Individual irrationality and lack of common knowledge of rationality in experimental asset markets

VERY PRELIMINARY

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Abstract

We investigate the extent to which the “bubbles” and “crashes” in the experimental asset markets are due to individual irrationality and lack of common knowledge of rationality. We do so by comparing between the forecasted prices initially submitted by subjects in two market environments: (a) All the six traders are human subjects (6H) and (b) One human subject is interacting with five rational computer traders who assume all the traders are rational (1H5C). Results from our pilot experiment show that there is no significant difference in distribution of the initial deviations of the forecasted prices from the fundamental values in two market environments. Thus, we tentatively conclude that lack of common knowledge of rationality plays little role, but individual irrationality does, in experimental asset markets when subjects are inexperienced.

Keywords: Rationality, Common knowledge, Experiment, Asset Markets, Computer Traders

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1 Introduction

Following the seminal study by Smith, Suchanek, and Williams (1988), it has been repeatedly shown, under variety of experimental conditions and subjects pools, that the market prices of assets deviate substantially from their fundamental values in experimental asset markets.1

Such deviations of the observed prices from the fundamental values poses a challenge to economic theory. An interpretation put forward by Smith, Suchanek, and Williams (1988, p.1148) is as follows: “What we learn from the particular experiments reported here is that a common dividend, and common knowledge thereof, is insufficient to induce initial common expectations. As we interpret it, this is due to agent uncertainty about the behavior of others.” In other words, as noted by Lei, Noussair, and Plott (2001, p.832), “traders are uncertain that future prices will track the fundamental value, because they doubt the rationality of the other traders.” Lei, Noussair, and Plott (2001) elaborates on this further and states “(subjects) speculate in the belief that there are opportunities for future capital gains” and such speculations result in observed price deviations from the fundamental values.

In order to test this “speculative hypothesis,” Lei, Noussair, and Plott (2001) performs a set of experiments in which capital gains are not possible. Based on the observed deviations of prices from fundamental values even in the absence of possibilities of capital gain, Lei, Noussair, and Plott (2001) rejects the speculative hypothesis and concludes that it is not the lack of common knowledge of rationality but individual irrationalities that cause “bubbles” and “crashes” in these experimental markets. Lei, Noussair, and Plott (2001) also suggests that subjects in these experiments who are

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1 King, Smith, Williams, and van Boening (1993) investigates the effect of possibilities of short-selling, margin-buying, equal endowment, and circuit breakers. They have also conducted experiments with cooperate executives and stock market dealers to see the effect of subjects pool. The “bubble” and “crashes” were observed in most of their experiment, except in those experiments where transaction fees were introduced, or subjects have experienced the same market condition twice. (EFFECT OF SHORT-SELLING POSSIBILITIES ARE NOT YET CLEAR YET.) Haruvy and Noussair (2006) shows allowing short-selling lowers the degree of prices deviating from fundamental values than the case without such a possibility but not enough to eliminate them. Porter and Smith (1995) eliminates the uncertainty about dividend payments to investigate the effect of, if any, varying degree of risk aversion among subjects. They did not find significant difference in the observed pattern of mispricing from the one with uncertain dividend payments. Nousair, Robin, and Ruffieux (2001) reports the “bubbles” in markets with a constant fundamental price, i.e., the expected value of per period dividend is zero, and a asset is converted into a fixed sum of money at the end of the final trading period. Dufwenberg, Lindqvist, and Moore (2005) mixes the twice-experienced subjects and inexperienced subjects to investigate whether presence of inexperienced subjects among experienced subjects induces greater price deviation. They show that presence of 2 (4) inexperienced subjects in the market market with 4 (2) other experienced subjects (they have experienced the same market three times) did not produce larger price deviation than the market with 6 twice experienced subjects. Hussam, Porter, and Smith (2008) studies whether (twice) experienced subjects, when facing a new market environment with a large variance of dividend payments and higher initial cash holdings, would avoid creating “bubbles.” The answer was negative, the learning to trade close at the fundamental values which took place in one market condition did not carry over to a different market condition. See Stöckl, Huber, and Kirchler (2010) and references there in for other experiments.
trained to engage in trading simply want to trade because there are no other activities available for them to do during the experiment. Lei, Noussair, and Plott (2001, p. 857) notes that “the hypothesis that the traders are rational, and that the bubble is due to the fact that this rationality is not common knowledge, cannot be the whole story behind the bubbles.” The recent development in experimental game theory that demonstrates the heterogeneity in the depth of strategic thinking by subjects (Nagel, 1995; Ho, Camerer, and Weigelt, 1998; Costa-Gomes and Crawford, 2006) suggest that considering interaction among heterogeneous boundedly rational agents helps us to better understand experimental outcomes.2

In this paper, we revisit the same question more directly while taking into account that both individual irrationality and lack of common knowledge of rationality play their role in generating substantial deviation of prices from fundamental values in these experiments. Instead of eliminating the possibility of capital gains, we eliminate the uncertainty about the behavior of other traders in the market by introducing risk neutral computer traders who behave rationally while assuming all the other traders are also rational and risk neutral. We assume that these rational computer traders prefer to trade when they are indifferent between trading and not trading, thus when the market consists only of these computer traders, transactions take place only at the fundamental values in the absence of any explicit transaction fees.

We consider two types of markets consisting of six traders: one human and five rational computers (1H5C) and all human (6H). In 1H5C markets, a unique human trader, who is informed about the behavior of all the other computer traders in the market, does not face any uncertainty regarding the behavior of other traders in the market. If a subject is rational, then s/he will anticipate that the profit maximizing trading strategy is to trade at the fundamental values each period, thus the price will follow fundamental values. Any deviation from this must be due to some kind of individual irrationality. On the contrary, in 6H markets, a rational subject, who are not sure about rationality of other traders in the market, can expect variety of outcomes including possibilities of capital gains. Of course, subjects may not act rationally. Thus, deviations from fundamental values in 6H markets are due to both lack of common knowledge of rationality and individual irrationality. Thus, comparing behaviors of human traders in 1H5C and 6H markets will give us the direct measure of extent to which the failure of common knowledge of rationality explains the deviation of prices from the fundamental values.

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2See Camerer (2003, Ch. 5) and Crawford, Costa-Gomes, and Iriberri (2010) for reviews.
Reducing the uncertainty about the behavior of others by introducing rational computer agents in laboratory experiments\(^3\) have been employed in several experiments. Cason and Friedman (1997), in their experiments of price formation in a simple market institution, introduce robot traders who follow Baysian Nash Equilibrium strategy to facilitate the learning by human subjects.\(^4\) Fehr and Tyran (2001), which is also discussed in Fehr and Tyran (2005), introduces robots that players Nash Equilibrium strategy in investigating nominal (money) illusion to decompose the reason for non-immediate adjustment against negative nominal shock into (i) those coming from individual irrationalities and (ii) those due to lack of common knowledge of rationality. Fehr and Tyran (2001) considers price setting games and vary two aspects of the game: (a) whether negative nominal shocks are present or not, and (b) whether a human subject play the game with other human subjects or rational computer programs. This 2 by 2 design allows them to achieve the objective of the experiments. They report that both individual irrationality and lack of common knowledge of rationality equally accounted for the failure of immediate adjustment to the new equilibrium after the negative nominal shock in the game.\(^5\)

In our experiment, we employ call market rules similar to the one used by Haruvy, Lahav, and Noussair (2007) instead of continuous double auction employed by Smith, Suchanek, and Williams (1988) and various other studies. Our choice of call market rule is to minimize the effect of subjects’ “desire to trade” in the absence of other activities during the experiments pointed out by Lei, Noussair, and Plott (2001).\(^6\) In a call market, all the subjects are asked to enter their bids and asks every periods, thus they don’t spend their time doing nothing during the experiment. In addition, the call market rule has an advantage in facilitating our introduction of computer traders because all the orders are submitted simultaneously.

Under the call market rule we employ, however, the presence of our computer traders make the

\(^3\)Costa-Gomes and Crawford (2006) introduces, in addition to rational robots that follow the equilibrium strategy, boundedly rational robots that follow Level-1,2,3 or Dominance 1,2 strategies in their experiments of two person guessing game to better analyze the responses by human subjects who are informed about the behavioral rules of various opponents.

\(^4\)When human subjects are playing against other human subjects who are also learning, the learning process can become very slow. They do not consider markets for assets with life for several periods. In addition to robot that follow Baysian Nash Equilibrium strategy (BNE robots), Cason and Friedman (1997) introduces “Revealing Robot” to investigate the convergence of the equilibrium is due to human subjects mimicking the behavior of BNE robots or best responding against BNE robots. Their results suggest it is the latter.

\(^5\)Noussair, Richter, and Tyran (2008) studies the effect of nominal shocks in experimental asset markets with constant fundamental values (Noussair, Robin, and Ruffieux, 2001) by changing, in the middle of experiment, the exchange rate between the experimental currency unit and the real currency with which subjects are paid. Noussair, Richter, and Tyran (2008) found that while it took a long time for the price to adjust to the new real fundamental value after a deflationary nominal shock, the same adjustment was immediate after an inflationary nominal shock.

\(^6\)Lei, Noussair, and Plott (2001) call this the “active participation hypothesis.”
prices closer to the fundamental values. Thus, investigating the realized prices is not very informative for our purpose. We, therefore, elicit subjects' expectation about future prices as Haruvy, Lahav, and Noussair (2007). It has been shown that the expected future prices deviate quite substantially from the fundamental values in all human markets (Haruvy, Lahav, and Noussair, 2007, Fig.3, p.1909), and the deviations disappear gradually as subjects gain more experiences from trading under the same market conditions. This is similar to what is observed from the realized prices. Thus, our focus on the forecasted prices is informative in studying the cause of realized price deviation.

Our experimental results suggest that eliminating uncertainty about behavior or other traders does not make subjects to forecast the prices to follow the fundamental values from the beginning of the experiment. We did not find significant differences in the way initial forecasted prices deviate from fundamental values in 1H5C treatment and 6H treatment. Thus, we arrive at the same conclusion as Lei, Noussair, and Plott (2001) that it is not the lack of common knowledge of rationality but the individual irrationality that is driving the initial deviation of price forecasts from fundamental values. As subjects gain experiences in the asset market, however, the deviations of forecasted prices from the fundamental values disappear much more quickly in 1H5C than in 6H treatment. The difference in how price expectations evolve between two treatments is consistent with the finding by Haruvy, Lahav, and Noussair (2007) that expectations are adaptive. Subjects in 1H5C treatment who observe the prices following the fundamental values quickly adjust their expectations in such a way. While those in 6H treatment do not because the observed price do not follow the fundamental values as closely as in 1H5C treatment.

The rest of the paper is organized as follows. The experimental design is discussed in detail in Section 2. Section 3 presents the results of our experiments. And Section 4 concludes.

## 2 Experimental design

We have set up an experimental asset market consisting of six traders. Traders can be human subjects as well as computer programs. We consider two treatments. In one treatment, all the six traders are human subjects (6H treatment). In another treatment, only one out of six traders is human subject (1H5C treatment). Other five traders are all computer traders who try to maximize their profits without making any mistake while assuming all the other traders are doing the same. In each treatment, subjects were told explicitly about composition of traders in the market they are
participating to as well as how computer traders behave. Our main interest lies in comparing the data between these two treatments to separate the effect of individual irrationality and the lack of common knowledge of rationality. In each market, traders could trade an asset with a life of ten periods. Subjects are also asked to submit their expectations regarding the future prices of an unit of the asset. We first describe the trading rule we have employed, and then proceed to the way we have elicited subjects’ expectation about future prices.

We employ a call market rule that is similar to the one employed by Haruvy, Lahav, and Noussair (2007). In each period, each trader can submit at most one buy order and one sell order. An order consists of a pair of a price and a quantity. That is, when submitting a buy order, a trader must specify the maximum price, \( PD \), at which s/he is willing to buy a unit of asset, and the maximum quantity, \( QD \), s/he is willing to buy. In the same manner, when submitting a sell order, a trader must specify the minimum price, \( PS \), at which s/he is willing to sell a unit of asset, and the maximum quantity, \( QS \), s/he is willing to sell. We introduce three constraints: the admissible price range, the budget constraint, and a minimum rationality constraint. The admissible price range is set so that, when \( QD \geq 1 \) \( (QS \geq 1) \), \( PD \) \((PS) \) has to be an integer between 1 and 600, i.e., \( PD \in \{1, 2, ..., 599, 600\} \). The budget constraint here simply means that borrowing of cash nor short-selling of asset were allowed. The minimum rationality constraint means that, when a trader is submitting both buy and sell orders, \( QD \geq 1 \) and \( QS \geq 1 \), the maximum buying price must be no greater than the minimum selling price, \( PS \geq PD \). Once all the traders in the market have submitted their orders, the computer calculated the price that clears the market, all the transactions take place with that price among traders who submitted the maximum buying price no less than, and the minimum selling price no greater than, the market clearing price. If there does not exist any such prices that allow positive transactions, no transaction takes place. We represent equilibrium price to be “zero” in the case of no transaction.

7That is, we explain behavioral assumption of computer traders to the subjects who participate in the 6H treatment as well. The exact statement we use to explain the behavior of computer traders is as follows: “Each computer trader maximizes his profits without making any mistakes while assuming all the other traders are doing the same. If the computer trader is indifferent between trading and not trading, he prefers to trade.” In our experiment, this means that computer traders submit orders at FV in each period respecting the budget constrained explained below. We did not tell subjects that computer traders submit their orders at FV in order to avoid such a trading strategy becoming the focal strategy and followed by many subjects from the beginning.

8There was a 60 second, non-binding, time limits, in submitting orders. When the time limit is reached, the subjects were simply told to submit their orders as soon as possible.

9Thus the budget constraint implies (i) \( QD \times PD \leq \) cash holding at the beginning of the period, and (ii) \( QS \leq \) units of asset at hand at the beginning of the period.

10When there are multiple such prices, the average price which is rounded down to an integer is chosen as the market clearing price.

11Any ties among the last accepted buy or sell orders are broken randomly.
At the end of each period, an unit of the asset pays 12 ECU (experimental currency unit). We have chosen a certain dividend payment to eliminate the possible effects, if any, varying degree of risk aversion among traders may have on experimental outcome to focus on the effect of (ir)rationality and the lack of common knowledge of rationality.\textsuperscript{12} The received dividend could be used to purchase the asset in the following periods. After the final dividend is paid at the end of period 10, the asset had no value. A part from this stream of dividend payments, the asset has no intrinsic value. Thus the fundamental value of an unit of asset at the beginning of period $t$ was $FV_t = 12 \times (11 - t)$.\textsuperscript{13}

Next, we turn to the way we have elicited expectation about future prices.

At the beginning of each period, subjects were asked to submit their price forecasts for all the remaining periods of the market. That is, in period $t$, each subject submitted $10 - t + 1$ forecasts.\textsuperscript{14} Therefore, subjects are submitting a total of 55 forecasted prices over 10 periods. Each price forecast could take an integer value between 0 and 600, where 0 represents forecasting no transaction. Subjects were told that they will be given following the bonus payments according to how accurate their forecasted prices were:

$$\text{Bonus (in ECU)} = 0.5\% \times (\text{Number of forecasts that were within } \pm 10\% \text{ of the actual market prices}) \times \text{Final cash holding in period 10}$$

Therefore, if all the 55 forecasts were within 10% range of realized prices, the subject could have received 27.5% of his/her final cash holding as a bonus payment.\textsuperscript{15} This incentive scheme for accurate forecasts was chosen in order to induce subjects not to make loses by trying to make the prices closer to their forecasts. When they submit their price forecasts, all the previous market clearing prices

\textsuperscript{12}Porter and Smith (1995) show that we do not need to worry too much about the effect of risk aversion. They report that eliminating the uncertainty about the dividend payments did not significantly lower the magnitude of price deviations from the fundamental values.

\textsuperscript{13}We distributed a table showing the sum of remaining dividends after the dividend for the period is paid out, the value we called “next value” in the experiment, for each period to our subjects. Thus subjects had a table showing $FV_t$ for $t = 2,\ldots,10$.

\textsuperscript{14}There was a 120 seconds, non-binding, time limits in submitting price forecasts. When the time limit is reached, the subjects were simply told to submit their forecasts as soon as possible.

\textsuperscript{15}Therefore if subjects forecasts there will be no transaction, it has to be indeed the case there is no transaction to receive the 0.5%.
The call market rule has several advantages: (i) the prices subjects have to forecast are clear, (2) within period learning based on observing orders submitted by other traders is not possible, (3) because all the subjects submit their order once every periods, the possible effect of “active participation hypothesis” (Lei, Noussair, and Plott, 2001) is minimized, and (4) it is easier to introduce computer traders because all the orders are submitted simultaneously.

As the end of each period, subjects are informed about the market clearing price of the period, units of asset they have traded, their cash and asset holding, the (total) number of price forecasts that were within 10% of actual market prices up to the period, and the “next value” of an unit of the asset.

Before the market opens in period 1, each trader is given an endowment of cash and units of the asset. Two out of six traders were given 3 units of the asset and 140 ECU, other two were given 2 units of the asset and 260 ECU, and the remaining two were given 1 unit of the asset and 380 ECU. Because an unit of the asset pays 12 ECU over ten periods, its initial value is 120 ECU. Thus, all the traders’ initial wealth were the same ex ante. The same group of traders, with identical initial endowment of cash and the asset, will repeat the same 10 periods market for three times in one experiment. We call a 10 periods market a round. Thus, the experiment consists of 3 rounds of 10 periods market with identical initial endowment and group of subjects. The purpose for repeating three time is to compare how quickly the price forecasts as well as market clearing prices converge to the fundamental values between 6H and 1H5C treatments.

At the end of experiment (after participating to 3 rounds of 10 periods market), subjects were paid in cash according to the sum of their final cash holdings (including bonus payment for accurately predicting future market prices) in each round plus a show up fee of 1500 yen. Exchange rate between

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16Huber and Kirchler (2012) reports that asking subjects about what is the fundamental values of the asset in next period can significantly reduce the realized price deviations from the fundamental value (FV) in an experimental asset market under continuous double auction. They also reports that showing the fundamental values of a unit of asset in a figure, instead of table, to subjects can also significantly reduce the price deviation. To test whether similar effect is present under call market rule, we have conducted a set of 6H experiment without eliciting subjects' expectation about future prices. We do find similar effect of belief elicitation in reducing the price deviation from the FV, although, our result is not statistically significant. The insignificance, however, is due to our small samples. See Appendix.

17According to the “active participation hypothesis”, subjects may engage in loss generating trades instead of not trading because they have no other activities during the experiments.

18The information was shown so that a positive (negative) number means they have bought (sold) certain units of asset.

19Next value of an asset at the end of period $t = 12 \times (10 - t)$

20Before entering the round 1, there was a practice period to let subjects familiarize themselves with the user interface of the software. Subjects were given their initial endowment of cash and asset, and asked to enter their price forecasts for 10 periods and their orders for period 1. The information regarding the resulting market clearing prices etc. were not shown to the subjects.
ECU and Japanese yen was 1 ECU = 1 Japanese yen. The experiment lasted about three hours including the instruction and a questionnaire after the experiment.

3 Results

A set of computerized experiments has been conducted at the University of Tsukuba. 38 subjects were recruited from all over the campus, and they were all undergraduate students. 3 out of 14 (1 out of 24) subjects in the 1H5C (6H) treatments were students of the College of Policy and Planning Sciences in which Economics is one of the majors. Table 1 summarizes the all the experimental sessions.

In this section, we first show the realized prices over time in two treatments: 6H and 1H5C. We then discuss the price forecasts, and their deviation from the fundamental values in the two treatments.

3.1 Realized Prices

Figure 1 shows the average mispricing, deviation of the price from the fundamental value, over 10 periods across groups for three rounds of two treatments: 6H (Gray) and 1H5C (Black). We define mispricing for group $g$ in period $p$ of round $r$, $MP_{p,r}^{g}$, as $MP_{p,r}^{g} = P_{p,r}^{g} - FV_{p}$ where $P_{p,r}^{g}$ is the realized price of the asset for group $g$ in period $p$ of round $r$. When there was no transaction for group $g$ in period $p$ of round $r$, we set $MP_{p,r}^{g} = 0$. There are 4 groups for 6H treatment and 14 groups in 1H5C treatment.

As one would expect, in 1H5C treatment, the average mispricing is zero for most of the periods in three rounds. In 6H treatment, on the other hand, we observe under pricing in early periods (period 1 and 2) then over pricing in later periods that disappears toward the final period of a round.

Table 1: Summary of experimental sessions.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of Subjects</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1H5C</td>
<td>14</td>
<td>Feb. 24, 2012</td>
</tr>
<tr>
<td>6H</td>
<td>24</td>
<td>Feb. 24, 2012</td>
</tr>
</tbody>
</table>

21 The experiments are implemented with Z-tree (Fischbacher, 2007).
22 It is different from the fundamental value only in the period 10 of round 1. This was due to one group which had market clearing price of 20. This mispricing was due to the human subjects submitting a large quantity of buy order (more than the total number of asset available in the market) at that price. There were also a few cases in which no transaction took place in period 10.
The observed pattern of mispricing over periods within a round in 6H treatment is similar to the previous studies. One can also observe, in 6H treatment, that, the magnitude of mispricing becomes smaller in round 3 than in round 1 (although not statistically significantly so).

To compare the magnitudes of mispricing across rounds and treatments, we use the measures of mispricing proposed by Stöckl, Huber, and Kirchler (2010) which have the following three desirable properties: (i) they relate the fundamental values and prices, (ii) they are monotone in the difference between fundamental values and prices, and (iii) they are independent of the total number of periods and the absolute level of the fundamental values. These two measure are relative absolute deviation, RAD, and relative deviation, RD.\textsuperscript{23} RAD is a measure of mispricing and is calculated by averaging absolute differences between the (volume-weighted) mean price and the fundamental value across all the periods and normalizing it with the absolute value of the average FV across all the periods. RD is a measure of overvaluation, and is calculated similarly, but uses raw, instead of absolute, difference between (volume-weighted) mean prices and fundamental values. Hence, it provides information on whether the mispricing stems from over- or undervaluation of the asset.

\[
\text{RAD}_p^{g,r} = \frac{1}{N} \sum_{p=1}^{N} \frac{|MP_{p,r}^{g}|}{|FV|}
\]

\[
\text{RD}_p^{g,r} = \frac{1}{N} \sum_{p=1}^{N} \frac{MP_{p,r}^{g}}{|FV|}
\]

where \(N\) is the number of periods (=10 in our experiments), \(MP_{p}^{g}\) is the mispricing of asset in period \(p\).

\textsuperscript{23}Because we are comparing the data from the set of experiment with the same number of periods and same fundamental values, we could use other measures used in the literature. We have chosen to use RAD and RD, however, to be able to compare results with other market settings in the future.
Figure 2: Mispricing over periods across three rounds for each group in 6H treatment, and associated measures of mispricing. The periods in which no transaction took place are not plotted. Blue (Group 1), Red (Group 2), Yellow (Group 3) and Green (Group 4).

\[ MP_{g,p,r} = P_{g,p,r} - FV_p = 0, \text{ i.e., no mispricing, when there was no transaction in period } p \] for group \( g \).

\[ p \] of round \( r \), and \( FV \) is the average fundamental value of the asset over the \( N \) periods. \(^{24}\)

Figure 2 shows dynamics of mispricing for each of the four groups in 6H treatment. As one can observe from the figure, there are substantial variation in the magnitude of mispricing across groups. Corresponding measures of mispricing, RAD and RD, are also reported in the bottom panel of the figure. \( RD > 0 \) suggests that most of the mispricing were due to over pricing, while \( RAD > RD \) shows that there also existed underpricing, which one can easily observe from the Figure 2. The magnitude of mispricing is lower in round 3 than in round 1 although, as noted above, the differences are not statistically significant. \(^{25}\)

We now move to analyze the forecasted prices.

### 3.2 Forecasted prices

Figure 3 shows the average deviation of the initially forecasted prices from the fundamental values in three rounds for two treatments 6H (Gray) and 1H5C (Black).

Contrary to our expectation, the initial magnitude of the average deviation of the forecasted prices from the fundamental values (Round 1) seems to be larger for 1H5C treatment (Black) than

\(^{24}\)As noted above, we set \( MP_{g,p,r} = P_{g,p,r} - FV_p = 0 \), i.e., no mispricing, when there was no transaction in period \( p \) for group \( g \).

\(^{25}\)p-value = 0.312. Mann-Whitney test. This may be simply because we have only 4 observations each.
Figure 3: Average deviation of forecasted prices over periods across three rounds for two treatments. Black: 1H5C. Gray: 6H.

Figure 4: Deviations of forecasted prices (in period 1, round 1) from fundamental values over periods for each individual for two treatment.

6H treatment (Gray), although in round 2 and 3, the order is reversed. This figure, however, can be misleading because the average is driven by a few subjects whose forecasts greatly deviate from the fundamental values as one can see from Figure 4.

To test whether the deviation of the forecasted prices from the fundamental values are different between two treatments, we construct two measures that are similar to the ones we used to measure the degree of mispricing. Since, every period, we elicit subjects’ price forecasts for all the remaining periods of a round, we can compute a measure of forecast deviation for each subject for every period. For subject $i$, the deviation of forecasted prices from the fundamental values in period $t$ are measured by

$$bRAD_i^t = \frac{1}{N - t + 1} \sum_{p=1}^{N} \frac{|B_{i,p}^t - FV_p|}{|FV|}$$

$$bRD_i^t = \frac{1}{N - t + 1} \sum_{p=1}^{N} \frac{(B_{i,p}^t - FV_p)}{|FV|}$$

where $N$ is the number of periods, $B_{i,p}^t$ is the forecasted price of period $p$ asset price by subject $i$ in
Figure 5: The distribution of bRAD in period 1 across three rounds for two treatments. Black: 1H5C. Gray: 6H.

period $t$.\textsuperscript{26} As above, $FV_p$ is the fundamental value of asset in period $p$. $|FV|$ is the absolute value of the average fundamental value of the asset over all the periods.\textsuperscript{27} We set $B_{t,p}^i = FV_p$, i.e., as if there is no deviation in forecasted price from the fundamental value, when subject $i$ forecasted no transaction would take place in period $p$.

Figure 5 shows the distribution of $bRAD_i^1$ for three rounds in two treatment, 6H (Gray) and 1H5C (Black).\textsuperscript{28} While we cannot reject the null hypothesis that observed distributions of $bRAD_i^1$ for two treatments are drawn from the same underlying distribution at the beginning of round 1 (p-value = 0.168, Mann-Whitney Test), we do reject the null hypothesis at the beginning of round 2 and 3 (p-value < 0.01, Mann-Whitney Test).\textsuperscript{29}

From this observation, we can conclude that, at least initially, being informed that all the other traders in the group are computer traders who try to maximize the profit without making any mistake while assuming other traders are doing the same does not make subjects to forecast the prices to follow the fundamental values. This suggests that the initial deviation of the forecasted prices from the fundamental values is not due to the lack of common knowledge of rationality but rather is a result of individual irrationality of the subjects, the conclusion put forward based on a different set of experiments by Lei, Noussair, and Plott (2001).

Yet, in 1H5C treatment, after experiencing one round of trading over 10 periods, the forecasted

\textsuperscript{26}As before, this measure is defined separately for each of three round. I have omitted the subscript $r$ to represent round for clarity of exposition.

\textsuperscript{27}One could also consider normalizing the measure with the average fundamental value of the asset over the remaining periods from period $t$. We do not do that, however, to keep the denominator constant for all the $t$.

\textsuperscript{28}Distributions of $bRAD_i^1$ for three rounds are very similar. See the Appendix.

\textsuperscript{29}Given that expectations of subjects in the same group is driven by the same realized info, subjects in the same group are no longer independent observations after period 2 of round 1. Thus, for all the observations after period 2 of round1, we take the group level averages and use them as independent samples. We obtain the same conclusion based on Kolmogorov-Smirnov test as well.
prices, on average, aligns themselves with the fundamental values (Round 2), while a substantial deviation remains for 6H treatment. Such differences in the forecasted prices in round 2 between two treatments can be easily understood from the differences in the realized prices in round 1 between two treatments. As noted by Haruvy, Lahav, and Noussair (2007), the expectations (thus forecasted prices) are adaptive. Thus, observing the prices to closely follow the fundamental values in round 1 have strong influence for subjects in 1H5C treatment to adjust their expectations accordingly in round 2.

It takes, however, several periods (in round 1) for subjects in 1H5C to adjust their forecasts to follow the fundamental values as one can see from Figure 6.\textsuperscript{30} Figure 6 shows the dynamics of mean $b_{RAD_t}$ for two treatments, 6H (Gray) and 1H5C (Black), in three rounds. It also reports the p-values of Mann-Whitney U-test for testing whether the distribution of $b_{RAD_t}$ in two treatments are drawn from the same distribution for each $t$ in three round (we have discussed that for period 1 for three rounds above).

In Round 1, the decreasing trend of mean $b_{RAD_t}$ is observed in both treatments. And the distributions of $b_{RAD_t}$ are not statistically different until round 6. It is only from round 7 that we observe the statistically significant differences in $b_{RAD_t}$ between 1H5C and 6H treatments. Thus, even without behavioral uncertainty regarding the behavior of other traders in the market, it requires several period in order to learn to forecasts prices at fundamental values.

### 3.3 Submitted orders

In addition to realized and forecasted prices, we investigate the orders submitted by our subjects in two treatments. In particular, we are interested in the extent to which subjects have submitted potentially loss generating orders. We define potential loss of subject $i$ in period $p$ to be

$$p_{l_i}^p = QD_{p}^i \times \max(PD_{p}^i - FV_{p}, 0) + QS_{p}^i \times \max(FV_{p} - PS_{p}^i, 0)$$

where $QD_{p}^i$ ($QS_{p}^i$) is the maximum quantity demanded (supplied) by subject $i$ in period $p$ and $PD_{p}^i$ ($PS_{p}^i$) is the maximum price at which the subject is willing to buy an asset (the minimum price at which the subject is willing to sell an asset).

We say these orders are “potentially” loss generating because while submitting orders with $PD_{p}^i >$
Figure 6: (Top) The dynamics of mean $bRAD_t$ overtime across three rounds for two treatments. Black: 1H5C. Gray: 6H. (Bottom) The p-value of Mann-Whitney U-test for comparing the distribution of $bRAD_i$ in two treatments for each $t$ in three rounds. For all the observation beyond period 2 of round 1 (thus round 2 and round 3), we take group level averages in 6H treatment and use them as independent observations.

Figure 7: Distribution of $PL^i$ across three rounds for two treatments. Black: 1H5C. Gray: 6H.

$FV$ or $PS^i_p < FV$ in the 1H5C treatment will surely result in losses but that may not be the case in 6H especially when not all the subjects in a group realize what the fundamental values of an asset are.

The measure of potential loss for subject $i$ within a round is, then,

$$PL^i = \frac{1}{N} \sum_{p=1}^{N} \frac{p^{i_p}}{|FV|}$$

Figure 7 shows the distribution of $PL^i$ in three rounds in two treatments, 1H5C (black) and 6H (gray). In round 1, we cannot reject the null hypothesis that two distribution are the same (p-value...
In round 2 and 3, however, this null hypothesis is rejected (p-value = 0.002 in round 2, and p-value = 0.036 in round 3.) \(^{31}\)

4 Conclusion

In this paper, we have investigated to what extent the deviation of forecasted prices from the fundamental values in experimental asset market is caused by individual irrationality and by uncertainty about the rationality of other traders (lack of common knowledge of rationality). We have compared the initial, as well as subsequent, forecasted prices submitted by subjects in two market environments: one is where all the six traders are human subjects (6H), and the other is where one human subject are interacting with five rational computer traders (1H5C). Our analysis shows that, initially, there is no statistically significant difference between distribution of forecasts deviation from the fundamental values in two cases. Thus, it is not the lack of common knowledge of rationality, or the uncertainty about the rationality of other traders, but the individual irrationality, that explains the initial deviation of forecasts from the fundamental values. We, therefore, have arrived at the same conclusion, while using the different methodology, with Lei, Noussair, and Plott (2001).

There are, however, significant differences in the way forecasts deviate from the fundamental values after subjects experiences the market once. Those in 1H5C market learned within the first round of experiment that the prices are to follow fundamental values and adjusted their expectation accordingly. While those in 6H, observing the prices to deviate from fundamental values, kept forecasting them so. This difference is consistent with the finding that expectations are adaptive presented by Haruvy, Lahav, and Noussair (2007).

Our next task is to investigate how do subjects who participated in 1H5C experiments will forecast the future prices if they are placed in 6H experiments. An obvious step is mix one subject who has experienced 1H5C treatment with 5 other subjects who have no experience in participating asset market experiments, and inform subjects about this fact. Given that those who have participated in the 1H5C experiments have learned about the prices to follow the fundamental values when other 5 traders are rational computer traders, any deviation of their initial forecasts in the 6H market must be due to their expectation about non-rational behavior of other 5 human traders. This set of experiments can provide clear answer to the individual irrationality versus the lack of common

\(^{31}\) As before, we take group level average for 6H treatment and use them as an independent observation in conducting statistical test. We obtain the same conclusion based on Kolmogorov-Smirnov test as well.
knowledge of rationality in the environments where speculation is possible. By varying the num-
ber of subjects who have experienced 1H5C treatment, we can also address the question asked by
Dufwenberg, Lindqvist, and Moore (2005): how many inexperienced subjects do we need to create
“bubbles” when short-selling and borrowing are not possible.
A Effect of Belief elicitation

Huber and Kirchler (2012) investigates the effects of the way in which the fundamental values (FVs) are presented to the subjects (a table versus a figure) as well as whether asking subjects about the next period fundamental values on the price deviating from the fundamental values. They consider experimental asset markets with continuous double auction rule. They show that presenting the FVs in a figure instead of in a table significantly reduce the magnitude of price deviations from the FV. They also found that when subjects are asked about the fundamental value of the asset in the next period, the magnitude of the price deviation was significantly smaller than the case without asking the same question to subjects.

We were interested in whether eliciting price forecasts from subjects would have the similar effect in our experiment. To investigate this issue, we have also conducted an experiment without eliciting price forecasts from subjects in 6H environment. All the instruction were the same except that the part related to the submission of expected prices and the bonus payments associated with correctly forecasting the future prices are deleted.

While the average mispricing for treatment without expectation elicitation seems larger (see Figure 8), we fail to reject the null hypothesis that distribution of \( RAD^9 \) for two treatment are the same even in Round 1 (p-value = 0.11, Mann-Whitney Test.)

Figure 8: Average mispricing over periods across three rounds for two treatments: 6H with (Gray) and without (Black) expectation elicitation.
<table>
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<th>Round 1 RAD</th>
<th>Round 1 RD</th>
<th>Round 2 RAD</th>
<th>Round 2 RD</th>
<th>Round 3 RAD</th>
<th>Round 3 RD</th>
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<tr>
<td>4</td>
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<td>0.020</td>
<td>-0.014</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Mean</td>
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<td>0.181</td>
<td>0.120</td>
<td>0.093</td>
<td>0.068</td>
</tr>
</tbody>
</table>

Table 2: RAD and RD for 4 groups under treatment 6H WITHOUT expectation elicitation.

B Instruction

Need to place instruction of experiment here.

References


