in faster convergence to an equilibrium in p -beauty contests (Ho, Camerer, and Weigelt [1998], Sutter [2005]).¹⁵ To check this, we increase the number of subjects in one group from five to 10 in session eight (see Table 1). The game ends when six members of the group, instead of three, decide to sell the asset before 20 periods have passed after the true value ceases to increase (i.e., α stays at two-thirds). The other settings are identical to those in the previous game.

In Tables 4 and 5, *Public 10persons* indicates the descriptive statistics of sessions with a public signal and 10 members in a group. The duration of holding an asset is lower than that

¹⁵However, the p -beauty contests in these studies differ from bubbles because the reward for the winner is fixed.

in *Public*, *Private 2*, and *Private 5* in both tables. Figure 3 compares the average duration of holding an asset between *Public* and *Public 10persons* over several rounds. In all rounds, the duration of *Public 10persons* is shorter than that of *Public*. The duration converges to 1–2 periods in round 12, while it takes around 25 rounds in *Public*. The difference in the duration of holding an asset between *Public* and *Public 10persons* is statistically significant. This result is consistent with our prediction that symmetric information induces subjects to cooperate, thereby increasing the duration of holding an asset. However, this incentive to cooperate decreases as the number of subjects increases.

[Figure 3 Here]

6 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 future. 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 for 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 the existence of a learning effect. Then, a possible question is how experienced actual traders are, or, in which round they are in our experiments. It is true that professional traders are more experienced than students in our experiments. However, bubbles rarely occur. In this regard, actual traders may not have sufficient experience of bubbles and, thus, might be situated in the early rounds in our experiments. In such a case, giving symmetric public information expands the size of a bubble.

As future work, it is important to further investigate why bubbles tend to occur after a public signal, especially in early periods, and why learning effects are absent after a pri-

vate signal. In the previous section, we discussed one possible reason, namely that (less experienced) subjects have more of an incentive to coordinate in the case of fair settings (symmetric information) than they do in the case of unfair settings (asymmetric information). However, careful experiments are necessary to prove that symmetric information is more likely to induce subjects to cooperate than is asymmetric information.

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A Instructions

Note: Numbers/terms in [.] are for sessions 1–7 and numbers/terms in {.} are for session 8.

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.

$$1 \text{ point} = 50 \text{ yen}$$

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] {three} groups, and [five] {10} 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 cannot know who are playing the game with you. Note that your choice 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. A 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.

Private: 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]

Private 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] {10} members of the group, [three] {six} members receive a signal in the period in which the true value ceases to increase. However, the remaining [two] {four} 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.

Public: 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 onto the next period. Note that you cannot buy back the asset.

Sessions 3–8 (Note that $y = 5$ in sessions 1–5 and 8, and $y = 2$ in sessions 6 and 7): Note that if y seconds have passed without any click, the game moves onto the next period automatically. If the game moves onto 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 onto 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] {six} 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] {six} members among the [five] {10} 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] {four} 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] {six} 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 onto 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] {10} 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 onto 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 your understanding this game more clearly, let us 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]

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

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

Public: 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] {10 members including you}, suppose that [A sells] {A and B sell} in period 35, [B sells] {C, D, and E sell} in period 45, [C] {F} sells in period 50, and [D sells] {G, H, and I sell} in period 55.

- Case 1: Suppose that you choose to sell the asset in period 5, i.e., 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, i.e., 1.22, and your earned points are 0.22. This round ends in period 45 where [B] {the sixth seller E} sells, and the other members receive the following earned points: [A receives] {A and B receive} 4.25, [B receives] {C, D, and E receive} 7.56, and [C and D] {F, G, H, and I} 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] {three} members, you [and A] {A and B}, 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] {six} members, you, A, [and B] {B, C, D, and E}, 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] {six} members, A, B, [and C] {C, D, E, and F}, 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] {A and B receive} 4.25, [B receives] {C, D, and E receive} 7.56, [C] {F} receives 9.92, and [D receives] {G, H, and I receive} 4.25.

Note that if you choose to sell in period 50, the timing to sell of the [third] {sixth} member

is the same as [C's] {F'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.

Private: 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.

Public: 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] {10 members including you}, suppose that [A sells] {A and B sell} in period 45, [B sells] {C, D, and E sell} in period 50, [C] {F} sells in period 55, and [D sells] {G, H, and I sell} in period 60. Answer the question by using the information provided in Table A-1.

- Q1: When do you receive a signal?

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

Public: 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 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 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 five minutes 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 of this experiment?
 - (b) Was there anything unclear or points 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 anything such as suspicious things during the experiment if any.
 - (e) Explain your strategy during the experiment.
 - (f) **Private:** 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 Definitions of the Variables

- *Private 5*: Dummy variable that takes one when the session has a private 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.
- *Private 2*: Dummy variable that takes one when the session has a private signal and type-*L* receives a signal two periods later than the period in which the true value ceases to increase.
- *Public*: Dummy variable that takes one when the session has a public signal. This includes both the baseline sessions and the first 14 rounds of the extended sessions.
- *Private 5 extend*: Dummy variable that takes one when the session has a private 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.
- *Public extend*: Dummy variable that takes one when the session has a public signal. This includes only the last 24 rounds of the extended session.
- *Public 10persons*: Dummy variable that takes one when the session has a public signal and the number of members is 10 in one group.
- 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 mean that subjective intellectual level is lower (1 to 5).
- *CRT*: Answer for Q4 of the questionnaires. Higher values mean that the score on the CRT test is higher (0 to 3).

- *Risk Attitude*: Answer for Q2 of the questionnaires. Higher values mean 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 mean that subjects spent less time on the practice questions.
- *lag Win*: Dummy variable that takes one when a subject sold before the bubble crashes in the previous round.

Table 1: Summary of Experimental Sessions

| Session | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|------------------|------------|------------|-----------|-----------|-----------|----------|-----------|-----------|
| Date | 2015/11/20 | 2015/11/20 | 2016/1/22 | 2016/1/27 | 2016/1/29 | 2016/3/2 | 2016/4/27 | 2016/5/26 |
| Signal | Private | Public | Private | Private | Public | Public | Private | Public |
| η | 5 | | 2 | 5 | | | 5 | |
| Group Members | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 10 |
| Rounds | 14 | 14 | 14 | 14 | 14 | 14+24 | 14+19 | 14 |
| Age (average) | 20.67 | 20.96 | 20.83 | 21.3 | 20.8 | 20.53 | 19.5 | 18.9 |
| Female | 11 | 9 | 13 | 7 | 10 | 9 | 14 | 10 |
| Silent Mouse | No | No | Yes | Yes | Yes | Yes | Yes | Yes |
| Time Limit (sec) | 5 | 5 | 5 | 5 | 5 | 2 | 2 | 5 |
| Profit (average) | ¥1896 | ¥1924 | ¥1851 | ¥1862 | ¥1930 | ¥3376 | ¥3094 | ¥1757 |

Table 2: The Stream of the Values of t_0

The 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 |

The last 19/24 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: Subsamples of the Data

| | | The first 14 rounds | The last 19 or 24 rounds |
|----------------|----------|---------------------|--------------------------|
| Private Signal | $\eta=2$ | <i>Private 2</i> | |
| | $\eta=5$ | <i>Private 5</i> | <i>Private 5 extend</i> |
| Public Signal | | <i>Public</i> | <i>Public extend</i> |

Table 4: Descriptive Statistics of *Delay*

| | Mean | Std Dev | Min | Max | Obs |
|------------------|-------|---------|-----|-----|-----|
| Private 5 | 3.516 | 5.808 | -47 | 16 | 789 |
| Private 2 | 3.760 | 3.595 | -18 | 15 | 283 |
| Public | 4.908 | 4.199 | -42 | 19 | 856 |
| Private 5 extend | 3.531 | 2.304 | -8 | 10 | 354 |
| Public extend | 1.996 | 1.238 | -12 | 7 | 554 |
| Public 10persons | 2.870 | 4.537 | -39 | 12 | 300 |

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

Table 5: Interval Regression of *Delay*

| | Mean | Std. Err. | Obs. |
|------------------|-------|-----------|------|
| Private 5 | 6.024 | 0.205 | 1260 |
| Private 2 | 5.644 | 0.240 | 420 |
| Public | 7.140 | 0.160 | 1260 |
| Private 5 extend | 4.171 | 0.122 | 570 |
| Public extend | 2.573 | 0.065 | 720 |
| Public 10persons | 4.910 | 0.281 | 420 |

Table 6: Test for Differences with Upper Bounds

| | First 14 Rounds | Last 19 or 24 Rounds |
|-----------|--------------------|-------------------------|
| Public | 1.484** (0.244) | -1.407** (0.127) |
| Private 2 | 0.199 (0.343) | |
| c | 5.778** (0.178) | 4.055** (0.100) |

Note: Standard errors are in parentheses. ** means 5% significance.

The dependent variable is the duration of holding an asset. The independent variables, Public and Private 2, take one when a session is Public and Private 2, respectively.

Table 7: Interval Regression

| | Private 5 | Private 2 | Public | Private 5 extend | Public extend | Public 10persons |
|--------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| t_0 | 0.0303 (0.0578) | -0.2133** (0.0638) | -0.1353** (0.0454) | -0.2481** (0.0482) | -0.0896** (0.0201) | 0.0254 (0.0871) |
| Round | -0.0482 (0.2240) | 0.0560 (0.2466) | -0.6940** (0.1774) | 0.0475 (0.1055) | -0.1783** (0.0333) | -0.8595** (0.3396) |
| t_0^2 | -0.0040** (0.0010) | 0.0020 (0.0012) | 0.0005 (0.0008) | 0.0040** (0.0012) | 0.0010** (0.0005) | -0.0023 (0.0016) |
| Round ² | 0.0030 (0.0136) | -0.0150 (0.0150) | 0.0230** (0.0107) | -0.0015 (0.0050) | 0.0023 (0.0012) | 0.0291 (0.0206) |
| Female | -0.6188 (0.3797) | -0.4302 (0.4146) | -0.9193** (0.3119) | -0.8643** (0.2820) | -0.0670 (0.1226) | -0.3746 (0.5784) |
| Age | 0.4458** (0.1090) | 0.3662** (0.1163) | 0.0197 (0.0784) | 0.0974 (0.0998) | -0.0042 (0.0344) | -0.0144 (0.2557) |
| Intelligence | -0.5030** (0.1736) | 0.5113** (0.2397) | -0.1918 (0.1470) | -0.2396 (0.1288) | -0.0165 (0.0567) | 0.4678 (0.3634) |
| CRT | 0.1471 (0.1912) | 0.1327 (0.1852) | -0.0336 (0.1393) | -0.2574** (0.1033) | -0.1020 (0.0542) | 0.1262 (0.2782) |

Table 7 continued

| | Private 5 | Private 2 | Public | Private 5 extend | Public extend | Public 10persons |
|---------------|----------------------|----------------------|-----------------------|----------------------|-----------------------|---------------------|
| Risk Attitude | 0.0255 (0.0696) | -0.0700 (0.0742) | -0.0121 (0.0594) | 0.0469 (0.0497) | -0.0899** (0.0218) | 0.0463 (0.1490) |
| Test Time | 0.0048** (0.0015) | 0.0048** (0.0014) | 0.0000 (0.0010) | -0.0001 (0.0011) | -0.0003 (0.0004) | 0.0036 (0.0021) |
| lag Win | 0.7153** (0.3349) | -0.1243 (0.3740) | 0.6561** (0.2649) | 0.5458** (0.2135) | -0.1219 0.0973 | 0.3760 (0.5194) |
| c | 0.1382 (2.4530) | 1.3764 (2.7768) | 13.0976** (2.0147) | 5.3379** (2.0760) | 6.0682** (0.8208) | 9.0359 (5.6915) |

Note: Standard errors are in parentheses. ** means 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 |

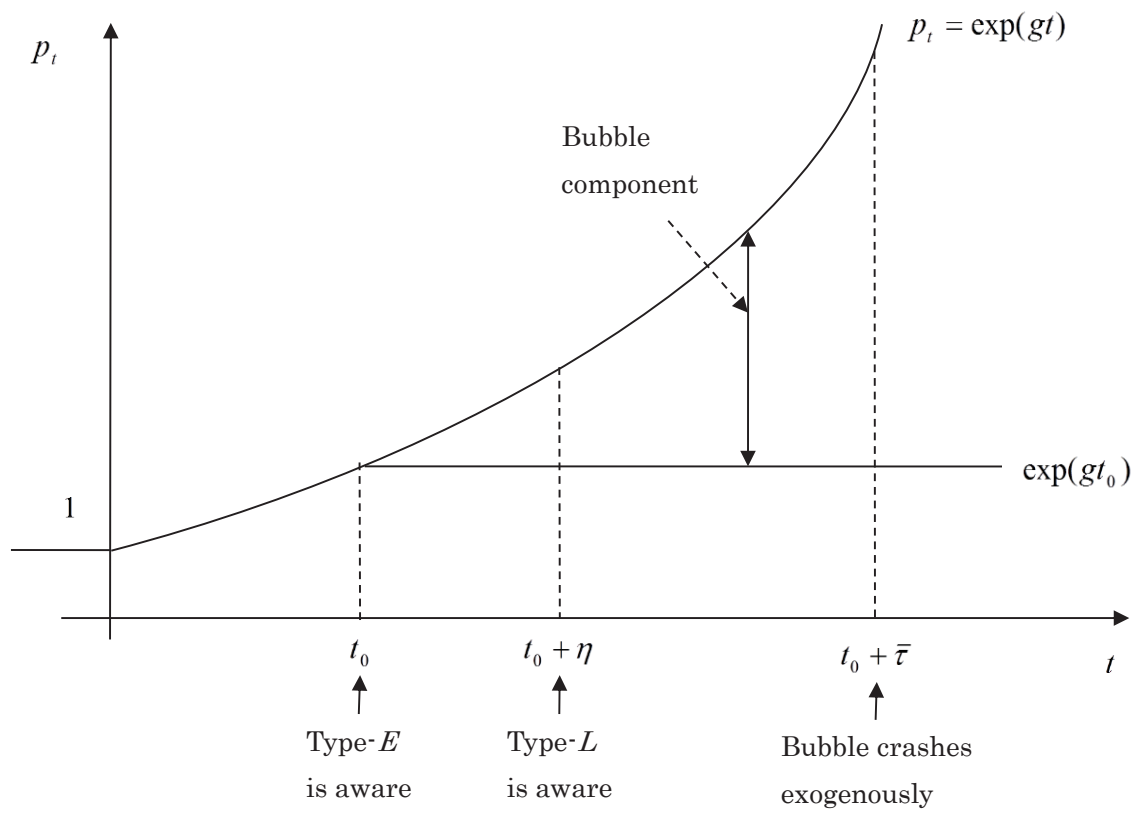


Figure 1: A Riding-bubble Model

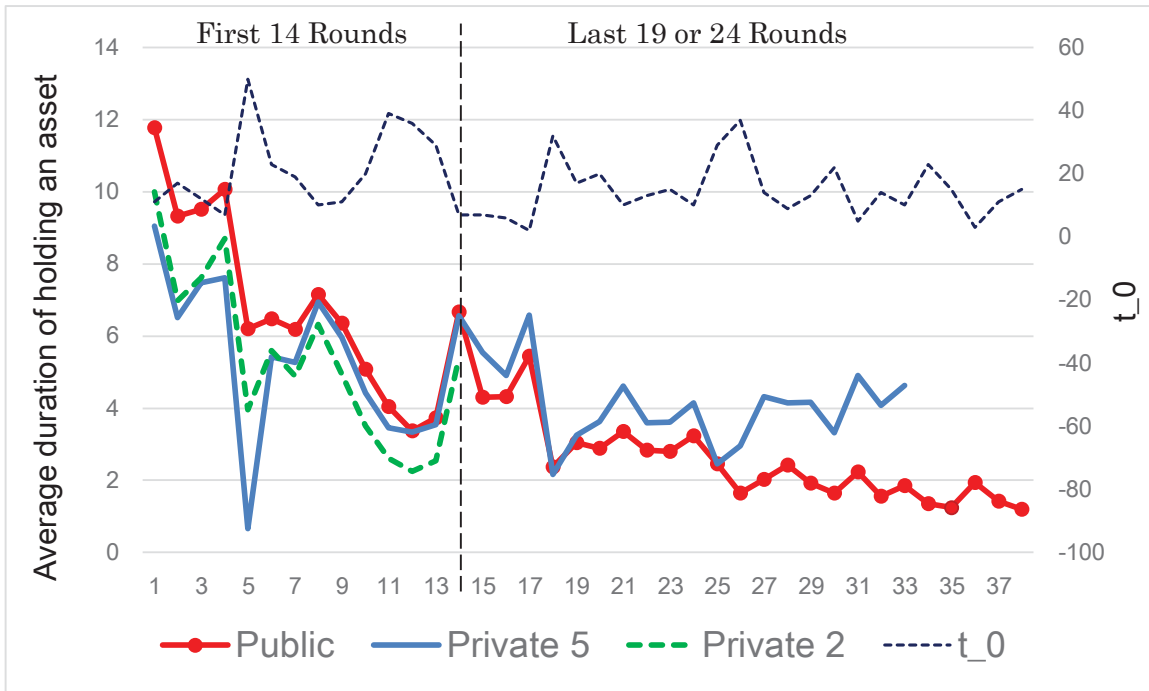


Figure 2: Average Duration of Holding an Asset after a Signal (τ)

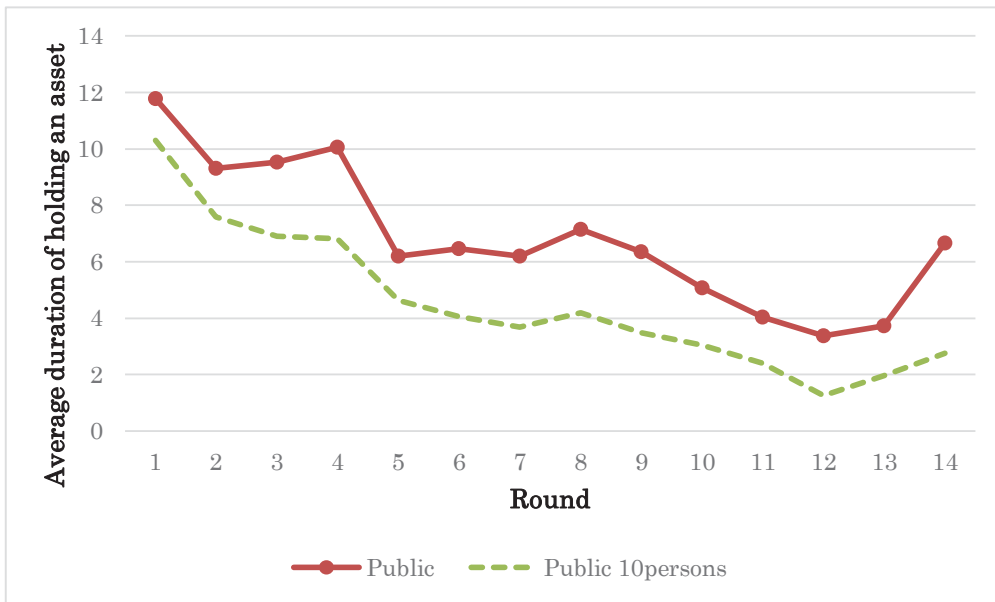


Figure 3: Average Duration of Holding an Asset after a Public Signal (τ)



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 a Private 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 Public 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 onto the next round after the group members are randomly re-matched. Please click OK.