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Experience Does not Eliminate Bubbles: Experimental Evidence

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Experience Does not Eliminate Bubbles: Experimental Evidence[*]

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Abstract

We study the role of experience in the formation of asset price bubbles. Therefore, we conduct two related experiments. One is a call market experiment in which participants trade assets with each other. The other is a learning-to-forecast experiment in which participants only forecast future prices, while the trade, which is based on these forecasts, is computerized. Each experiment comprises three treatments that vary the amount of information about the fundamental value that participants receive. Each market is repeated three times. In both experiments and in all treatments, we observe sizable bubbles. These bubbles do not disappear with experience. Our findings in the call market experiment stand in contrast to the literature. Our findings in the learning-to-forecast experiment are novel. Interestingly, the shape of the bubbles is different between the two experiments. We observe flat bubbles in the call market experiment and boom-and-bust cycles in the learning-to-forecast experiment.

JEL classification: G40; C92; D53; D90.

Keywords: Experimental finance; asset market experiment; asset pricing; behavioral finance; bubbles; experience.

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1 Introduction

Experimental investigations of asset markets have improved our knowledge on the workings and the efficiency of financial markets substantially. One finding that reappears regularly is that prices rise substantially above fundamental values when participants first take part in an experimental asset market, but that such large price deviations are no longer observed after the same market is repeated multiple times. In short: bubbles disappear with experience.

Most of these experimental asset markets let participants trade financial assets with others making use of a continuous double auction or a call market mechanism.[1] The finding that bubbles disappear when identical markets are repeated is very robust in these settings, in which participants trade for a finite number of periods, with usually about 10-20 periods per market (e.g., Smith et al., 1988; King et al., 1993; Van Boening et al., 1993; Dufwenberg et al., 2005; Haruvy et al., 2007; Hussam et al., 2008; the findings can even persist in considerably more difficult variations, e.g., Füllbrunn et al., 2014a; Weber et al., 2018).

However, markets in which participants directly trade assets with one another in the laboratory are not the only type of experimental asset markets. So called learning-to-forecast experiments have become increasingly important. In such experiments, participants only forecast future prices. The trading, which determines market prices, is carried out by computerized mean-variance maximizers that base their supply and demand decisions on the participants' price forecasts.[2] These learning-to-forecast markets usually have a longer horizon of about 50 periods. Similar to the experiments with trade in the laboratory, sizable price bubbles are regularly observed in such markets. However, it is unclear whether these bubbles disappear with experience as there is no prior literature containing repeated learning-to-forecast asset markets.[3]

[1]For very early studies, see Smith et al. (1988) and Plott and Sunder (1988). For more recent studies, see Haruvy and Noussair (2006), Bossaerts et al. (2007), Haruvy et al. (2007), Bossaerts et al. (2010), Palan (2010), Cheung and Palan (2012), Kirchler et al. (2012), Sutter et al. (2012), Huber and Kirchler (2012), Cheung et al. (2014), Füllbrunn et al. (2014b), Noussair et al. (2016), Holt et al. (2017), Hoshihata et al. (2017), and Bosch-Rosa et al. (2018). Bossaerts (2009), Noussair and Tucker (2013), Palan (2013), and Nuzzo and Morone (2017) review the literature.

[2]For recent contributions using the learning-to-forecast paradigm to analyze financial asset markets, see Hommes et al. (2005), Hommes et al. (2008), Sonnemans and Tuinstra (2010), Hüsler et al. (2013), Bao et al. (2016), Bao et al. (2017), Colasante et al. (2017), Colasante et al. (2018), Hennequin (2018), and Hommes et al. (2018). Learning-to-forecast experiments have also been used in other environments, including goods markets (e.g., Sonnemans et al., 2004, Hommes et al., 2007, Bao et al., 2013) and macroeconomics (e.g., Pfajfar and Žakelj, 2014, Arifovic and Petersen, 2017, Cornand and M'baye, 2018). See Hommes (2011) or Assenza et al. (2014) for reviews.

[3]The study that comes closest to repeating identical markets is that by Hennequin, 2018, where participants take part in one round with computerized players with pre-determined forecasts before playing one

Do bubbles also disappear with experience in the learning-to-forecast setting? Our prediction before designing the experiment was no. If bubbles indeed do not disappear with experience in this setting, the question is why we would observe this difference between the two market paradigms. Why could it be that bubbles disappear in the experiments with actual trade in the laboratory while the opposite is the case in the learning-to-forecast markets? Which of the differences between the two market paradigms could be driving such a difference? Our idea was that the difference lies in the way that information about the fundamental value is provided to participants. In the markets with trade, participants are told directly what the fundamental value (the buyout price) in the terminal period is. In learning-to-forecast markets, participants usually have enough information to calculate this value, but they are not provided with the fundamental value directly.

To test this, we design two experiments, one with trade in the laboratory, making use of a call market mechanism, and one learning-to-forecast experiment (we refer to these as the Call Market Experiment and the Learning-to-Forecast Experiment). The design makes the experiments as similar as possible but with the possibility of varying the information that participants receive about the fundamental value. Our design allows us to give no information about the fundamental value to participants, some information, or full information in both experiments.

In both experiments and all treatments, bubbles do not disappear with experience. This means the finding that bubbles disappear with experience in markets with actual trade in the laboratory is not as robust as previously thought. However, we believe that our findings are nevertheless reassuring for the experimental method: there is no important difference in such an important characteristic as whether bubbles occur between the two market paradigms when the experiments resemble each other where possible.

In addition to the question whether bubbles disappear with experience, we analyze how the general pricing pattern changes over time, how the shape of bubbles differs between the experiments, and whether the timing of when bubbles appear within a round changes with experience. We find that in general pricing only becomes slightly more accurate in the last round of the experiment in the two treatments with information in the Call Market Experiment, while pricing does not improve in the no-information treatment of this experiment and all treatments in the Learning-to-Forecast Experiment. Interestingly, bubbles have different shapes in the experiments. While bubbles are often relatively flat in the Call Market Experiment, there are clear boom-and-bust cycles in the Learning-to-Forecast Experiment. In both experiments, bubbles appear in earlier periods in the later

round with other humans.

rounds of the experiments.

This paper is organized as follows. In Section 2, we explain the designs of the two experiments. Section 3 contains the results. Section 4 concludes.

2 Experimental Designs

With our design, we attempt to make the experiments as comparable as possible (while leaving the underlying principles of these types of experiments untouched). Experiments with trade in the laboratory are usually relatively short compared to the learning-to-forecast ones (around 10-20 periods per round as compared to about 50). We opt for an intermediate number, so that we have on the one hand a sufficient number of periods to be able to observe bubbles in both experiments (earlier LtFEs often show bubbles appearing only after about 20 periods), while on the other hand rounds are short enough so that we can run three of them in an experimental session. As we desire one treatment in which subjects are not explicitly informed about the fundamental value in the terminal period of the experiment, while they still need to have enough information to infer the fundamental value, we use a constant fundamental value and an indefinite number of periods per round. A constant fundamental value is standard in the learning-to-forecast asset pricing literature and also not uncommon in the literature with trade in the laboratory. An indefinite number of periods is useful in the Call Market Experiment to have a clear benchmark of what the buyout price is when it is not explicitly communicated to subjects (the buyout price is the fundamental value of the infinitely lived asset; with a fixed finite horizon, the fundamental value would not be straightforward, especially a value of zero in the last period could look natural to many subjects). We also believe that indefinite end times are in general a more natural setting when investigating bubbles in asset markets: when talking about bubbles, one has often equity markets in mind, in which such bubbles appear regularly, and equity markets do not have a predetermined final period (as opposed to bond markets, for example, where the bonds mature at a predetermined time; see Weber et al., 2018).

In both experiments, subjects are randomized into groups of six. The group composition remains the same throughout the experiment. In both experiments, each multi-period market is repeated three times (there are thus three rounds). Subjects do not know the number of periods per round. However, they do know that the number of periods lies between 25 and 40.[4] The rounds are otherwise identical. In both experiments, only one

[4]The number of periods with a market price is 28 in the first round, 32 in the second round, and 26 in the

randomly chosen round is paid out. The round for payment is randomly determined by the computer on the individual level. In both experiments, subjects receive one euro for 900 points. The experiments are designed in a way that the interest rates and the dividend processes are identical. Consequently, the fundamental values are identical.

2.1 The Call Market Experiment

In the Call Market Experiment, subjects can trade assets with each other. Each subject starts with an initial endowment of three assets and 5500 points in their cash account. Each subject interacts with five others throughout the experiment. In each period, subjects can buy or sell assets in the market by submitting marginal bids and asks simultaneously. The computer then calculates the aggregate demand and supply schedules, and the market price is determined by market clearing, where the demand and supply functions intersect. When the lowest ask price is higher than the highest bid price, or when there is no bid or ask, there is no trade in the given period. Furthermore, in case of an excess supply or demand at the realized market price, which bids or asks are successful is decided at random among the bids or asks submitted exactly at the market price. In case of a possible price interval for the equilibrium price, the realized price is the midpoint of the interval. Subjects are allowed to submit as many bids and asks as they want with the following restrictions:

1. Both bid and ask prices can be at most 1500.
2. Subjects cannot try to sell more assets than they hold. Similarly, they cannot try to buy more assets than the available number on the market (18 minus their own holdings).
3. Subjects cannot enter bids that they would not be able to pay for with the points in their cash account.
4. Ask prices have to be higher than bid prices. That is, subjects cannot buy assets from themselves.

If any of these conditions is violated, the software displays an error message. Subjects can then adjust their bids and offers.

After the trade in a period is realized, dividend and interest earnings are paid ("overnight"). Both dividend and interest earnings are paid to a separate savings account, which yields

third round. This means that the number of periods in which subjects trade in the CME is also 28, 32, and 26, while the number of periods for which subjects forecast prices in the LtFE is 29, 33, and 27. This is so, because the market price in period t in LtFE depends on the expectations of the price in period $t+1$.

interest but cannot be used for buying assets. Therefore, the cash-to-asset ratio is constant over time. The realized dividend from an asset in each period is either ten or zero (uniform for everybody), each with equal probabilities. The interest rate is 4%, for both money in the cash account and in the savings account.

When a round ends (abruptly), each asset is bought back from subjects for a "fair price", which is the constant fundamental value of 125 (the fundamental value equals the expected dividend divided by the interest rate, i.e. 5/0.04; this is the amount at which expected earnings from the dividend equal the interest payment of this amount in the cash account). Depending on the treatment (which we discuss in Section 2.3 below), subjects receive differential information about this "fair price". In each round, subjects' earnings equal the sum of the money in the cash and savings accounts and the money they receive for the assets that they hold once the round is terminated.

Subjects have the possibility to submit an empty schedule when they do not want to trade. Once all subjects submit their bids and offers, the market price is determined, and trade takes place. Each period, a history table is displayed on the screen containing information about past market prices (which are also shown on a graph), past cash holdings, savings, and asset holdings, and past trades. However, subjects do not have any information on others' trades or cash balances. Figure 1 shows a screenshot of a subject's decision situation.

We impose a time limit on subjects' decisions. Subjects have two minutes in the first 10 periods of the first round and one minute in all other periods to make their decision. If subjects do not make a decision on time, the computer automatically proceeds to the next period. No decision by a subject is equivalent to this subject submitting an empty form of bids and asks (that is, this subject does not trade in the given period).

2.2 The Learning-to-Forecast Experiment

The Learning-to-Forecast Experiment is similar to the experiment conducted in Hommes et al. (2008). Subjects take the role of advisers of a company. Their only task is to predict the price of a risky asset two-periods ahead. Computerized companies then trade based on the adviser's forecast (their decisions about trading in period t determine market prices in period t and are based on the forecasts of prices in period $t+1$, hence the two-period-ahead structure).

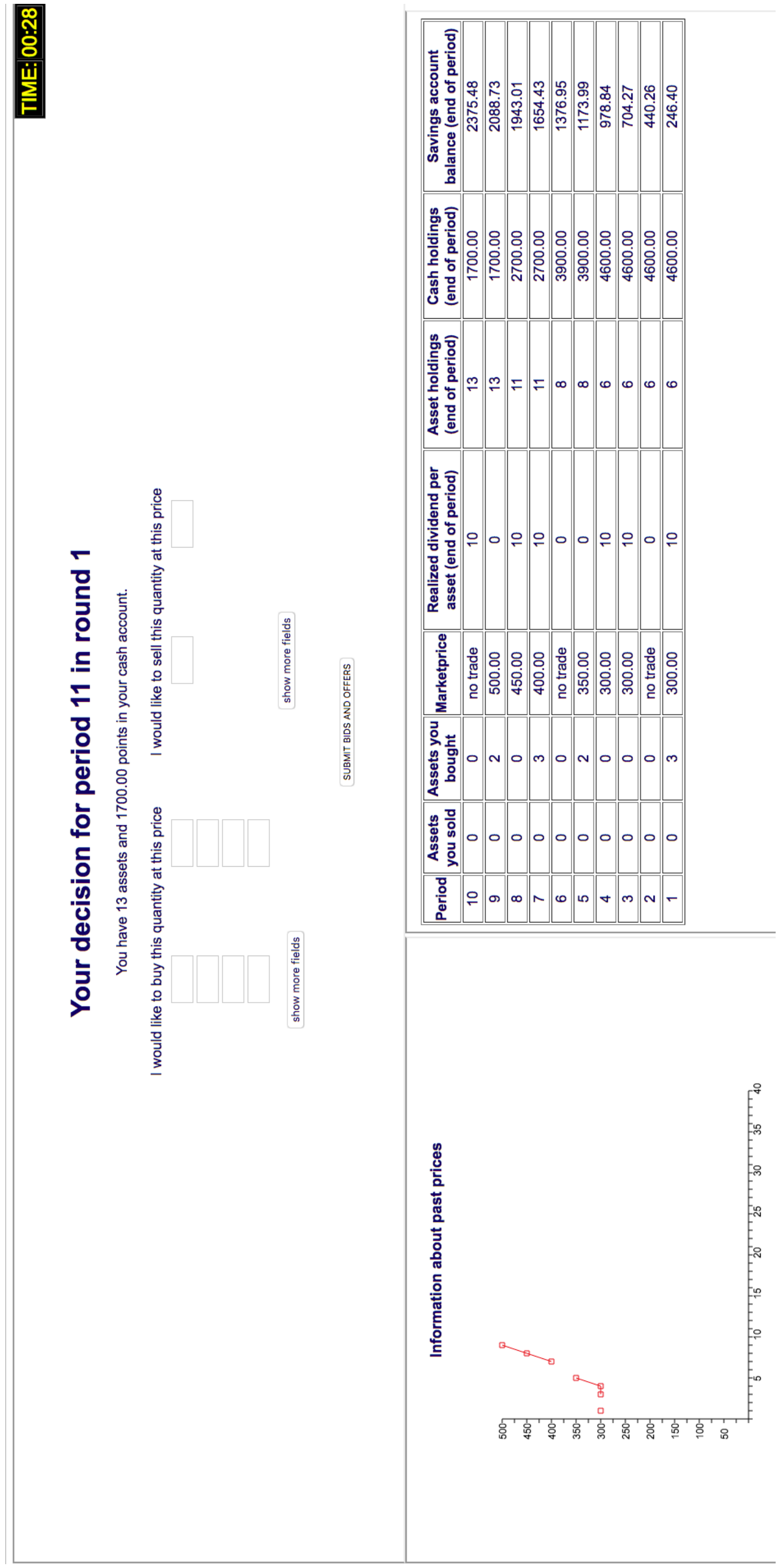


Figure 1: Decision Screen in the CME

2.2.1 Market Structure

The companies allocate their money optimally between the (risky) financial asset and a risk-free investment based on mean-variance optimization. The asset pays a dividend of y_t in period t, the risk-free investment yields a gross rate $R = 1 + r$. The companies choose how many assets to hold by maximizing their utility

$$\max_{z_{i,t}} \left\{ E_{i,t} W_{i,t+1} - \frac{a}{2} V_{i,t}(W_{i,t+1}) \right\}, \tag{1}$$

where $W_{i,t+1} = RW_{i,t} + z_{i,t}(p_{t+1} + y_{t+1} - Rp_t)$ denotes the wealth of firm i in period $t+1$, p_t is the price of the risky asset in period t, and a is a parameter of risk-aversion. $E_{i,t}$ and $V_{i,t}$ are a company's individual expectations about their future wealth and the variance of their future wealth. The latter is assumed to be homogeneous across agents and constant over time, $V_{i,t} = \sigma^2$. Taking the first-order-condition, and solving for $z_{i,t}$ gives the net demand schedule for the risky asset in period t by firm i:

$$z^*_{i,t} = \frac{E_{i,t}(\rho_{t+1})}{aV_{i,t}(\rho_{t+1})} = \frac{p^e_{i,t+1} + y_{t+1} - Rp_t}{a\sigma^2}. \tag{2}$$

The price is then set by market clearing. For simplicity we assume that the outside supply of the risky asset is zero (companies only trade with each other). This leads to the market clearing equation:

$$\sum_{i=1}^{N} z^*_{i,t} = 0 \quad \Rightarrow \quad \sum_{i=1}^{N} \frac{p^e_{i,t+1} + y_{t+1} - Rp_t}{a\sigma^2} = 0. \tag{3}$$

This, in turn, leads us to the market clearing price

$$p_t = \frac{1}{R}(\bar{p}^e_{t+1} + \bar{y}), \tag{4}$$

where $\bar{p}^e_{t+1}$ is the average of the companies' expectations of the price in period $t+1$ (that is, the average of the advisers' price forecasts for period $t+1$), and $\bar{y}$ is the expected dividend (which is constant over time). Companies are assumed to have homogeneous, rational expectations about the dividend. Taking into account that the fundamental price is $p^f = \bar{y}/r$, we arrive at the pricing equation

$$p_t = p^f + \frac{1}{R}(\overline{p}^e_{t+1} - p^f). \tag{5}$$

In the experiment, we use the same values for the interest rate and the dividend process as in the Call Market Experiment, namely $r = 0.04$ and $y_t \in \{0, 10\}$ with 50% probability each. This results in $\bar{y} = 5$ and the fundamental value $p^f = 125$.

2.2.2 Experimental Implementation

Subjects are randomized into groups of six. Their task consists of submitting price forecasts two-period ahead. That is, they make a forecast for period $t+1$ after observing the price in period $t-1$. Market prices in period t are then calculated based on the computerized trading of the six companies that the six subjects in the group advise (each company bases its trading decision on the price forecast it receives from its adviser as described above). Subjects are supposed to predict future prices as accurately as possible. Therefore, their earnings only depend on their forecasting accuracy, according to the following formula:

$$\pi_{i,t+1} = \max\left\{1300 \cdot \left(1 - \frac{(p^e_{i,t+1} - p_{t+1})^2}{100}\right), 0\right\}. \tag{6}$$

$\pi_{i,t+1}$ is the payment for a subject's forecast for period $t+1$. Subjects receive this formula along with a payoff table summarizing their earnings for different forecasting errors (see Appendix B.4). Subjects' earnings from a round are the sum of their earnings in each period of a round.

Subjects receive qualitative but not quantitative information about the environment in which they operate. To be more precise, they do not know that the market price is determined by (5), but they know that the price depends positively on the submitted forecasts. Furthermore, they know r and the details of the dividend process (so that they can in theory easily calculate the fundamental value).

To reduce the effects of extreme forecasts and to mimic possible liquidity constraints, companies are programmed to base their decisions on subjects' forecasts only up to a certain deviation from the last observed price. If a price forecast deviates from the last price by more than a third of the last price and by more than 40, the company trades as if the prediction deviated by exactly one third of the last price or by 40 (whichever of the two deviations is greater in absolute terms). Subjects have full information about these limits. Furthermore, we implement an upper limit of 1500 on the forecasts (similarly to the Call Market Experiment, where we prohibit bids and offers above 1500), which is also communicated to subjects before the experiment starts.

In each period, subjects have access to a history table and a history graph. In the table they can track past prices, past forecasts, as well as past and cumulative earnings. In the graph, the past prices and own predictions are shown. Subjects do not receive any information about other subjects' forecasts. Figure 2 shows a screenshot of a subject's decision situation.

We impose the same time limit as in the Call Market Experiment. That is, subjects have two minutes in the first 10 periods of the first round and one minute in all other periods to make their decision. If subjects do not make a decision on time, the computer automatically proceeds to the next period. If a subject does not submit a forecast, the corresponding company remains inactive and subjects earn no points for the given period. The average forecast in Equation (5) is then calculated with the number of subjects in the group with valid forecasts.[5]

2.3 Treatments

In both experiments, we implement three information treatments. The treatment differences consist in the information that subjects receive about the fair price (that is, the fundamental price) of the asset. Subjects always have full information about the interest rate and the dividend process, so that they can always calculate the fundamental value (also in the NO_INFO treatments, where they receive no explicit information about the buyout price).

In the NO_INFO treatments, subjects receive no explicit information about the buyout price (the fundamental value) until the experiment ends. In the Call Market Experiment, they know that the asset will be bought back for a fair price, but they receive no information about what this price is until the third and last round of the experiment is finished. In the Learning-to-Forecast Experiment, we tell subjects that the company that they advise receives a fair price for the asset (in this experiment subjects also know that this price does not affect their earnings).

In treatment INFO_AFTER, we communicate the buyout price (i.e. the fundamental value) of a round after the round ends. The fundamental value is of course the same in the different rounds, but we nevertheless repeat giving this information.

[5] One could argue that the two market paradigms differ in the following way: whereas median prices matter in the CME, mean forecasts determine the prices in the LtFE. We decided to keep the mean forecast in the LtFE pricing equation, in line with previous literature. Changing to the median would not be consistent with the underlying theoretical argument. Note that the imposed liquidity constraint mitigates the effect of extreme forecasts (somewhat similar to relying on median instead of mean forecasts).

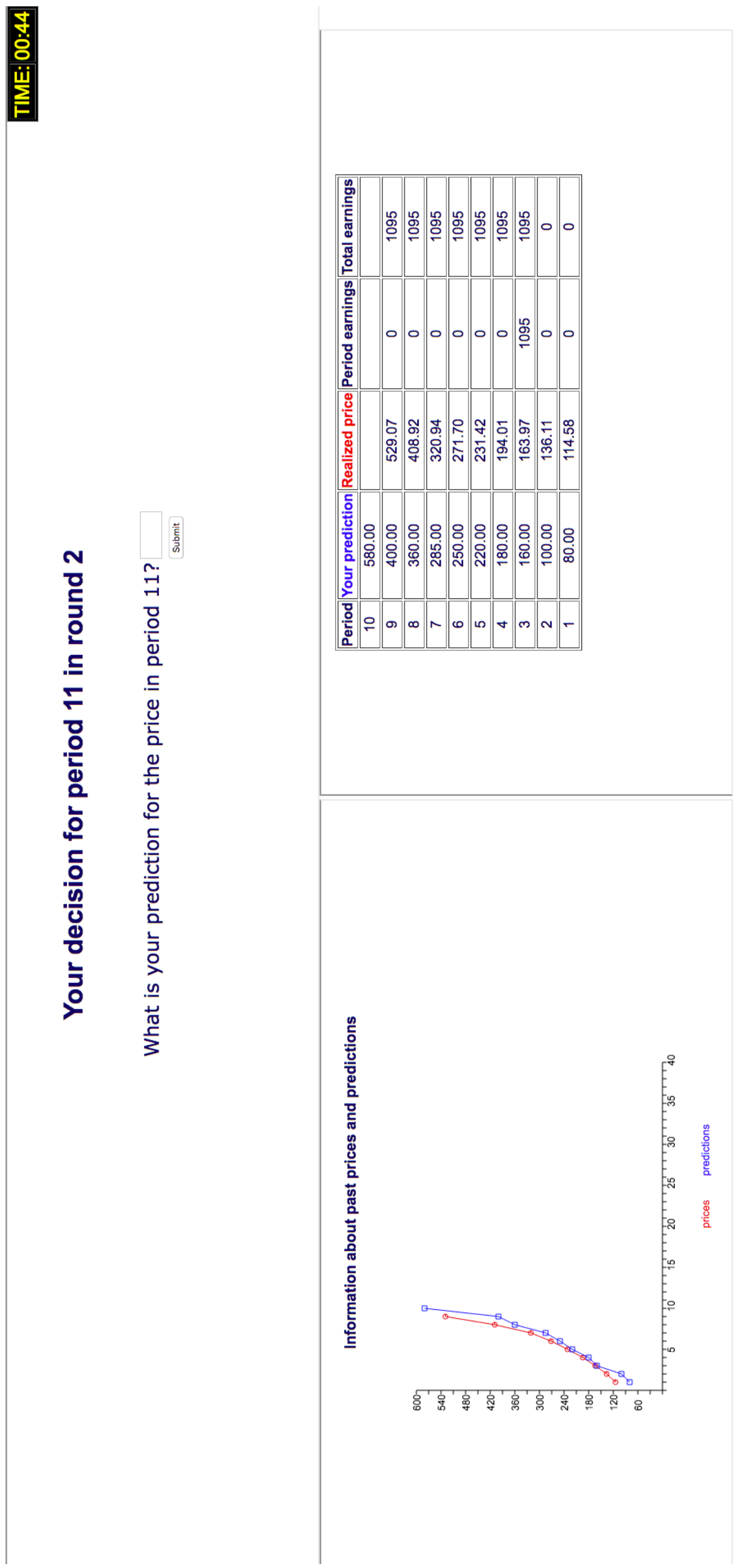


Figure 2: Decision Screen in the LtFE

Table 1: Design Summary

	NO_INFO	INFO_AFTER	FULL_INFO
Call Market Experiment	54 (9)	42 (7)	54 (9)
Learning-to-Forecast Experiment	48 (8)	42 (7)	54 (9)

Notes: This table summarizes the design and gives the number of subjects per treatment (and the number of markets in parentheses).

In treatment FULL_INFO, we communicate the buyout price (i.e. the fundamental value) already in the instructions before the experiment starts.

The design of the experiments is summarized in Table 1. The number of subjects per treatment is indicated in the cells of the table (with the number of markets given in parentheses). The summary table shows many similarities to a two-by-three design. We prefer to speak of two experiments with three treatments each instead, as there are multiple differences between the Call Market Experiment and the Learning-to-Forecast Experiment (the two are two different market paradigms rather than a single treatment variation).

2.4 Procedures

The experiments were programmed in `PhP/MySql` and run in the CREED laboratory of the University of Amsterdam. In total, 294 subjects participated in 12 sessions, two per treatment in each experiment.[6] Subjects were mainly economics undergraduate students. None of them participated more than once. Subjects read the instructions on paper and had to answer multiple comprehension test questions on screen. The experimental instructions and the comprehension test questions are presented in Appendix A for the Call Market Experiment and in Appendix B for the Learning-to-Forecast Experiment. Subjects were provided with pocket calculators, pens, and scratch paper. The experiment took about 160 minutes, with average earnings of about 25.5 euros, including a participation fee of 10 euros.

[6] Initially, two additional groups started the experiment. One of these groups was excluded due to a serious software failure during the experiment (in CME-INFO_AFTER). One group (in LtFE-NO_INFO) was excluded as a participant refused to sign the data consent form. Minimal software failures appeared in three of the groups that we did not exclude. In one group, this consisted in a subject proceeding to the third round after the first round ended. This was realized almost immediately and the subject was moved to the correct second round. This group, in LfFE-FULL_INFO, is represented by a light blue to turquoise line in Figures 3 to 5 below. In two further groups, one subject skipped one period in one round. These groups are represented by the pink (LtFE-INFO_AFTER) and purple (CME-INFO_AFTER) lines in Figures 3 to 5.

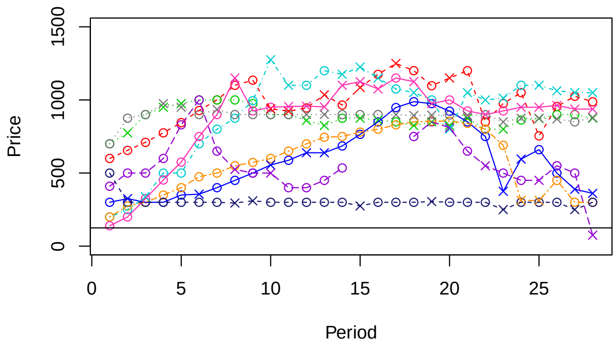
3 Results

In this section we present the results of both experiments jointly. For the Call Market Experiment, our data contains 9 groups in NO_INFO, 7 in INFO_AFTER, and 9 in FULL_INFO. In the Learning-to-Forecast Experiment, there are 8 groups in NO_INFO, 7 in INFO_AFTER, and 9 in FULL_INFO. As the different groups do not interact with each other in any way during the experiment, observations at the group level can be treated as statistically independent. All tests that we conduct are two-sided. Additional data can be found in Appendix C.

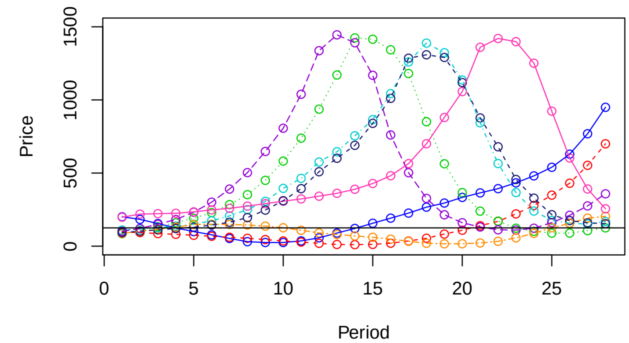
Figure 3 shows the market prices in all treatments in both experiments in the first round of the experiment. The prices in the Call Market Experiment are shown on the left side. Each color and line type represents one group. The circles show realized market prices. The crosses show the midpoints between the highest submitted bid price and the lowest submitted ask price if no trade occurs in a period (while both bids and offers are present). Circles and crosses in subsequent periods are connected (if the line representing one group is interrupted somewhere, this represents one or more time periods without trade and with no bids or offers submitted). The prices of the Learning-to-Forecast Experiment are shown on the right side of Figure 3. In this experiment, there are no periods without trade, so that there is a circle representing the realized market price in each period. Figures 4 and 5 show the market prices for both experiments in the second and third rounds, respectively.

In the remainder of this section, we analyze the data and present the results. In short, the results are the following:

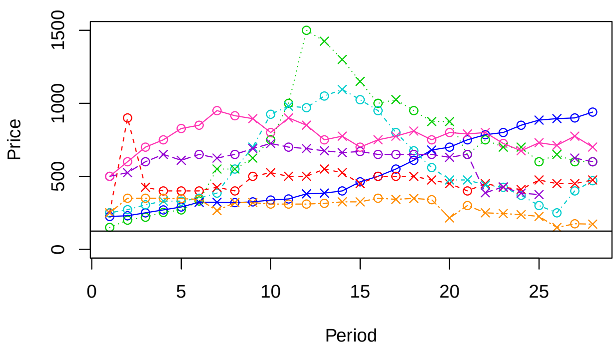
1. In the Call Market Experiment, bubbles do not disappear with experience.
2. In the Learning-to-Forecast Experiment, bubbles do not disappear with experience.
3. In the Call Market Experiment, we observe no more accurate pricing in later rounds in NO_INFO, while we observe very slow improvements of pricing in the information treatments.
4. In the Learning-to-Forecast Experiment, we observe no more accurate pricing in later rounds independent of the treatment.
5. Market prices in the Call Market Experiment usually exhibit flat bubbles.
6. Market prices in the Learning-to-Forecast Experiment exhibit boom-and-bust cycles.
7. Bubbles appear earlier in later rounds of the Call Market Experiment than in the first round.
8. Bubbles appear earlier in later rounds of the Learning-to-Forecast Experiment than in the first round.



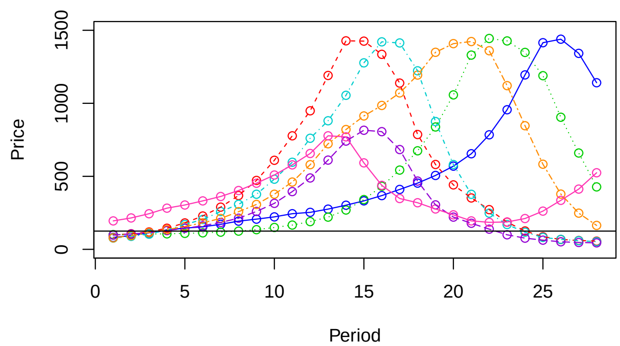
(a) CME NO_INFO Round 1



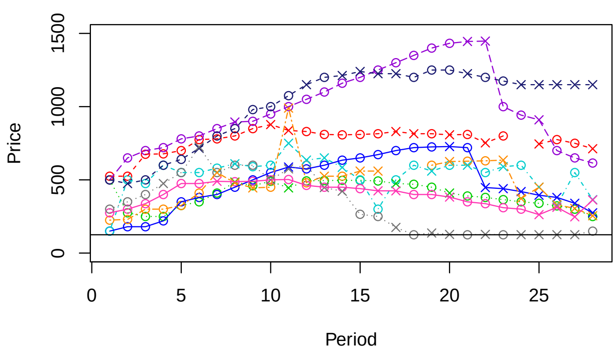
(b) LtFE NO_INFO Round 1



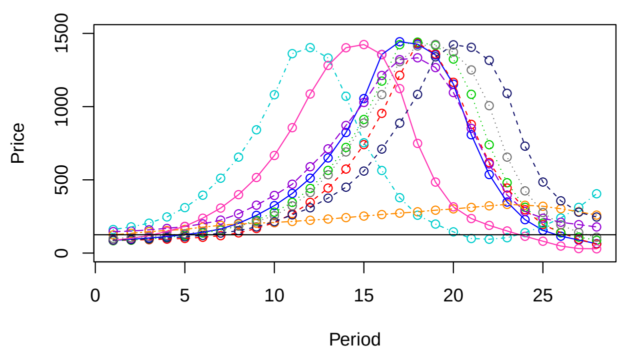
(c) CME INFO_AFTER Round 1



(d) LtFE INFO_AFTER Round 1



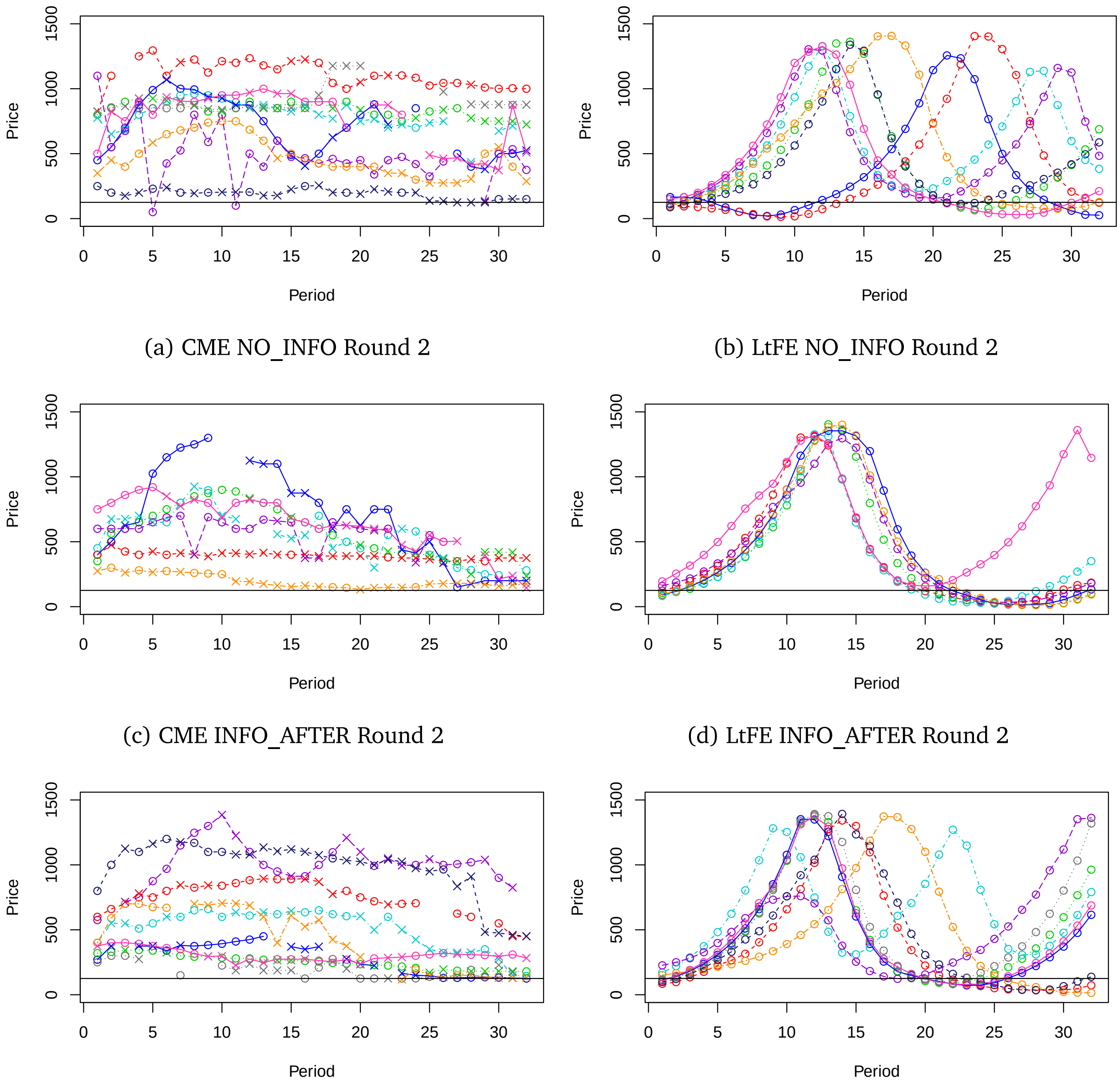
(e) CME FULL_INFO Round 1



(f) LtFE FULL_INFO Round 1

Figure 3: First round prices in all treatments in both experiments

Notes: This figure shows prices in the first round in all treatments of the Call Market Experiment (left) and the Learning-to-Forecast Experiment (right). Market prices are indicated with circles. In the CME, crosses indicate midpoints between highest bids and lowest asks in periods without trade (but with both bids and asks present). Each color represents one group.



(a) CME NO_INFO Round 2

(b) LtFE NO_INFO Round 2

(c) CME INFO_AFTER Round 2

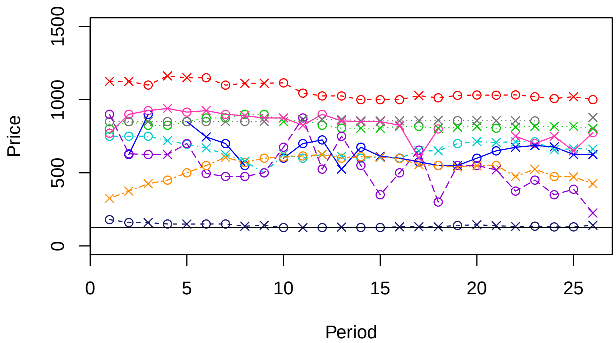
(d) LtFE INFO_AFTER Round 2

(e) CME FULL_INFO Round 2

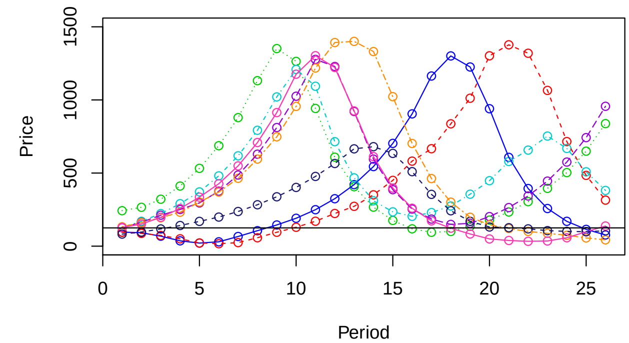
(f) LtFE FULL_INFO Round 2

Figure 4: Second round prices in all treatments in both experiments

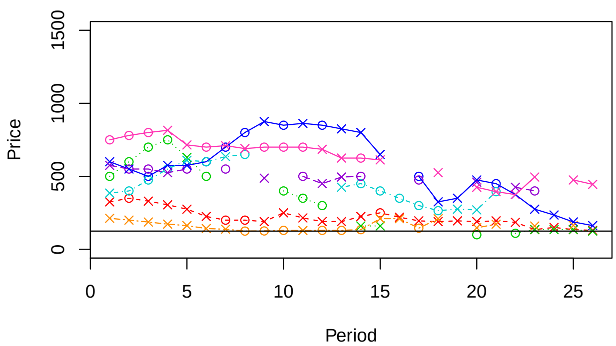
Notes: This figure shows prices in the second round in all treatments of the Call Market Experiment (left) and the Learning-to-Forecast Experiment (right). Market prices are indicated with circles. In the CME, crosses indicate midpoints between highest bids and lowest asks in periods without trade (but with both bids and asks present). Each color represents one group.



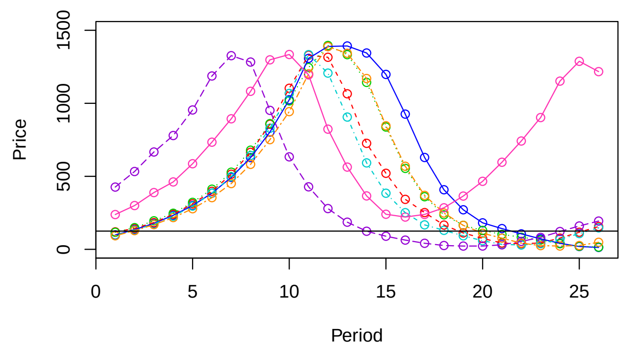
(a) CME NO_INFO Round 3



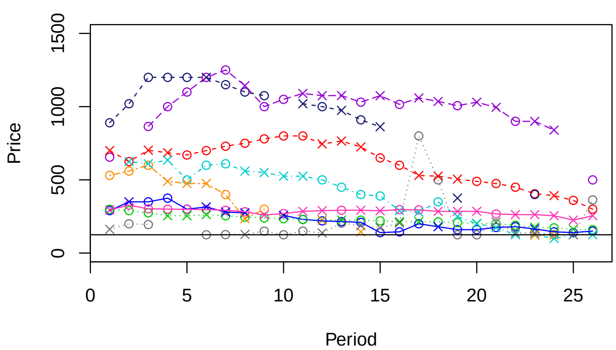
(b) LtFE NO_INFO Round 3



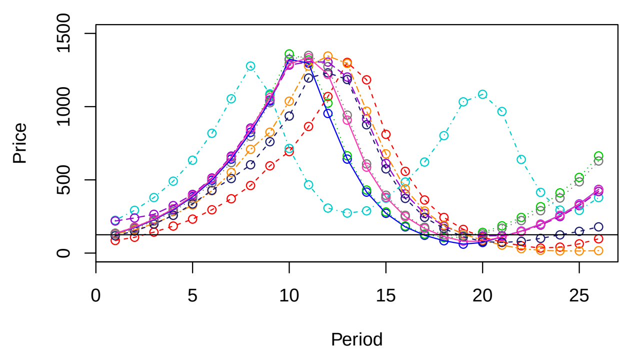
(c) CME INFO_AFTER Round 3



(d) LtFE INFO_AFTER Round 3



(e) CME FULL_INFO Round 3



(f) LtFE FULL_INFO Round 3

Figure 5: Third round prices in all treatments in both experiments

Notes: This figure shows prices in the third round in all treatments of the Call Market Experiment (left) and the Learning-to-Forecast Experiment (right). Market prices are indicated with circles. In the CME, crosses indicate midpoints between highest bids and lowest asks in periods without trade (but with both bids and asks present). Each color represents one group.

3.1 Experience and Bubbles

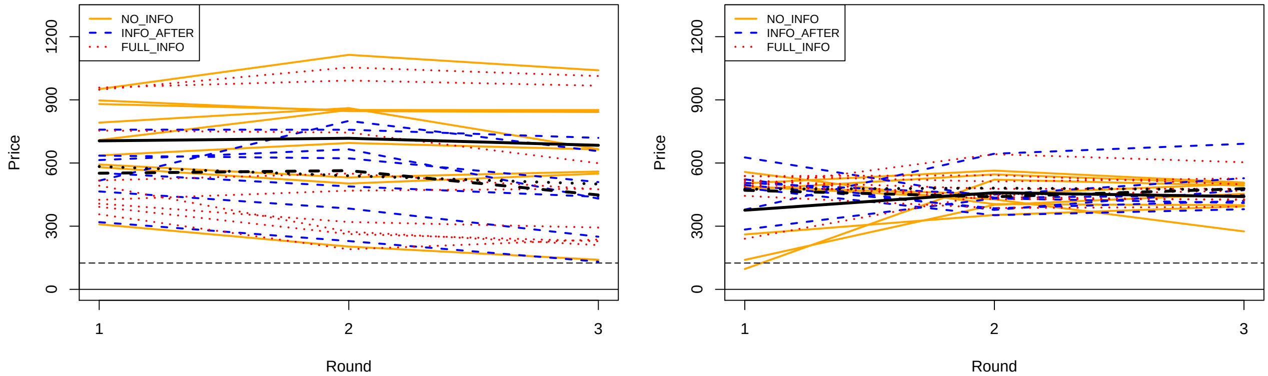
Our main research question is the analysis of whether bubbles disappear with experience. As can be seen from the graphs of the market prices in Figure 5, this is not the case.

In our case, a good measure for the mispricing in a given round is the mean price. In general, other measures of mispricing have been proposed and can be better suited to measure mispricing, in particular the so called relative absolute deviation (RAD; see Stöckl et al., 2010, and for an adaption to call markets Weber et al., 2018). However, as the fundamental value is constant in our case, and as we observe a lot of overpricing and hardly any underpricing, using the mean or RAD for the analysis are almost equivalent (they are fully equivalent for constant fundamentals when only overpricing is observed). We have therefore decided to only use mean values (one graph of RAD is shown in Appendix C.1 to illustrate the similarity to mean values with our data). There is no generally accepted definition of what a bubble is, but the precise definition of a bubble does not influence our conclusions (as long as this definition is somewhat reasonable). When the average price across all periods of a round is at least twice the fundamental value, one can certainly speak of (at least one) bubble being present in this round.[7] In the Call Market Experiment, we only consider realized market prices for the analysis (that is, the prices represented by circles in Figures 3 to 5, not the prices represented by crosses).

Figure 6 depicts the mean prices across all periods of a round. Each line corresponds to the mean prices in one group (the round number is on the horizontal axis). Which treatment a group belongs to is indicated by color and line type. The thick black lines correspond to the mean across all groups of a treatment. Table 2 summarizes the graph by showing the average value of the mean prices across all groups of a treatment (the values thus correspond to the values of the thick black lines in Figure 6). Figure 6 shows that in almost all groups and all rounds, mean prices are considerably above the fundamental value (that is, more than twice the fundamental) in both experiments. It is also notable that there is hardly any trend in the mean prices across the rounds in all treatments in both experiments. There is at best a very slight downward trend in the INFO_AFTER and FULL_INFO treatments of the Call Market Experiment, but even such a trend is hardly visible.[8]

For the important question of whether bubbles disappear with experience, the results are

[7] This is a rather strict criterion in the sense that there could be price developments that one may consider to be a bubble that do not fulfill this criterion. Imagine, for example, a price that increases sharply to a multiple of the fundamental vale in the first few periods and collapses after, staying close to the fundamental value for the rest of the round. There would clearly be a bubble while the mean price may still fail to be as high as twice the fundamental due to the many periods with accurate pricing after the bursting of the



(a) CME (b) LtFE

Figure 6: Mean prices in all rounds and treatments in both experiments

Notes: This figure shows the mean market prices across all periods of a round. Each thin colored line corresponds to one group. Thick black lines show the mean values of these lines per treatment.

Table 2: Mean Prices

	Treatment	Round 1	Round 2	Round 3	Fundamental
	NO_INFO	705	717	684	125
CME	INFO_AFTER	552	564	448	125
	FULL_INFO	583	540	500	125
	NO_INFO	376	459	441	125
LtFE	INFO_AFTER	471	440	478	125
	FULL_INFO	475	481	474	125

Notes: This table shows the mean prices across groups and periods in all treatments of the experiment (rounded to integers and corresponding to the thick black lines in Figure 6).

clearcut. They do not disappear, independent of the amount of information that subjects receive about the fundamental value (the treatments) and independent of the market paradigm employed (Call Market or Learning-to-Forecast). We state these results here and then situate them within the existing literature and briefly discuss their relevance.

bubble. However, as noted above, details of what is considered a bubble do not drive our conclusions.

[8]The exact numbers of bubbles (according to the definition stated above) is as follows. In the Call Market Experiment, the number of bubbles in NO_INFO is 9 in the first round, 8 in the second round, and 8 in the third round (out of 9 markets). In INFO_AFTER bubbles occur in the three rounds in 7, 6, and 6 markets (out of 7). IN FULL_INFO, these numbers are 9, 8, and 6 (out of 9). In the Learning-to-Forecast Experiment the respective numbers are 6, 8, and 8 (out of 8) in NO_INFO, 7, 7, and 7 (out of 7) in INFO_AFTER, and 8, 9, and 9 (out of 9) in FULL_INFO. These numbers are not significantly different from each other according to any reasonable statistical test.

Result 1: In the Call Market Experiment, bubbles do not disappear with experience.

This result, which holds in all of the treatments, stands in stark contrast to the literature concerning similar call market or double auction experiments. Of course, we cannot say that bubbles would never disappear; if we repeated the market many times, we could possibly observe that the bubbles disappear (we discuss this in more detail in Section 3.2). But nevertheless, the literature on such markets usually shows the disappearing of bubbles after already very few repetitions of an identical market. There are two key differences between our FULL_INFO treatment and the vast majority of literature on the topic: (1) we use an indefinite horizon instead of a fixed horizon and (2) we use a longer time horizon (in addition to this, the provision of information is mildly different in the INFO_AFTER treatment and very different in the NO_INFO treatment). No matter whether an indefinite end time or a longer horizon or a combination of both of them drive the difference to the results in the literature (we will investigate this in a follow-up experiment), a longer horizon and an indefinite end time seem to be the most relevant setting with actual equity markets in mind. Given that markets outside the laboratory are basically never repeated in an identical manner, the fact that we do not observe the disappearance of bubbles even when repeating the same market in such a simple setting sheds doubt on the view that the classical finding of bubbles disappearing fast with experience carries over to the field.

Result 2: In the Learning-to-Forecast Experiment, bubbles do not disappear with experience.

This is a novel finding. As there is thus far no literature investigating how the pricing behavior changes when the markets are repeated, we cannot compare our findings to the existing literature. There also appears no difference in treatments with respect to whether bubbles form or not.

Taking both of these findings together, we believe that it is reassuring for the experimental method that the results mirror each other. Keeping as many features constant between the two experiments, relying on one or the other market paradigm does not lead to strikingly different results concerning such an important characteristic as whether bubbles occur (with or without experience).

3.2 Development of Pricing Accuracy across the Rounds

Bubbles do not disappear with experience in our experiment. However, we have not yet discussed whether or to what extent the pricing of the asset improves over the rounds. Figure 6 and Table 2 suggest that pricing improves slowly in the Call Market Experiment in the information treatments, while it stays roughly similar in the NO_INFO treatment. In the Learning-to-Forecast Experiment, pricing seems to remain similarly accurate across the rounds in the information treatments while it even seems to worsen over time when subjects receive no information on the fundamental value.

Testing whether mean prices are significantly different in the third and first rounds with a two-sided Wilcoxon signed-rank test leads to the following results. In CME-NO_INFO pricing is not significantly different ($p = 0.426$), neither in CME-INFO_AFTER ($p = 0.109$), but it is marginally different in CME-FULL_INFO ($p = 0.098$). In the Learning-to-Forecast Experiment differences are not significant in any treatment (p-values are 0.383, 0.938, and 0.570, in the order of increasing information provided to subjects).

We interpret these results overall as weak evidence for very slow learning in CME-INFO_AFTER and CME-FULL_INFO and as evidence for no learning in CME-NO_INFO and all treatments of the Learning-to-Forecast Experiment. How slow the learning is can be seen by the following thought-experiment. Imagining that one can extrapolate the linear trend between rounds 1 and 3 (this is of course highly problematic, therefore this should really just be seen as a thought-experiment), average pricing across groups would be no longer considered a bubble after 7 rounds in CME-INFO_AFTER and 10 rounds in CME-FULL_INFO (and much more or even never in the other 4 cases). Note that this only means that *average pricing across groups* would then not be considered a bubble anymore, not that no more bubbles would arise after this time period (in addition, remember that the definition of a bubble that we use is rather strict, as discussed in Footnote 7). Given this and given how simplistic these call markets are, the repetition of a perfectly identical market setting for 7 or 10 rounds until the average behavior would no longer be considered a bubble, seems extremely long (looking at markets outside of the laboratory, no situation is ever repeated exactly and fundamental prices are often very hard to estimate even for experts). We summarize the above discussion in the next two results.

Result 3: In the Call Market Experiment, we observe no more accurate pricing in later rounds in NO_INFO, while we observe very slow improvements of pricing in the information treatments.

There are no comparable markets in the literature that do not provide the information about the fundamental value explicitly to subjects. As such, our result of no more accurate pricing in the later rounds of NO_INFO is novel. There are studies providing partial information about the fundamental value to subjects. Most closely related to our experiment is the work by Sutter et al. (2012), who provide partial information about dividend payments (see Huber et al., 2008, and Stanley, 1997, for other experiments with a focus on information; these studies are less comparable to ours, however). With their treatments, Sutter et al. (2012) vary the structure of the information that subjects receive. In particular they vary whether there is asymmetry across subjects in the information that is provided. They find that the assets are priced more accurately in the third and last round of the experiment in all treatments but find particularly accurate pricing in the asymmetric treatments where some subjects are informed better than others. The second part of Result 3, which states that the accuracy of pricing only increases very slowly in the information treatments (which are most comparable to the standard literature), differs from the literature as the learning is slower in our experiment, while the tendency is the same. We attribute the slowness of learning to the fact that the end time is indefinite (and that rounds are a bit longer than usually in the literature), which is only a small deviation from the most classical setting but seems to be enough for subjects to have much bigger problems learning to price the assets accurately.

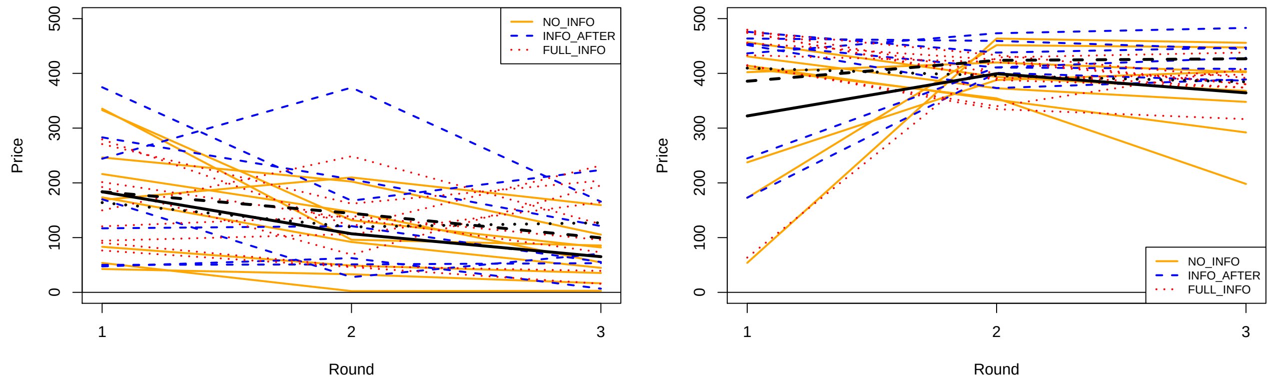
Result 4: In the Learning-to-Forecast Experiment, we observe no more accurate pricing in later rounds independent of the treatment.

This is again a novel finding as no repeated LtFE asset markets have previously been conducted. We are surprised to observe absolutely no more accurate pricing in later rounds even in the information treatments.

3.3 Shapes of Bubbles

The first two results show very similar behavior regarding the formation of bubbles among experienced traders for the two market paradigms. However, as Figures 3 to 5 also show, market prices look generally quite different between the experiments. One particularly interesting difference concerns the shape of the bubbles in the two experiments.

In the Call Market Experiment, we often observe long periods of severe mispricing in which the market price does not change a lot from period to period. Such bubbles have been termed flat bubbles by Hoshihata et al. (2017). In our experiment, we observe different variations of such flat bubbles in different markets. The bubbles can burst, which means that after market prices are high for a longer time, there is an abrupt change in one period with no further trade or trade only close to the fundamental price in subsequent periods (e.g., the dark blue line in Figure 3e, where no more trade is observed after period 21). The bubbles can also deflate, which signifies a slow decrease of market prices toward the fundamental value (e.g., the red line in Figure 5e). In addition to these two kinds of bubbles, there can also be sustained flat bubbles that last until the market is terminated



(a) CME

(b) LtFE

Figure 7: Standard deviation of prices in all rounds and treatments in both experiments

Notes: This figure shows the standard deviation of market prices in a round. Each thin colored line corresponds to one group. Thick black lines show the mean values of these lines per treatment.

without showing prior signs of bursting or deflating (e.g., the red line in Figure 4a). In the Learning-to-Forecast Experiment, on the other hand, we always observe boom-and-bust cycles. Prices increase and decrease smoothly, but with large amplitudes. The developments of market prices here look very homogeneous across markets.

This discussion can be quantified by looking at the standard deviations of market prices over periods in a given round. Flat bubbles go hand in hand with relatively low standard deviations of prices, while boom-and-bust cycles go together with a high standard deviation. This is naturally so as flat bubbles arise because many consecutive prices are similar; boom-and-bust cycles, on the other hand, have a high standard deviation as they feature a lot of different prices (at a large amplitude). The mean standard deviations across groups are presented in Figure 7 and Table 3, split according to treatment and round.

The standard deviations confirm what the eye-inspection of market prices reveals. Standard deviations in the Call Market Experiment are much lower than in the Learning-to-Forecast Experiment. These differences are also statistically significant.[9] This leads us to the next two results, which we subsequently compare to the existing literature.

Result 5: Market prices in the Call Market Experiment usually exhibit flat bubbles.

Flat bubbles are also observed by Hoshihata et al. (2017). They consider a very long

[9]Differences between CME and LtFE are statistically significant for all treatment-round combinations, tested with two-sided Wilcoxon-Mann-Whitney tests (p-values are 0.046 (NO_INFO R1), < 0.01 (NO_INFO R2), < 0.01 (NO_INFO R3), 0.011 (INFO_AFTER R1), < 0.01 (INFO_AFTER R2), < 0.01 (INFO_AFTER R3), < 0.01 (FULL_INFO R1), < 0.01 (FULL_INFO R2), and < 0.01 (FULL_INFO R3).

Table 3: Standard Deviation of Prices

	Treatment	Round 1	Round 2	Round 3
CME	NO_INFO	184	107	65
	INFO_AFTER	184	144	100
	FULL_INFO	164	119	127
LtFE	NO_INFO	322	399	364
	INFO_AFTER	386	424	427
	FULL_INFO	410	396	385

Notes: This table shows the standard deviations of market prices in a round in all treatments of the experiment (rounded to integers and corresponding to the thick black lines in Figure 7).

but fixed horizon of 100 periods. The fact that flat bubbles are observed in the call and continuous double auction markets in Hoshihata et al. (2017) and in the call markets in this paper but not in the typical asset market experiments could be due to the fact that the horizon is longer in the research reported in these two papers (much longer in the case of Hoshihata et al., 2017, and moderately longer and indefinite in our experiment).

Comparing our results to those of Hoshihata et al. (2017), a difference consists in the fact that we also observe bubbles that continue until the market terminates. This does not happen in their study. The most likely explanation for this difference (at least when looking at our INFO_AFTER and FULL_INFO treatments) is that it is due to the indefinite end time. Some subjects may expect the market to continue for longer and therefore trade at higher prices (however, we must note that there are not many bubbles that do not burst or deflate before the market ends in the later rounds of INFO_AFTER and FULL_INFO). In NO_INFO and the first round of INFO_AFTER, the information about the fundamental value that has to be inferred from subjects instead of being given to them directly may in addition drive such bubbles as subjects may have a wrong perception about the fundamental value of the asset.

Result 6: Market prices in the Learning-to-Forecast Experiment exhibit boom-and-bust cycles.

These kinds of bubbles are generally observed in financial market experiments using the learning-to-forecast paradigm. However, while we are not surprised to observe similar shapes of bubbles in later rounds (conditional on bubbles still appearing in later rounds), such behavior has not been documented previously.

3.4 Qualitative Changes of the Bubbles over Time

Bubbles appear in all treatments of both experiments in all rounds. The pricing of the assets hardly improves over time, if at all (mean prices do not decrease very much over the rounds, in some treatments they even increase, as shown in Table 2 and discussed above). However, the pricing behavior does change over time; the bubbles seem to speed up in both experiments, meaning that bubbles form earlier in the later rounds (and burst or deflate earlier in the Call Market Experiment) than in the first round. Figures 3 to 5 suggests this and we quantify it below.

There is no established measure of how early in a market a bubble occurs, but we consider the following measure natural. In each round, we take the mean price in the first half of the round and divide it by the mean price over the whole round. This fraction measures how high prices are in the beginning as compared to the whole round. If bubbles indeed speed up over the different rounds (i.e. if they occur earlier in later rounds), this fraction should increase over the rounds. These data are reported in Table 4.[10]

Table 4: Mean Prices in the first Half of a Round as Fraction of Mean Prices

	Treatment	Round 1	Round 2	Round 3
CME	NO_INFO	0.91	1.06	1.04
	INFO_AFTER	0.92	1.15	1.08
	FULL_INFO	0.98	1.14	1.07
LtFE	NO_INFO	0.74	1.04	1.03
	INFO_AFTER	0.73	1.58	1.42
	FULL_INFO	0.70	1.29	1.38

Notes: This table shows the mean across groups of mean prices in the first half of a round divided by mean prices in the same round.

The data confirm that bubbles appear earlier in the later rounds of both experiments in all treatments. The fraction of mean prices increases sharply from the first to the second round in all treatments. However, thereafter, from the second to the third round there is

[10] An alternative possibility would be to measure volatility in the Learning-to-Forecast Experiment by $v(p) := \frac{1}{T-1}\sum_{t=2}^{T}(p_t - p_{t-1})^2$ (this measure is discussed and applied in Hommes et al., 2017). If bubbles in boom-and-bust cycles speed up over time, one should see an increase in this measure as prices move faster from period to period. This is indeed what we observe. This measure is 12, 18, and 18 in the three rounds in LtFE-NO_INFO, 12, 16, and 20 in LtFE-INFO_AFTER, and 16, 18, and 21 in LtFE-FULL_INFO (always rounded to integers). However, this measure cannot be straightforwardly applied in the Call Market Experiment where periods without trade exist and where flat bubbles bursting earlier would not necessarily be detected by this measure.

no additional increase in this measure. Numbers are similar in the second and third round, mostly with slightly lower numbers in the third round. The differences between the first and the second round are mainly statistically significant, the differences between the first and the third round are still mainly at least marginally significant while the differences between the second and the third round are mainly insignificant.[11] We summarize this discussion in the following two results.

Result 7: Bubbles appear earlier in later rounds of the Call Market Experiment than in the first round.

This result is also observed in the previous literature. Several studies find that bubbles are smaller and shifted to the left (i.e., they appear earlier) when subjects are experienced (e.g., King et al., 1993, Dufwenberg et al., 2005, and Haruvy et al., 2007).

Result 8: Bubbles appear earlier in later rounds of the Learning-to-Forecast Experiment than in the first round.

The last result (which mirrors the corresponding results in the Call Market Experiment) can again not be compared to similar literature as no repeated learning-to-forecast asset market literature exists.

4 Concluding Remarks

Bubbles do not disappear with experience in our experiments. These findings are novel for the Learning-to-Forecast Experiment and stand in contrast to the literature for the Call Market Experiment. In both experiments, we find reoccurring bubbles that appear earlier in later market repetitions. We can only observe slight improvements in pricing accuracy in the Call Market Experiment with explicit information about the buy-out value. An interesting difference between the two experiments is the shape of the bubbles. While we observe relatively flat bubbles in the Call Market Experiment, bubbles inflate and deflate fast in the Learning-to-Forecast Experiment.

One may wonder why our findings in the Call Market Experiment differ from the literature. After all, the experiment that we conduct is very similar to existing experiments making use of a call market or continuous double auction mechanism. We believe the reason lies

[11] p-values from two-sided Wilcoxon signed-rank tests are < 0.01 (R1-R2), 0.016 (R1-R3), and 0.074 (R2-R3) in CME-NO_INFO. The respective numbers for CME-INFO_AFTER are 0.016, 0.078, and 0.219, and for CME-FULL_INFO 0.074, 0.164, and 0.910. For LtFE-NO_INFO these numbers are 0.148, 0.148, and 0.844, for LtFE-INFO_AFTER they are 0.016, 0.031, and 0.078, and for LtFE-FULL_INFO they are 0.027, 0.012, and 0.203.

in one of the following two modifications from the standard setup. To keep the two experiments similar and to allow for a no-information treatment in the Call Market Experiment, the number of periods in the Call Market Experiment is higher than in most other such experiments and the horizon is indefinite (we investigate in a follow-up experiment which of these elements are important for the results). However, the differences between the information treatments of our Call Market Experiment and earlier similar experiments are rather small. In addition, our specification with an indefinite end time and a longer horizon are a more natural setting with markets outside the laboratory in mind. Therefore, the finding that bubbles disappear with experience is clearly less robust than previously thought. Of course, our findings do not show that bubbles would never disappear. Possibly, the bubbles would disappear after a few more repetitions. However, three repetitions of absolutely identical markets are already a lot, both with respect to prior literature and particularly in light of the fact that markets outside of the laboratory never repeat in an identical way (market participants and the economic environment change continuously, among many other factors). Given how much more complicated markets outside the laboratory are, how long-lived they are, and that they usually do not have a predetermined end time, it is likely that pricing in actual markets can deviate substantially from fundamental values. Experience in such markets may thus play a smaller role than parts of the experimental literature suggests.

Our findings suggest that the availability of information only plays a minor role. Participants in the experiment do not price the asset poorly because of limited information, but they seem to be unable to process this information appropriately and transform it into economic decisions. Already the lack of a predefined ending period together with a moderately elevated number of periods per round seem to be enough to make the situation so complex that participants are not able to price the assets accurately.

In our eyes, the findings are still good news for the experimental method. After all, the two different market paradigms implemented in the Call Market Experiment and the Learning-to-Forecast Experiment yield very similar outcomes with respect to such an important characteristic as whether bubbles disappear with experience in all of our treatments.

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A Online Appendix: Experimental Instructions and Comprehension Test Questions for the Call Market Experiment

We reproduce the complete experimental instructions for the treatment NO_INFO of the Call Market Experiment in Section A.1. Bold or italic text is also bold or italic in the original instructions and text in boxes is similarly in such boxes in the original instructions. In Section A.2 we discuss the differences in instructions between the treatments. Section A.3 reproduces the comprehension test questions as used in treatments NO_INFO and INFO_AFTER. Section A.4 reports the difference in the test questions used in FULL_INFO.

A.1 Instructions CME NO_INFO

Welcome to this experiment!

Please read these instructions carefully as they explain how you earn money from the decisions that you make. You will be paid privately at the end, after all participants have finished the experiment.

During the experiment you are not allowed to use your mobile phone or other electronic devices. You are also not allowed to communicate with other participants. If you have a question at any time, please raise your hand and someone will come to your desk to answer your question in private.

The experiment consists of 3 rounds. Each round consists of multiple periods. Except for the number of periods in each round, the rounds are identical. Your earnings for each of the 3 rounds will be in points. **At the end, only your earnings from one randomly selected round will be paid out to you! The points from the selected round will be exchanged into euros at the exchange rate 900 points = 1 euro.** In addition you will receive 10 euros for your participation.

All participants will be randomly divided into **groups of 6 people**. The group composition will not change during the experiment. You will not know the identity of any group member nor will they know your identity even after the experiment is over.

The following describes what you will be doing in **each** of the 3 rounds.

General information

You will be given an opportunity to trade in an asset with the other participants in your group. You will start each round with an endowment of 5500 points (booked on your "cash account") and with 3 assets. In total there are 18 identical assets that you can trade. Holding assets can give you earnings in a way that will be explained below. Each round consists of multiple time periods in which you can trade. **However, you do not know the exact number of time periods (it may be any number between 25 and 40 and this number will be different in different rounds).**

Trading

If you want to buy assets, you can enter the number of assets that you want to buy (bid for) at a certain price using the computer interface. You can state as many different bid prices and quantities as you like.

> Example (the numbers here provide no indication of what you should enter in the experiment): Imagine that you would like to buy no assets if the price per asset is more than 200 points. If the price is at most 200 but more than 150 points, you would like to buy one asset. If the price of the asset is at most 150 points, you would like to buy four assets altogether. Then you should enter the following information:
> – One bid for 1 asset with a price of 200
> – One bid for 3 assets with a price of 150
> Note: At a price of less than 150 you want to buy four assets – nevertheless, the quantity that you enter with the price of 150 should be only three in this case. This is so, because you are already bidding for one asset at a price of up to 200.

If you want to sell assets that you previously bought (or assets that you are endowed with in the beginning of a round), then you can do something similar. You enter the number of assets that you want to sell (offer quantity) and the ask price (or offer price), which is the minimum price that you would like to receive for those units of the asset. You can again enter multiple combinations of quantities and prices.

> Example (the numbers here provide no indication of what you should enter in the experiment): Imagine that you would like to sell none of your assets if the price per asset is below 100 points. If the price is at least 100 points, but less than 700 points, you would like to sell two assets. If the price of the asset is at least 700 points, you would like to sell three assets altogether. Then you should enter the following information:
> – One offer of 2 assets with a price of 100
> – One offer for 1 asset with a price of 700
> Note: At a price of at least 700 you want to sell three assets – nevertheless, the quantity that you enter with the price of 700 should be only one in this case. This is so,

because you are already offering two assets at a price of at least 100.

In each period, you may enter both buy and sell orders, only buy orders, only sell orders, or no orders at all.

In each period you have enough (but limited) time to submit your bids and offers. If you do not submit bids or offers during this time frame, the computer will consider this as no bids or offers. This means that if you have entered bids or offers into the computer interface but not submitted them by the time the period ends, these bids or offers will be lost. A timer will show you the remaining time for each period (2 minutes in the first 10 periods of the first round, 1 minute in all other periods).

The bids and offers that you can enter into the computer interface are restricted as follows:

- You can only enter positive integer number as quantities.
- You can only enter positive numbers as prices, up to a maximum of 1500 (if you want to enter a decimal number, use a point and not a comma).
- You cannot try to sell more assets than you have at that moment. Similarly, you cannot try to buy more assets than there are available (which is 18 minus the number of assets you have).
- You cannot enter bids that you would not be able to pay for with the amount of cash that you have.
- All of your asks (offer prices) must be higher than your bids (that is, you cannot sell to yourself).

Market Price and Traded Quantity

The market price in each period is determined by supply and demand. This means that the price will be chosen that makes the most trades possible. All trades are then carried out at this single market price, which is centrally determined for your group in each period.

Explanation (this is a very simple example and the numbers here provide no indication of what you should enter in the experiment): Imagine you enter that you would like to buy 2 assets if the price is at most 550 points and one other participant enters that she would like to buy 4 assets if the price is at most 550. Imagine further that nobody else in the market enters a buying bid at 550 points or at a higher price. This means that *all participants of the market together* would like to buy 6 assets if the price is at most 550 points per asset. The aggregation of the buy orders can be done for all prices and yields the market demand schedule. This demand schedule contains the information of all buy orders for *all participants of the market together* and can be represented by a step function as below. On the horizontal axis you can see the total quantity demanded for each price on the vertical axis. In the graph of this simple example you can see that all participants of the market together are willing to buy up to 19 assets at a price of 80 points per asset, only 14 assets at a price of 300 points per asset, and only 6 assets at a price of 550 points per asset.

[Figure 8 appears here in the experimental instructions.]

A similar schedule can be derived for the supply side of the market, aggregating all the sell offers. When drawn it in the same graph, the supply schedule is an increasing step function.

[Figure 9 appears here in the experimental instructions.]

The market price is the price at which the two curves intersect (in this example 300). Similarly, the traded quantity is the quantity at which the two curves intersect (in this example 11). Note that at this price, 3 more assets are demanded than supplied (14 assets are demanded while only 11 are supplied). In this case a random selection of 3 bids *from all the bids at the market price* would not be fulfilled (it is similarly possible that there is more supply at the market price than demand).

In some rare cases there can also be a whole interval of prices at which the most trades can be carried out and the demand and supply schedules overlap vertically. In such cases the middle of the interval will be the market price. If no bids or offers are made at all or if all bids to buy are at lower prices than all offers to sell, there will be no trade and also no market price.

You will always see the market prices of previous periods in a round on your screen. Similarly, you will see how many assets you bought or sold at this price. You will not be told the total number of trades in the market (except if there are none).

Properties of the Asset and Interest Rate

The financial asset pays a random dividend in each time period. This dividend is 10 points per asset with 50% probability and 0 points with 50% probability. In each period either all assets pay the high dividend or all assets pay the zero dividend. The dividend earnings will be paid to a separate account called "savings account" – they are part of your earnings for the round, but you cannot use points in this separate account to buy more assets.

The money that you do not spend on buying assets (and the money that you receive when selling assets) is stored in your cash account. You can use this money to buy more financial assets if you so wish. For the money in the cash account you receive an interest rate of 4% per time period. These interest earnings are not paid to the cash account but to the savings account.

Both dividends and interest rates will be paid "overnight"; this means that if you buy an asset in one period, you will have received your dividend from this asset by the time you are trading in the next period (similarly, the money that you hold after the trades of one period have been conducted will have yielded the interest by the time the trading of the next period begins). In the information table that you will see during the experiment, the dividend and interest payments following the trading of one period will already be included in the fields showing cash and savings account balance at the end of this period.

The points in your savings account cannot be used to buy assets, but they still yield interest. The interest rate for the money in the savings account is the same as for the money in the cash account, namely 4%. The interest is paid to the savings account at the same moment as the interest for the money in the cash account.

A round ends abruptly at some point between period 25 and 40. **When a round ends, the financial asset ceases to exist and you receive a fair price for your holdings of the asset at that moment. Note, however, that you will not be told what this price is until all rounds of the experiment have finished.** That is, if you hold assets when a round is terminated, you will not get to know your exact earnings for this round until all rounds have been completed. A round always ends right after the dividend and interest payment for the last period in which you could trade.

You can now start to answer the comprehension questions on the screen.

A.2 Differences in Instructions between the Treatments of the Call Market Experiment

The instructions in the treatments INFO_AFTER and FULL_INFO are identical to those in NO_INFO except for one sentence in the second to last paragraph (starting with "A round ends abruptly") after the sentence "When a round ends, the financial asset ceases to exist and you receive a fair price for your holdings of the asset at that moment." The sentence that is different between treatments reads as follows in the three treatments:

- NO_INFO: Note, however, that you will not be told what this price is until all rounds of the experiment have finished.
- INFO_AFTER: You will be told immediately what this price is when the round ends.

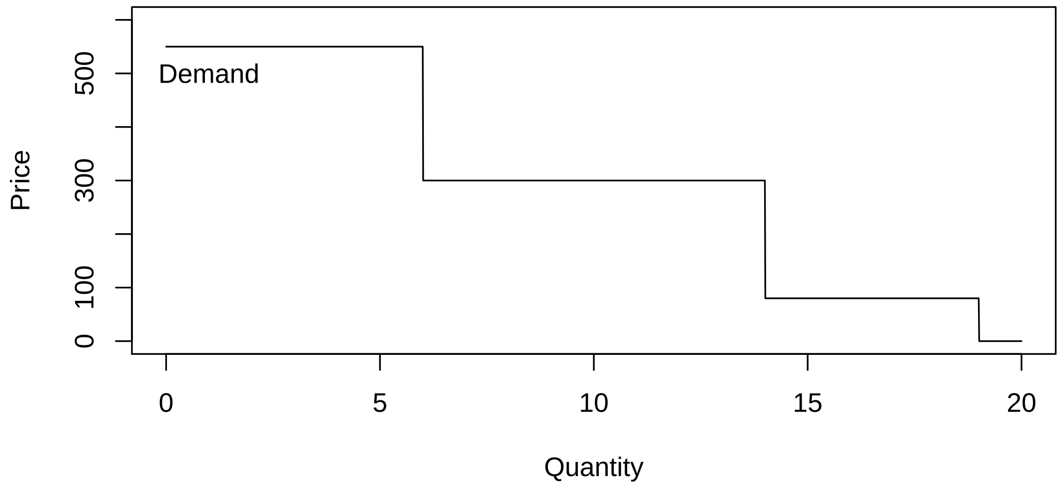


Figure 8: Example of a demand curve (not labeled in the experimental instructions)

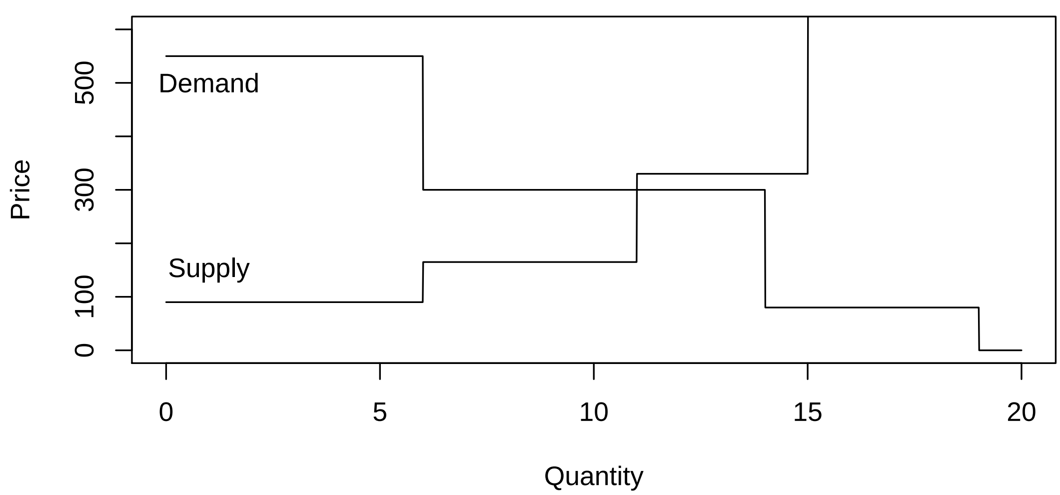


Figure 9: Example of demand and supply curves (not labeled in the experimental instructions)

- FULL_INFO: This price is 125 points per asset.

A.3 Comprehension Test Questions CME NO_INFO and INFO_AFTER

We reproduce here the comprehension test questions of the Call Market Experiment in the treatments NO_INFO and INFO_AFTER. The test questions are numbered on the screens and appear on two screens (the first four questions on the first screens). Note that subjects had to answer all questions on a screen correctly to proceed. If they did not answer all questions correctly and tried to proceed, they received the following error message: "You did not answer all questions correctly. Take another look at the instructions or raise your hand if you need help." We add a checkmark after each correct answer (or give the correct answer in brackets if the question is not a multiple choice problem). In Section A.4 we discuss how the test questions in treatment FULL_INFO differ from those below.

1. Imagine the following situation. You want to buy 8 assets in total if the price is at most 30 points per asset. You want to buy 5 assets in total if the price is above 30 points but at most 100 points. You want to buy 1 asset if the price is above 100 points but at most 311.5 points. What do you enter in the corresponding part of the computer interface?
   a. Quantity: 8, Price: 30; Quantity: 5, Price: 100; Quantity: 1, Price: 311.5.
   b. Quantity: 3, Price: 30; Quantity: 4, Price: 100; Quantity: 1, Price: 311.5. ✓
2. Imagine the following situation. All members in your group except for you offer to sell 2 assets at a price of 50. You bid to buy 5 assets at a price of 200. Which of the following is the result of this?
   a. The market price will be 50. You will buy 5 assets at this price. Which 5 of the 10 assets offered at this price will be traded is determined randomly. ✓
   b. The market price will be 200. You will buy 5 assets at this price. Which 5 of the 10 assets offered at this price will be traded is determined randomly.
   c. The market price will be 125. You will buy 10 assets at this price.
3. You can enter bids to buy assets and offers to sell assets. Imagine that you consider both, buying and selling assets. Which of the following is correct?
   a. You can try to bid for as many assets as you like at any price. If the market price turns out to be high, your cash holdings may become negative.
   b. You cannot try to buy assets at a higher price than the lowest price at which you are willing to sell assets. ✓
4. Suppose that you earn 27000 points in the round that is randomly selected for payment. How much is that in euros?

- [Correct answer: 30]

5. Are the 3 rounds of the experiment different?
   a. No, they are absolutely identical.
   b. Yes, they are different in a variety of aspects.
   c. They only differ in the number of periods per round, otherwise they are identical. ✓
6. What happens if you have not submitted your bids and offers when the time of a period elapses?
   a. The computer will automatically submit the bids and offers that you have entered into the computer interface (but not yet submitted).
   b. The computer will not consider any bids or offers from you for this period. ✓
7. Which of the following is true about the savings account?
   a. Points in the savings account do not yield any interest.
   b. Points in the savings account cannot be used to buy assets. ✓
   c. Points in the savings account do not count towards your round earnings.
8. Each round is terminated abruptly between period 25 and 40. When the round is terminated, how are your round earnings determined?
   a. They depend on your points in the cash and savings accounts. Assets are worthless at the moment that the round terminates.
   b. They depend on your points in the cash and savings accounts and on the points that you receive for the assets that you hold when the round terminates. The latter depend on the fair price of the asset (this is not necessarily the same as the last market price of the asset). ✓
   c. They depend only on your points in the cash account and on the last market price of the assets that you hold when the round terminates.

A.4 Differences in Comprehension Test Questions between the Treatments of the Call Market Experiment

The test questions and correct answers in the treatments NO_INFO and INFO_AFTER are identical. The test questions in FULL_INFO are almost identical and only differ in answer b to question 8 (which is still the correct answer). The difference between the treatments is as follows:

- NO_INFO and INFO_AFTER: They depend on your points in the cash and savings accounts and on the points that you receive for the assets that you hold when the round terminates. The latter depend on the fair price of the asset (this is not necessarily the same as the last market price of the asset).

- FULL_INFO: They depend on your points in the cash and savings accounts and on the points that you receive for the assets that you hold when the round terminates (125 points per asset).

B Online Appendix: Experimental Instructions and Comprehension Test Questions Learning-to-Forecast Experiment

We reproduce the complete experimental instructions for the treatment NO_INFO of the Learning-to-Forecast Experiment in Section B.1. Bold text is also bold in the original instructions and text in boxes is similarly in such boxes in the original instructions. In Section B.2 we discuss the differences in instructions between the treatments. Section B.3 reproduces the comprehension test questions, which were identical in all treatments. Section B.4 reproduces a payoff information sheet (the payoff table) that subjects had on their desk.

B.1 Instructions LtFE NO_INFO

Welcome to this experiment!

Please read these instructions carefully as they explain how you earn money from the decisions that you make. You will be paid privately at the end, after all participants have finished the experiment.

During the experiment you are not allowed to use your mobile phone or other electronic devices. You are also not allowed to communicate with other participants. If you have a question at any time, please raise your hand and someone will come to your desk to answer your question in private.

The experiment consists of 3 rounds. Each round consists of multiple periods. Except for the number of periods in each round, the rounds are identical. Your earnings for each of the 3 rounds will be in points. **At the end, only your earnings from one randomly selected round will be paid out to you! The points from the selected round will be exchanged into euros at the exchange rate 900 points = 1 euro.** In addition you will receive 10 euros for your participation.

All participants will be randomly divided into **groups of 6 people**. The group composition will not change during the experiment. You will not know the identity of any group member nor will they know your identity even after the experiment is over.

The following describes what you will be doing in **each** of the 3 rounds.

General information

You are an **advisor** to a company that wants to optimally invest its money. The company has two investment options: a risk-free investment (on a bank account) and a risky investment (in a financial asset). As their financial advisor, you have to predict the price of the financial asset during a number of subsequent time periods. The more accurate your predictions are, the higher your total earnings will be.

Forecasting task

Your only task is to forecast the price of the financial asset in each time period as accurately as possible. The price of the financial assets has to be predicted two time periods ahead. You may only enter forecasts that are at least 0 and at most 1500. Prices of the asset are in experimental currency units (ECU); however, the unit of the prices is of no importance for your forecast. At the beginning of a round, you have to predict the price of the financial asset in the first two periods without information about past prices. It is very likely that the price of the asset will be between 0 and 150 ECU in the first two periods of the first round. After all participants have entered their predictions for the first two periods, the price of the financial asset for the first period will be revealed and, based upon your forecasting error, your earnings for period 1 will be determined. After that you have to make a prediction for the price of the financial asset in the third period. After all participants have given their predictions for the third period, the price of the asset in the second period will be revealed and, based upon your forecasting error, your earnings for period 2 will be determined. This process continues for a number of time periods. **You do not know the exact number of time periods (it may be any number between 25 and 40 and this number will be different in different rounds).**

The available information for forecasting the price of the financial asset in period t consists of

- all past prices up to period t – 2,
- your past predictions up to period t – 1, and
- your earnings up to period t – 2.

In each period you have enough (but limited) time to make your forecasting decision. If you do not submit a forecast during this time frame, you will not earn any points in that given period. A timer will show you the remaining time for each period (2 minutes in the first 10 periods of the first round, 1 minute in all other periods).

Earnings

Your earnings depend only on the accuracy of your predictions. The maximum possible points you can earn for each period (if you make no prediction error) is 1300, and the larger your prediction error is, the fewer points you earn. You will earn 0 points if your prediction error is greater than 10 (that is, if the absolute difference between the realized price and your prediction is greater than 10 ECU). There is a Payoff Table on your desk, which shows the points you can earn for different prediction errors.

Information about the financial asset and the decision making of the company

The price of the financial asset in each period is determined by its demand and supply. Supply and demand of the asset on the market are determined by the decisions of the companies in the economy (there are six companies per group in this experiment, each advised by one participant; no one else except for these six firms trades in this financial asset). The higher the companies' demand for the financial asset and the lower the supply, the higher will be the realized price. Whether companies want to buy or sell shares of the financial asset depends on the forecast of future prices by their financial advisor. If the financial advisor of a company expects the future price of the asset to be higher, the company is willing to hold more of the asset now at a given price; that is, the higher its demand or lower its supply for the asset will be. A company whose financial advisor does not enter a forecast neither buys nor sells assets in the corresponding period.

You have the following information about the financial asset and the decision situation of the company. The bank account of the risk free investment pays a fixed interest rate of 4% per time period. The financial asset pays a random dividend in each time period. This dividend is 10 ECU with 50% probability and 0 with 50% probability. The return that a company makes from investments of the financial asset from one time period to the next depends on the dividend and upon changes in the price of the asset.

A round ends abruptly at some point between period 25 and 40. **When a round ends, the financial asset ceases to exist and the company receives a fair price for its holdings of the asset at that moment. You will not be told what this price is.** This price has no influence on your earnings; as mentioned above, you are only payed according to the accuracy of your forecasts.

Note that the company that you advise can only buy and sell up to a maximum amount of the asset in each period. If your forecast of the price (two periods ahead) deviates from the last price by more than a third of the last price and by more than 40, the company will trade as if your prediction deviated by exactly one third of the last price or by 40 (whichever of the two deviations is greater). For example, if the last price is 240 and your forecast is 50, the company will act as if your forecast was 160 (because your forecast deviates by more than 240/3=80 from the last price and the last price minus a third of the last price is 240-80=160). However, if the last price is 60 and your price forecast is 85, the company will act regularly on your price forecast; the difference between forecast and last price is 25 and thus more than 60/3=20, but 60+25=85 is still less than 60+40=100.

You can now start to answer the comprehension questions on the screen.

B.2 Differences in Instructions between the Treatments of the Learning-to-Forecast Experiment

The instructions in the treatments INFO_AFTER and FULL_INFO are identical to those in NO_INFO except for one sentence in the second to last paragraph in the box (starting with "A round ends abruptly") after the sentence "When a round ends, the financial asset ceases to exist and the company receives a fair price for its holdings of the asset at that moment." The sentence that is different between treatments reads as follows in the three treatments:

- NO_INFO: You will not be told what this price is.
- INFO_AFTER: You will be told what this price is.
- FULL_INFO: This price is 125 ECU per asset.

B.3 Comprehension Test Questions LtFE All Treatments

We reproduce here the comprehension test questions of the Learning-to-Forecast Experiment. These test questions are identical in all three treatments. The test questions are numbered on the screens and appear on two screens (the first four questions on the first screens). Note that subjects had to answer all questions on a screen correctly to proceed. If they did not answer all questions correctly and tried to proceed, they received the following error message: "You did not answer all questions correctly. Take another look at the instructions or raise your hand if you need help." We add a checkmark after each correct answer (or give the correct answer in brackets if the question is not a multiple choice problem).

1. Suppose that in one period, your prediction for the market price of the asset is 45.5, and the realized market price turns out to be 45.9, how many points do you earn in this period (please use the payoff table)?
   - [Correct answer: 1298]

2. Suppose that the price of the financial asset is the same in periods 8 and 18 and that a financial advisor predicts that the price increases from period 8 to 10 and decreases from period 18 to 20. In which of the periods 9 and 19 does the company want to hold more units of the asset (for each given price)?
   - [Correct answer: 9]
3. Imagine that all of the advisors predict that the market price will decrease substantially. What will happen to the market price?
   a. It will increase.
   b. It will decrease. ✓
4. Suppose that you earn 27000 points in the round that is randomly selected for payment. How much is that in euros?
   - [Correct answer: 30]
5. Are the 3 rounds of the experiment different?
   a. No, they are absolutely identical.
   b. Yes, they are different in a variety of aspects.
   c. They only differ in the number of periods per round, otherwise they are identical. ✓
6. Suppose that the price in the previous period (that is, p_{t-1}) is 93, and your price forecast for the next period (t+1) is 150. What is the price that the company bases its decision on? Remember that the company can only buy and sell assets up to a limit so that it may base its decision on a different price than the forecasted 150.
   - [Correct answer: 133]
7. Are your personal earnings affected by the amount of money that the company receives for its holdings of the financial asset when the market stops?
   a. Yes, you receive the same amount of money that the company receives.
   b. No, your earnings depend solely on the accuracy of your forecasts. ✓
8. What happens if you have not entered a price forecast when the time of a period elapses?
   a. A pop-up window will ask you for your forecast.
   b. The software will proceed to the next period. You will not receive any earnings for this period. ✓

B.4 Payoff Information Sheet (LtFE)

Payoff Table

The earned points are based on the following formula:

$$\text{points} = \max\left\{1300 \cdot \left(1 - \frac{\text{error}^2}{100}\right), 0\right\},$$

where the error is the absolute difference between the realized and predicted price in period t.

[Table 5 appears here on the payoff information sheet.]

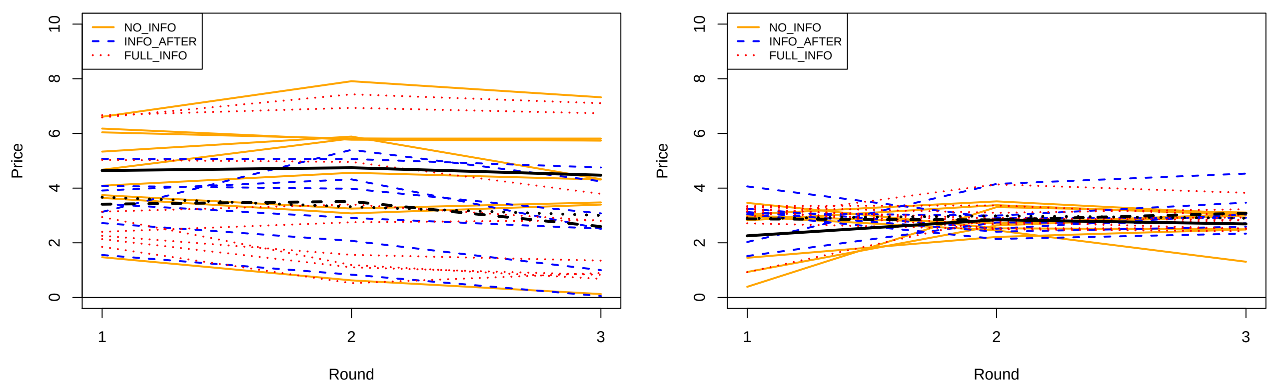
Table 5: Payoff Table (not Labeled in the Experimental Instructions)

error	point	error	point	error	point	error	point	error	point
0.1	1300	2.1	1243	4.1	1081	6.1	816	8.1	447
0.2	1299	2.2	1237	4.2	1071	6.2	800	8.2	426
0.3	1299	2.3	1231	4.3	1060	6.3	784	8.3	404
0.4	1298	2.4	1225	4.4	1048	6.4	768	8.4	383
0.5	1297	2.5	1219	4.5	1037	6.5	751	8.5	361
0.6	1295	2.6	1212	4.6	1025	6.6	734	8.6	339
0.7	1294	2.7	1205	4.7	1013	6.7	716	8.7	316
0.8	1292	2.8	1198	4.8	1000	6.8	699	8.8	293
0.9	1289	2.9	1191	4.9	988	6.9	681	8.9	270
1	1287	3	1183	5	975	7	663	9	247
1.1	1284	3.1	1175	5.1	962	7.1	645	9.1	223
1.2	1281	3.2	1167	5.2	948	7.2	626	9.2	200
1.3	1278	3.3	1158	5.3	935	7.3	607	9.3	176
1.4	1275	3.4	1150	5.4	921	7.4	588	9.4	151
1.5	1271	3.5	1141	5.5	907	7.5	569	9.5	127
1.6	1267	3.6	1132	5.6	892	7.6	549	9.6	102
1.7	1262	3.7	1122	5.7	878	7.7	529	9.7	77
1.8	1258	3.8	1112	5.8	863	7.8	509	9.8	51
1.9	1253	3.9	1102	5.9	847	7.9	489	9.9	26
2	1248	4	1092	6	832	8	468	error $\geq$10	0

C Online Appendix: Additional Data

C.1 Relative Absolute Deviation

Figure 10 shows the relative absolute deviation of prices for each group and round in both experiments. It can be noted, that this figure is extremely similar to Figure 6 in the main text showing mean prices. This similarity illustrates that our use of mean prices to define bubbles does not drive our conclusions.



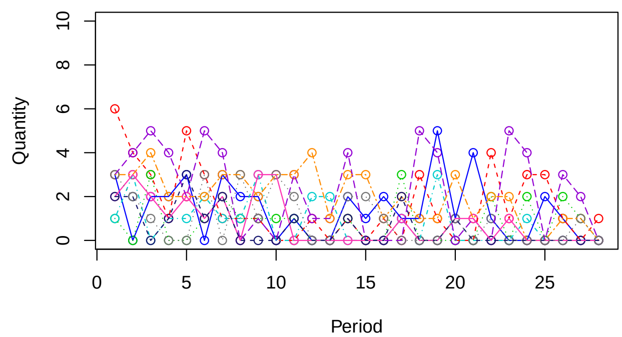
(a) CME (b) LtFE

Figure 10: RAD in all rounds and treatments in both experiments

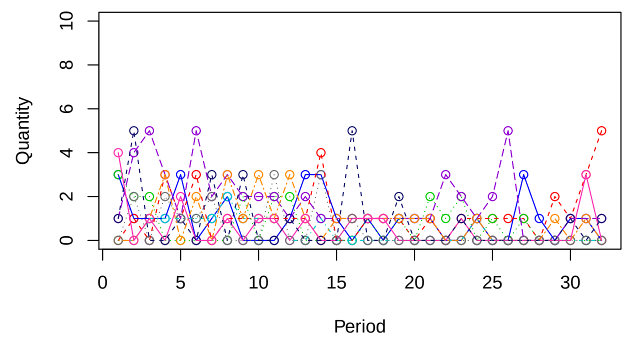
Notes: This figure shows the relative absolute deviation of market prices. Each thin colored line corresponds to one group. Thick black lines show the mean values of these lines per treatment.

C.2 Quantities Traded in the Call Market Experiment

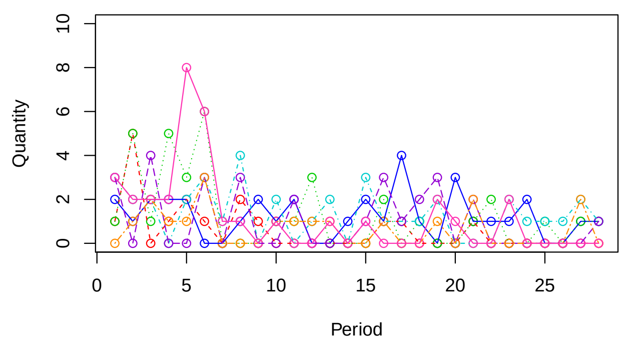
Figures 11 and 12 show the quantities of assets traded in the Call Market Experiment in all rounds and treatments. The number of trades decreases across the rounds in all treatments. In NO_INFO, the mean number of trades per period decreases from 1.23 in the first round over 0.85 in the second to 0.82 in the third. In INFO_AFTER, the corresponding numbers are 1.03, 0.77, and 0.51. In FULL_INFO, the numbers are 1.31, 0.81, and 0.68. The decrease in trade from the first to the last round is significant in all treatments when tested with a Wilcoxon signed-rank test (p-values are < 0.01 for NO_INFO and FULL_INFO and 0.016 for INFO_AFTER). Testing whether the decrease in trade is faster in one treatment than in another with Wilcoxon-Mann-Whitney tests yields insignificant results for all pairwise comparisons.



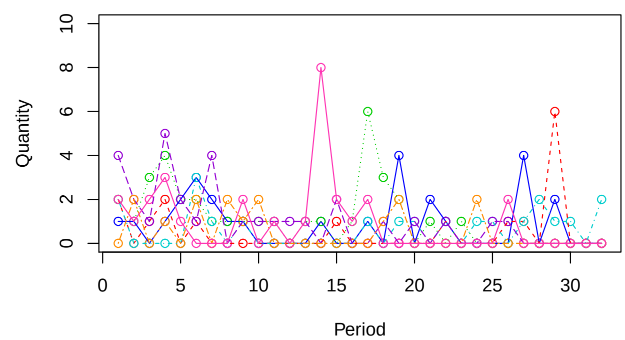
(a) CME NO_INFO Round 1



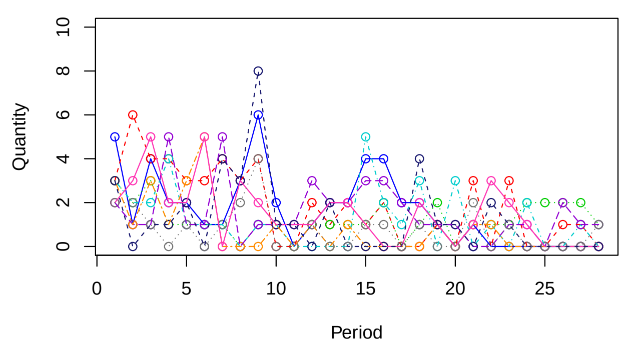
(b) CME NO_INFO Round 2



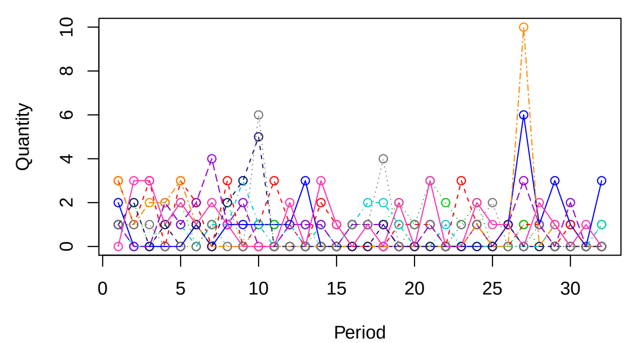
(c) CME INFO_AFTER Round 1



(d) CME INFO_AFTER Round 2



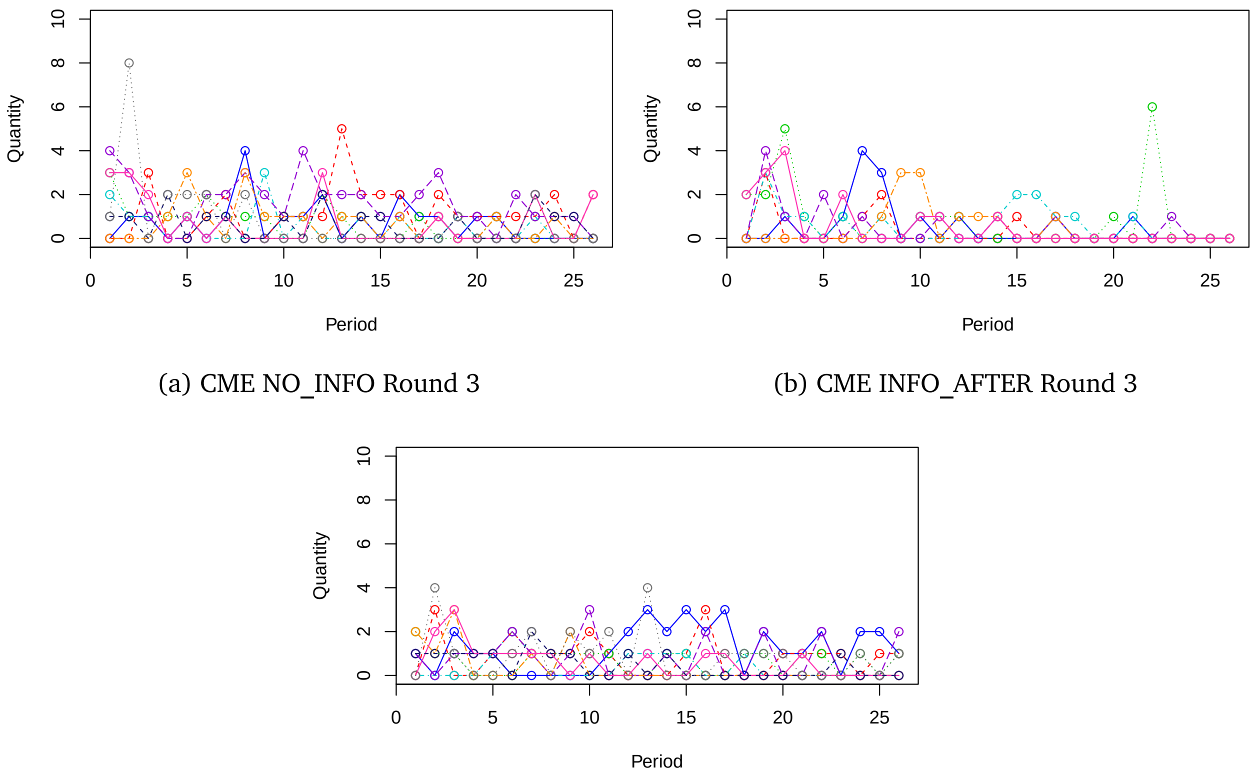
(e) CME FULL_INFO Round 1



(f) CME FULL_INFO Round 2

Figure 11: Quantities traded in rounds 1 and 2 in all treatments in the CM Experiment

Notes: This figure shows traded quantities in the Call Market Experiment in the first round (left) and the second round (right) of the experiment. Each color represents one group.



(a) CME NO_INFO Round 3

(b) CME INFO_AFTER Round 3

(c) CME FULL_INFO Round 3

Figure 12: Quantities traded in round 3 in all treatments in the CM Experiment

Notes: This figure shows traded quantities in the Call Market Experiment in the third round of the experiment. Each color represents one group.