Bubbles in Asset Markets and the Heterogeneity of Beliefs

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Abstract

We examine the relationship between information about trader expectations and pricing in asset markets. In a laboratory experiment, we elicit long-term beliefs from traders about future prices, and make different subsets of the belief information common knowledge, depending on the treatment. As hypothesized, there is a strong tendency for traders to adjust their beliefs toward the median belief in their market. Surprisingly, we find that making the median price prediction for the entire future time horizon common knowledge eliminates mispricing.

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1. Introduction

Why do people trade assets in markets in which no trade theorems should apply? A compelling explanation, commonly voiced since the work of Lintner (1965), has been that trade is a consequence of heterogeneous expectations about future asset prices. Those with pessimistic beliefs about future prices tend to sell to those who are more optimistic about the asset's future prospects. If this is the case, then homogenizing beliefs would, at least in principle, reduce disagreement about future prices and, as a consequence, the volume of trade. Furthermore, homogenizing beliefs might remove speculative demand for the asset and lead to closer adherence of prices to fundamental values.

In this study, we conduct an experiment designed to consider the effect of homogenizing beliefs on market activity. Because we cannot impose beliefs on our participants, we attempt to influence them indirectly. We do so by eliciting incentivized forecasts of future prices from traders and making components of the predictions common knowledge. Using four different treatments, we vary the extent of the belief information available to traders. The public information consists of: (1) the median price prediction among all traders for the next market period, (2) the entire profile of traders' predictions for the next market period, (3) the median belief among all traders for every period remaining in the life of the asset, and (4) a baseline condition in which all beliefs are kept private.

Our main focus is on whether making belief information public reduces belief dispersion, mispricing and transaction volumes. The environment that we choose to evaluate this question typically exhibits high transaction volumes and mispricing, allowing scope for the revelation of beliefs to potentially reduce these two measures. The setup is the most widely used in experimental finance, the paradigm originally introduced by Smith et al. (1988). The choice of this environment enables us to readily interpret our results in the context of a large body of literature. The choice of this environment is not without controversy, and we discuss some issues surrounding this

aspect of the experimental design in Section 4.2. In this environment, there is an asset with a finite lifespan that pays a stochastic dividend in each of several periods and is traded in a market. Smith et al. (1988) found that transaction prices, rather than tracking fundamental value, exhibit bubbles and crashes. The bubbles are accompanied by high volume, suggesting considerable disagreement in beliefs about future prices.[1]

Our findings show that beliefs do become more homogeneous when they are made common knowledge. However, the volume of trade is unaffected. Making short-term beliefs (i.e. predictions of prices in the following market period) public does not reduce mispricing. However, making long-term beliefs (i.e. predictions about the entire future price trajectory for the remaining life of the asset) common knowledge greatly reduces mispricing, essentially leading to the asset price tracking its fundamental value. It appears that by fixing the expectations of prices at the end of the asset's life, posting long-term expectations allows individuals to avoid unsustainable price trajectories. Therefore, the effect is similar to that of including a futures market for contracts realized in the last period of the asset's life (see Noussair and Tucker, 2006 or Noussair et al., 2014).

In our view, the rationale for the use of a laboratory experiment to study the questions at issue here is compelling. The purpose of this study is to investigate how differences in beliefs among traders in experimental asset markets influence market prices and trading volume. While the relationship between beliefs and asset market behavior has been investigated in the past, both empirically and experimentally, non-laboratory research on traders' beliefs faces two main challenges. First, direct

[1] The volume traded over the life of the market is typically several times the total stock of units (King et al., 1993). The volume of trade depends on the manner in which the market is organized, with institutions allowing purchase and resale in the same period, such as a continuous double auction, generating greater volume than rules under which resale cannot occur until a subsequent period, such as a call market (Van Boening et al., 1993). Permitting short sales (Haruvy and Noussair, 2006) and having greater cash available for purchases (Caginalp et al., 2001), either through greater endowments or margin buying relaxing constraints on trade and thus also tend to lead to greater trading volume.

measurements of beliefs are typically not available, but must be inferred from traders' behavior. The quality of these proxies is difficult to accurately establish. Second, researchers cannot replicate a particular market under identical conditions to gather ever stronger evidence either in support of or against the hypothesis in question. The laboratory experimental approach can overcome these two constraints. First, beliefs can be directly elicited in an incentivized manner. Second, an experimenter can exercise a great degree of control over the market environment, particularly in relation to the traders' access to information. This means that markets can be replicated under identical informational conditions, allowing as many independent observations to be gathered as deemed necessary.

2. Previous Literature

Heterogeneity of beliefs exists when traders differ in their opinions about future prices (Harrison and Kreps, 1978; Harris and Raviv, 1993). Brock and Hommes (1997, 1998), Goeree and Hommes (2000), and Chiarella and He (2002, 2003) concluded that when investors can choose from a set of prediction mechanisms or learning processes that differ in terms of effort levels, the result is constant disagreement in relation to beliefs. Basak (2000, 2005) assumed that heterogeneity in beliefs arose as a result of differences in the process of acquiring external (or non-fundamental) information. Jouini and Napp (2006) characterized this type of heterogeneity as differences in opinions rather than differences in information.

The theoretical foundation for this type of research is the no-speculation theorem proposed by Milgrom and Stokey (1982), and Tirole (1982). This theorem demonstrates that when speculators with differing information engage in transactions, they do not rely solely on rational and efficient market-provided price information. Based on this theorem, it is suggested that some form of irrationality or inefficiency underlies speculative transactions in the market.

The seminal work of Smith et al. (1988) was the first to explicitly analyze such irrationality and unreasonableness in market transactions from the perspective of

experimental economics. In this experiment, Subjects are endowed with several units of an asset and some cash, and they can trade the asset in a computerized market. The asset has a known life (either 15 or 30 trading periods) and pays a stochastic dividend that is common knowledge. This means that participants have all of the information necessary to compute the fundamental value of the asset during each period. Smith et al. observed that the markets had a strong tendency to exhibit bubbles and crashes. Before each trading period, they elicited incentivized beliefs from subjects about the market price in the upcoming period. Using these data, they showed that beliefs tended to be based on previous forecast errors and price trends, and crashes were unanticipated by participants.

Over the last 20 years, an interesting body of experimental work has focused on how beliefs about asset prices are formed and how they affect choices. Sonnemans et al. (2004), Hommes et al. (2005, 2008), Sonnemans and Tuinstra (2010), and Bao et al. (2013) argued that beliefs are formed based on learning rules that use previous data. These include trend following, adaptive expectations, and hybrids of these two types of rules.

Haruvy et al. (2007) were the first to elicit both short-term and long-term beliefs in relation to long-lived asset markets. They defined the short-term belief of an individual as their prediction of the price in the next period. An individual's long-term belief is the vector of their predicted prices, elicited at a given moment in time, in the current period and all future periods over the life of the asset. In addition to showing that beliefs are biased as price predictors, Haruvy et al. (2007) also presented an econometric model of belief formation based on previous price trends. Their findings are consistent with those of Smith et al. (1988), namely, that beliefs are backward-looking. Afik and Lahav (2015) further developed the model proposed by Haruvy et al. (2007) to study how reinforcement and past disappointment affect the process of belief formation.

Akiyama et al. (2014) also found that subjects formed beliefs in accordance with past realizations. Experienced traders who had previously observed a bubble and a

crash forecast the same price patterns as inexperienced traders. In addition, Akiyama et al. (2017) used long-term beliefs to determine the source of price deviations from fundamental values. They found that in general, both bounded rationality and strategic uncertainty (uncertainty about the behavior of others) accounted for the difference between beliefs and fundamental values, and that the former was more present among traders with lower cognitive ability. Hanaki et al. (2018b) studied the relationship between forecasting confidence and trading behavior. They found no significant relationship between forecasting confidence and the number of buy and sell orders, but did find that traders with a high level of confidence in their long-term price forecasts exhibited better trading performance. Carle et al. (2019) used beliefs to explain investment decisions and showed that more optimistic (pessimistic) individuals tended to be net buyers (sellers), and that traders with more accurate beliefs achieved higher earnings.

3. Experimental Design

3.1 The experiment

We conducted 24 sessions in the computerized experimental laboratory at the School of Economics and Political Science at Waseda University in Tokyo, Japan, using the z-Tree software (Fischbacher, 2007). The experimental instructions are provided in Supplement A. Our experimental design consisted of four treatments, with six sessions conducted under each treatment. The design draws on that of Haruvy et al. (2007). In each session, nine subjects participated in two consecutive independent markets in which 18 assets were traded. The assets had a life of 15 trading periods, and thus each session included a total of 30 periods. Each session lasted for approximately 150 minutes, including 40 minutes spent reading the instructions. We used "Marks" as the experimental currency, with a conversion rate of 2 ¥ for each 1 Mark. The average compensation for participants was 4,000¥ (approximately US$36), including a participation fee of 500 Yen (US$4.50).

At the beginning of each market, subjects receive shares of an asset, as well as some cash. There are three initial endowment profiles. Three traders are given three shares and 112 Marks, three are endowed with two shares and 292 Marks, and three are given one share and 472 Marks. The shares are identical and pay a dividend at the end of each period. The dividend is randomly drawn from a distribution known to the subjects, and independently determined after each period. The dividend distribution has four possible, equally likely outcomes: 0, 4, 14, and 30.[4] The shares pay the same dividend regardless of the investor holding them.

Trades occur under call-market rules. At the beginning of each period, each subject can trade by submitting buy and sell orders. Each order contains the quantity of shares the subject is willing to buy (sell), and the amount he or she is willing to pay (accept) for each share. Only one buy and one sell order can be submitted in each period. Subjects are not obliged to submit an order. After all subjects have submitted their orders for the period, the computer creates market supply and demand curves based on the orders submitted. The market price for the period is then determined by the point of intersection of the calculated supply and demand curves, and transactions are executed at the market price between those willing to buy at a price equal to or higher than the market price, and those willing to sell at a price equal to or lower than the market price.[5] Short selling and margin buying are not allowed.

At the end of each period, subjects receive information consisting of the quantity of shares they purchased or sold during the period, the actual dividend realized, the market price, and the quantities of shares and cash they are holding. Cash and shares are carried over from one period to the next. At the end of the 15th period, after the transactions for the period are executed and the information is revealed to the

[4] These are the same values used by Haruvy et al. (2007) and half the values used in design 4 of Smith et al. (1988).

[5] In cases of excess supply or demand at the market clearing price, priority is given to bid (ask) orders with higher (lower) prices than the equilibrium price, and the computer randomly breaks remaining ties of orders that are equal to the market clearing price. If there is a range of prices at which quantity supplied equals quantity demanded, the market clearing price is chosen to be the one that is 1 Mark higher than the lower bound of the range.

subjects, a new market is initialized with subjects receiving the same initial cash and share endowments as they received prior to the previous market.

At the beginning of each period, before submitting their orders, each subject is required to submit a vector of beliefs about the prices in each of the future periods within the current market. For each belief, subjects are compensated based on the proximity of their prediction to the actual price. They receive 5 Marks if their prediction is within 10 percent of the actual realized price in the relevant period, 2 Marks if it is within 25 percent, and 1 Mark if it is within 50 percent of the realized price.[6] Thus, subjects can earn money both though capital gains and dividends, and through accurately predicting future prices.

We used two measures of beliefs in our analysis. Individual *i*'s *short-term belief* $B_{i,t}$ is his or her prediction, submitted at the beginning of period *t*, regarding the market price in period *t*. His or her *normalized long-term belief* is given by $NLTB_{i,t} = \frac{1}{T-t+1}\sum_{\tau=t}^{T}\frac{B_{it}^{\tau}-f_t}{f_t}$, where f_t is the fundamental value in period *t*, *T* is the total number of periods, and τ represents future periods (ranging from the current period *t* to the last period *T*).[7] This measure was constructed using the vectors $(B_{it}^{t},\ldots,B_{it}^{T})$ that subjects submitted in each period.[8]

The first treatment, *C*, is a control treatment, which was conducted as described above and was identical to that used by Haruvy et al. (2007) except for the number of markets presented in each session. Each of the other three treatments had the same structure, and only differed from the control treatment in terms of the information

[6] We are aware that our compensation scheme is not incentive compatible (Selten, 1998). However, like Haruvy et al. (2007), we chose to make the payment schedule as simple as possible, given our relatively complex experimental design. Hanaki et al. (2018a) maintain appropriate incentives for subjects by randomizing rewards across multiple reward schemes, suggesting that this method could be a viable alternative.

[7] We also conducted our analysis using $NLTB_{i,t}$, as calculated by Akiyama et al. (2017), namely: $NLTB_{i,t} = \frac{1}{T-t+1}\sum_{t=\tau}^{T}\frac{B_{it}^{\tau}-f_t}{\overline{f_t}}$, where $\overline{f_t}$ represents average fundamental value across periods. We obtained the same results as with the measure we employed.

[8] We use the terms "long-term beliefs" to describe beliefs for periods *t+1*, and *NLTB* for the specific measure.

provided to subjects about the beliefs of others. Under each of these three treatments, this information was provided in every period between the belief elicitation phase and the opening of the market. Under the control treatment, subjects were given no information about the predictions of others.

Under the second treatment, *SNB* (short-no-bar), we provided subjects with the median short-term belief of others in their market. This information consisted of the median price prediction for the current period submitted by all traders at the beginning of the current period. This information provided subjects with feedback about their distance between their belief and the median, assuming that they could recall their own short-term belief (submitted a few seconds earlier). However, feedback in this treatment provided no information about the difference between their beliefs and the beliefs of each of the other traders.

Under the third treatment, *SWB* (short-with-bar), we provided subjects with the profile of all other traders' short-term beliefs for the current period. The beliefs were displayed using a bar diagram. That is, subjects saw each of the other traders' predictions submitted at the beginning of the current period regarding the price in the current period. The bar representing their own belief was shown in a different color, facilitating a comparison between their own belief and those of other traders. This way, in addition to the distance between their own beliefs and the median beliefs, traders could observe how optimistic or pessimistic they were compared to others.

Under the fourth treatment, *L* (long-term beliefs), subjects received information about the median predicted price for each remaining period. This was displayed in the form of a graph that revealed the median prediction, submitted by all subjects in the current period, regarding the market price in each future period until the end of the market in period 15.

The display of belief information seen by subjects under each treatment is shown in our Instruction. Figure 1 provides two graphs for the treatment *SWB* and *L*, respectively. The bar graphs provided in the treatment SWB is the top one and the line graph in the treatment *L* is the bottom one in figure 1. The graph for each

treatment is provided in the screen labeled "Belief Elicitation," which appears at the beginning of each period (before trading) and in the "Trade Phase," which is the trading screen that is displayed while the market is open for trading.

[Figure 1: About Here. These figures are additional graphs for SWE & L treatments]

3.2. The Smith et al. paradigm

The Smith et al (1988) paradigm is the most well-known and widely employed in experimental finance and has been so for over three decades. It has a structure that is simple in many ways. The life of the asset is finite and common knowledge. The dividend process is independent and identically distributed from one period to the next. The asset has a common value for each participant. Nevertheless, despite the simplicity of the structure, when traders are inexperienced with the setting, the paradigm has a robust tendency to generate asset price booms, followed by crashes near the end of the life of the asset. As a canonical setup that generates such striking behavioral patterns, it has been subject to much replication, scrutiny and comment. The bubble and crash pattern has been both strictly and conceptually replicated in numerous studies and shown to be robust to a number of changes in institutions, fundamental value processes, and trader populations (see Palan, 2013, for a survey).

A number of researchers have advanced varying criticisms of the paradigm. The first line of arguments is on the grounds of external validity. This critique appears to center on two features of the market and is reliant on the notion that in the field, stocks and housing are the asset classes of primary interest. The first feature is that the fundamental value of the asset in the Smith et al. (1988) paradigm is decreasing over time, and the second is that the asset has a finite lifespan that is common knowledge to traders. Neither of these features is characteristic of many important classes of assets such as stocks or housing. Our view is that this critique is quite

misleading. Many types of assets in the field do exhibit a declining fundamental value over time. These included assets such as bonds paying a coupon and options to buy or sell stock, whose underlying value decreases over time. Any asset that depreciates over time, such as industrial machinery or vehicles, also exhibits a declining intrinsic value. A similar downward trend in value characterizes any deposit of a non-renewable resource that can be depleted such as a silver mine or an oil field. It is clear that many assets of interest are characterized by fundamental value processes that decrease over time.[9]

A second line of criticism for the use of the Smith et al. (1988) paradigm in research is based on the fact that it has already been widely employed and studied. This idea has been advanced eloquently by Oechssler (2010) who argues that it can be an inefficient use of researcher time and resources to stick to one paradigm. He refers to this behavior as "searching under the lamppost", looking for a missing object only where the light is shining. He cites the Smith et al. (1988) paradigm as one of two examples in his paper of the field of experimental economics engaging in such behavior. While we see the beneficial side of considering new paradigms and not having the field draw its entire evidence about asset markets from a single or a small number of experimental designs, we think that there is a tradeoff. Sticking to a design in which behavior is well-understood facilitates validation of procedures in Baseline treatments because one can check whether the data are similar to those of previous similar studies. But perhaps more importantly, the results from new treatments can be readily interpreted against a backdrop of previous studies. This facilitates the placement of new results within the existing literature, making it easier to understand what has been learned from a new study.

[9] Indeed, it may be debated whether external validity is a valid criterion at all for evaluating an experimental design. Laboratory experiments are usually not intended as attempts to simulate field settings, but rather to facilitate understanding of how an economic process, such as an asset market, operates more generally. To this end, experimental markets involve trading off simplicity of the experiment with the inclusion of features that are considered essential to investigate the research question that motivates the experiment.

A third line of criticism comes from authors have remarked that this type of asset market generates some activity that can be classified as decision errors or "confusion" (Lei et al., 2001; Kirchler et al. 2012). Whether such errors occur in any alternative paradigms we could have used has not been evaluated because no alternative paradigm has been so influential or so widely employed, and therefore attracted nearly as much critical scrutiny. Our belief is that any paradigm of comparable complexity would generate a comparable amount of "confusion". There is no reason to suppose that alternative paradigms would lead to fewer errors. Indeed as Smith (2010) observes, the claim that subjects making such errors are "confused" refers to a failure to reason about asset trading the way an economist would. Thus, observing such errors leads us to learn something about how humans behave in asset markets, rather than indicating a need to change the experimental paradigm. If we interpret the mispricing as the result of confusion, and making beliefs common knowledge leads to pricing closer to fundamentals, it would also suggest that the belief information helps reduce confusion.

4. Hypotheses

Our first pair of hypotheses evaluate whether making beliefs common knowledge makes them more homogeneous. We consider this question in two ways. The first involves measuring whether the dispersion of individuals' beliefs within a market differs among treatments. The second involves considering whether beliefs tend to move toward the publicly observed median belief. The rationale underlying these hypotheses is that information about others' predictions, especially information about a central tendency of beliefs, can be valuable in updating one's own beliefs. This updating would presumably be in the direction of the consensus, but the design also allows for other patterns to appear. We evaluate the hypotheses for short- and long-term beliefs separately. Hypothesis 1 states that homogenization of short-term beliefs occurs when they are made public.

H1a: When traders are informed of the median short-term belief of others, short-term beliefs become more homogenous. The dispersion of short-term beliefs is smaller under the SNB, SWB, and L treatments than under the control treatment C.

H1b: Under the SNB, SWB, and L treatments, traders tend to update their short-term beliefs in the direction of the median short-term belief of the preceding period.

While knowing the consensus of short-term beliefs may drive later short-term beliefs to be similar among subjects, it does not necessarily imply homogeneity of long-term beliefs. Our second hypothesis states that a similar effect on the homogenization of long-term beliefs occurs when long-term beliefs are made common knowledge.

H2a: When traders are informed of the median long-term beliefs of others, future long-term beliefs become more homogenous. The dispersion of long-term beliefs is smaller under the L treatment than under the SWB, SNB, and C treatments.

H2b: Under the L treatment, traders tend to update their long-term beliefs in the direction of the median long-term belief elicited in the preceding period.

For our second group of hypotheses, we consider the effect of making beliefs common knowledge on market outcomes. As specified by the "no-trade" theorem of Milgrom and Stokey (1982) and Tirole (1982), perfectly identical beliefs among all traders result in no trade, and if agents are rational and risk-neutral, they result in prices tracking fundamental values. In this framework, any deviation in prices from fundamental values is a consequence of differences of opinions regarding future asset values. Indeed, Smith et al. (1988) attributed the price bubbles they observed to a lack of common expectations (see also Smith, 1994).

Hypothesis 3 concerns the effect of revealing information about beliefs on transaction volumes. On one hand, when beliefs differ among traders, they might be more willing to trade based on their beliefs, interpreting the difference between their own beliefs and the beliefs of others as an advantage. This is the basis of the proposition that heterogeneous beliefs lead to trade. However, it is also conceivable that traders lose confidence in their own opinion if they realize that their beliefs differ from those of others, and decline to trade. Nevertheless, we hypothesize that more information about others' beliefs leads to more agreement about future prices, and thus to less trade. It is clear that there is greater information about beliefs available under the *L* and *SWB* treatments than under the *SNB* treatment, and in turn that there is more under the *SNB* treatment than under the *C* treatment. Therefore, we propose Hypothesis 3.

H3: Trade volume decreases as more belief information becomes common knowledge. Hence, volume is lowest under treatments L and SWB, followed by treatment SNB and in turn by treatment C.

Our fourth hypothesis is based on the conjecture of Smith et al. (1988) that mispricing, that is, a significant difference between prices and fundamental values, is due to a lack of common expectations on the part of traders. The hypothesis states that the more belief information that is made public, the closer prices adhere to fundamental values. It is not obvious a priori that this hypothesis holds, because it is possible that the majority of participants believes that future prices will depart from fundamental values. This implies that releasing information about median short-term beliefs and the resulting conformity to the median belief may not reduce price deviations from fundamental values, even if it does reduce the variance among beliefs.

H4: The more information about others' beliefs that is available to traders, the closer prices are to fundamental values. Therefore, price differences from fundamentals are smallest under treatments L and SWB, followed by treatment SNB and treatment C.

5. Results

5.1. Summary of the data

Figure 2 shows the time series of median transaction prices in Markets 1 and 2, averaged over all sessions under each of the four treatments. Figures 3a and 3b show the data for each session separately. In these figures, each panel corresponds to one treatment and each data series corresponds to one session. Figure 3a shows that in Market 1, bubbles and crashes are commonly observed under the *C*, *SNB*, and *SWB* treatments, and prices under these three treatments behave similarly. However, the final panel in the figure also shows that prices track fundamental values closely under the *L* treatment, with the exception of one session in which a large bubble forms. Figure 3b shows that in Market 2, prices under the *C* and *SNB* treatments are closer to fundamental values than in Market 1, while under the *L* treatment, they remain very close to fundamental values in Market 2. Under the *SWB* treatment, prices in Market 2 continue to exhibit bubbles and crashes.

Figure 4 shows the quantities traded under the four treatments in both markets. Each bar in the graph represents a five-period segment within a 15-period market. The Market 1 panel reveals that transaction volumes are highest in the first five periods under all four treatments, and lower thereafter. Volumes are similar under all treatments, but lower in Market 2 than in Market 1. There is generally a decline in volume over time within a market. These patterns are similar to those typically observed in previous studies.[10]

[10] See for example Smith et al. (1988) and Haruvy et al. (2007).

[Figures 2, 3a, 3b, and 4: About Here]

Figures 5a and 5b show how individuals update short-term beliefs in period t as a function of how their beliefs differed from the median prediction in the prior period $t - 1$, for Markets 1 and 2 respectively. In each figure, the impression is that the data are arrayed on an axis from northwest to southeast. The least squares line plotted through each panel has a negative slope, a pattern consistent with adjustment between periods $t - 1$ and t in the direction of the period $t - 1$ median. Under all four treatments and in both markets, individuals tend to reduce (increase) their predictions regarding the next period's price if their beliefs were higher (lower) than the median in the previous period. This suggests a tendency for short-term beliefs to achieve greater homogeneity over time.

However, the graphs also indicate that this tendency is not necessarily the result of the public posting of belief information, as the homogenization occurs even when the belief information is not made public under the C treatment. Presumably, the effect also appears under the C treatment because the price in the previous period, which is a function of prior beliefs, also influences subsequent predictions.

5.2. Tests of Hypotheses

We now formally evaluate the hypotheses advanced in Section 3. Hypotheses 1a and 2a are concerned with whether the public display of beliefs makes them more homogenous. Our first finding, indicating support for Hypothesis 1a, is reported as Result 1a:

Result 1a: Making short-term beliefs public lowers the dispersion of beliefs in Market 1.

Support: We modify the short-term belief in period t by subtracting the concurrent median short-term belief. That is, we calculate $B_{i,t,m,s} - median_i B_{t,m,s}$, where $median_i B_{t,m,s}$ is the median short-term belief submitted by individuals in period t of

market m in session s. We calculate this measure for each trader in each period. Table 1 provides the variances across traders for period 3 of both markets 1 and 2, as a representative early period in each market (the data from periods 1 or 2 of both markets generate similar results).[11] The table shows that in Market 1, the variance is much greater under the C treatment than under the other three treatments, with the L treatment having the lowest variance.

[Tables 1 and 2: About Here]

In Market 2, the variance is lower than in Market 1 under three of the four treatments. An F-test for differences in the variance between treatments shows that in Market 1, the C treatment has significantly higher variance than the other three treatments ($p < 0.01$). Both the SWB and L treatments have lower variance than the SNB treatment ($p < 0.01$), while the SWB and L treatments are not significantly different from each other ($p = 0.11$). These findings show a positive correlation between the type of information on beliefs provided to traders and the homogeneity of their short-term beliefs. The variance is greatest when traders need to infer beliefs from prices, lower when they receive information about median beliefs, and even lower when they observe the beliefs of each trader or when they observe long-term beliefs. However, in Market 2, the F-test shows significantly lower variance under the C and SWB treatments than under the L and SNB treatments ($p \leq 0.01$). Thus, Hypothesis 1a is supported in Market 1 but not in Market 2.

We now evaluate Hypothesis 1b and consider how beliefs are updated. Table 2 shows the influence of a number of variables on belief adjustment, by treatment type and market. In the specification, the change in traders' short-term beliefs between the current period and the next period is the dependent variable. We control for some of the known determinants of beliefs, specifically the tendency to follow prior trends and

[11] Test results for all periods are provided in Supplement B, for short-term and long-term beliefs separately.

to adjust expectations adaptively. The regressors[12] include *PriceTrend*, the most recent change in price. Other regressors are *L1BeliefPrice*, the difference between trader *i*'s price prediction (his or her short-term belief) for period $t-1$ and the actual observed price in period $t-1$. *L1BeliefDiff*, the main variable of interest here, is the difference between trader *i*'s short-term belief in period $t-1$ and the average short-term belief in period $t-1$. If the estimated coefficient for the variable *PriceTrend* is positive, traders believe that the previous trend will continue. If it is negative, they believe that the trend is reversing, perhaps because mean reversion is anticipated. If the coefficient for *L1BeliefPrice* is negative, beliefs are adjusted in the direction of the previous period's price, a pattern that is the hallmark of adaptive expectations. Finally, a negative coefficient for *L1BeliefDiff* indicates that beliefs are being adjusted in the direction of the median belief of the preceding period. The estimates reveal the following result:

Result 1b: In general, short-term beliefs from one period to the next move toward the median of the previous period.

Support: The regression estimates presented in Table 2 confirm the results shown in Figure 4. They show that under each treatment in Market 1, the coefficient for *L1BeliefDiff* is significantly negative at the level of at least $p < 0.1$. However, we can observe differences between treatments. The absolute value of the coefficient is highest under the SWB treatment, followed by the SNB treatment, both at the significance level of $p < 0.01$. The next highest is the coefficient under the *C* treatment ($p < 0.05$), followed by the coefficient under the *L* treatment ($p = 0.11$).

While the *SNB* treatment provides only the median belief, the information provided under the *SWB* treatment also shows how far each trader is from the median. Thus,

[12] The specifications do not include fundamental values, or differences between prices or prior beliefs and fundamental values, as independent variables. Previous studies (e.g. Haruvy et al., 2007) have shown that including fundamental values does not provide additional explanatory power beyond prior beliefs and prices. The same applies to our data, and estimates from specifications including fundamental values are available from the authors.

there is more information about where the consensus lies, perhaps causing those with relatively extreme beliefs to update their short-term beliefs more strongly in the direction of the median. Indeed, the absolute value of the coefficient under the *SWB* treatment is higher than that under the *SNB* treatment. Under the *C* treatment, no information on the median belief is provided, but traders indirectly infer this information from the previous market prices. However, this effect is not as strong as when belief information is available, and this is reflected in the fact that the absolute value of the coefficient under this treatment is lower.

When discussing our theoretical model in Section 3, we introduced the coefficient $\lambda_{i,\tau}$, representing the tendency of trader i to adopt a new information relevant to future period τ. The relatively low absolute value of the coefficient under the *L* treatment may serve as evidence that the information provided to traders under this treatment emphasizes long-term beliefs, which draws the traders' attention away from their short-term beliefs.

Market 2 presents a different picture, with a significantly negative effect seen only under the *SNB* and *L* treatments. Interestingly, the absolute value of the coefficient is similar to that of Market 1 only under the *L* treatment, and is lower under *L* than in all other treatments. We suggest that the reason for the weaker tendency to update beliefs in the direction of the median is the following. Figures 1 and 2 show that prices deviate significantly from fundamental values under the *C*, *SNB*, and *SWB* treatments, while they track fundamental values in most sessions under the *L* treatment. Haruvy et al. (2007) showed how experience affects traders' belief formation and that as markets come to track fundamental values more closely, beliefs track future prices more closely as well. Afik and Lahav (2015) found that inaccurate predictions affect the updating of beliefs in a way that reflects disappointment in the traders' inability to make accurate predictions. The proximity of prices to fundamental values under the *L* treatment leaves traders with no reason to change their model of belief formation, which results in similar coefficients for both *L1BeliefDiff* and *L1BeliefPrice* in Markets 1 and 2 under the *L* treatment.

[Figures 5a and 5b: About Here]

We now turn to long-term beliefs. To evaluate Hypothesis 2a, we compare the variance of long-term beliefs in a similar way to our analysis of short-term beliefs. To do so, we calculate the variance of the measure: $NLTB_{i,t,m,s} - median_i NLTB_{i,t,m,s}$), where *NLTB* is defined in Section 3. The results of the tests are presented in Table 1. They show that the variance in long-term beliefs is lowest under the *L* treatment, followed by the *C*, *SWB*, and *SNB* treatments. An F-test of the difference in variances shows no significant difference between the *L* and *C* treatments and between the *SNB* and *SWB* treatments. However, the variances under the *L* and *C* treatments are significantly lower than those under the *SNB* and *SWB* treatments ($p < 0.01$). These results are consistent with our hypothesis regarding the way in which information affects beliefs. Under the *SNB* and *SWB* treatments, the information provided to traders only includes short-term beliefs, which draws the traders' attention away from long-term beliefs. The lower variance under the *C* treatment compared with those under the *SNB* and *SWB* treatments may simply be because traders are not being provided with any information about beliefs. With no distraction in the form of short-term belief information, traders under the *C* treatment are less focused on short-term beliefs. This is a second piece of evidence that traders' attention is drawn based on the type of information they receive. Information on long-term beliefs drives traders' attention away from short-term beliefs and vice versa.

Thus, we obtain the following result regarding long-term beliefs:

Result 2a: Making long term beliefs public makes them more homogenous.

We now consider whether long-term beliefs tend to move toward the group median. To test this hypothesis, we compare the vector of submitted beliefs to the vector of the previous period's median belief for each trader in each period. To do so, we compare each future belief, $B_{i,t}^{t+k}$, with the prediction regarding the same future period submitted in the previous period, $B_{i,t-1}^{t+k}$. We consider whether each future

forecast was updated toward the median prediction for the same future period submitted in period $t-1$. We define a dummy variable $D_{i,t}$ that takes a value of 1 each time a belief is not updated away from the median as follows:

$$(1) \qquad D_{i,t} = \begin{cases} 1, & if\ sign\left\{B_{i,t-1}^{t+k} - \overline{B_{t-1}^{t+k}}\right\} = sign\left\{B_{i,t-1}^{t+k} - B_{i,t}^{t+k}\right\} \\ 0, & otherwise \end{cases},$$

where $0 \leq k \leq T-t+1$. $B_{i,t}^{t+k}$ is the belief submitted by trader i during period t for future period $t+k$, and $\overline{B_{t-1}^{t+k}}$ is the median belief submitted during period $t-1$ for future period $t+k$. We consider $D_{i,t} = 1$ in cases where at least one difference is zero. Finally, for each trader, we calculate:

$$(2) \qquad D_i = \sum_{t=1}^{T} \sum_{k=0}^{T-t+1} D_{i,t},$$

where D_i represents the number of times trader i updated his or her beliefs in the direction of the most recently observed median.

[Table 3: About Here]

Table 3 shows the average values of D_i for each treatment and market. As can be seen, the values of D_i under the *C*, *SNB*, and *SWB* treatments are similar, while the highest values are those under the *L* treatment. A series of pairwise t-tests and Mann–Whitney U-tests confirmed that the number of times beliefs moved toward the median was significantly greater under the *L* treatment than under the other three treatments, and that there were no significant pairwise differences among the *C*, *SNB*, and *SWB* treatments. Thus, it can be concluded that the tendency of traders to update their long-term beliefs toward the median belief is stronger when information on long-term beliefs is available. Thus, we state our next result as follows:

Result 2b: When information on long-term beliefs is available to traders, they have a stronger tendency to update their long-term beliefs toward the median.

We now turn to evaluating how information on beliefs affects trading volume. Figure 4 shows that trading volume is very similar under each of the four treatments,

suggesting that Hypothesis 3 is not supported by our results. The average quantities traded over the course of a market are shown in Table 4 in the row labeled "Turnover."

To test the differences in trading volume across treatments, we conducted the following regression analysis:

$$(3) \qquad Volume_t = \alpha + \beta_1(C) + \beta_2(SNB) + \beta_3(L) + \beta_4(Period) + \beta_5(Period2) + \varepsilon_t,$$

where $Volume_t$ is the quantity of asset traded in period *t*, the variables *C*, *SNB*, and *L* are treatment dummies, *Period* is the market period, and *Period2* is the squared value of *Period*. We conducted separate regression analyses for each market. The results presented in the two left columns of Table 5 show no treatment effects in Market 1 that are significant at $p < .05$. However, in Market 2, the average per-period trading volume under the *C* and *SNB* treatments is approximately 0.5 shares lower than that under the other treatments. The table also reveals a significant downward trend of approximately 0.2 shares per period.

According to the call trading market rules that we implement, *VOLUME* is defined as the number of shares that switch hands after considering all buy and sell orders submitted by traders. Naturally, some submitted orders are not executed. However, they can still be regarded as traders' intentions – or willingness – to buy and sell (Lahav and Meer, 2022). The two right columns of Table 5 show the results of the regression equation above, this time using *Buy Orders* as the dependent variables. The results show that the number of buy orders is significantly higher under the Control treatment, where subjects receive no information on others' beliefs. There is no significant difference in the number of buy orders between other treatments.[13] We conclude that while the number of traders' shares is not affected by information on

[13] When using Sell Orders as the dependent variable, significantly lower sell orders are observed under the *SNB* treatment.

beliefs, the information does reduce traders' bid orders. We state our third result as follows:

[Tables 4, 5, and 6: About Here]

Result 3: Trading volume is unaffected by making belief information public, but it reduces traders' willingness to buy, as is evident from the higher number of buy orders under treatment C than in the other treatments.

Hypothesis 4 asserted that treatments involving a greater amount of public belief information would exhibit prices that adhered more closely to fundamental values. To measure the extent of the deviation in prices from fundamental values, we used measures of *Turnover* (King et al., 1993), as well as *Relative Absolute Deviation* (RAD) and *Relative Deviation* (RD) (Stöckl et al., 2010). Turnover is the total volume transacted over the entire market divided by the total number of shares held by traders. $RAD = \frac{1}{T}\sum_{t=1}^{T} |P_t - FV_t|/\overline{FV_t}$ is a measure of absolute mispricing relative to fundamental value. $RD = \frac{1}{T}\sum_{t=1}^{T} (P_t - FV_t)/\overline{FV_t}$, is a measure of the difference between price level and fundamental value.

The median values of each of these measures (across sessions for each treatment and market) are shown in Table 6 for each market and treatment, and p-values for Mann–Whitney U-tests are shown in Table 6 for the RAD and RD measures. As noted above, and as can be seen in Figures 1 and 2, in the majority of our sessions under the L treatment, prices are fairly close to fundamental values in both markets, with the exception of session 5. Therefore, in Table 6, we also provide (in parentheses) the p-values for the Mann–Whitney U-tests excluding this session. As can be seen from the table, and considering the relatively low number of observations, even without excluding session 5, we can conclude that the bubble measures under the L treatment are lower than those under the other treatments.

Two exceptions are the difference in the RD measure between the *L* treatment and the *C* and *SWB* treatments. Figure 2 provides an explanation. It can be seen that the prices under both the *C* and *SWB* treatments start below the prices under the *L* treatment, but unlike the prices under the *L* treatment, they increase to levels above fundamental values thereafter. Since RAD measures the absolute distance between prices and fundamental values, this measure is greater under the *C* treatment. However, because the negative values are offset by the positive values in the calculation of RD, the summation results in insignificant differences between treatments, even when RAD is significant. Since the large majority of prices under the SNB treatment is above fundamental values, both bubble measures indicate significant differences from the *L* treatment.

Accordingly, we find support for Hypothesis 4. Revealing median long-term beliefs leads to prices tracking fundamental values more closely. However, providing information on short-term beliefs does not reduce (and in some cases even increases) mispricing. Thus, we state our fourth result as follows:

Result 4: Providing information on long-term beliefs to traders reduces price deviations from fundamental values, although information on short-term beliefs does not reduce mispricing.

5.3. Other Determinants of Beliefs

Our theoretical framework is based on the tendency of traders to form and update their beliefs according to specific rules. In Section 3 we mentioned that traders can use different rules in different periods or use the same rules with different propensities. The regression equation presented in Table 2 is based on an implicit rule of beliefs updating. Accordingly, belief updating depends on the most recent price trends and the accuracy of traders' beliefs in the previous period.

Table 2 reveals that there are a number of influences on beliefs other than the beliefs of others. The variable *PriceTrend* is positive and significant in both markets under

all four treatments. This indicates that the change in price between periods $t-2$ and $t-1$ influences belief adjustment between $t-1$ and t. The negative coefficient for the variable *L1BeliefPrice* in seven of the eight equations reveals an adaptive component to expectations. Beliefs adjust between periods in the direction of the prices in the previous period. Taken together, both previous beliefs and previous prices are factors in belief formation. Accordingly, we update our eq. 5 as follows:

(4) $B_{i,t}^{\tau} = \varphi_{i,t}(F_t, P_1, \dots, P_{t-1}, B_{it-1}^{t}, B_{it}^{t}, \dots, B_{it}^{\tau-1})$

Table 7 presents more detail regarding the determinants of short-term beliefs under each of the four treatments. It shows the estimates from extensions of the model used by Haruvy et al. (2007), who showed that beliefs were influenced by trends in the current market as well as price patterns in the previous market in which traders participated. Their model can be used as another rule for belief formation. We repeated their analysis, but include variables capturing the difference between an individual's prior short-term belief and the median, as well as the difference between their long-term belief and the median. The estimated regression equation is:

(5) $B_{i.m.t}^{t+k} = C_i + \beta_1 * PeriodTrend + \beta_2 * MarketTrend + \beta_3 * ShortBeliefDiff + \beta_4 * LongBeliefDiff + \epsilon_{i,m,t}$,

where $B_{i.m.t}^{t+k}$ is the belief regarding the price in future period $t+k$ submitted by trader i during market m in period t. The variable *PeriodTrend* is a measure of the perceived trend in prices between (possibly future) periods $t+k-2$ and $t+k-1$, and is defined as:

(6) $PeriodTrend(i,m,t,k) = B_{i,m,t}^{t+k-1} + B_{i,m,t}^{t+k-1}\frac{B_{i,m,t}^{t+k-1} - B_{i,m,t}^{t+k-2}}{B_{i,m,t}^{t+k-2}}$.

The variable *MarketTrend* captures the trend in prices between periods $t+k-1$ and $t+k$ in market $m-1$, the market immediately preceding the current market, as follows:

(7) $MarketTrend(i,m,t,k) = B_{i,m,t}^{t+k-1} + B_{i,m,t}^{t+k-1}\frac{P_{m-1,t+k}-P_{m-1,t+k-1}}{P_{m-1,t+k-1}}$.

The variable *ShortBeliefDiff* represents the difference between trader *i*'s short-term belief and the median belief regarding the price in the current period t submitted in the previous period $t-1$:

(8) $ShortBeliefDiff(i,m,t-1) = Belief_{i,m,t-1} - median(Belief_{m,t-1})$.

Finally, the variable *LongBeliefDiff* represents the normalized difference between individuals' beliefs and the median belief, summed over all future periods within the current market, submitted in the previous period:

(9) $LongBeliefDiff(i,m,t-1) = \sum_{\tau=t-1}^{T}\frac{Belief_{i,m,\tau}-median(Belief_{m,\tau})}{median(Belief_{m,\tau})}$.

[Table 7: About Here]

The results presented in Table 7 are consistent with those of Haruvy et al. (2007), in that both *MarketTrend* and *PeriodTrend* are significant determinants of current predictions under all of the treatments. In addition, *ShortBeliefDiff* and *LongBeliefDiff* are significant in the first market. The coefficient of *ShortBeliefDiff* is negative, indicating an adjustment toward the median belief. While *LongBeliefDiff* has a positive effect, it should be noted that we would not necessarily expect this coefficient to be negative because it consists of a vector of beliefs, which might be both below and above the median simultaneously. In this case, adjustment to the median belief means that once information on median long-term beliefs is available, the coefficient of *LongBeliefDiff* is reduced. Under the *C*, *SNB*, and *SWB* treatments, information on long-term beliefs is not revealed to traders. When this information is revealed under the *L* treatment, the coefficient is significantly lower.

The regression results confirm that short-term beliefs tend to adjust toward the median belief, even under the *C* treatment, in which the median belief is not revealed. This suggests that even when other predictions are not revealed, there is a tendency to align one's own beliefs with those of others, presumably via commonly observed market data. This tendency exists in addition to the adaptation of beliefs to observed price trends in the current and prior markets.

5.4. Beliefs and Behavior

Next, we examine the relationship between beliefs and traders' decisions to buy and sell. Our analysis is based on whether traders who believe that prices will be relatively high (low) are more likely to try to buy (sell) in the current period. Table 8 presents the results of our analysis. In the regressions, the dependent variable, *New Stock*, indicates the change in an individual's inventory in period *t*. The variable is positive if they purchased stock during the period and negative if they sold stock.

The estimates show that the coefficient of *ShortBeliefDiff* is significantly positive under the *SNB* and *SWB* treatments, indicating that when provided with the median belief, the more optimistic that traders realize they are, the more likely they are to purchase stock. This is because they believe that the expectation of future price increases will result in more capital gains. This indicates consistency between traders' beliefs and their actions. Interestingly, this realized optimism does not appear in the regression for the *L* treatment, where traders are also informed about long-term median beliefs. This is an additional indicator that information on long-term beliefs diverts traders' attention away from short-term beliefs.

To better understand the source of this difference among treatments, we conducted the same regression analysis using bid price and bid quantity as dependent variables. The results, presented in Tables 9 and 10, clearly indicate that under the *SNB* and *SWB* treatments, more optimistic beliefs are reflected in higher bid prices rather than greater bid quantities. This is consistent with the higher prices seen under the *SNB* and *SWB* treatments compared with those under the *C* treatment, as shown in Table

1, 2 and 3 and in the bubble measures presented in Table 5. This finding is crucial to understanding how revealing information about short-term beliefs affects prices. The higher prices under the *SNB* and *SWB* treatments compared with those under the *C* treatment appear to be caused by increased demand by those traders who realize – based on the information they have received – that most others do not share their optimistic view regarding future prices.

At first glance, it might appear that the fact that the most optimistic traders tend to bid the highest prices is at odds with the result reported earlier that beliefs tend to move toward the median of the prior period. However, the adjustment in the direction of the median is incomplete, as shown by the coefficients for *L1BeliefDiff* and *ShortBeliefDiff* in Tables 3 and 7, which are always greater than −1 (a coefficient of −1 would indicate full adjustment to the median). This incomplete movement toward the median indicates that those who are optimistic in period t will typically still have period $t + 1$ beliefs that are more optimistic than the period t median. Thus, for them to bid prices higher than the average remains consistent with their relatively high price predictions for the next period. The opposite logic applies to those who have pessimistic beliefs in period t.

[Tables 8, 9 & 10: About Here]

6. Discussion and Conclusion

In our study, we examined the effects of providing public information about predictions of future asset prices. We found that making median long-term beliefs common knowledge has a strong effect in terms of moving prices toward fundamental values. However, public availability of short-term beliefs does not exert an appreciable effect on pricing. If anything, making the entire vector of individuals' short-term beliefs available exacerbates mispricing.

Thus, it appears that making long-term beliefs public anchors expectations regarding the future price trajectory. The presence of a summary vector of long-term beliefs

appears to prompt traders to consider which price trajectories are sustainable until the end of the asset's life. This is presumed to be the same function that is performed by futures markets, which are known to greatly reduce mispricing in experimental spot asset markets (Noussair and Tucker, 2006; Noussair et al., 2014). Under the *L* treatment, market participants seem to come to realize that price bubbles cannot last. This does not occur under the other treatments, suggesting that it is crucial that expectations regarding the final period or periods in the life of the asset are made public.

We observed strong patterns in the manner in which beliefs are determined, and confirmed that beliefs are influenced by the recent trend in the current market, as well as the price trajectory in the prior market in which a trader has participated, as observed by Haruvy et al. (2007). We also found that median belief information affects a trader's expectations, which tend to adjust toward the median. Previous price information also influences expectations, which are updated in an adaptive manner in the direction that reduces prediction error. Using this observation, in addition to previous price trends and the deviation of prior beliefs from observed prices, we can add a third important determinant of expectations: the beliefs of other traders.

Four hypotheses guided our study. Hypotheses 1 and 2, which asserted that beliefs move toward median beliefs, were strongly supported. Beliefs have a strong tendency to move in the direction of the median. However, this tendency was also observed under the *C* treatment, indicating that it is not solely the belief information that causes expectations to converge. Presumably, price data and second-order beliefs (i.e. beliefs about other traders' expectations) are also influential. We also observed a tendency for the resulting variance in beliefs to be lower when more belief information was made public, at least in the first market in which traders participated.

Hypotheses 3 and 4 related to how making belief information public would lower the quantity of asset exchanged and deviations in prices from fundamental values.

However, we found only partial support for these hypotheses. Publicizing belief information reduced the number of purchase orders significantly, but trading volume was not affected. However, as noted earlier, median long-term belief information exerted a very strong effect of driving prices toward fundamental values, while short-term belief information had no such effect. The results establish that providing long-term belief information is one of the very few known means of reliably reducing the incidence of bubble formation among inexperienced traders.

A recurring theme in our results is how information about the beliefs of others affects the updating of investors' own beliefs. Information about others' short-term beliefs influences traders' own short-term beliefs and drives their attention away from long-term beliefs. Similarly, information about long-term beliefs affects beliefs about the more distant future. The latter is somewhat counterintuitive because long-term beliefs also contain information about short-term beliefs. Despite this, it seems that investors' attention, when long-term beliefs are available, is focused on the distant rather than the near future.

Our results suggest that providing long-term belief information is helpful in achieving price discovery. It is now common practice for investment banks and large brokerage firms to use predictions for stock indices for ten years into the future. However, it is rare to see contracts for stock or commodity futures with horizons of more than three years. Experimental results show that futures markets help stabilize spot prices and it may be the case that longer-term futures contracts beyond the traditional horizon may further increase market stability. Central banks might also publish their own predictions taking into account anticipated future monetary policy, in effect issuing forward guidance for asset markets.

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Appendix A: Theoretical Framework

This appendix provides a possible scenario to explain subjects' behavior based on their observed information.

A.1 The market

Consider a market for a single financial asset, populated by risk neutral investors and lasting T discrete periods. At the end of each period, each unit of the asset pays a stochastic dividend d_t to its owner, drawn independently and identically from a distribution with mean $E(d_t)$, which is common knowledge among investors. We assume that the distribution of the dividend is constant over time, so that $E(d_t) = E(d) = \bar{d}$. This known expected periodic dividend determines the fundamental value of the asset (F_t) as common knowledge at any given time (considering a known risk-free discount rate).

Before the beginning of period 1 ($t = 1$), each investor is endowed with cash $C_{i,0}$ and some units of the asset $A_{i,0}$. During each period, investors trade the asset by simultaneously submitting to the market a single purchase order and a single sell order. Each purchase (sell) order contains the number of assets they wish to purchase (sell) and the amount of cash they are willing to pay (receive) for each unit of the asset. In each period, after all orders are submitted, an equilibrium price P_t is determined as an intersection between supply (aggregated sell orders) and demand (aggregated purchase orders). Those who submitted purchase orders greater than or equal to the equilibrium price purchase assets from those who submitted sell orders lower than or equal to the equilibrium price. All transactions are made at the equilibrium price.

We define $B_{i,t}^{\tau}$ as the belief formed by investor i at time t regarding the market price in future period τ ($t \leq \tau \leq T$). We also define long-term beliefs $B_{i,t}$ as the vector of all beliefs held by investor i during period t for all future periods (i.e., $B_{i,t} = \{B_{i,t}^{t}, B_{i,t}^{t+1}, \dots, B_{i,t}^{T}\}$). We also define $B_{i,t}^{t}$ as investor i's short-term belief. Note that since

information accumulates over time, investors are uncertain about their future beliefs, so it is possible that:

$$\forall \tau, \exists k \; such \; that \; B_{i,t}^{\tau} \neq B_{i,t+k}^{\tau} \tag{10}$$

where $0 < k \leq \tau - t$. Beliefs are formed and updated based on a certain rule, $\varphi_{i,t}$. This rule can be, for example, the model of belief formation presented by Haruvy et al. (2007), where traders form beliefs based on previous price trends. Other possibilities might be, for example, reinforcement belief learning models or adaptive expectational models. We use the Haruvy et al. (2007) model in our analysis below. Investors may adopt different rules or use the same rule with different characteristics (coefficients).

We assume that investors do not consume while the market is open, so the objective of investors is to maximize their wealth:

$$W_{i,T} = C_{i,T} + A_{i,T} \cdot V_T \tag{11}$$

where $A_{i,t}$ and $C_{i,t}$ are the traders' accumulated cash and asset units respectively, T is the last period of the market, and V_T is the asset terminal value. The wealth $W_{i,T}$ is subject to the traders' initial endowments $A_{i,0}$ and $C_{i,0}$, and given their periodic short- and long-term beliefs, which are updated every period based on the fundamental value, previous prices, and their own beliefs (the values and prices being common knowledge and the beliefs private information) using their own belief rule:

$$B_{i,t}^{\tau} = \varphi_{i,t}(F_t, P_1, \dots, P_{t-1}, B_{it}^{t}, \dots, B_{it}^{\tau-1}) \tag{12}$$

Since all prices and the fundamental value are common knowledge, there are two reasons for belief heterogeneity: the differences in investors' decision rules and differences in prior beliefs.

To maximize wealth, during each period, each investor (being risk neutral) follows two principles during the periodic trade:

(13) $$p_{i,t}^{\pi} \geq max\{F_t, \tilde{B}_{i,t}^{\tau}\}$$
$$p_{i,t}^{\theta} \leq max\{F_t, \tilde{B}_{i,t}^{\tau}\}$$

Where $p_{i,t}^{\pi}$, $p_{i,t}^{\theta}$ and $\tilde{B}_{i,t}^{\tau}$ represent the asking price, bidding price, and the highest perceived value of the asset based on $B_{i,t}$ and future dividends:

(14) $$\tilde{B}_{i,t}^{\tau} = \max_{\tau}\left[B_{i,t}^{\tau} + \bar{d} \cdot (\tau - t)\right]$$

The first principle dictates that a sell order should not be priced lower than the current fundamental value of the asset. However, if investors think that the fundamental value is lower than what they can earn from selling the asset in the future, their selling limit price should equal that value. According to the second principle, investors may purchase assets for resale. In this case, the timing of future resale is set to maximize profit. Therefore, the purchase order price should not be higher than the highest perceived future value of the asset, though it may be higher than the fundamental value. If an individual holds the belief that the price will never exceed the fundamental, then the purchase order price cannot exceed the fundamental value (in which case the investor believes that resale is not profitable). In other words, investors who believe that others may wish to pay more than the fundamental value in the future, may offer to purchase it today at a price higher than the fundamental value. This act may seem irrational at first, but it is simply a speculative act of profit maximization based on one's future price expectations.

The second principle enables prices to possibly be higher than fundamental value until period $T-1$, while the first principle prevents prices from being below fundamentals. This lower bound on prices is relaxed if at least some investors are risk averse. Finally, eq. 3, which proposes that new price-relevant information arrives in each period, prevents investors from selling all their asset inventories or spending all their cash to purchase assets in any period other than period T. Eq. 3 means that investors are aware of the possibility that the value of the asset may change in the future based on market activity providing investors with new information that affect their $B_{i,t}$.

a.2 Possible scenarios

This theoretical market structure can shed light on how prices are affected by beliefs. First, it can be seen that prices can either track fundamentals or exceed fundamentals even if there is a consensus in beliefs. Second, even when beliefs are in consensus, prices can deviate from beliefs themselves. To see this, consider the market above with two investors (i and j), both form beliefs according to the same rule:

$$B_{i,t}^{\tau} = B_{j,t}^{\tau} = \begin{cases} \alpha_0 & if \quad \tau = t = 1 \\ P_{t-1} + \alpha & if \quad \tau = t > 1 \\ B_{i,t}^{\tau-1} + \alpha & if \quad \tau > t \end{cases} \tag{15}$$

Also assume that the asset has zero terminal value (i.e. $V_T = 0$). To show how prices can deviate from fundamental values when beliefs are in consensus, consider $\alpha_0 = F_1$ and $\alpha > -\bar{d}$. In this case (and following eq. 4), sell and purchase price orders at the beginning of the first period should either lead to no trade, or to the price F_1. From then on, in any given period, $\tilde{B}_{it}^{\tau} = B_{i,t}^{T}$, which means that traders believe that prices will peak in the last period of trade. Both sell and purchase orders in this case will be above fundamental values, which results in equilibrium prices that increase over time. If $\alpha > -\bar{d}$ then prices would even increase over time, resulting in a bubble.

To show how prices can follow fundamental values even if beliefs are in consensus and different from fundamentals, assume that $\alpha_0 \leq F_1$ and $\alpha < -\bar{d}$. In this case, sell and purchase price orders at the beginning of the first period should either lead to no trade, or to the price F_1. From that point on, $\tilde{B}_{it}^{\tau} = B_{i,t}^{t}$, which means that traders do not believe that there exist future resale options at higher prices than the current price. Both sale and purchase orders in this case would all be at the fundamental value, which results in equilibrium prices that track fundamentals.

a.3 Information about beliefs of others

Thus far, the process of belief formation is only characterized by the rule $\varphi_i(B_{i,t})$. It is reasonable to assume that when forming beliefs, investors tend to incorporate what they perceive to be the beliefs of others. Our model allows for such thinking, as part of the rule itself.

Assume now, that at the beginning of a certain period, after each investor has already established $B_{i,t}^{\tau}$, investors receive a new public information, $\overline{\overline{\mathrm{B}_t}}$, about beliefs in general (e.g., the average or median of short-term or long-term beliefs of all investors). It is reasonable to assume that individual beliefs would be updated in some way. We consider the following process of belief updating:

$$\bar{B}_{i,t} = \lambda_{i,\tau} \cdot \overline{\overline{B_t}} + \left(1 - \lambda_{i,\tau}\right) \cdot B_{i,t} \tag{16}$$

where $\bar{B}_{i,t}$ is investor i's updated beliefs following the new information, and $\lambda_{i,\tau}$ is the tendency of investors to incorporate the new information into their beliefs. We think of $0 \leq \lambda_{i,\tau} \leq 1$, although it is plausible that it lies outside such bounds. As $\lambda_{i,\tau}$ approaches zero, investor i is more conservative, hence does not tend to be influenced by new information.[14] Notice that our approach allows investors to update their beliefs differently for different future periods. For example, if $\overline{\overline{\mathrm{B}_t}}$ contains short-term information, then $\lambda_{i,\tau}$ may diminish with τ. If, on the other hand, $\overline{\overline{\mathrm{B}_t}}$ contains long-term information, than it may be more likely that $\lambda_{i,\tau}$ remain constant over τ.

Consider, for example, a market with two traders ($i = j, k$) that lasts six periods ($T = 6$), and investors that follow the rule provided in eq. 6. In period 5, investors receive information on the average short-term beliefs (i.e., $\overline{\overline{\mathrm{B}_t}} = \frac{B_{j,t}^{t} + B_{k,t}^{t}}{2}$). If $0 < \lambda_{i,5} < 1$ for all investors, then we should expect investors' updated short-term beliefs $\bar{B}_{i,5}^{5}$ to be closer to $\overline{\overline{\mathrm{B}_t}}$. However, the effect of this information on their long-term belief $\bar{B}_{i,5}^{6}$ is not known. If $\lambda_{i,5} = \lambda_{i,6}$, the new information would move $\bar{B}_{i,5}^{6}$ closer to the norm. If

[14] $\lambda_{i,\tau} < 0$ would indicate a person with contrarian tendencies, who believes that the market will tend to move in the opposite direction as the consensus.

$\lambda_{i,5} \neq \lambda_{i,6}$, then the new information dictates a change in the rule parameters. Lastly, if $\lambda_{i,5} < \lambda_{i,6}$ we may observe relatively larger differences in long-term beliefs, following a convergence in short-term beliefs.

This model makes a number of predictions. The presumption that $0 < \lambda_{i,\tau} < 1$ implies that beliefs should be updated in the direction of the consensus. Moreover, Eq. 5 implies that prices exceed fundamental values throughout the life of the asset except in the final period of the asset's life, when it should equal the fundamental value. Prices in excess of fundamentals are typically observed in experimental markets for long-lived assets, unless the amount of cash available for transactions is very low.

Appendix B: Instructions

This Appendix contains an English translation of the instructions. We distributed handouts in Japanese to our subjects while reading the following script aloud. The pages with titles highlighted in red **[Order entry screen]** differ depending on the treatment (*C*, *SNB*, *SWB*, or *L*). The page headed **[Earning a profit by predicting future prices correctly]** under treatment *L* differs from that provided for the other treatments. The following instruction was provided for treatment *C*. This instruction is followed by the various **[Order entry screen]** pages and other pages for the other treatments (*SNB*, *SWB*, and *L*).

The original instructions in Japanese are available from the authors upon request.

[Treatment *C*]

Instructions for the Stock Trading Experiment:

Please do not turn over a page until instructed to do so. Before the experiment begins, we kindly request that you:

- Confirm that you are seated in your designated seat
- Do not log in until you are instructed to do so
- Inform us immediately if your computer is not working correctly.

Please turn to the next page.

[Today's schedule]

Today, you will be asked to complete two games and a questionnaire. We will proceed in the following order.

1. Explanation of the experiment (games) and a practice round
2. Games 1 and 2 (each game consists of 15 periods)
3. Questionnaire and quizzes
4. Payment: The participation fee (500 Yen) plus any profit that you earn during the

games will be paid out in cash at the end of the experiment.

- The questionnaire and quizzes do NOT affect the results of the games.
- Games are independent of each other. The result of one game does not affect the other game.
- If you need to go to the toilet, please inform an instructor at the end of a game.

[Today's experiment]

Today you will participate in stock trading games in which you trade stocks in an artificial stock market. Please listen to the instructions carefully and if you do not understand any part of an instruction, ask for clarification by raising your hand. If you have any questions during the experiment, raise your hand and an instructor will come to you and answer your question.

Throughout the experiment, please respect the following rules:

1. Do not talk to the other participants during the experiment or the breaks.
   - ✓ This may affect the results of the experiment.
2. Use your mouse or keyboard only when instructed to do so by the instructor, otherwise this may cause a problem.
   - ✓ If any malfunction occurs, all participants will have to restart the game.

Please turn to the next page.

[Outline of stock trading game]

- You have been divided into groups, but you do not know the identity of the other members of your group.
- In each experiment, you trade stocks with the other members of your group in an artificial market.
- Each group consists of nine traders.

[Objectives of the game]

Your objective in this game is to maximize your profit. We have termed the currency used in the experiment the "Mark." One Mark is equivalent to two Yen. At the end of the experiment, your total profits in Marks will be converted to Yen and paid to you.

There are two ways of making a profit:

- First, by buying and selling stocks, and receiving dividends on your stock holdings.
- Second, by accurately predicting the future prices of stocks.

Please turn to the next page.

[Earning a profit]

Before each game begins, three of the nine traders in the group will be given either

(1) 3 stocks + 112 Marks,

(2) 2 stocks + 292 Marks, or

(3) 1 stock + 472 Marks

as their initial holding.

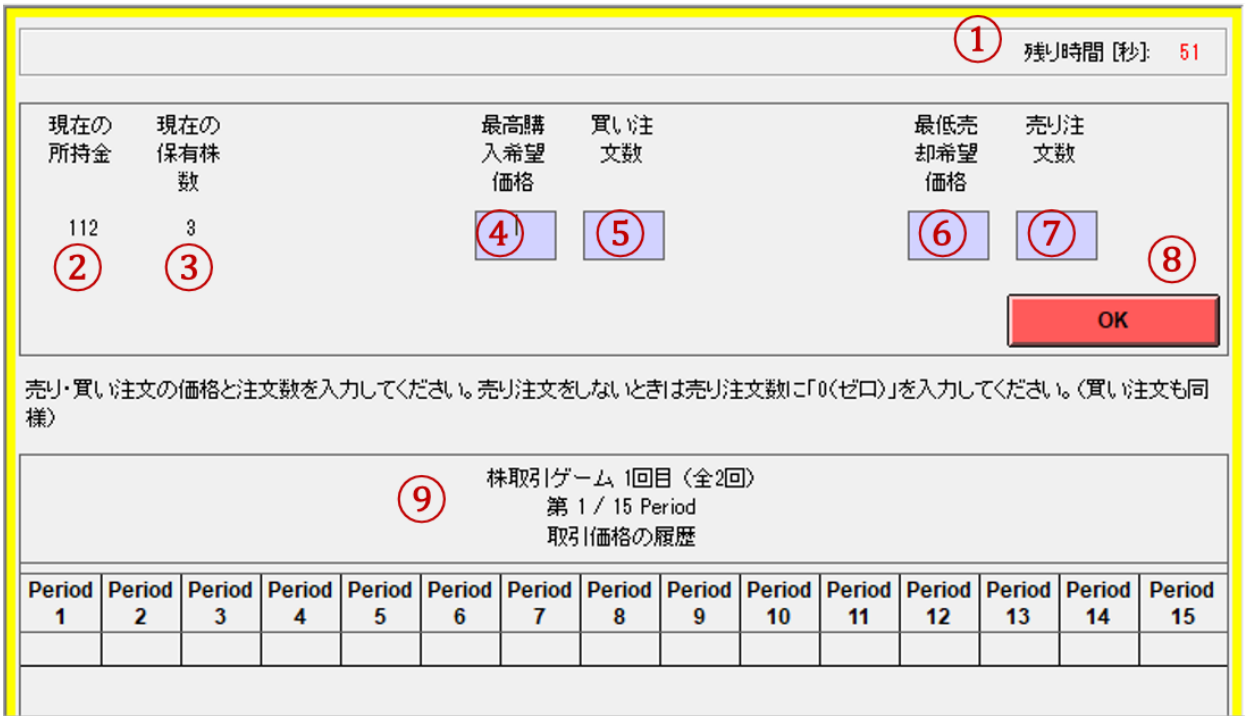
To make a profit from trading, you need to buy stocks and then sell them at a higher price. For example, suppose you buy a stock for 100 Marks, and then the price of the stock increases to 120 Marks. If you sell the stock, you will make 120 (selling price) – 100 (purchase price) = 20 Marks profit. In contrast, suppose you buy a stock for 100 Marks, and then the price of the stock decreases to 80 Marks. If you sell the stock, you will make a loss of 80 (selling price) – 100 (purchase price) = 20 Marks. Later, we will explain how the prices are determined.

Now we will explain how to use the experimental program interface and how to trade stocks. Please do not perform any operations other than those you are instructed to perform, otherwise this could jeopardize the results of the experiment.

Please double-click on the indicated icon on the computer screen.

[Order entry screen]

The following screen will appear, through which you can enter your orders in each period.



(1) This shows the time remaining for you to place your order. You will be given 60 seconds to enter your order. When that period of time has elapsed, a red warning message will flash in the top right corner of your screen and you must enter your order as soon as possible if you haven't already done so. A period ends when every member of the group has pressed "OK"; note that this could occur prior to the expiry of the 60-second time limit.

(2) This indicates your cash balance, that is, the amount of money at your disposal; you may buy stocks up to this value.

(3) This shows the number of stocks that you have. This is the maximum number of stocks you can sell.

(4) This is where you enter the maximum price you are willing to pay for a stock in this period. You must enter a whole number between 1 and 2000.

(5) This is where you enter the maximum number of stocks you want to purchase in this period. If you do not want to purchase any stocks, you should enter 0. The product of (4)

and (5) must be no greater than the cash balance shown in (2). An error message will appear if (the number of stocks you wish to purchase) × (the maximum price you are prepared to pay for each stock) exceeds your cash balance.

In practice, the price you actually pay for a stock may not be the same as the maximum price you are willing to pay. This is because the market price is set based on all the orders placed by market participants. If the market price is greater than the maximum price you are willing to pay, your order will not be processed. This will be explained in more detail later.

Please turn to the next page.

(6) This is where you enter the minimum price at which you are prepared to sell your stocks in this period. You must enter a whole number between 1 and 2000. The price you enter here should not be greater than that entered in (4).

(7) This is where you enter the number of stocks you want to sell in this period. If you do not want to sell any stocks, you should enter 0. The maximum number of stocks you can sell is the number of stocks you hold, as shown in (3). If the number of stocks you want to sell exceeds the number of stocks you hold, an error message will appear.

In practice, the price at which you sell a stock may not be the same as the minimum price at which you are willing to sell. This is because the market price is set based on all the orders placed by market participants. If the market price is lower than your minimum selling price, your order will not be processed. This will be explained in more detail later.

(8) After entering appropriate values in fields (4)–(7), press the "OK" button. Once all market participants have pressed this button, the current period ends.

(9) This table shows the history of market prices. Thus, the cells beyond the current period are blank.

The most important points regarding the buying and selling of stocks are summarized below.

- ✓ <u>You can simultaneously place both buy and sell orders, or you can place only a buy order or a sell order. You can also decide not to submit any orders at all.</u>
- ✓ <u>If you do not want to submit a buy order, please enter 0 as the quantity you want to</u>

buy. If you do not want to submit a sell order, please enter 0 as the quantity you want to sell.

- ✓ When you enter 0 as the quantity you want to buy or to sell, you do not have to enter a bid price or an asking price.

The screen displays an error message if any of the following conditions are violated:

1. The maximum quantity you want to sell must be less than or equal to the number of stocks you hold.
2. The maximum purchase price multiplied by the quantity of stocks you want to buy must be less than or equal to the cash you have available at the time.
3. If you simultaneously place both buy and sell orders, the maximum price at which you are prepared to buy must be less than or equal to the minimum selling price you are prepared to accept.

Please turn to the next page.

[End of each period screen]

(1) Market prices

The price is set according to the order book within your market. There is a single price for all stocks in each period. The price is set to equate the number of buy orders and the number of sell orders.

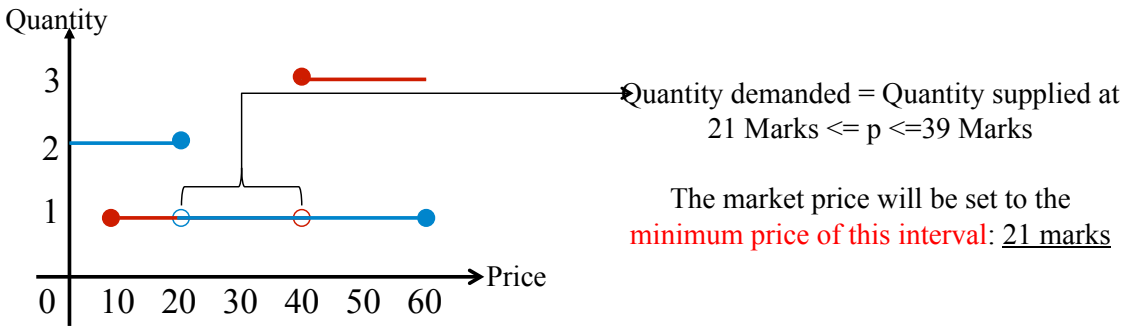
We explain how the market prices are set using the following two examples.

[Example 1: how the market price is determined]

Consider the following buy/sell orders placed by four traders:

- Trader 1: One sell order, which can be executed at 10 Marks or higher
- Trader 2: Two sell orders, which can be executed at 40 Marks or higher
- Trader 3: One buy order, which can be executed at 60 Marks or lower
- Trader 4: One buy order, which can be executed at 20 Marks or lower

A graph summarizing these orders is shown below:



A seller is willing to sell at the price requested or a higher price. A buyer is willing to buy at the price offered or a lower price. As shown above, Trader 1 is willing to sell a stock at 10 Marks or higher. If the price rises to 40 Marks, the number of stocks supplied increases to three because Trader 2 is willing to sell two stocks at the price or higher. Conversely, Trader 3 demands a stock at 60 Marks or lower. If the price falls to 20 Marks, the quantity demanded increases to two because Trader 4 additionally demands a stock at the price or lower. Therefore, the quantity demanded is equal to the quantity supplied at prices between 21 Marks and 39 Marks. The market price is set to the minimum price in this range, that is, 21 Marks. Then, trader 1 sells a stock to Trader 3 for 21 Marks.

Now, let us consider the second example.

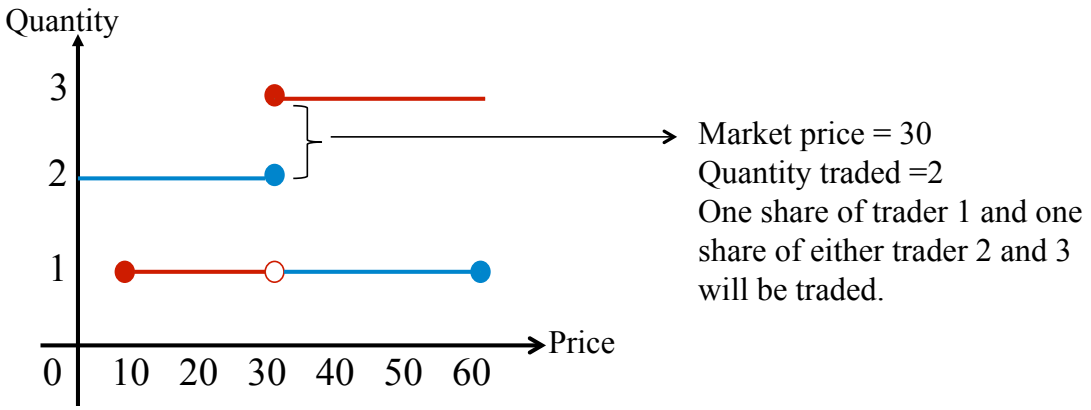
Please turn to the next page.

[Example 2: how the market price is determined]

Consider the following buy/sell orders placed by five traders:

- Trader 1: One sell order, which can be executed at 10 Marks or higher
- Trader 2: One sell order, which can be executed at 30 Marks or higher
- Trader 3: One sell order, which can be executed at 30 Marks or higher
- Trader 4: One buy order, which can be executed at 60 Marks or lower
- Trader 5: One buy order, which can be executed at 30 Marks or lower

A graph summarizing these orders is shown below:

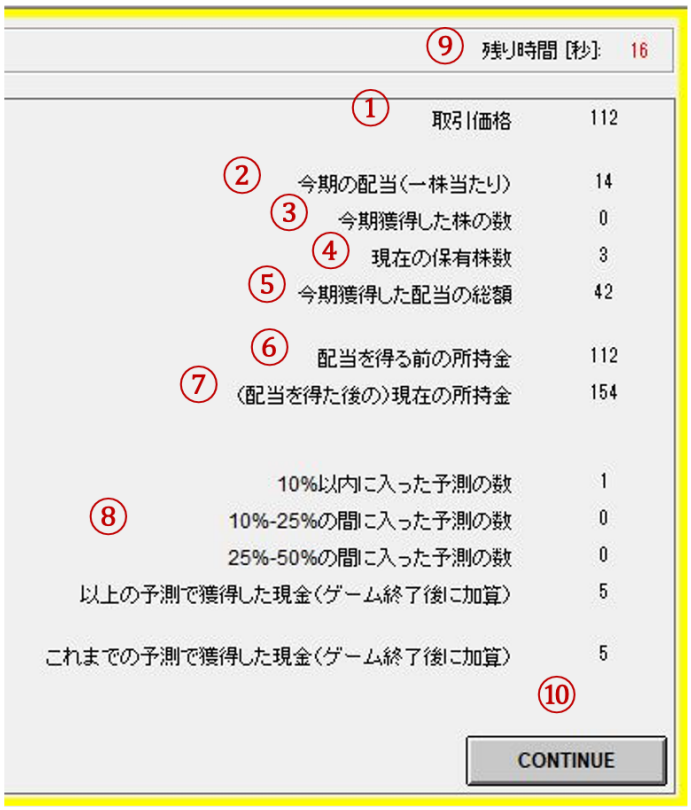


As shown above, Trader 1 is willing to sell at 10 Marks or higher, as in the previous example. If the price rises to 30 Marks, the number of stocks that are supplied increases to three because Traders 2 and 3 are willing to sell their stocks at the price or higher. In contrast, Trader 4 demands a stock at 60 Marks or lower. If the price falls to 30 Marks, the quantity demanded increases to two because Trader 5 additionally demands a stock at the price or lower. As a result, the market price is set to 30 Marks, and then two transactions can be completed at the price. In this case, which orders will be fulfilled is determined as follows.

Priority is given to Trader 1, because he/she requested a price less than the market price. In addition to the order of Trader 1, the order of either Trader 2 or Trader 3 will be filled. This is determined randomly by the computer program.

[End of each period screen]

At the end of each period, the following screen displays the information described below.



(1) This is the market price, as explained previously.

(2) This is the dividend per stock in this period, which is explained later.

(3) A positive value here denotes the number of stocks you have purchased in the current period, while a negative value denotes the number of stocks you have sold in the current period.

(4) This is the number of stocks you currently hold.

(5) This is the total dividend payments you received in this period.

(6) This is your cash holding before receiving the current period dividend payments.

(7) This is your cash holding after receiving the current period dividend payments.

(8) This is the number of correctly predicted prices and the cash bonus to be received at the end of the game. An explanation of this is given in the slide entitled “Earning a profit by predicting future prices correctly.”

(9) This is the time (up to a maximum of 20 seconds) that this screen will remain visible. After observing the information on the screen, press the “Continue” button (10). Once all of the participants have pressed this button, the computer will display the next screen.

Please turn to the next page.

[Earning dividends]

In each game, there are 15 periods in which you can submit your buy/sell orders and trade with other traders in your group. You will also be randomly offered a dividend of either 0, 4, 14, or 30 Marks per stock. Dividend income at the end of each period is calculated as (the current dividend per stock) × (the number of stocks you hold).

[Next value]

"Next Value" depicts **the sum of the average dividend** per stock that will be offered in the remaining periods. The average dividend is (0+4+14+30)/4 = 12 Marks. For example, consider *Next Value* at the end of the second period. There are 13 periods remaining, and thus an average dividend of 12 Marks per stock will be offered 13 times. Therefore, *Next Value* is 12×13=156 Marks.

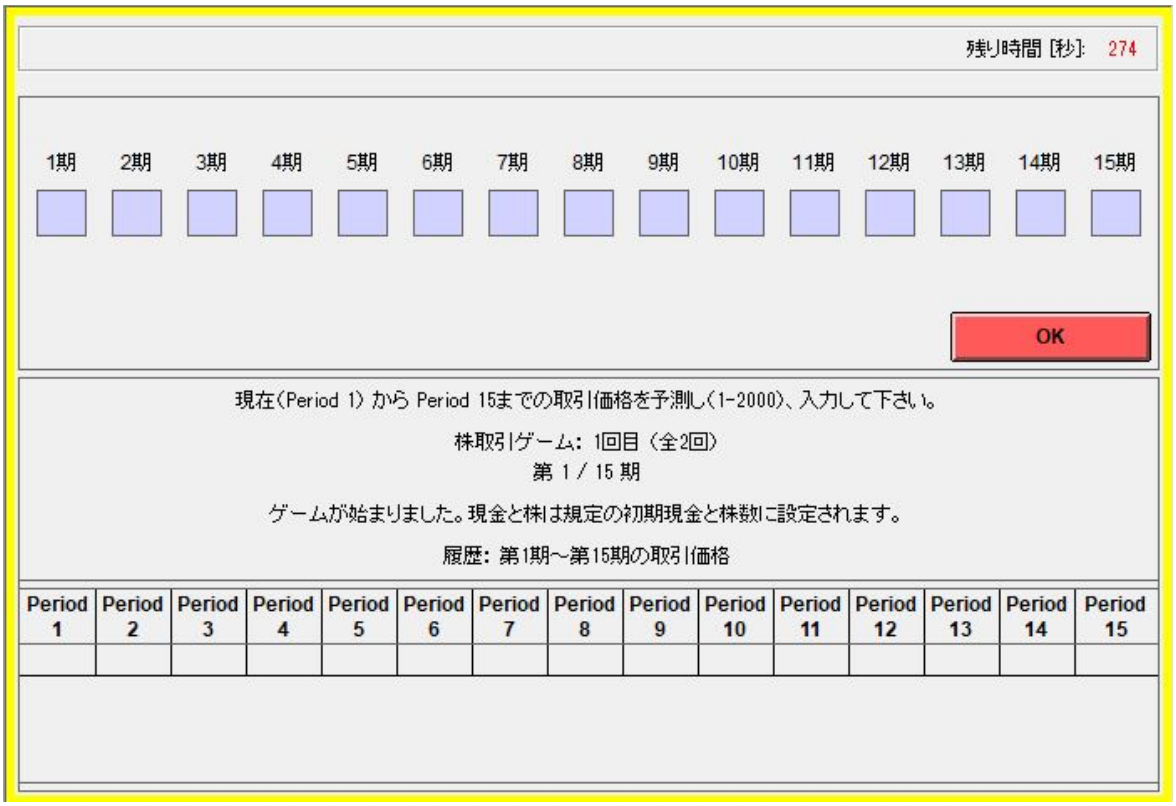
After period 15, a dividend is also paid based on your stock holdings, while the stocks themselves are now worthless. Recall that 12 Marks is only the average value, and the actual dividend paid will be either 0, 4, 14, or 30 Marks.

Please turn to the next page.

This is a table of *Next Values*. A copy of this table will be handed out separately from the instructions. You should refer to this copy during the experiment as necessary.

[Making a profit by predicting future prices correctly]

Before each period begins, you will be asked to predict the market prices in each of the remaining periods. The following screen will appear. The time limit is 12 seconds × the number of remaining periods.



When the time limit is reached, a message warning you to finish entering your predictions will flash in red in the upper right corner of your screen. The next period will begin when everyone has finished entering their predicted prices and pressed "OK"; note that this may occur prior to the expiry of the time limit.

Please turn to the next page.

[Prediction of future prices]

You will be asked to predict the prices for all the remaining periods before each period begins. In other words:

- before the beginning of period 1, there are 15 remaining periods, and therefore you must predict 15 prices
- before the beginning of period 2, there are 14 remaining periods, and therefore you must predict 14 prices

. . .

- before the beginning of period 15, only one period remains, and therefore you only need to predict one price.

Thus, you will be making a total of 120 predictions regarding market prices.

After all of the predicted prices are entered, the median of the prices for the current period predicted by the members of the group is displayed for 10 seconds, after which the display automatically changes to the order entry screen.

[What is the median?]

The median value that is displayed after the forecast price for each period has been entered is the middle value when the forecast prices entered by the members of the group are sorted in ascending order.

Since the group consists of nine members, this means that the median is the fifth value in the order from smallest to largest (or vice versa). For example, if the nine people in the group enter values of 1, 4, 5, 5, 6, 6, 8, 8, and 10, the fifth value from either the bottom or the top is 6, which is the median.

The median value does not change if one person enters either an extremely large value or an extremely small value. For example, if values of 1, 4, 5, 5, 6, 6, 8, 8, and 1000, are entered, the median is still 6.

Please turn to the next page.

[Making a profit by predicting future prices]

The computer will keep a record of the accuracy of your predictions based on the following conditions. If the predicted price is 10% above or below the actual price for each period, you receive 5 Marks. If the predicted price is 25% above or below the actual price for each period, you receive 2 Marks. If the predicted price is 50% above or below the actual price for each period, you receive 1 Mark.

At the end of each game, you will be offered a bonus based on the number of accurate predictions in accordance with the following formula: 5 × (the number of predictions within 10% of the actual price) + 2 × (the number of predictions between 10% and 25% from the actual price) + 1 × (the number of predictions between 25% and 50% from the actual price).

[Summary of ways to make a profit]

There are two ways of making a profit: (1) buying and selling stocks and receiving dividends on stocks held and (2) predicting market prices. After the two games are completed, the Marks you have earned in both games are aggregated and exchanged at the rate of 2 Yen per Mark. In addition to the aforementioned rewards, you will be paid 500 Yen for participating in the experiment.

[End of instructions]

Please turn to the next page.

[Practice]

Now we will conduct a practice round so that you can familiarize yourself with the software and learn how to enter the required information. The first screen displayed is for the prediction of future prices. Press the "OK" button after you have entered all of your price forecasts. The computer will display the order entry screen once everyone has pressed "OK."

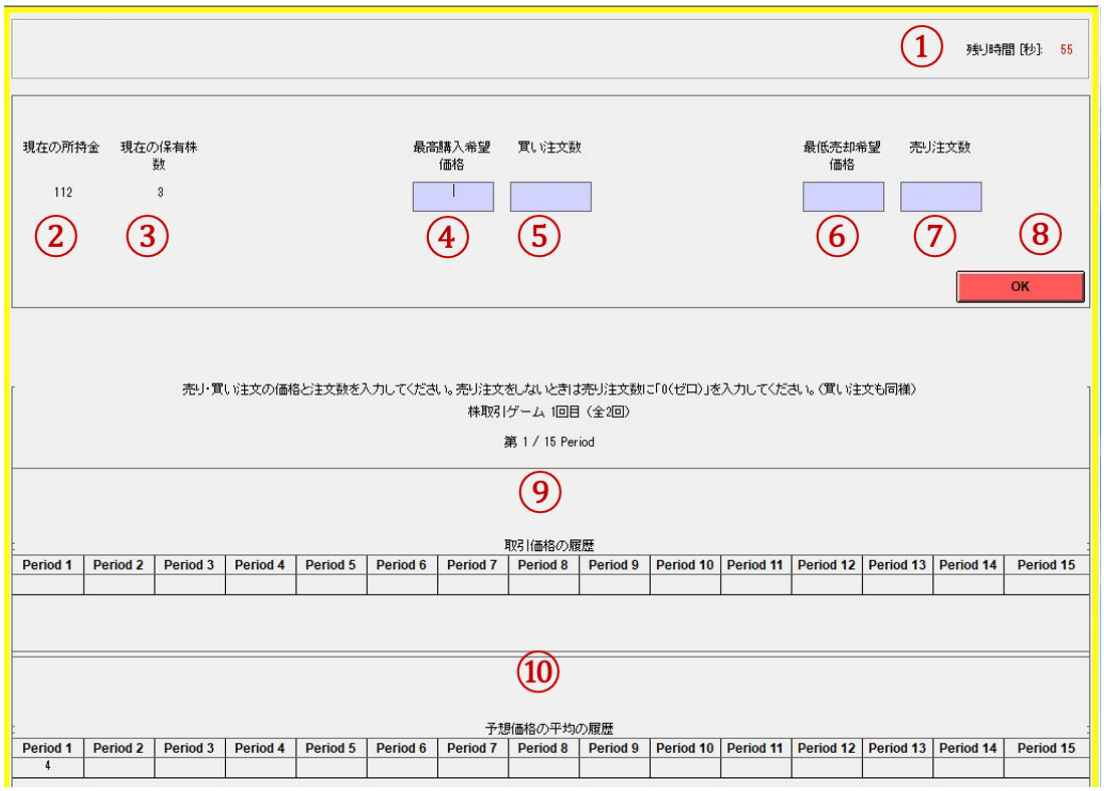
The practice round ends when everyone has pressed the "OK" button after entering their price forecasts. The results of the practice round will not be displayed. Rewards do NOT take into consideration the practice round.

Now, let us start the practice round.

[End of the practice round]

Instructions for other treatments

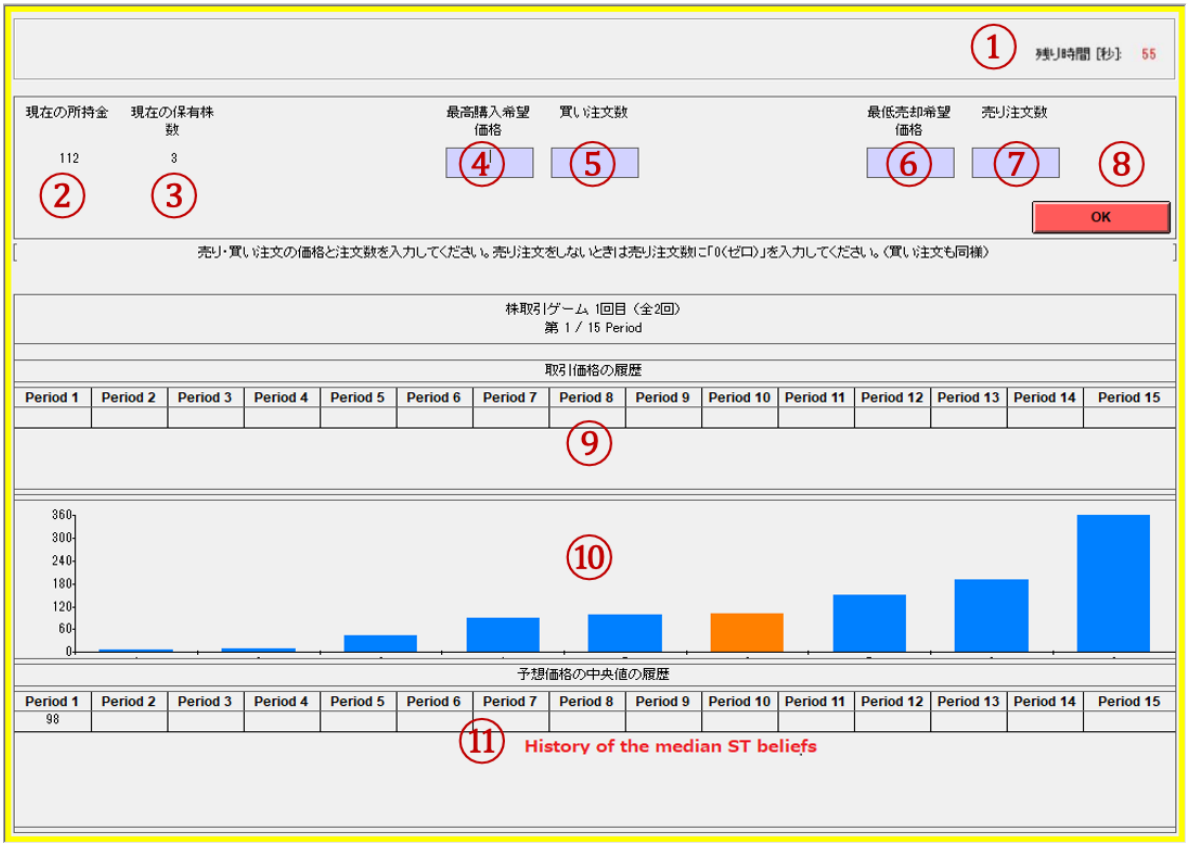
[Order entry screen] for treatment SNB



Items (1)–(9) on the screen are the same as those for treatment C.

(10) is the median of the prices predicted by the members of your group. This will be explained in more detail later.

[Order entry screen] for treatment SWB



Items (1)–(9) are the same as those for treatment C.

(10) This shows a distribution of the prices predicted by the members of your group. This will be explained in more detail later.

(11) This shows the median of the prices predicted by the members of your group. This will be explained in more detail later.

In addition to the above information, the following description/handout was inserted after [**Prediction of future prices**]:

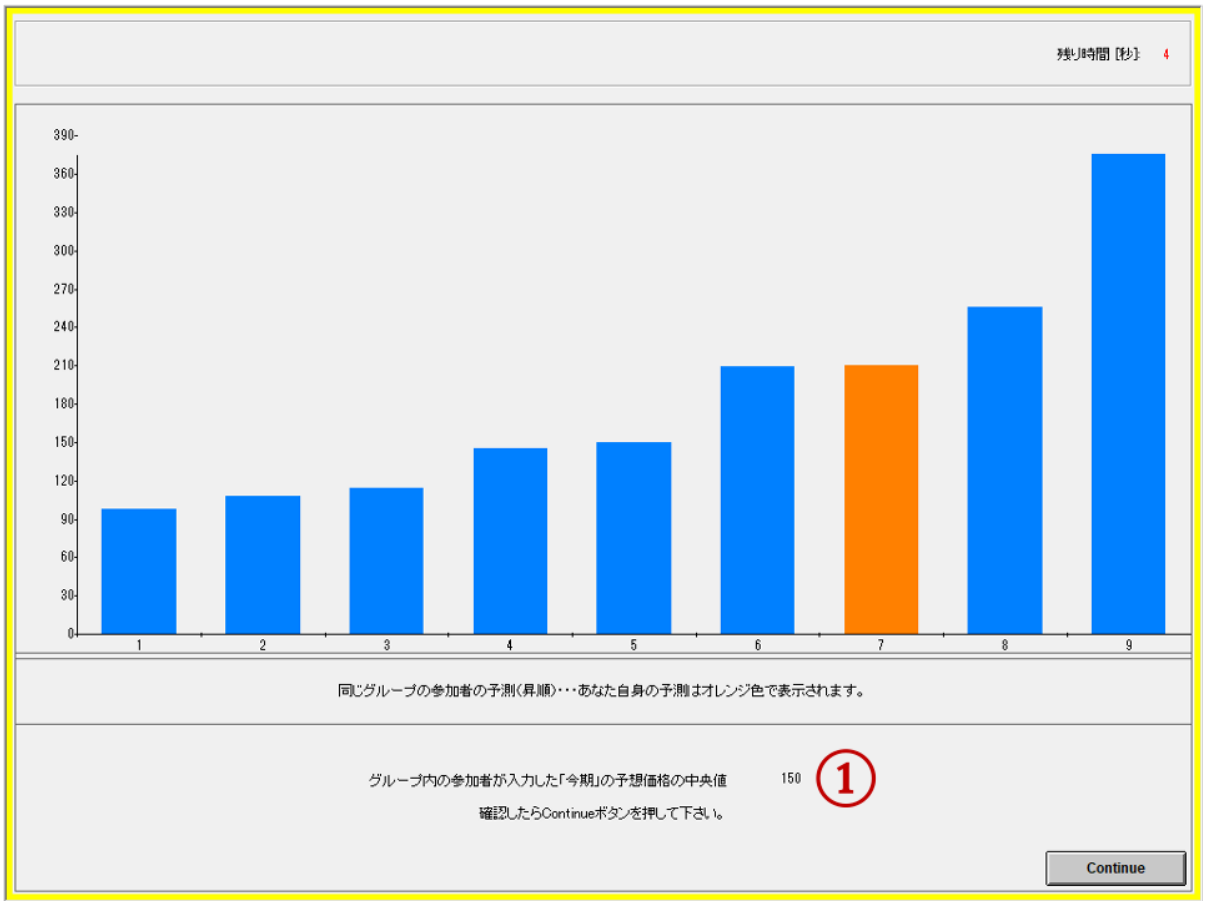
[Distribution of predicted prices and its median]

- The bar graph below shows the prices predicted by members of your group, sorted in ascending order. The vertical axis represents the predicted price, and the scale changes

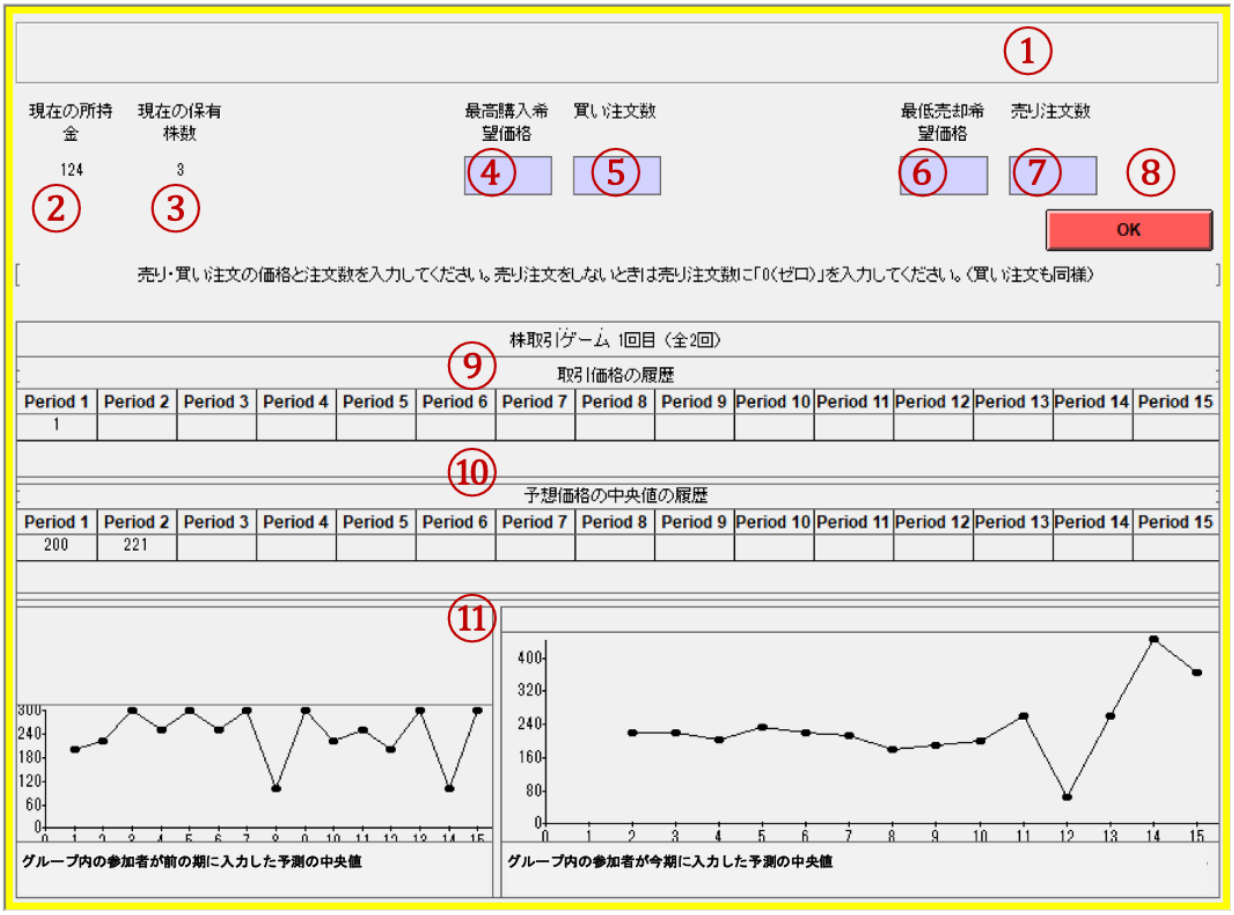
depending on the overall value.

- The maximum display time is 10 seconds, but it will change to the order screen after all of the members of the group have clicked the “Continue” button at the bottom right of the screen.
- Your own predictions are shown in orange.

- (1) shows the median value of this distribution.
- You can also check this bar graph and the history of the median on the order screen.



[Order entry screen] for treatment L



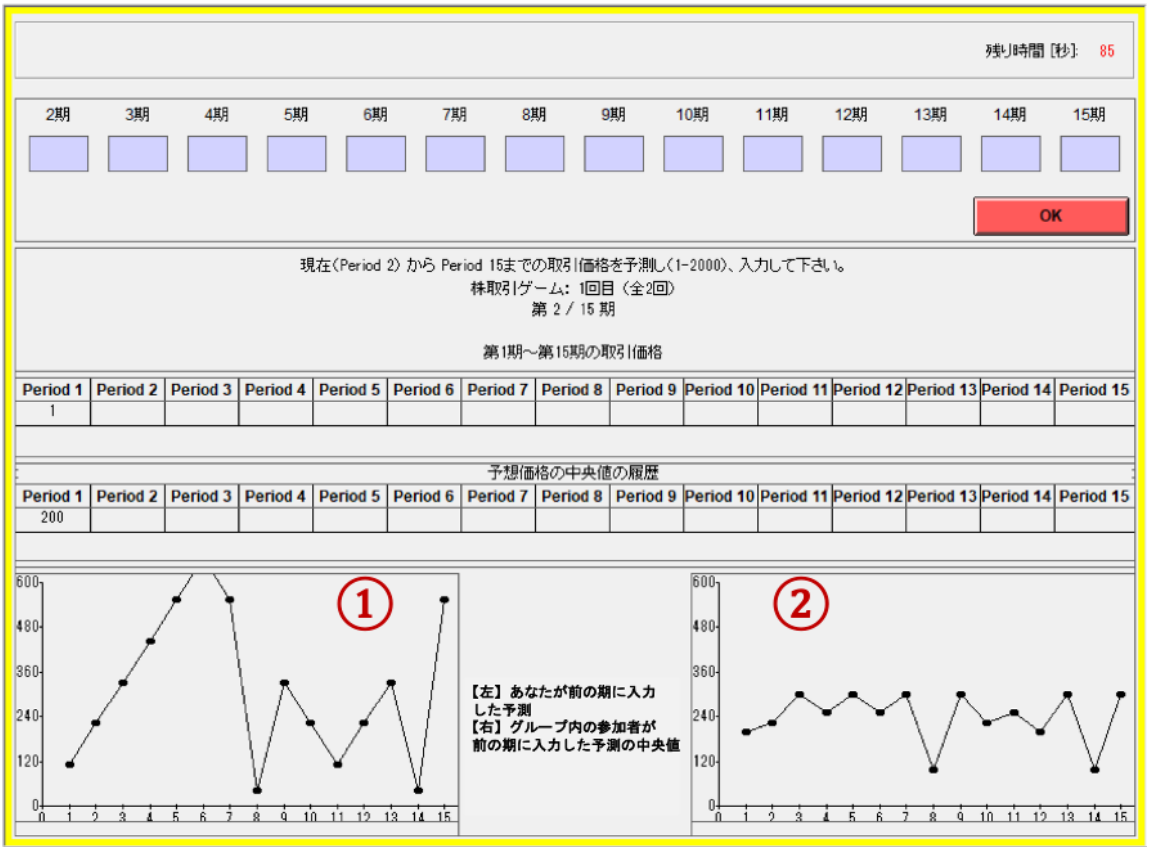
Items (1)–(9) are the same as those for treatment C.

(10) This shows the median of the prices predicted by the members of your group. This will be explained in more detail later.

(11) This shows the distribution of the prices predicted for the previous and current periods by the members of your group. This will be explained in more detail later.

[Making a profit by predicting future prices correctly]

Before each period begins, you will be asked to predict the market prices in each of the remaining periods. The following screen will appear. The time limit is 12 seconds × the number of remaining periods.



When the time limit is reached, a message warning you to finish entering your predictions will flash in red in the upper right corner of your screen. The next period will begin when everyone has finished entering their predictions and pressed “OK.” Note that this may occur prior to the expiry of the time limit.

(1) shows the predicted prices you entered in the previous period

(2) shows the median of the predicted prices your group members entered in the previous period.

In addition to the above information, the following description/handout is inserted after [**Prediction of future prices**]:

[Distribution of predicted prices and its median]

- The graph below shows the median of the predicted prices the members of your group entered in the previous period (left) and that of the predicted prices the member of your group entered in the current period (right).
- The horizontal axis represents the period and the vertical axis represents the predicted price. The scale of the vertical axis changes depending on the overall value.
  - The maximum display time is 10 seconds, but it will change to the order screen when all of the members of the group have clicked on the "Continue" button at the bottom right of the screen.
  - The graph on the left is also displayed on the screen used to enter predicted prices for the current period.
  - Both graphs are also displayed on the order screen for the current period.

[END]

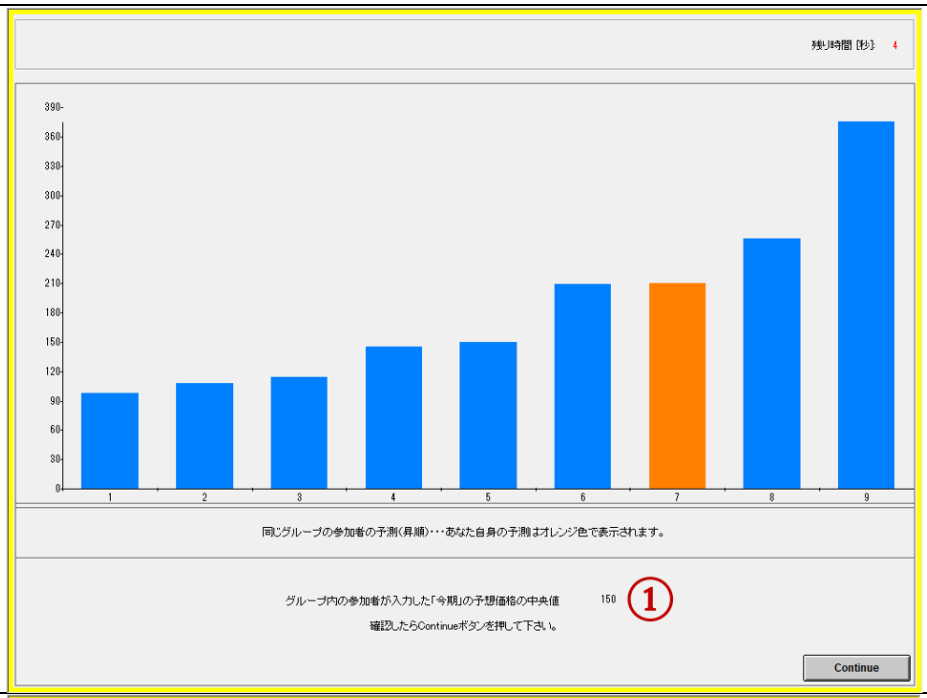
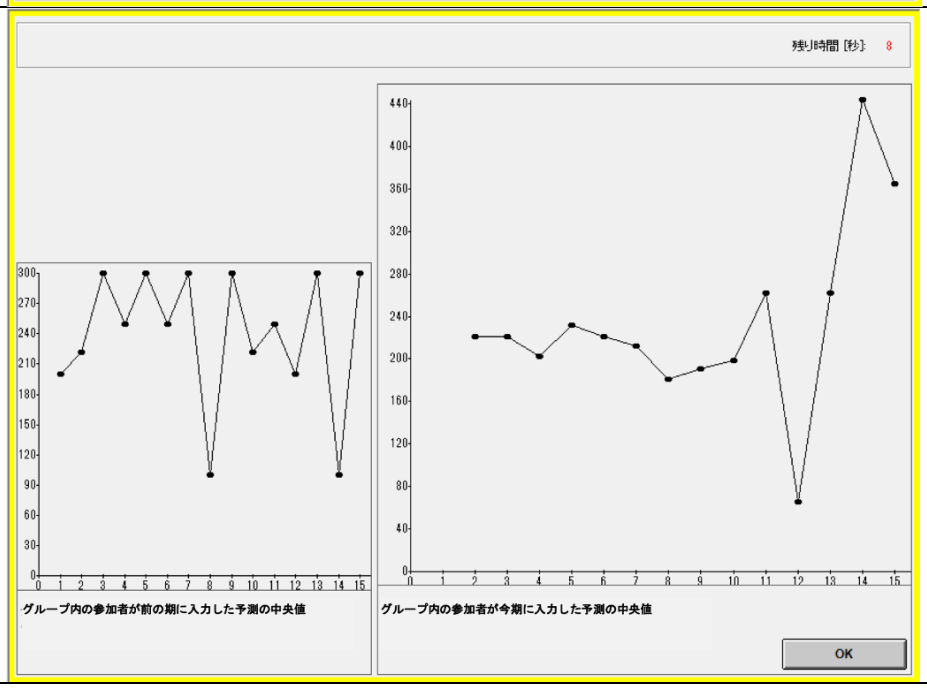
SWB	
L	

Figure 1: Additional information in the SWB and L treatments, respectively. The bar graph above represents the predictions of a coming period by subjects. The orange bar graph indicates the subject who entered the data and is viewing this screen. The line graph below shows the median price forecast for each of the remaining periods, entered before the starts of the previous and the current periods.

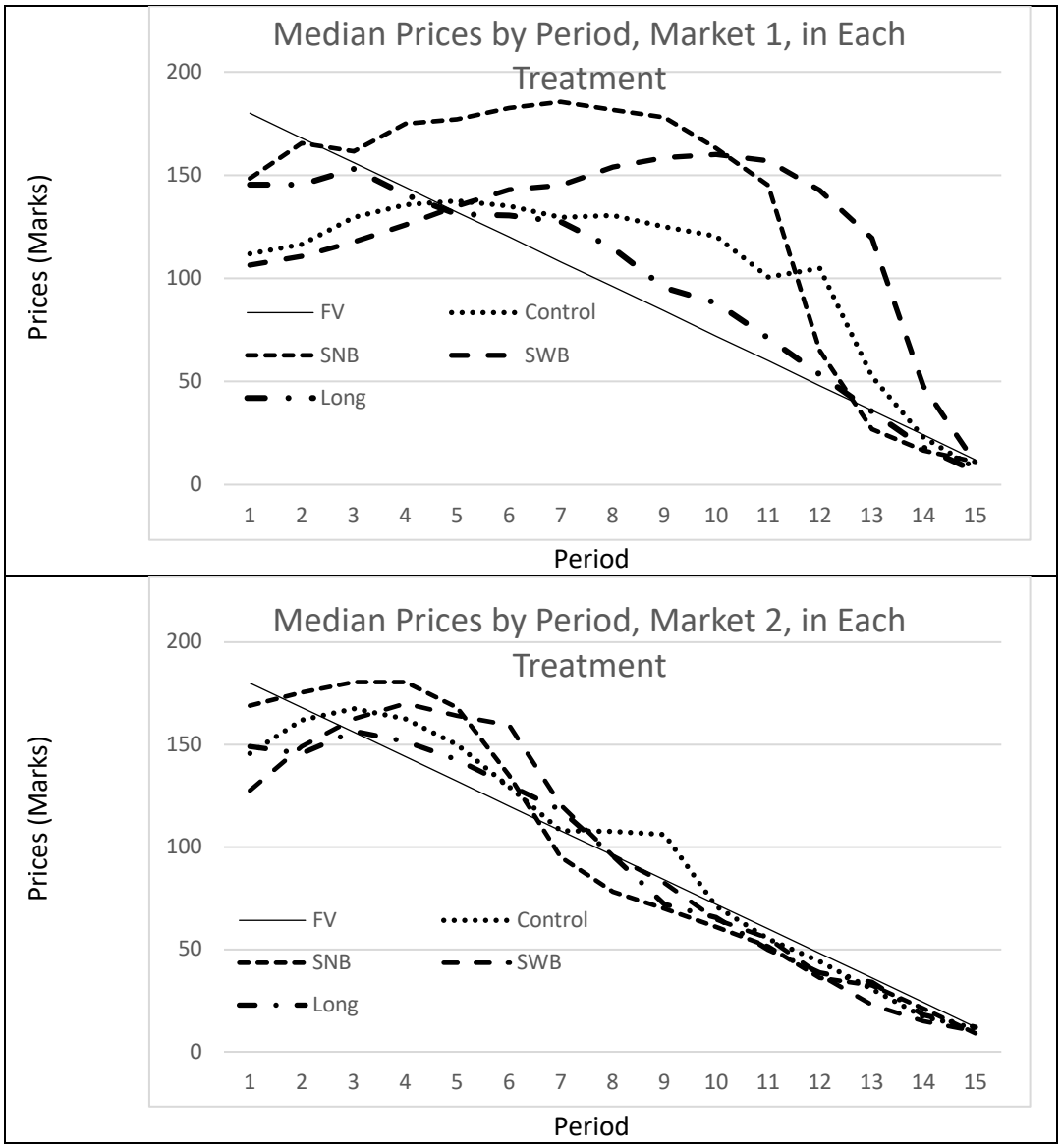


Figure 2: Median prices in each period by treatment, over all sessions.

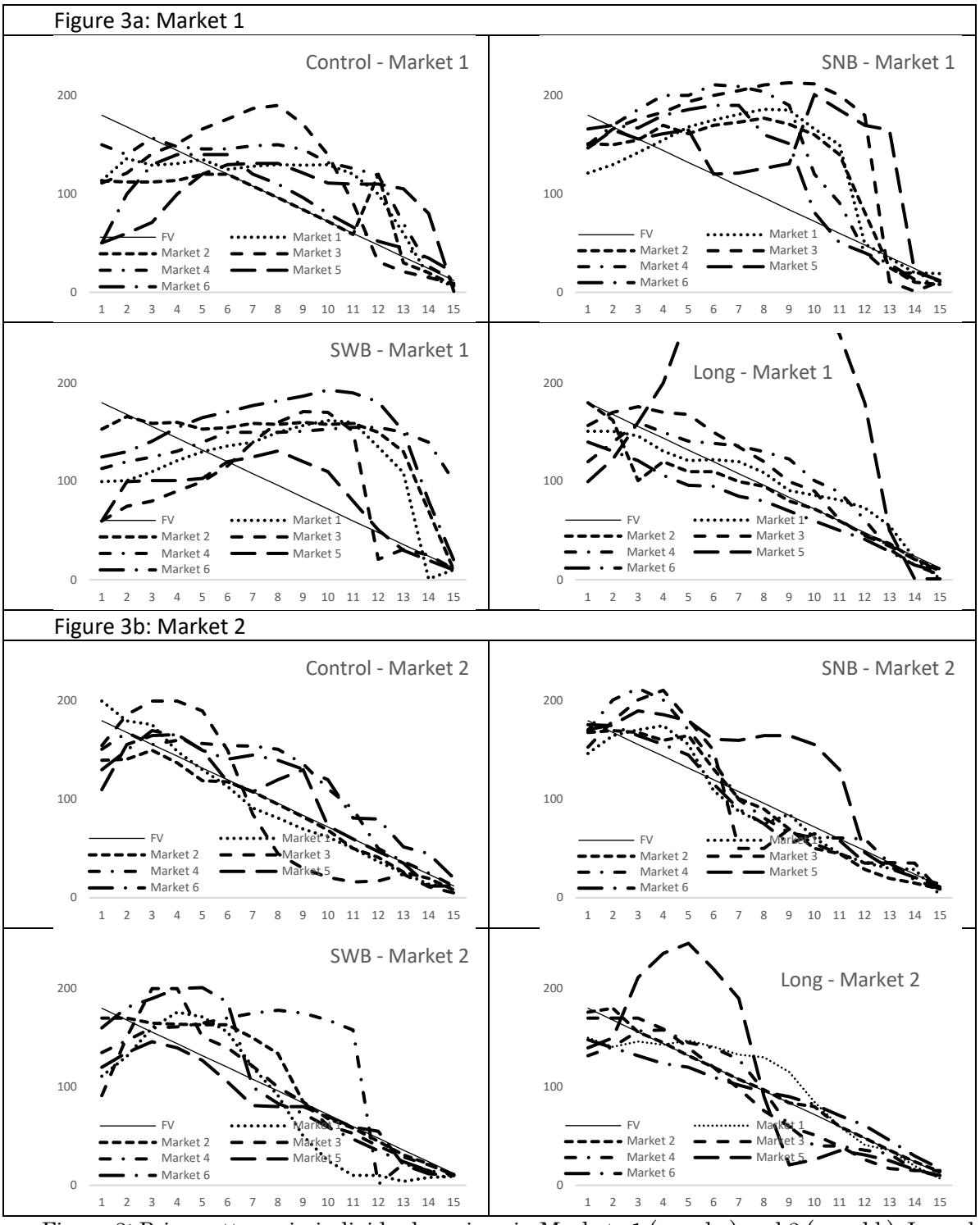


Figure 3: Price patterns in individual sessions in Markets 1 (panel a) and 2 (panel b). In each panel, the horizontal axis indicates the market period and the vertical axis indicates the price level. Some prices in Session 5 are not shown to allow presentation of all panels at the same scale.

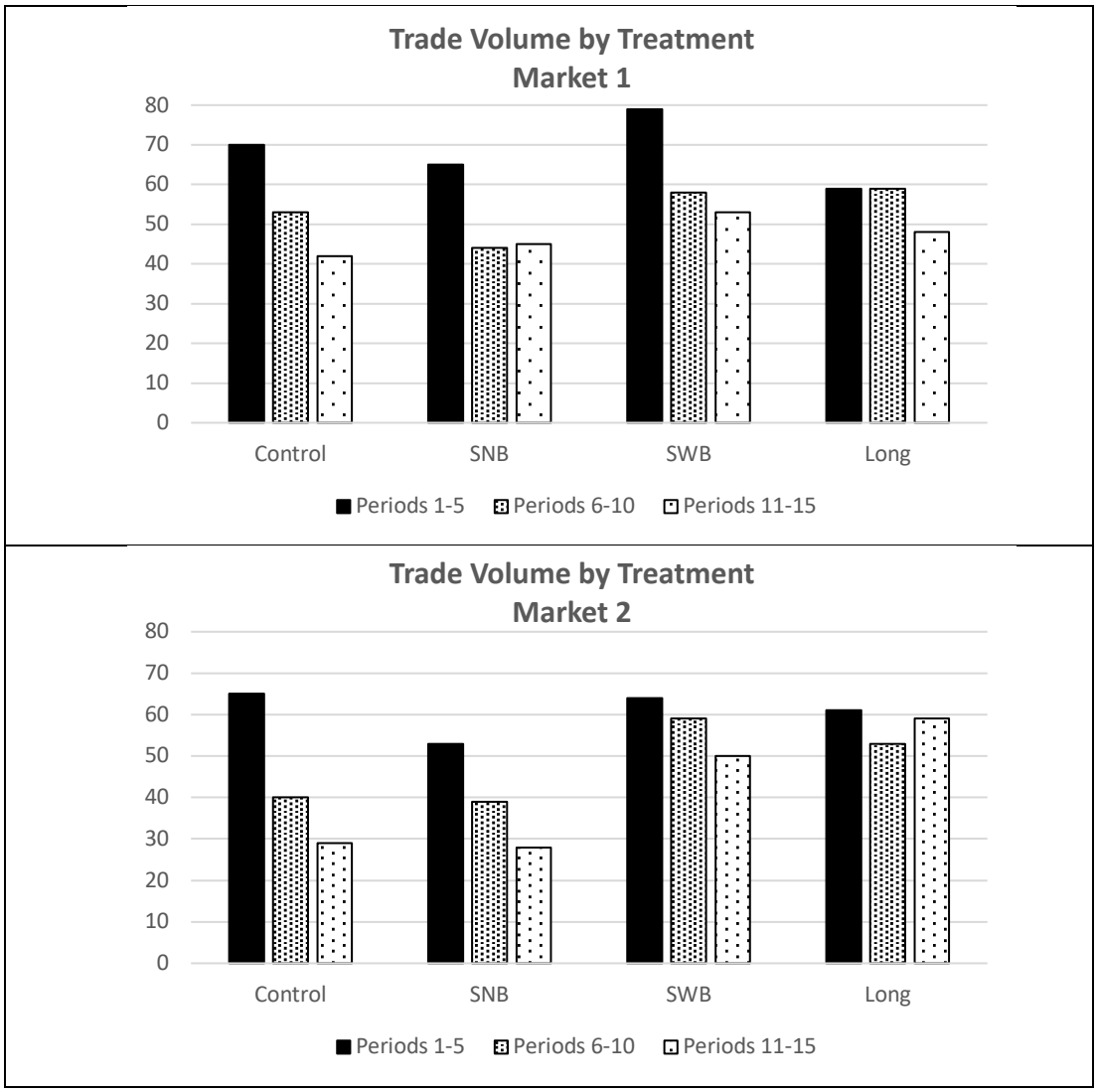


Figure 4: Quantity traded over blocks of five periods. Values are averaged across sessions, with each treatment presented separately.

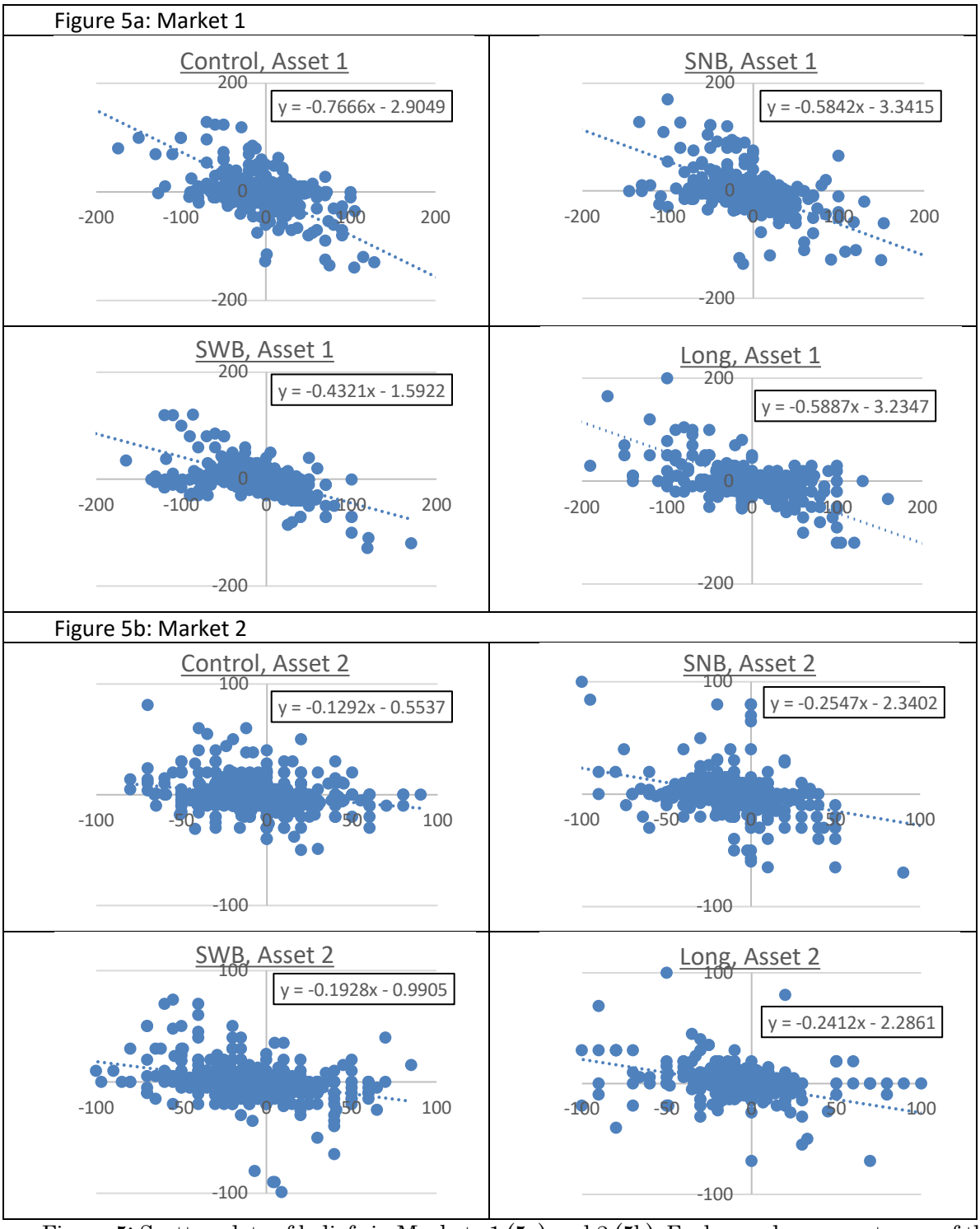


Figure 5: Scatter plots of beliefs in Markets 1 (5a) and 2 (5b). Each panel represents one of the four treatments. The vertical axis indicates differences between an individual's current belief and the median belief in the previous period ($\boldsymbol{B_{i,t} - \bar{B}_{t-1}}$). The horizontal axis indicates differences between an individual's previous belief and the median belief in the previous period ($\boldsymbol{B_{i,t-1} - \bar{B}_{t-1}}$). We excluded extreme values by restricting values to between –200 and 200 for both axes in Market 1 and between –100 and 100 for both axes in Market 2.

Table 1: Between-session variance in short-term beliefs and normalized long-term beliefs ($\boldsymbol{NLTB_{i,t}} = \frac{1}{T-t+1}\sum_{t=\tau}^{T}\frac{B_{it}^{\tau}-f_t}{f_t}$) under each treatment in period 3 of each market.

Treatment	C	SNB	SWB	L
Short-term beliefs				
Period 3 in Market 1	8,207	959	301	194
Period 3 in Market 2	171	497	113	354
Long-term beliefs				
Period 3 in Market 1	0.10	0.45	0.33	0.06
Period 3 in Market 2	0.02	0.02	0.03	0.02

Table 2: Determinants of changes in beliefs

$$B_{i,t} - B_{i,t-1} = \alpha_i + \beta_1 * (P_{t-1} - P_{t-2}) + \beta_2 * \left(B_{i,t-1} - P_{t-1}\right) + \beta_3 * \left(B_{i,t-1} - \overline{B_{t-1}}\right) + \varepsilon_{i,t}$$

Asset	Market 1				Market 2			
Treatment	Control	SNB	SWB	L	Control	SNB	SWB	L
Variables								
PriceTrend, β_1	0.197*	0.525***	0.819***	0.290***	0.551***	0.654***	0.113**	0.531***
	(0.105)	(0.131)	(0.113)	(0.066)	(0.047)	(0.080)	(0.047)	(0.062)
L1BeliefPrice, β_2	-0.708***	-0.283**	-0.115	-0.788***	-0.570***	-0.316***	-0.706***	-0.549***
	(0.138)	(0.141)	(0.127)	(0.082)	(0.060)	(0.090)	(0.051)	(0.082)
L1BeliefDiff, β_3	-0.280**	-0.494***	-0.670***	-0.157*	-0.002	-0.200**	-0.049	-0.233***
	(0.139)	(0.142)	(0.130)	(0.084)	(0.067)	(0.094)	(0.061)	(0.088)
Constant, α_i	-5.049***	-2.806***	-1.591***	-2.709***	-4.090***	-3.067***	-3.401***	-5.095***
	(1.233)	(1.017)	(0.589)	(0.582)	(0.502)	(0.697)	(0.597)	(0.748)
Observations	702	702	702	702	702	702	702	702
R-squared	0.718	0.613	0.755	0.895	0.787	0.681	0.696	0.653
Number of Player	54	54	54	54	54	54	54	54

Standard errors are shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 3: Average number of long-term belief updates toward the median belief per individual, averaged across subjects under each treatment and in each market.

Treatment	Control	SNB	SWB	L
Market 1	72.24	73.26	73.89	77.89
	(1.29)	(1.29)	(1.22)	(1.19)
Market 2	74.78	75.35	73.30	79.78
	(1.44)	(1.02)	(0.94)	(1.22)

The number of long-term predictions in each market was 105 per participant after excluding current predictions. The figures shown in parentheses represent standard errors of the means.

Table 4: Median bubble measures by treatment type and market.

	Market 1				Market 2			
Variable	Control	SNB	SWB	Long	Control	SNB	SWB	Long
Turnover	9.17	8.56	10.56	9.22	7.44	6.67	9.61	9.61
RD	0.05	0.36	0.32	0.04	-0.01	-0.01	0.05	-0.02
RAD	0.33	0.47	0.54	0.19	0.19	0.17	0.54	0.15

Table 5: Estimates of treatment effects on trading volumes

Asset	Market 1	Market 2	Market 1	Market 2
VARIABLES	Volume	Volume	Buy Orders	Buy Orders
C	-0.278	-0.433**	11.211**	43.756***
	(0.213)	(0.211)	(4.734)	(10.495)
SNB	-0.400*	-0.589***	-2.056	-0.544
	(0.213)	(0.211)	(4.734)	(10.495)
L	-0.267	0.000	-1.300	2.678
	(0.213)	(0.211)	(4.734)	(10.495)
Period	-0.185**	-0.212***	-5.286***	3.161
	(0.075)	(0.074)	(1.661)	(3.681)
Period2	0.007*	0.010**	0.406***	0.058
	(0.005)	(0.004)	(0.005)	(0.224)
Constant	2.973***	6.003***	23.216***	-57.184
	(0.290)	(1.350)	(0.290)	(67.239)
Observations	360	360	360	360
R-squared	0.055	0.074	0.093	0.083

Standard errors are shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: P-values for Mann–Whitney U-tests of differences between treatments of the bubble measures RAD and RD (medians shown in Table 4) in each market.

Market 1		RAD			
		C	SNB	SWB	L
RD	C		0.150	0.037**	0.110 (0.018**)
	SNB	0.007***		0.200	0.055* (0.066*)
	SWB	0.262	0.631		0.055* (0.066*)
	L	0.873 (0.465)	0.055* (0.006***)	0.423 (0.144)	
Market 2		RAD			
		C	SNB	SWB	L
RD	C		1.000	0.522	0.749 (0.361)
	SNB	0.749		0.423	0.575 (0.234)
	SWB	0.873	0.873		0.150 (0.045**)
	L	0.631 (0.465)	0.423 (0.201)	0.873 (0.584)	

The figures shown in parentheses represent p-values excluding session 5 under treatment L.

Table 7: Determinants of short-term beliefs.

$$B_{i.m.t}^{t+k} = C_i + \beta_1 * Periodtrend + \beta_2 * Markettrend + \beta_3 * ShortBeliefDiff + \beta_4 * LongBeliefDiff + \epsilon_{i,m,t}$$

	Control		SNB		SWB		L	
Market	1	2	1	2	1	2	1	2
PeriodTrend	0.021***	0.424***	0.164***	-0.074***	0.154***	0.004***	0.096***	-0.002***
	(0.002)	(0.009)	(0.005)	(0.003)	(0.005)	(0.001)	(0.004)	(0.000)
MarketTrend		0.502***		0.894***		0.564***		0.872***
		(0.008)		(0.007)		(0.007)		(0.005)
ShortBeliefDiff	-0.189***	0.025*	-0.160***	-0.001	-0.643***	-0.011	-0.072***	0.009
	(0.019)	(0.015)	(0.028)	(0.028)	(0.030)	(0.044)	(0.015)	(0.020)
LongBeliefDiff	36.063***	0.867***	41.972***	7.117***	36.516***	-0.911	13.193***	0.941***
	(1.039)	(0.216)	(1.449)	(1.146)	(1.151)	(1.903)	(1.347)	(0.106)
Observations	5,616	5,616	5,616	5,616	5,616	5,616	5,616	5,616
R-squared	0.499	0.937	0.546	0.803	0.514	0.605	0.640	0.862

Table 8: The effect of belief information on net purchases, by treatment and market

$$\text{Net } Purchases_{i,t} = \alpha_i + \beta_1\left(short\ term\ belief_{i,t} - median\ short\ term\ belief_t\right) + \varepsilon_{i,t}$$

Asset	Market 1				Market 2			
Treatment	C	SNB	SWB	L	C	SNB	SWB	L
BeliefDiff (optimism)	0.001	0.004***	0.004***	0.000	0.008***	0.004**	-0.000	0.005**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)
Constant	-0.002	-0.006	-0.001	-0.001	-0.003	-0.000	0.000	0.000
	(0.032)	(0.028)	(0.032)	(0.033)	(0.026)	(0.023)	(0.036)	(0.033)
Observations	810	810	810	810	810	810	810	810
R-squared	0.001	0.035	0.010	0.000	0.017	0.006	0.000	0.006
N	54	54	54	54	54	54	54	54

Table 9: The effect of belief information on bid prices, by treatment and market.

$$Bid\ price_{i,t} - median\ short\ term\ belief_t = \alpha_i + \beta_1(short\ term\ belief_{i,t} - median\ short\ term\ belief_t) + \varepsilon_{i,t}$$

Asset	Market 1				Market 2			
Treatment	C	SNB	SWB	L	C	SNB	SWB	L
BeliefDiff (Optimism)	0.045	0.306***	0.368***	0.054	0.505***	0.281*	0.058	0.367***
	(0.031)	(0.061)	(0.090)	(0.050)	(0.163)	(0.153)	(0.166)	(0.133)
Constant	-46.139***	-53.522***	-58.043***	-57.806***	-51.959***	-55.126***	-55.489***	-45.839***
	(1.806)	(2.075)	(2.123)	(2.535)	(1.887)	(2.024)	(2.256)	(2.044)
Observations	810	810	810	810	810	810	810	810
R-squared	0.003	0.033	0.022	0.002	0.013	0.004	0.000	0.010
N	54	54	54	54	54	54	54	54

Table 10: The effect of belief information on bid quantity, by treatment and market.

$$numBid_{i,t} - median\ short\ term\ belief_t = \alpha_i + \beta_1(short\ term\ belief_{i,t} - median\ short\ term\ belief_t) + \varepsilon_{i,t}$$

Asset	Market 1				Market 2			
Treatment	C	SNB	SWB	L	C	SNB	SWB	L
BeliefDiff (Optimism)	0.000	-0.008	-0.016	0.004	-0.113	-0.001	-0.004	0.005
	(0.011)	(0.005)	(0.010)	(0.003)	(0.106)	(0.010)	(0.013)	(0.009)
Constant	2.858***	1.395***	1.616***	1.457***	6.106***	1.135***	1.197***	1.493***
	(0.654)	(0.160)	(0.234)	(0.167)	(1.221)	(0.129)	(0.170)	(0.139)
Observations	810	810	810	810	810	810	810	810
R-squared	0.000	0.003	0.003	0.002	0.002	0.000	0.000	0.000
N	54	54	54	54	54	54	54	54