

DIVERSITY IN COGNITIVE ABILITY ENLARGES MISPRICING

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Diversity in cognitive ability enlarges mispricing^{*}

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Abstract

How does known diversity in cognitive ability among market participants influence market outcomes? We investigated this question by first measuring subjects' cognitive ability and categorizing them as 'H' type for those above median ability and 'L' type for those below median ability. We then constructed three kinds of markets with six traders each: 6H, 6L, and 3H3L. Subjects were informed of their own cognitive type and that of the others in their market. We found heterogeneous markets (3H3L) generated significantly larger mispricing than homogeneous markets (6H or 6L). Thus, known diversity in cognitive ability among market participants impacts mispricing.

Keywords: Cognitive ability, Heterogeneity, Mispricing, Experimental asset markets

JEL Code: C90, D84

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1 Introduction

Historical episodes of economic bubbles are often characterized by euphoria and an inflow of new and possibly naïve investors (Kindleberger and Aliber, 2005). Such an inflow of new investors can amplify the heterogeneity among market participants regarding their belief about future prices of the asset being traded, and thus may inflate the mispricing as noted by Xiong and Yu (2011) in their study of “bubbles” in a subset of China’s warrant market. Several theoretical works (Allen and Gale, 1992; Aggarwal and Wu, 2006; Allen et al., 2006) build upon such an idea and show how heterogeneities in terms of (strategic) sophistication among traders can lead to large mispricing. Allen and Gale (1992), for example, show that sophisticated strategic traders try to generate an initial upward price trend to influence the belief of naïve trend followers in order to later profit from their naïveté.

Recent experimental studies have demonstrated the relationship between the cognitive abilities of subjects and the mispricing in asset market experiments *à la* Smith et al. (1988).¹ Breaban and Noussair (2014) show that the average score of subjects in a market on the Cognitive Reflection Test (CRT, Frederick, 2005) is negatively correlated with the magnitude of observed mispricing in the market. Corgnet et al. (2014) and Cueva and Rustichini (2014) demonstrate that subjects with higher cognitive skill earned more than their lower cognitive skill counterparts. Cognitive skills are measured by the CRT in the former and by Raven’s progressive matrix test (see Raven, 2008, for an overview) and Race to X or Hit X game (Gneezy et al., 2010; Dufwenberg et al., 2010) in the latter. These experimental findings are in line with findings from empirical studies based on large-scale surveys that tend to report that people with high cognitive skills make better financial decisions (see, for example, Korniotis and Kumar, 2010, for a survey of the empirical literature).

These experimental and empirical studies led us to speculate that the mispricing observed in experimental and real financial markets is primarily due to bad decisions made by naïve market participants, and not so much by the strategic interactions among

¹See Palan (2013) for a recent survey of the literature. However, the body of literature is expanding very quickly with many new papers being presented each year at the annual meeting of the Society of Experimental Finance. See <http://www.experimentalfinance.org/> for a list of papers presented at recent meetings.

traders of varying degrees of strategic sophistication. Yet, two recent experimental studies, Cheung et al. (2014) and Akiyama et al. (2013), have convincingly demonstrated that this may not be the whole story. Cheung et al. (2014) found that uncertainty regarding the fundamental value (FV) of the asset being traded among market participants generated a large mispricing. Akiyama et al. (2013) found that subjects with perfect CRT scores reacted more strongly to the presence of strategic uncertainty than others with lower CRT scores. Because known diversity (or heterogeneity) in cognitive ability among market participants can be an important source of heterogeneous belief about future prices and strategic uncertainty, these two experimental studies hint at the possibility that such diversity can amplify the mispricing of the asset being traded.

To our knowledge, however, the effect of interactions among traders with varying degrees of strategic sophistication has never been explicitly investigated experimentally. The above-mentioned studies relate cognitive skills and market outcomes only ex-post, and thus do not use cognitive skills as an experimental variable. What we aim to do in this paper is to experimentally manipulate the composition of traders in markets according to their measured cognitive ability. In particular, we ask the following research question: *How does the average cognitive ability among market participants, as well as their known diversity, influence mispricing in an experimental market?*

We approach this research question by first measuring subjects' cognitive ability by employing part of the advanced version of Raven's progressive matrix (RPM) test, and grouping subjects based on their relative test scores. The RPM test measures what is called "fluid intelligence", that is "the capacity to think logically, analyze and solve novel problems, independent of background knowledge" (Mullainathan and Shafir, 2013, p.48),² and its score has shown to be correlated with a degree of strategic sophistication (Carpenter et al., 2013; Gill and Prowse, 2014).³ This correlation between the degree of strategic sophistication and the score from the RPM test is ideal for our purpose given our interest in the interaction among traders with varying degrees of strategic

²"Fluid intelligence" should be distinguished from what is called "executive control." The latter is an ability to control one's impulsive behavior or response. The CRT, from this point of view, can be interpreted as a measure of one's executive control and not their fluid intelligence.

³Carpenter et al. (2013) and Gill and Prowse (2014) use the standard, not advanced, version of the RPM test. Strategic sophistication is measured in terms of the number of wins in the Race to 5, 10, and 15 game (Carpenter et al., 2013) as well as deviation from the equilibrium in a three-player Beauty Contest game (Gill and Prowse, 2014).

sophistication.

Our study is unique because it explicitly groups subjects according to their relative score on the RPM test and *subjects are informed of their own classification as well as the classifications of the other five traders in the same market*.⁴ In a study that was conducted independently and almost simultaneously to ours, Bosch-Rosa et al. (2015) created a group explicitly based on the subjects' relative ranking on measures of cognitive abilities that were collected ex-ante. They first conducted an experimental session consisting of the CRT, guessing games, and multiple rounds of the Race to 60 game to measure and to create a composite index of cognitive abilities of their subjects. Then, they later re-recruited subjects from the top 30% ("high sophistication") or from the bottom 30% ("low sophistication") of their subject pool according to the index and conducted an asset market experiment in which markets consisted only of high-sophistication subjects or of low-sophistication subjects. They found large mispricing in the markets that consisted only of low-sophistication subjects but almost no mispricing in those that consisted only of high-sophistication subjects. Bosch-Rosa et al. (2015), however, did not inform their subjects about their relative ranking nor the ranking of others in the same market except in some of their all high-sophistication subject markets. What we intend to study in our experiment - how known heterogeneity regarding cognitive ability among traders within a market might affect mispricing - is therefore quite different from what Bosch-Rosa et al. (2015) investigated.

2 Experiment

In each session of 24 subjects, we first ask subjects to answer a part of Raven's advanced progressive matrix test (24 questions to be answered in 15 minutes).⁵ We do not inform our subjects why we ask them to answer the RPM test (which we called a quiz during the experiment), nor what kind of experiments will follow after completing the test. Thus, when our subjects are answering the RPM test, they are not aware that their

⁴We do not, however, inform our subjects that the RPM is meant to measure their "fluid intelligence" nor do we reveal their exact score.

⁵The full advanced RPM test consists of 48 questions to be answered in 30-40 minutes. We used all the odd-numbered questions from the full test in the original ordering to keep the questions becoming progressively more difficult.

relative scores will be later used to place them into different groups in an asset market experiment. Following the standard practice in administrating the RPM test, we do not offer monetary incentives to our subjects for answering as many questions correctly as possible.

Once the RPM ends, we divide our subjects into two types based on their relative scores on the RPM test. We call those above the median score ‘H type’ and those below the median score ‘L type’. We then create three versions of a 20-period call asset market with six traders: in version one, all six traders are H type (6H markets); in version two, all the six traders are L type (6L markets); and in version three, there is an equal number of H and L types (3H3L markets). In one experimental session of 24 subjects, we create two 6H markets and two 6L markets. In another session, we create four 3H3L markets.⁶ We inform our subjects of their own type (H or L) as well as the composition of the six traders in the same market. Thus, if an H-type subject is in a 6H market, s/he is informed that s/he is H type and all the other five traders in the market are also H type. If an H-type subject is in a 3H3L market, s/he is informed s/he is H type and that the other five traders consist of two H-type traders and three L-type traders. Similarly, if an L-type subject is in a 6L market, s/he is informed that s/he is L type and all the other five traders in the market are also L type. We do not inform our subjects how many questions, out of 24 questions, they or others in the same group have answered correctly.

In all the markets, traders are initially given 4 units of the asset and 1040 experimental currency units (ECUs) which they can use to trade over 20 periods. Each unit of asset pays a dividend of 12 ECUs at the end of each period, which will be added to traders’ cash holdings and can be used for trading in the future periods. After the final dividend payment at the end of period 20, all the assets lose their value. Under these conditions, the fundamental value of a unit of the asset during period t ($t = 1, 2, \dots, T$), FV_t , is the sum of the remaining dividend payments, that is, $FV_t = 12(21 - t)$. For example, a unit of asset initially has a value of 240 ECUs. Thus the value of initial endowment is 2000

⁶Groups are created according to the rankings on the RPM test of the participants in that session. In the 24-subject 6H and 6L sessions, the first 6H market consist of subjects with rankings of $\{1, 3, 5, 7, 9, 11\}$ and the second consists of subjects with rankings of $\{2, 4, 6, 8, 10, 12\}$; for the two 6L markets, the first consists of subjects with rankings of $\{13, 15, 17, 19, 21, 23\}$ and the second of subjects with rankings of $\{14, 16, 18, 20, 22, 24\}$. For the 3H3L markets, we have four markets that consist of those subjects with rankings of $\{1, 5, 9, 13, 17, 21\}$, $\{2, 6, 10, 14, 18, 22\}$, $\{3, 7, 11, 15, 19, 23\}$, and $\{4, 8, 12, 16, 20, 24\}$, respectively. In cases where subjects have identical scores, rankings are assigned randomly.

ECUs for all the market participants (1040 ECUs in initial currency plus 960 ECUs for the four units of the asset). We have eliminated the uncertainty in dividend payments in order to minimize the presence of uncertainty beyond the strategic uncertainty in the market. Even with fixed and known dividend payments, mispricing has been observed in these markets (Porter and Smith, 1995; Akiyama et al., 2014, 2013).

We employ a call market mechanism as in van Boening et al. (1993); Haruvy et al. (2007); Akiyama et al. (2014, 2013) instead of continuous double auction as in many other studies. In our call market, in each period, each trader can submit at most one buy order and one sell order.⁷ An order consists of a pair of values: a price and a quantity. When submitting a buy order in period t , trader i must specify the *maximum price*, pd_t^i , at which s/he is willing to buy a unit of asset, and the *maximum quantity*, d_t^i , s/he is willing to buy. In the same manner, when submitting a sell order in period t , trader i must specify the *minimum price*, ps_t^i , at which s/he is willing to sell a unit of asset, and the *maximum quantity*, s_t^i , s/he is willing to sell. We attached three constraints: the admissible price range, a budget constraint, and the relationship between pd_t^i and ps_t^i in the case that a subject submits both buy and sell orders. The admissible price range is set so that, when $d_t^i \geq 1$ ($s_t^i \geq 1$), pd_t^i (ps_t^i) must be an integer between 1 and 2000, i.e., $pd_t^i \in \{1, 2, \dots, 2000\}$ ($ps_t^i \in \{1, 2, \dots, 2000\}$). The budget constraint simply means that neither borrowing of cash nor short-selling of an asset is allowed.⁸ The final constraint is such that when a trader is submitting both buy and sell orders, i.e., $d_t^i \geq 1$ and $s_t^i \geq 1$, the maximum buying price must not be greater than the minimum selling price, i.e., $ps_t^i \geq pd_t^i$. Once all the traders in the market have submitted their orders, the price that clears the market is calculated,⁹ and all transactions are processed at that price among traders who submitted a maximum buying price no less than, or a minimum selling price no greater than, the market clearing price.¹⁰

⁷Of course, a trader can choose not to submit any orders by specifying zero as the quantities to buy and sell. We imposed a 60-second, non-binding, time limit for submitting orders. When the time limit was reached, the subjects were simply informed, though a flashing message in the upper right corner of their screen, to submit their orders as soon as possible.

⁸Thus, the budget constraint implies (i) $d_t^i \times pd_t^i \leq \text{cash holding at the beginning of the period } t$, and (ii) $s_t^i \leq \text{units of asset on hand at the beginning of the period } t$.

⁹When there are several such prices, the lowest one is chosen as the market clearing price. This is important to ensure the price does not jump up in the absence of transactions at the market clearing price.

¹⁰Any ties among the last accepted buy or sell orders are resolved randomly. It is possible that no transaction will take place given the computed market clearing price.

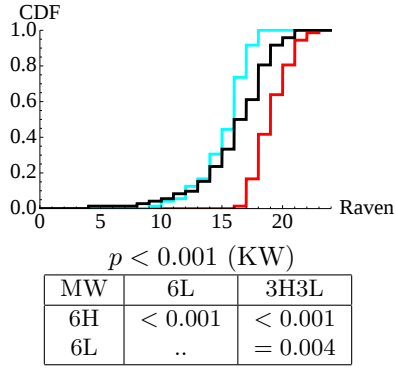


Figure 1: Distribution of scores from Raven's (RPM) test in 6H (red), 6L (light blue), and 3H3L (black). There are 72 subjects in each group: 6H, 6L, and 3H3L. P-values from the Kruskals-Wallis (KW) test (multiple comparison) as well as a pair-wise Mann-Whitney test are shown. The highest score obtainable is 24.

The entire experiment is computerized with z-Tree (Fischbacher, 2007). Each session lasted about 1.5 hours including a post-experimental questionnaire. On average, subjects earned 3000 yen (≈ 22 euros at the average exchange rate during the time of experiment) including a 1000-yen participation fee. See Appendix for English translation of the instructions.

3 Result

The experiment was conducted at Waseda University (in Tokyo, Japan) between November 2014 and June 2015. A total of 216 subjects (144 subjects in 6H/6L sessions and 72 subjects in 3H3L sessions) participated. These subjects had never participated in a similar experiment before and each subject only participated in one session.

Figure 1 shows the distributions of the scores from the RPM test among the participants in each treatment. There are significant differences in the distribution of RPM scores among the three treatments. The results from the previous studies mentioned in the introduction suggest a positive relationship between the average level of cognitive ability among traders and mispricing in markets. If the known diversity (or the heterogeneity) of a cognitive ability among traders does not have a strong effect, then we would expect there to be larger mispricing in 6L than in 3H3L, and, in turn, in 3H3L than in 6H. On the other hand, if the diversity has a significant effect, then we may

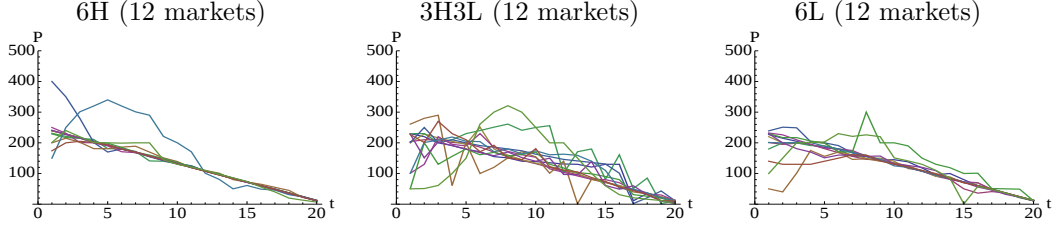


Figure 2: Realized price dynamics in three treatments: 6H (left), 3H3L (center), and 6L (right).

observe larger mispricing in the 3H3L markets than in the two homogeneous markets.

3.1 Prices

Figure 2 shows the observed price dynamics from the three treatments: 6H (left), 3H3L (center), and 6L (right). In 6H markets, prices follow the fundamental value very closely in most of the sessions. In 6L markets, on the other hand, we observe prices to deviate more from the fundamental value than in 6H markets. Compared to 3H3L markets, however, the mispricing observed in 6L markets seems to be much smaller.

We measure the magnitude of deviation of prices from the fundamental values by relative absolute deviation (RAD) and relative deviation (RD) proposed by Stöckl et al. (2010). For each market m , RAD and RD are defined as

$$RAD^m = \frac{1}{20} \sum_{p=1}^{20} \frac{|P_p^m - FV_p|}{|\overline{FV}|} \quad (1)$$

$$RD^m = \frac{1}{20} \sum_{p=1}^{20} \frac{P_p^m - FV_p}{|\overline{FV}|} \quad (2)$$

where P_p^m is realized price in period p in market m . FV_p is fundamental value of asset in period p . $|\overline{FV}| = |\frac{1}{20} \sum_{p=1}^{20} FV_p|$.

Figure 3 shows the empirical cumulative distribution (CDF) of RAD (left) and RD (right) observed in 6H (red), 6L (light blue), and 3H3L (black). As one could expect from the price dynamics shown in Figure 2, the distribution of RAD from 3H3L lies on the right of 6H and 6L markets. The pair-wise comparisons show that the median RAD in 3H3L is significantly greater than those in 6H and 6L. Between the latter two,

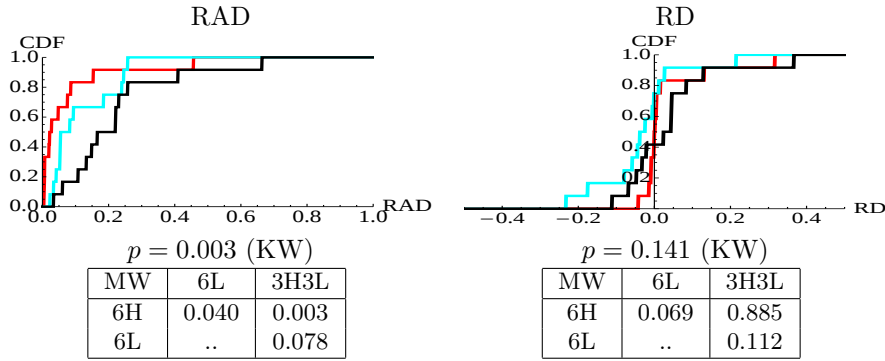


Figure 3: Distribution of RAD (left) and RD (right) in 6H (red), 6L (light blue), and 3H3L (black). P-values from the Kruskals-Wallis (KW) test (multiple comparison) as well as a pair-wise Mann-Whitney test are shown.

in 6L the median RAD is significantly greater than in 6H. On the other hand, with the distributions of RD , we do not observe a significant difference across the three treatments according to the Kruskal-Wallis test. Thus, while the mispricing is indeed larger in the heterogeneous 3H3L markets than in the two homogeneous markets (6H and 6L), the direction of price deviation from the fundamental value is not systematically different across three treatments.

In addition to the treatment effects, we report the correlation between the average score on the RPM among market participants as well as their standard deviation and RAD in Figure 4. The right panel of the figure shows a negative correlation, although the correlation is marginally insignificant, between the within-market average score on the RPM and RAD . The left panel of the figure shows a positive and significant correlation between the within-market standard deviation of the score on the RPM and RAD .

3.2 Trading volumes

Figure 5 shows the observed dynamics of trading volume from the three treatments: 6H (left), 3H3L (center), and 6L (right). Unlike the price dynamics we have seen in Figure 2 above, there are no large variations across the three treatments except that several 6H or 6L markets demonstrate large trading volumes around period 15 and 20 while none of the 3H3L markets do so.

Figure 6 reports the empirical cumulative distribution of the total share of outstand-

ing assets that are traded over 20 periods. This measure is called *turn-over* (TO), and the TO for market m is defined as follows:

$$TO^m = \sum_{p=1}^{20} \frac{Q_p^m}{24} \quad (3)$$

where Q_p^m is the units of asset traded in period p of market m , the 24 in the denominator is the total number of outstanding assets. (Recall, each of the 6 traders had 4 units of the asset to begin with.)

While the 6H and 6L markets seem to generate higher turnover than the 3H3L markets because those former markets had higher trading volumes between periods 10 and 20 compared to those in 3H3L, the Kruskals-Wallis test failed to reject the null hypothesis that the median turnovers, 1.17 (6H), 1.17 (6L), and 1.06 (3H3L), are the same across the three treatments.

We also report the measures of volume-adjusted mispricing. It is possible that large mispricing takes place only when trading volume is low. If this is the case, the straight measure of mispricing such as RAD and RD may over-represent the effective magnitude of mispricing. We define volume-adjusted RAD and RD for market m , $vRAD^m$ and

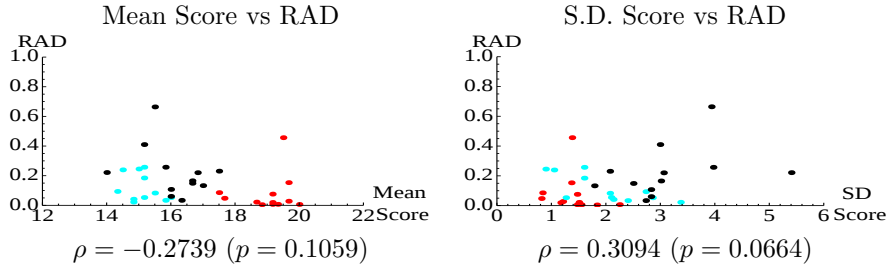


Figure 4: Relationships between the within-market average Raven score (mean score) and RAD (left) and within-market standard deviation of Raven Score (S.D. Score) and RAD (right) in 6H (red), 6L (light blue), and 3H3L (black). Correlation coefficient and its significance level (Pearson's product moment correlation coefficient) are also reported

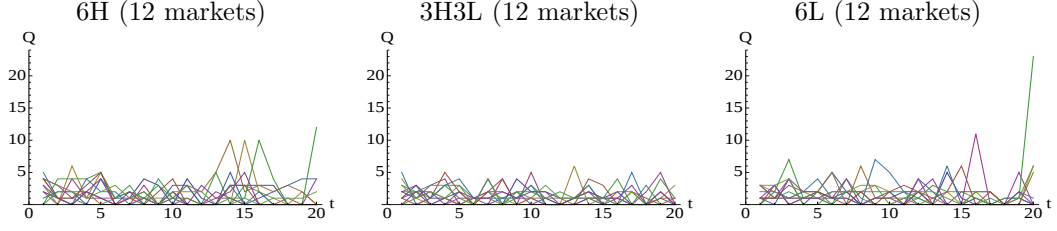


Figure 5: Realized trade volume dynamics in three treatments: 6H (left), 3H3L (center), and 6L (right).

vRD^m respectively, as follows:

$$vRAD^m = \frac{1}{20} \sum_{p=1}^{20} \frac{Q_p^m}{24} \left(\frac{|P_p^m - FV_p|}{|FV|} \right) \quad (4)$$

$$vRD^m = \frac{1}{20} \sum_{p=1}^{20} \frac{Q_p^m}{24} \left(\frac{P_p^m - FV_p}{|FV|} \right) \quad (5)$$

As one can see from the definition of $vRAD^m$ and vRD^m , these are the composite measures of the turnover and the mispricing.

Figure 7 shows the empirical cumulative distributions of $vRAD$ (left) and vRD (right) for 6H (red), 6L (light blue), and 3H3L (black). These distributions, however, are very similar to the distributions of non-volume adjusted RAD and RD reported in Figure 3 above, although the median $vRAD$ s are not significantly different between 6L and 3H3L (according to the two-tailed test). Thus, the significantly higher mispricing in 3H3L markets compared to 6H and 6L markets is not totally driven by the mispricing generated

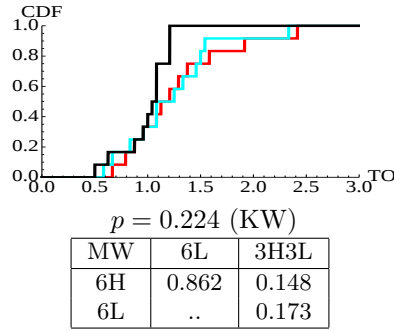


Figure 6: Distribution of Turn-over (TO) in 6H (red), 6L (light blue), and 3H3L (black). P-values from Kruskals-Wallis (KW) test.

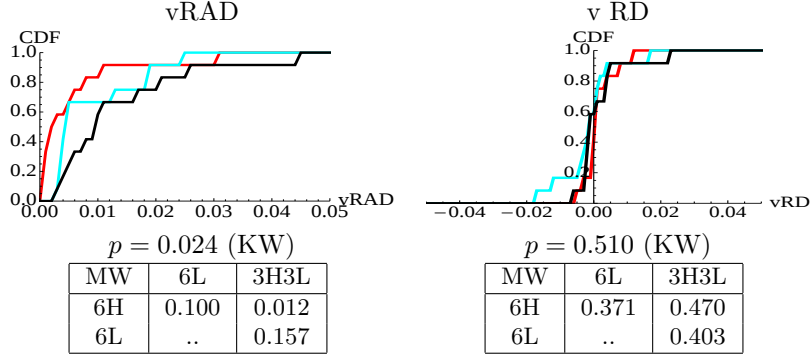


Figure 7: Distribution of $vRAD$ (left) and vRD (right) in 6H (red), 6L (light blue), and 3H3L (black). P-values from Kruskals-Wallis (KW) test (multiple comparison) as well as pair-wise Mann-Whitney test are shown.

when little trading activity took place.

3.3 Trading behavior and profits

In this subsection, we investigate individual trading behavior to better understand the aggregate results we have discussed so far. We do so first by analyzing the orders submitted by our subjects. We use a measure of the potential losses that can be generated by orders submitted by a subject over the 20 periods. Akiyama et al. (2014) defines the potential loss for subject i , PL^i , as:

$$PL^i \equiv \frac{1}{2000} \sum_t (d_t^i \max(pd_t^i - FV_t, 0) + s_t^i \max(FV_t - ps_t^i, 0))$$

where pd_t^i and ps_t^i are the maximum price at which i is willing to buy and the minimum price at which i is willing to sell an asset, respectively, specified in subject i 's orders submitted in period t . d_t^i and s_t^i are the maximum quantities, demanded or supplied, associated with pd_t^i and ps_t^i , respectively. The potential loss is normalized by the value of the initial endowment ($=2000$) so that PL^i denotes the share of the initial endowment that a subject i would potentially lose if his/her orders were executed at the prices submitted. It should be noted, however, that submitting such orders may not result in any losses in our experiment because the actual trading prices can differ from those submitted by the subjects.

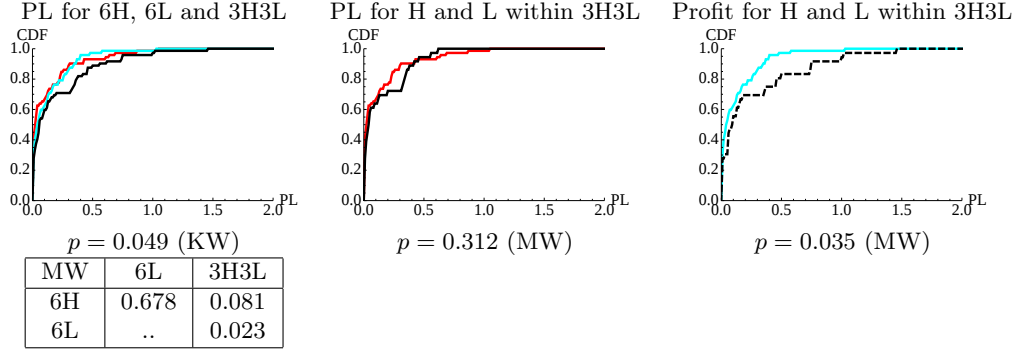


Figure 8: Left: Distribution of PL in 6H (red), 6L (light blue), and 3H3L (black). Middle: Distribution of PL for H in 6H (red) and 3H3L (black). Right: Distribution of PL for L in 6L (light blue) and 3H3L (black dashed). For the left panel, p-values from the Kruskals-Wallis (KW) test (multiple comparison) as well as a pair-wise Mann-Whitney test (two-tailed) are shown. For the middle and right panel, p-values from a Mann-Whitney test (two-tailed) are shown. The statistical tests are conducted based on the within-group average PL and not at an individual subject level.

Figure 8 shows, in the left panel, the empirical cumulative distributions of PL in the three treatments 6H (red), 6L (light blue), and 3H3L (black). As one could expect from the price dynamics, subjects in 3H3L submitted orders that deviate more from the fundamental values than those in 6H and 6L. Taking the within-group average PL as an independent observation, we do not reject the null hypothesis that the median PL is the same between 6H and 6L ($p = 0.678$, MW, two-tailed). We do, however, reject the null hypothesis between 6H and 3H3L ($p = 0.081$, MW, two-tailed) and 6L and 3H3L ($p = 0.023$, MW, two-tailed) as reported in the table below the left panel. If we focus only on H types in 3H3L and 6H markets, we do not reject the null hypothesis that the within-group average PL is the same in 3H3L and 6H ($p = 0.312$, MW, two-tailed) as shown in the middle panel of Figure 8. However, we do reject the null if we compare the within-group average PL for L types in 3H3L and 6L ($p = 0.035$, MW, two-tailed) as shown in the right panel of Figure 8.

Let us now investigate the results from 3H3L. In the left panel of Figure 9, we compare the distribution of PL for H-type subjects (solid) and L-type subjects (dashed) in 3H3L markets. We do reject the null hypothesis that there is no within-market difference between the average PL of H- and L-type subjects ($p = 0.065$, signed-rank sum (SR) test, two-tailed). Thus, our H-type subjects in 3H3L markets are acting significantly

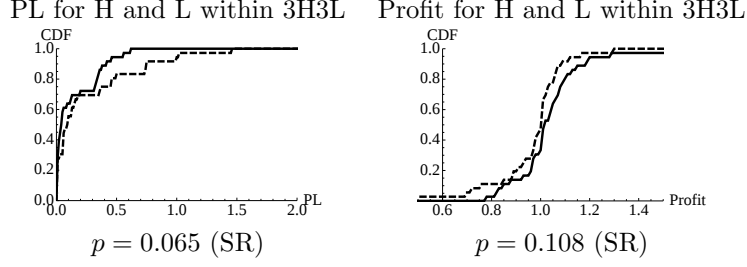


Figure 9: Left: Distribution of PL for H (solid) and L (dashed) in 3H3L. Right: Distribution of the relative profit for H (solid) and L (dashed) in 3H3L. p-values from the signed rank test are reported. The statistical tests are conducted based on the difference in within group averages PL (left) and the relative profit (right) between H and L and not at individual subject level.

differently from L-type subjects in the same market. In particular, L-type subjects are on average submitting orders that result in higher losses than H-type subjects.

Finally, the right panel of Figure 9 shows a comparison of the distributions of the final cash holdings relative to the value of the initial endowment (relative profit) for H type (solid) and L type (dashed) in 3H3L markets. While we fail, marginally, to reject the null hypothesis that there is no within-market difference between the average relative profit of H- and L-type subjects ($p = 0.108$, signed-rank sum test, two-tailed), the figure shows that the distribution of the relative profit for H types lies on the right of that of L types. Our H-type subjects in 3H3L markets are marginally successful, on average, in taking advantage of the existence of L-type subjects in the same market.

We further investigate the differences between the trading behavior of L and H types in 3H3L. Figure 10 shows, for each of the twelve 3H3L markets, the dynamics of mispricing (black, left-axis) and the average sales from L types to H types (red, right-axis). The average final cash holdings of H types $\bar{\pi}_H$ (the average final cash holdings of L types is simply $2000 - \bar{\pi}_H$) as well as the average potential loss for H and L types, $\overline{PL}_H$ and $\overline{PL}_L$, respectively, are also shown.

Figure 10 illustrates that for markets where $\bar{\pi}_H$ is greater than $\bar{\pi}_L$, i.e., $\bar{\pi}_H > 2000$ such as Market 6 and Market 12, the H types tend to buy assets from L types in periods where the market price is below the fundamental value (FV), and sell the asset to L types in periods where the opposite is true. This is best seen in Market 12, where initially the market price is well below the FV, and then the market price exceeds FV between

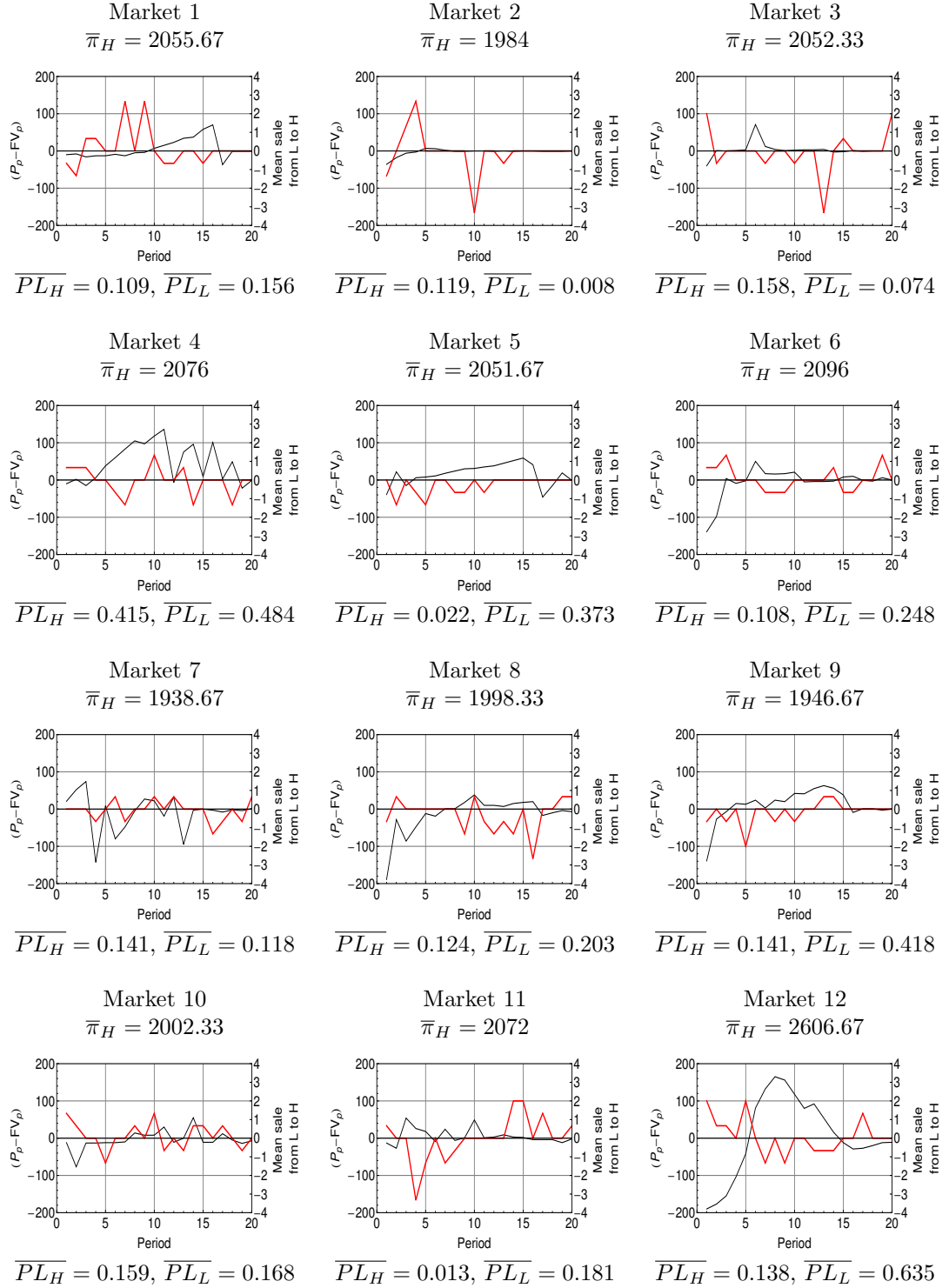


Figure 10: Dynamics of mispricing (on the left-axis) and average sales from L types to H types (on the right-axis) for each market. Average final cash-holdings for H types ($\bar{\pi}_H$) (average final cash-holdings for L types are simply $2000 - \bar{\pi}_H$, as well as the average potential loss for H and L types, $\overline{PL}_H$ and $\overline{PL}_L$, respectively, are also shown.

period 5 and 15, before dipping slightly below FV in the last 5 periods. H types bought assets from L types in the first 5 periods, then sold them to L types between periods 5 and 15, and then bought them back from L types during the last 5 periods. Also, in these markets, as one can imagine, $\overline{PL_H}$ tends to be smaller than $\overline{PL_L}$.

On the other hand, for markets where $\bar{\pi}_H < 2000$, e.g., Market 2 or Market 9, H types sold the asset to L types in the first period when its price was far below FV, and bought it back (in case of Market 9) later, when the price was above the FV. Not surprisingly, $\overline{PL_H}$ was greater than $\overline{PL_L}$ in Market 2.

4 Summary and conclusion

How does the average cognitive ability among market participants, as well as their known diversity, influence mispricing in an experimental market? We investigated this question by first measuring an aspect of cognitive ability of our subjects with the advanced version of Raven's progress matrix test, and then constructing markets by grouping subjects based on their relative test scores. We define those subjects whose scores are above and below the median score in the session to be H type and L type, respectively. We have considered three kinds of markets: all 6 traders were H type (6H), all 6 traders were L type (6L), and H and L types were equally mixed (3H3L).

We informed our subjects of their own type (H or L) as well as the types of the other five traders in the market. Thus, for example, those in 6H markets were informed that they were H type and all the other five traders in the same market were also H type.

Contrary to what one may infer from the results of earlier experimental studies which report the negative relationship between the average cognitive ability of subjects in a market and the magnitude of mispricing, the magnitude of mispricing observed in 3H3L was significantly larger than that observed in 6H and 6L markets. Thus, it is not only the average cognitive ability of traders in the market but also their known diversity that matters when it comes to the magnitude of mispricing.

A possible explanation for this result is that the known heterogeneity (or homogeneity) induced by informing our subjects about the types of traders in their market resulted in increasing (or decreasing) the strategic uncertainty they faced. Strategic uncertainty

has been shown to be an important factor in generating mispricing (Cheung et al., 2014) or deviation of price forecasts from the fundamental value (Akiyama et al., 2013). Possible reasons for a larger mispricing in heterogeneous market include, as suggested by the theoretical analysis of Allen and Gale (1992), more sophisticated traders trying to strategically manipulate the price dynamics to exploit the less sophisticated types. Due to the closed-book call market structure we have employed in our experiment, however, the results are not sufficient to investigate such a theoretical possibility. We, therefore, leave investigations of price dynamics and trading behavior in either an open-book call market or a continuous double auction structure for future research.

Finally, Levine et al. (2014) reported that the known ethnic diversity among market participants reduces the magnitude of mispricing in a similar experimental set up. Their interpretation of the data is that participants do not think critically of others' decisions in ethnically homogeneous markets, and thus tend to ride on "bubbles," compared to those participants in ethnically diverse markets. An interesting avenue for future research would be to compare the possible effects generated by various kinds of diversity among market participants including ethnic, cognitive skill, and gender (see, for example, Cueva and Rustichini, 2014; Eckel and Füllbrunn, 2015, for gender effects). It would also be fruitful to conduct future research to investigate how the potential effects of these various diversities interact among themselves in determining the price dynamics.

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Appendix

This Appendix contains English translation of the script used for the instruction videos. We have distributed handouts based on the instruction videos that are shown to our subjects as well. The handouts are available from the authors upon request. The parts highlighted with [6H/6L] or [3H3L] are shown only during the sessions with corresponding treatments. Original instructions in Japanese are also available from the authors upon request.

Instructions for Today's Experiment

Let's start today's experiment. We will explain it in the handout in front of you.

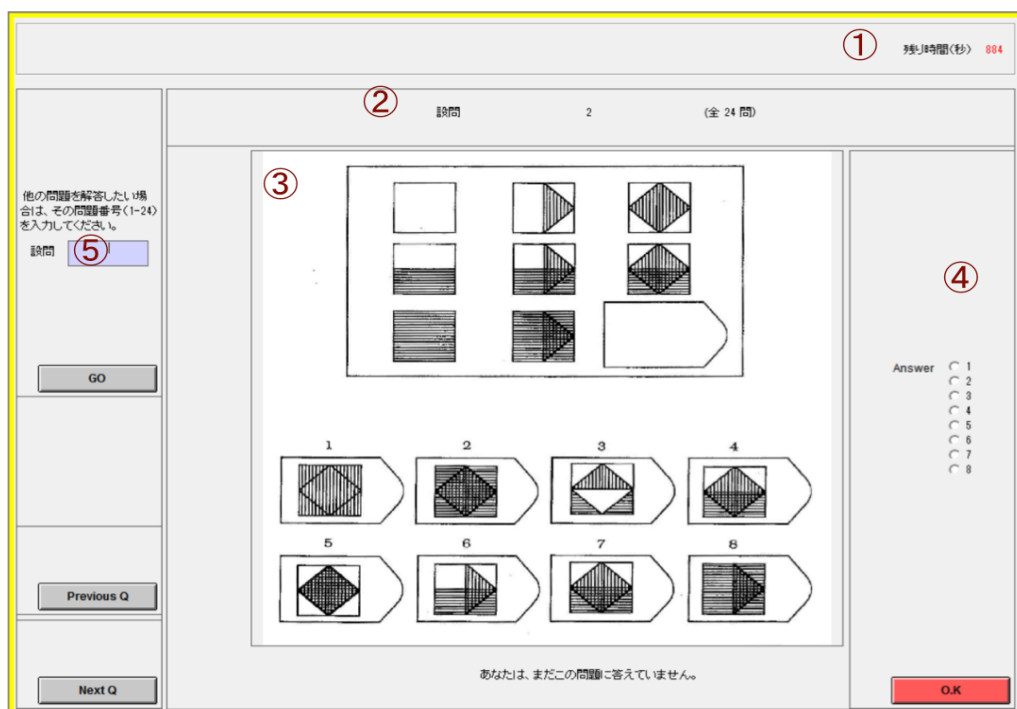
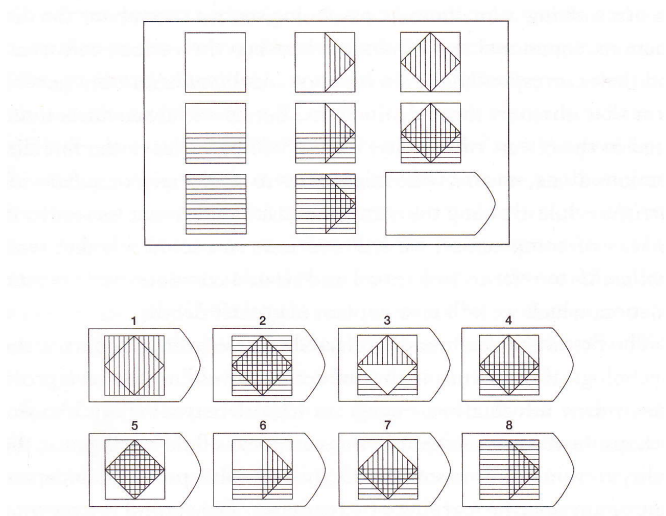
Please turn to the next page.

First, you will be asked to take a quiz. After this quiz, the instructions for today's game will be explained to you. There will be a practice period for the game so that you may familiarize yourself with the computer interface before the real experiment. Finally, we will ask you to respond to a questionnaire and take quizzes. Your earnings will be paid in cash at the conclusion.

Your earnings will consist of a common participation fee of 500 yen, and the result of the game. The questionnaire and quizzes will not impact your earnings. You will have a short bathroom break before the game begins.

We will now explain the first quiz. This quiz consists of 24 questions to be answered within a 15 minute timeframe. For each question, you will view a set of pictures at the top of the screen that are ordered according to a certain pattern. One picture is missing. Your task will be to guess the underlying pattern, and then select the best suited replacement for the missing picture from among the options shown at the bottom of the screen.

(The source of the picture used is Mullainathan and Shafir (2013, p.48). This sentence was not shown to our subjects.)



Please turn to the next page.

When the quiz begins, the following information will appear on the screen:

- (1) This notes the time remaining. You have 900 seconds to answer as many of the 24 questions as possible.
- (2) This indicates the question number.

- (3) This is the display of the question.
- (4) This is where you will select your option from the corresponding choices found in the bottom part of the picture in (3).
- (5) You may request another question to an answer by entering that question number here. We will explain this in detail in the following instructions.

Once you have determined the answer to a question, please select from the options shown on the right side of the screen and click OK; the screen for the next question will appear. If you would like to answer another question that is different from the one shown in the screen, please enter the question number on the top left side of the screen and click GO. The screen for the question selected will appear. You can return to the previous question by clicking the [Previous Q] button, or proceed to the next question by clicking the [Next Q] button. If you would like to skip the present question, please click the [Next Q] button without selecting any options. If you answer the same question more than once, the computer will only record your last answer.

Please begin the quiz when the first question appears on the screen.

Instructions for the Stock Trading Experiment

[Today's experiment]

Today you will participate in a stock trading game 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 clarity by raising your hand. Moreover, 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, it 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 are divided into the top 12 scorers and the bottom 12 scorers of 24 people from the previous quiz. Before starting the game, you will know which your rank is, the top or the bottom.

The 24 people in the room are divided into four groups, each of which consists of six people:

[6H/6L] Two of the four groups consist of the top scorers, and the other two groups consist of the bottom scorers.

[3H3L] Each of four groups consists of three people in the top and three people in the bottom.

You play the stock trading game with other five people in the group you belong to.

[Objectives of the game]

Your objective in this game is to make as much profit as you can. We use Mark as the currency for the experiment. At the end of the experiment, 1 Mark will be converted into 1 yen and paid out to you. There are two ways of making a profit:

- First, you can realize a profit margin through buying and selling stocks.
- Second, you can earn dividends on your stock holdings.

Please turn to the next page.

[Earning a profit margin]

You will be given four stocks + 1040 Marks at the beginning of the game. To earn a profit margin by trading, you need to buy stocks at a lower price and sell these 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 earn $120 \text{ (selling price)} - 100 \text{ (purchase price)} = \underline{20 \text{ Marks profit}}$. 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 $80 \text{ (selling price)} - 100 \text{ (purchase price)} = \underline{20 \text{ Marks loss}}$. We will explain later how the prices are determined.

Now we will explain how to use the experimental program interface. We will also explain how to earn a profit margin. Please do not perform any operations other than those which you are instructed to carry out; otherwise, it may jeopardize our 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 for each time period.

The screenshot shows the 'Order entry screen' with the following elements:

- Top Bar:** Contains a timer labeled '残り時間 [秒]: 22' (Remaining time [seconds]: 22), marked with a red circle ①.
- Order Entry Section:**
 - Left Side:** '現在の所持金' (Current cash balance) showing 1040 (marked ②) and '現在の保有株数' (Current number of shares held) showing 4 (marked ③).
 - Center:** '最高購入希望価格' (Maximum purchase price) with an input field containing '1' (marked ④) and '買い注文数' (Buy order quantity) with an empty input field (marked ⑤).
 - Right Side:** '最低売却希望価格' (Minimum sell price) with an empty input field (marked ⑥) and '売り注文数' (Sell order quantity) with an empty input field (marked ⑦).
 - Bottom Right:** An 'OK' button (marked ⑧).
- Instructions:** A text block below the input fields reads: '売り・買い注文の価格と注文数を入力してください。売り注文をしないときは売り注文数に「0(ゼロ)」を入力してください。(買い注文も同様)' (Please enter the price and order quantity for sell/buy orders. When you do not place a sell order, please enter '0 (zero)' for the sell order quantity. (The same applies to buy orders)).
- Game Information:** A section labeled '株取引ゲーム' (Stock Trading Game) showing '第 1 / 20 期' (Period 1 / 20) and '履歴: 第1期～第20期の取引価格' (History: Trading prices for Period 1 to Period 20).
- Table:** A table with 20 columns labeled 'Period 1' through 'Period 20'.

- (1) This shows the remaining time for entering your orders. The time limit to enter your order is 60 seconds. When the time has elapsed, a red warning message will flash at the top right corner of your screen. A period ends once everyone has pressed “OK”; note that this could be within the 60 second time limit.
- (2) This indicates your cash balance or the amount of money at your disposal; you may buy stocks up to this amount.

- (3) This shows the number of stocks you have. You may sell a maximum of this number of stocks.
- (4) This is where you enter the maximum price you are willing to pay to buy a stock in this period. You must enter a whole number between 1 and 2000.
- (5) Here you need to enter the maximum number of stocks that you want to buy in this period. If you do not want to purchase any stocks, enter 0. The product of (4) and (5) must be no greater than your cash balance shown in (2). An error message will appear if (the number of stocks you wish to buy) $\times$ (the maximum price you are prepared to pay for these) 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 you are willing to pay, your order will not be processed. This will be further clarified at a later stage.

Please turn to the next page.

- (6) Here please enter the minimum price at which you would be 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 given in (4).
- (7) This is where you should enter the number of stocks you want to sell in this period. If you do not want to sell any of your stocks, 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 price, your order will not be processed. This will be further clarified at a later stage.

- (8) After entering appropriate values in (4)~(7), press the “OK” button. Once all market participants have pressed this button, the current period ends.
- (9) This table gives a history of the market prices. Thus, the cells after the current period are blank.

Before proceeding, the most important points in buying and selling stocks are summarized below.

- You can simultaneously place buy and sell orders, or you can place only a buy or a sell order. It is also possible not to submit any orders at all.
- If you do not want to submit a buy order, please enter 0 as the quantity to buy. If you do not want

to submit a sell order, please enter 0 as the quantity to sell.

- The screen displays an error message, if any of the following conditions are violated:
 1. The maximum quantity to sell must be less than or equal to the number of units you hold.
 2. The maximum purchase price multiplied by the quantity to buy must be less than or equal to the cash you have available at the time.
 3. If you simultaneously place buy and sell orders, the maximum price at which to buy must be less than or equal to the minimum selling price.

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 so as to equate the number of buy orders and sell orders.

We will explain how the market prices are set by 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 higher. A buyer is willing to buy at the price specified or lower. As shown above, there is only one stock supplied at 10 Marks or higher. If the price rises to 40 Marks, the number of stocks supplied increases to three. On the other hand, only one stock is demanded at 60 Marks. If the price falls to 20 Marks, the quantity demanded increases to two. 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 of this interval, i.e., 21 Marks.

Now let us consider the second example.

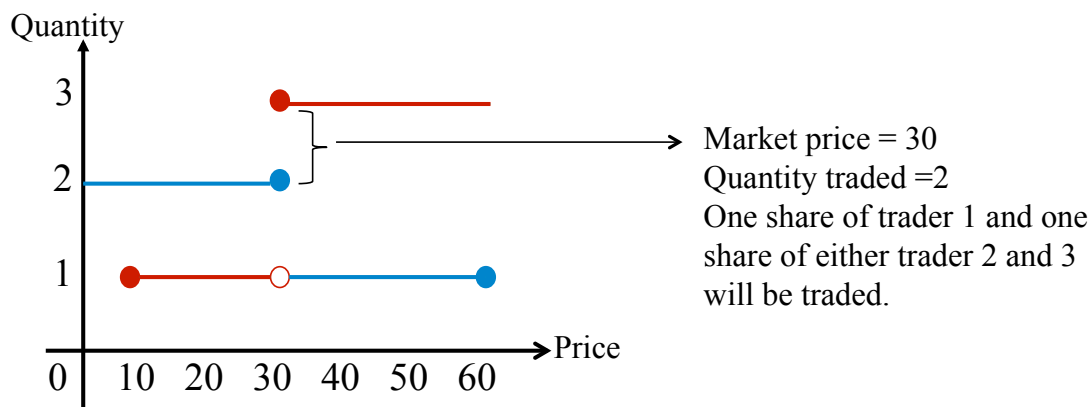
Please turn to the next page.

[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, only one stock is supplied 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. However, there is only one stock demanded at 60 Marks or lower. If the price falls to 30 Marks, the quantity demanded increases to two. As a result, two transactions can be completed at 30 Marks. In this case the market price is set to 30 Marks. 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 fulfilled. Which order is chosen is determined randomly by a computer.

[End of each period screen]

At the end of each period, the following screen is displayed, with the information described below.

⑥ 残り時間 [秒]:	17
① 取引価格	501
② 今期(Period)購入した株の数	0
③ 現在の所持金	1088
④ 現在の保有株数	4
⑤ Next Value	228
⑦ CONTINUE	

- (1) This shows the market price as explained previously.
- (2) A positive value 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.
- (3) This shows your cash holding after the transactions and dividend payments have been processed for the current period.
- (4) This is the number of stocks you currently hold.
- (5) An explanation of *Next Value* is given on the next slide.
- (6) The remaining time (maximum of 30 seconds) that this screen will be visible is displayed here. After observing the information on the screen, press the “Continue” button (8). Once all of the participants have pressed this button, the computer will display the next screen.
- (7) By clicking this “Continue” button, you move to the next period.

Please turn to the next page.

[Earning returns from dividends]

In the game, there are twenty periods in which you can submit your buy/sell orders and trade with other traders in your market. You will also be offered a dividend of 12 Marks per stock based on the number of stocks you have at the end of each period. Dividend income at the end of each period is calculated as: 12 Marks × (number of stocks you hold).

[Next value]

As mentioned above, at the end of each period an amount is displayed as the “Next Value”. This amount depicts **the sum of the dividends** per stock that will be offered in the remaining periods. For example, consider *Next Value* at the end of the second period. There are 18 periods left. A dividend of 12 Marks per stock will be offered 18 times. Thus, the *Next Value* is $12 \times 18 = 216$ Marks.

After period 20, a dividend is also paid according to your stock holdings. Your cash balance after payment of the dividend for period 20 is the final amount you will earn in the game.

Turn to the next page to see a table of the *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.

Please turn to the next page.

[Summary of ways to make a profit]

There are two ways of making a profit: (1) earning a profit margin, and (2) earning returns from dividends. At the end of the experiment, 1 Mark will be converted into 1 Yen and paid out to you. In addition to the aforementioned rewards, you will be offered 500 yen as a payment for participating in the experiment.

[The instruction ends here]

Before stating the game, we will announce the following:

Let's start the game.

- There are six people in a market.
- All the people of the group are in this room. Each group consists of:
[6H/6L] only the top scorers or only the bottom scorers from the previous quiz.
[3H3L] three people in the top scorers and three people in the bottom scorers.
- Your rank, the top or the bottom, from the previous quiz is noted on the first screen.
- You will be given four stocks + 1040 Marks at the beginning of the game.
- After 20 periods, “You have completed the game” will appear on the screen. When this appears, please click the continue button and wait for instructions.

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