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A Quantitative Easing Experiment*

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Abstract

We experimentally investigate the effect of a central bank buying bonds for cash in a quantitative easing (QE) operation. In our experiment, the bonds are perfect substitute for cash, and have a constant fundamental value (FV) which is not affected by QE in the rational expectations equilibrium. We found that QE raised the bond prices beyond those in the benchmark treatment without QE and these differences became larger as subjects gained experience. While subjects in the benchmark treatment learned to trade the bonds at its FV, those in treatments with QE became more convinced that QE boosts bond prices.

Keywords: Quantitative easing, experimental asset market, expectation dynamics

JEL Code: C90, D84

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1 Introduction

Quantitative easing (QE) in its most basic form is the purchase of government bonds in exchange for central bank reserves with the intention to retain them for a significant length of time.¹ In an era in which interest is paid on reserves, this amounts to the exchange of one interest-bearing liability of the state for another. In textbook models with frictionless and complete markets and fully rational and infinitely living agents, such a transaction can have no temporary or permanent effects on any macroeconomic variables in an equilibrium (Eggertsson and Woodford, 2003). In particular, short-term and long-term interest rates will be unchanged and there will be no effect on output and inflation.² In these circumstances, QE would just be an irrelevant shortening of the average maturity of net public debt.

There is, however, strong evidence that QE programmes have moved bond prices and yields, although the scale and duration of such effects is still debated (Krishnamurthy and Vissing-Jorgensen, 2011; Joyce et al., 2011; Arrata and Nguyen, 2017). The literature has focused on two departures from the textbook model to explain these effects. One theory is that central bank money and government bonds are not perfect substitutes (Tobin, 1958) perhaps because markets are segmented due to investors’ ‘preferred habitat’ (Vayanos and Vila, 2009) or investors do not like holding the interest rate risk associated with long-term bonds. If long-term government bonds and central bank reserves are not perfect substitutes, a fall in the volume of long-term bonds in private hands can raise the price and drop the yield relative to short-term rates. The alternative explanation is that QE is a means by which central banks can give credibility to forward guidance commitments to deviate from established monetary policy behaviour, such as a Taylor rule (Eggertsson and Woodford, 2003). QE reinforces the signal that the short-term rate will remain low for longer than a time-consistent policy rule would suggest. Lowering the expected path of short-term rates drags down long-term rates through the expectations hypothesis of the term structure.

This paper considers a different explanation. As currently implemented, QE is a commitment to buy relatively quickly a fixed value of bonds at any price. Indeed since the intermediate objective of the policy is to lower bond yields, the greater the rise in bond prices, the more “successful” the instrument. The central bank is thus an unusual participant in the bond market because it is not

¹The scale of the purchases and the holding period distinguish quantitative easing from standard open market operations. QE programmes have also bought non-government bonds but this is outside the scope of this paper.

²Older irrelevance propositions for open market operations were described in Wallace (1981) and Sargent and Smith (1987).

deterred from buying by a higher market price (at least up to some point). If there were only one seller of government bonds, he or she could offer to sell at a price at which the central bank was just indifferent between buying and reneging on its commitment at a reputational cost. In other words, once the central bank has committed to buy, there is an exploitable opportunity for sellers collectively.

However, in a completely competitive market with fully rational agents, common knowledge, no segmentation and assuming the central bank is not buying the entire market, such an effect will not exist. Each participant has an incentive to offer marginally below the offer of the marginal seller to grab a share of this surplus until this is completely eroded away. Since the central bank will buy (and sell) at the fundamental price, there is no reason for the market price to deviate in periods when the central bank is not active. But what if some of these assumptions do not hold?³

We anticipate that many participants will have an instinctive response that the presence of a large external buyer should raise the price. But even a very sophisticated trader could not know the level of strategic depth of the other participants. This combination of less than complete rationality and lack of common knowledge could only be expected to raise prices above fundamentals because it is implausible to think that anyone would believe that the presence of an additional buyer would cause prices to fall.

The objective of this paper, therefore, is to test whether QE can influence the market price for bonds in an environment in which cash and bonds have identical payoffs in the rational expectations equilibrium and there is no role for monetary policy. In other words, does QE work if both of the channels described in the literature are switched off by construction? Does the announcement of QE itself influence the expectations of market participants? Does the holding period of the central bank matter? Do the answers to these questions change as traders gain experience and learn about the effect of QE? These questions are investigated using a set of laboratory experiments.

Three treatments are set up in which players are given “bonds” and “central bank cash” with equivalent per unit payoffs per period in a rational-expectations equilibrium. The players can trade bonds between each other in a market over eleven periods. There was no uncertainty in the returns on bonds or cash and the principal repaid at the end of the experiment was equal to its fundamental value according to rational expectations.

In the benchmark treatment, there is no central bank and the players simply trade among each

³See Iovino and Sergeyev (2018) for a model of k-level thinking applied to QE.

other. Even in these experiments of quite simple trading games, there is an accumulated evidence that prices diverge significantly from fundamentals (see, for example, Bostian and Holt, 2009, and Smith et al., 2014), so these benchmark results can help us avoid attributing to QE the effects of a bubble that might be an inherent feature of the experimental trading environment.

In the remaining two treatments, there is a central bank⁴ that announces at the beginning of the game that it will buy a significant fraction of the outstanding bonds before periods 4 and 5 through a discriminatory auction.⁵ In one treatment it holds these bonds until the end and in the other it commits to sell them before periods 8 and 9. Since these operations by themselves do nothing to change the returns to either asset and markets are competitive, the rational expectations (with common knowledge) path for the price of bonds should also not deviate from its fundamental value. In line with other experiments with buy interventions, we expect that our experiments will show and increase in bond prices (see, for example, Haruvy et al., 2014).⁶

In all the three treatments, we gather subjects' expectations about future prices of bond to study how announcements of QE (with and without subsequent resale) influence their expectations. We investigate the effect of announcement of QE on expectations because expectations play central role in modern Macroeconomics and Financial economics, and various policies, both monetary and fiscal, are increasingly described as policies that influence expectations of market participants (Honkapohja, 2015; Mertens and Ravn, 2014). Moreover, the event studies show that prices jump at the date of announcement rather than at the time of purchases (Krishnamurthy and Vissing-Jorgensen, 2011; Joyce et al., 2011; Arrata and Nguyen, 2017). However, there still is considerable room for research into the dynamics of expectation formations as Palan (2013) points out.

Furthermore, we let the same group of subjects to repeat the same experiment under the same experimental condition three times to investigate the effect of learning. The experimental literature shows that, in the benchmark treatment without policy interventions, subjects learn to trade the asset at its fundamental value if the experiment is repeated under the same condition three times.⁷

⁴Note that the experiment was framed in a neutral language, i.e., in the instruction, it was stated that “the computer will buy the bond” instead of “the central bank will buy.”

⁵We intend to capture, although in a highly simplified manner, how the Bank of England conducted her QE in our experiment as detailed in The Bank of England’s Asset Purchase Facility (2017) in terms of its magnitude and the method.

⁶The experiment by Haruvy et al. (2014), however, is quite different from ours in terms of its frame (issuing firms re-purchasing or re-issuing its own stock vs QE), its market structure (continuous double auction vs call market), the way interventions take place (hidden operations in the market vs clearly separate auctions), as well as the information subjects receive regarding these interventions (vague information vs clear and explicit information about their magnitude and timing). In addition, while we elicit future price expectations in our experiments and repeat the experiment to investigate the effect of learning, Haruvy et al. (2014) do not.

⁷See Palan (2013), Powell and Shestakova (2016), and Nuzzo and Morone (2017) for recent reviews of the literature.

Although the literature is silent about the effect of learning in experiments with policy interventions, it is possible that whatever the effect of QE we find in our experiment disappears as subjects gain experience. This is plausible in our set-up because QE should not have any effects under rational expectations.

This possibility that QE could become ineffective through learning is not just an interesting academic exercise or robustness check but has important policy implications. For example, one could conjecture that QE worked once when it was a surprise and strategic uncertainty (i.e., uncertainty about behavior of other market participants) was high but will not work repeatedly and thus cannot be a substitute for conventional policy at the effective lower bound in future.

We found that although the announcement of QE had no impact on our (inexperienced) subjects' initial expectations about future prices, it raised the market price of bonds from the first round of the experiment. The average prices peaked in period 7 in the treatment with QE – well after the central bank has stopped buying (before period 5). The termination of QE then reduced the prices to its fundamental value. After experiencing the same experiment twice, those in the benchmark treatment clearly learned that prices should not deviate from its fundamental value. In the two QE treatments, on the contrary, most came to “learn” that prices should rise and then fall back to fundamentals. These subjects came to believe that there was a pattern in the data. We observed clearly that subjects' expectations were anchored by the price paths they have observed. Another interesting feature of the QE results was that traders started to anticipate price increases. In the second round, prices peaked in periods 4 to 6 instead of 7 in the first round, and in the third round they peak in periods 1 to 3.

The paper is organised as follows. Section 2 describes the experiment in more detail, section 3 presents the main results and section 4 concludes.

2 Experiment

We first describe the aspects of the experiment that are common to all the treatments. We then describes each of our three treatments. See Appendix B for an English translation of the instruction.

2.1 Basic experimental set-up: Market structure

We set up an experimental bond market very similar to Bostian and Holt (2009). A market consists of N traders who are put into the situation of large commercial banks which hold a portfolio of riskless bonds and central bank reserves (“cash” from here on).⁸ At the start of the experiment, each trader is endowed with 8 bonds and 800 Experimental Currency Units (ECUs) of cash. Each round of the experiment lasts for $T = 11$ periods. Each bond pays a dividend of 6 ECU per period and matures at the end of period 11 for 120 ECUs. Cash receives a 5% interest rate per period. In this setting, the fundamental value (FV_t) of a unit of bond at the beginning of period t is 120 ECU for all $t = 1, \dots, T$.⁹

In each period the participants have the opportunity (but not the obligation) to trade bonds and cash with each other in a call market as in van Boening et al. (1993), Haruvy et al. (2007), and Akiyama et al. (2014, 2017). In a call market, traders submit order by specifying a price-quantity pair. In period t , for example, if trader i wishes to submit a buy order, he must specify the maximum price at which he is willing to pay for a unit of bond (bid, b_t^i) and how many units of bond he wishes to purchase (d_t^i). If i wishes to submit a sell order in period t , he must specify the minimum price at which he is willing to sell a unit of bond (ask, a_t^i) and how many units of bond he wishes to sell (s_t^i). In each period, each trader can submit both a buy order and a sell order, just one of them, or none. Neither short-selling or borrowing of cash is allowed. Thus, in case i submits a sell order in period t , he must have s_t^i units of bond in his portfolio. Similarly, if i submits a buy order in period t , his cash holding has to be no less than $b_t^i d_t^i$. Finally, in case i submits both buy and sell orders, we require $b_t^i \leq a_t^i$.¹⁰ Once all the traders in the market submit their orders, the orders are aggregated and a market clearing price is computed. Following the existing studies (Haruvy et al., 2007; Akiyama et al., 2014, 2017), when there are multiple market clearing prices, we choose the minimum among them.

⁸Note, however, that we did not frame experiment in such a way. In particular, we did not tell subjects that they are acting as large commercial banks. Instead, we simply told our subjects that they are going to trade hypothetical government bonds using the hypothetical experimental currency.

⁹Consider at the beginning of period T . If a trader buys a unit of bond at price FV_T , then it will be $6+120$ ECU at the end. If the trader kept the same amount cash until the end, then, it will become $1.05FV_T$ after the interest payment. Since these two have to be the same in the equilibrium, we have $1.05FV_T = 126$, i.e., $FV_T = 120$. Now, consider the beginning of period $T - 1$. If a trader buys a unit of bond at FV_{T-1} , its value at the end of the period is $6 + FV_T = 126$. If the same amount of cash is held until the the end of period, it will become $1.05FV_{T-1}$. Since these two have to be equivalent, $1.05FV_{T-1} = 126$, i.e., $FV_{T-1} = 120$. One can apply the same reasoning for all the remaining periods to obtain $FV_t = 120$ for all $t = 1, \dots, T$.

¹⁰There was an additional technical constraint. We only allowed both a_t^i and b_t^i to be an integer value between 1 and 2000. This was purely due to the way experimental software were programmed.

We have employed the call market structure, instead of a continuous double auction, to facilitate the forecasting task performed by participants (to be described in the next subsection). In the call market, because there is only one market clearing price per period, the prices participants need to forecast are defined clearly. Note that the existing experimental results show that call markets and continuous double auctions generate similar price dynamics (Palan, 2013, Obs. 27), although trading volumes can be different.

2.2 Basic experimental set-up: Forecasting

We elicit traders' expectation regarding future prices to better understand how QE, in the form considered in our experiment, influences the expectations and behavior of market participants. By eliciting traders' expectations regarding the current and future periods prices at the beginning of each period, we aim to better understand the link between price expectations and market prices and how and why price expectations evolve over time.

At the beginning of each period, before traders submit their orders, we ask subjects to submit their forecasts of the bond price in the current as well as in all the remaining periods. That is, at the beginning of period t , subject i is submitting his forecasts for bond prices in periods $t, t + 1, \dots, T$. This elicitation methods allow us to observe dynamics of subjects' short-run and long-run forecasts, and have been employed, for example, by Haruvy et al. (2007) and Akiyama et al. (2014, 2017).

Subjects receive a bonus of 0.5% of their final cash holding (after their bonds have matured) for each forecast that contained the realized price plus or minus 10%. Thus, if all the 66 forecasts i submitted during 11 periods satisfy this condition, they receive a bonus payment of 33% of their final cash holding.¹¹

¹¹Akiyama et al. (2014, 2017) introduced this incentive scheme for the forecasting performance to minimize the possibility of subjects trying to improve their forecasting performances by engaging in unprofitable trading strategies just to make the market prices closer to their forecasts. Recently, however, Hanaki et al. (2018b) found that rewarding subjects for their forecasting performance this way can enlarge mis-pricing compared to the experiments where subjects only trade and no forecast is elicited. Although the set-up considered by Hanaki et al. (2018b) is slightly different from ours, it is possible that the similar effects operate in the current experiment. It should be noted, however, because the way subjects are rewarded for their forecasting performances is identical across all the treatments we consider in this paper, it will not influence our analyses based on treatment comparisons.

2.3 Three treatments

We consider three treatments: (T1) Benchmark, (T2) Buy&Hold, and (T3) Buy&Sell. The benchmark treatment is without any outside purchases and is conducted under our basic setting described above. In both the Buy&Hold and Buy&Sell treatments, there is a pre-announced policy intervention that the central bank will try to buy a total of $1/3$ of outstanding bonds from market participants through a discriminatory auction before the beginning of period 4 and 5 (we call this the buy-operation). In Buy&Sell treatment, there is additional pre-announced policy intervention that the central bank will try to sell the same amount of bonds to market participants through a discriminatory auction before the beginning of period 8 and 9 (we call this the sell-operation).¹²

During the buy-operations in T2 and T3, the central bank aims to buy $1/3$ of the stock of outstanding bonds. The central bank tries to buy equal amounts in periods 4 and 5. If it fails to buy the bonds planned in period 4, the residual amount was added to its operation in period 5. If it fails to buy its revised target in period 5, the shortfall is ignored.¹³

During these two buy-operations, each trader can submit a sell order that specifies a price/quantity pair. Once all the orders are submitted, the central bank sorts them based on the specified prices in the ascending order, and buys up to the targeted amount, from the lowest price, each at its specified price.¹⁴

In the Buy&Hold treatment, once the central bank complete its buy-operation, it will hold the bonds its bought until the end of period T. In other words, the central bank permanently removes those bonds from the market. In the Buy&Sell treatment, the central bank will try to sell the same target amount of bonds to the market participant during its sell-operation before the period 8 and 9.

The sell-operation in Buy&Sell treatment is conducted in a similar manner as in the buy-operation. It tries to a half of the targeted amount of bonds in period 8, and whatever amount remains in period 9. If it fails to sell back all the units of bond during these two sell-operation, it will simply keep them until the end of period T. During these sell-operations, each trader can submit a buy order that specifies (price, quantity) pair. Once all the orders are submitted, the

¹²As noted in above, the experiment was framed in a neutral language. Subjects were told that “the computer will buy (or sell) the bond” instead of “the central bank will buy (or sell).”

¹³In practice the central bank almost always bought or sold its planned amount in each period. There were only two cases where the central bank failed to meet the target.

¹⁴In cases with multiple offers at the same marginal offer price, purchases are randomly allocated across those participants.

central bank sorts them based on the specified prices in the descending order, and sells up to the targeted amount, from the highest price, each at its specified price.

In both treatments, these policy interventions are announced before the beginning of the experiment.

2.4 Other aspects of the experiments

In all the three treatments, the same group of subjects repeat the same 11 periods bond market game three times. We call one play of the 11 periods market game a round. We are interested in how subjects learn and adjust their forecasts and trading behavior based on their experience in playing the same game. At the end of the final round of the game, one of the three round is chosen randomly for payment. Subjects are paid based on their final cash holding and the bonus for their forecast performance of this chosen round, in addition to their participation fee of 500 JPY. The exchange rate between ECU and JPY was $1 \text{ ECU} = 1 \text{ JPY}$.

We conducted the whole exercise with two market sizes: $N = 6$ and $N = 12$. This was intended to test whether the result of $N = 6$, which we conducted first, were robust to the degree of competition in each market. Since the results were not statistically significantly different between the two market sizes, however, we combined the two datasets and report pooled results. See Appendix A for the comparisons.

Computerized experiments¹⁵ were conducted at Waseda University and University of Tsukuba between January and July 2017. 438 students from a variety of disciplines who had never participated in similar experiments were recruited.¹⁶ Experiments took around 3 hours including the instruction and the payment. Subjects earned, on average, 4400 JPY ($\approx 39 \text{ USD}$) including the participation fee.

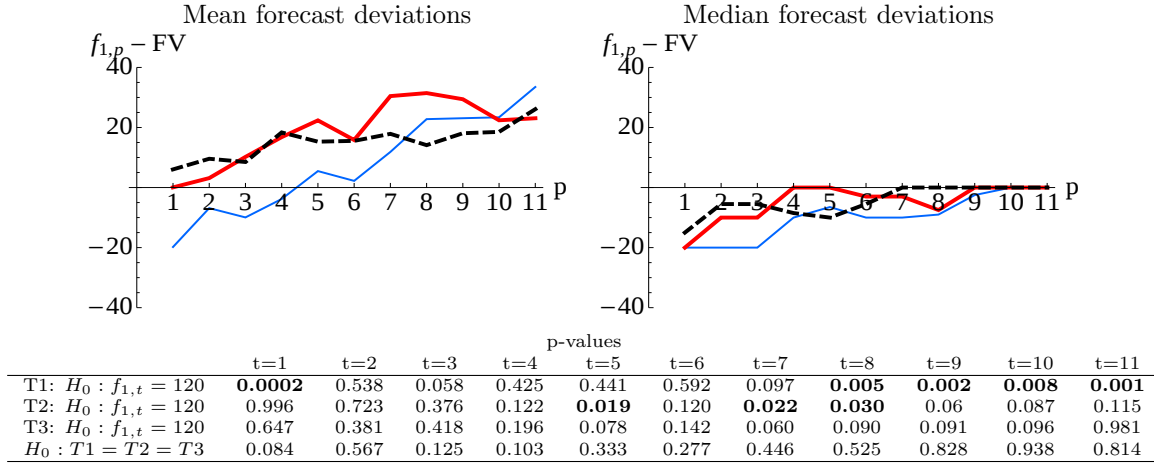


Figure 1: The average (left) and the median (right) initial forecasts deviations from FV for 11 periods in three treatments. T1: Benchmark (thin blue), T2: Buy&Hold (thick red), and T3: Buy&Sell (black dashed)

3 Results

3.1 Initial forecasts

We start by presenting the first thing that all the participants in each treatment do - provide an initial forecast for the market price across the 11 periods of the first round. The deviations of the mean and median paths from FV are presented in Figure 1 (T1: Benchmark (thin blue), T2: Buy&Hold (thick red), and T3: Buy&Sell (black dashed)). Both paths show a tendency to increase, although this is much more evident for the mean than the median. The median paths are very similar across the three treatments and quite close to the FV. Indeed it is interesting to note that the median forecast for the final period (when bonds mature at FV) is exactly FV for the three treatments. The means are all above the median suggesting that there is an upward skew in the initial distribution across the participants. This is particularly the case for the two QE treatments.

The benchmark forecast is mostly below the two QE forecasts, although this difference is generally not statistically significant. Figure 1 shows the p-values for testing whether, for each treatment, the forecast for period p price is different from FV, as well as the forecasts for period p price are different

¹⁵The experiment was computerized using z-Tree (Fischbacher, 2007)

¹⁶We had 8 markets for each of the two market sizes for each of the three treatments (except for the benchmark treatment with $N = 6$, where we have 9 markets). Thus, we have 150 subjects (9 markets with 6 subjects each and 8 markets with 12 subjects each) for the benchmark treatment, and 144 subjects each for the Buy&Hold and the Buy&Sell treatments.

across three treatments. Those periods in which the test rejects the null hypothesis at 5% significance level are shown in bold. These tests are conducted based on running the following OLS regression (for each period) and testing the equality of the estimated coefficients.

$$f_{1,p}^i = \alpha_1 D_{T1}^i + \alpha_2 D_{T2}^i + \alpha_3 D_{T3}^i + \epsilon_p^i \quad (1)$$

where $f_{1,p}^i$ is subject i 's forecast for period p price elicited at the beginning of period 1, D_x^i s are dummy variables that takes value 1 if i has participated in treatment $x \in \{T1, T2, T3\}$. The standard errors are corrected for potential within group clustering effect. We have chosen this test in order to control for possible correlation among subjects within a group.¹⁷

There is not much discernible difference between the initial price forecast paths between T2 and T3. The average expected prices around periods 8 and 9 when the central bank sells in treatment T3 are below T2 but this difference is not statistically significant. It is also worth noting that the mean forecast in the benchmark case is well below those of the two QE treatments, although this difference is not statistically significant. Overall, we do not observe a significant effect of the announced differences in treatment on initial forecasts.

Observation 1 *The announcement of large intervention does not have a strong influence on initial expectations of inexperienced subjects.*

Given the wide variations in the initial set of price forecasts submitted by our subjects, we believe this absence of a significant effect of policy announcement on initial forecasts is due to our subjects not being able to think about the implication of the announced interventions on market prices rather than them thinking that prices will follow the rational expectations equilibrium.

3.2 Price dynamics

We now turn to the core results of the experiment illustrated in Figure 2. The columns are respectively the benchmark treatment, the Buy&Hold treatment and the Buy&Sell treatment. The rows are the first, second and third rounds for each treatment. In each panel, a thin line represents the observations from one market, while the thick line represents their median.¹⁸ We observe substantial

¹⁷Note however that given that this is the first set of forecasts submitted by the subjects without observing the past realized prices, the effect of such correlation should be very limited. Not correcting for clustering effect does not change the result qualitatively.

¹⁸Thin lines are not always connected because periods with the zero transaction are not shown.

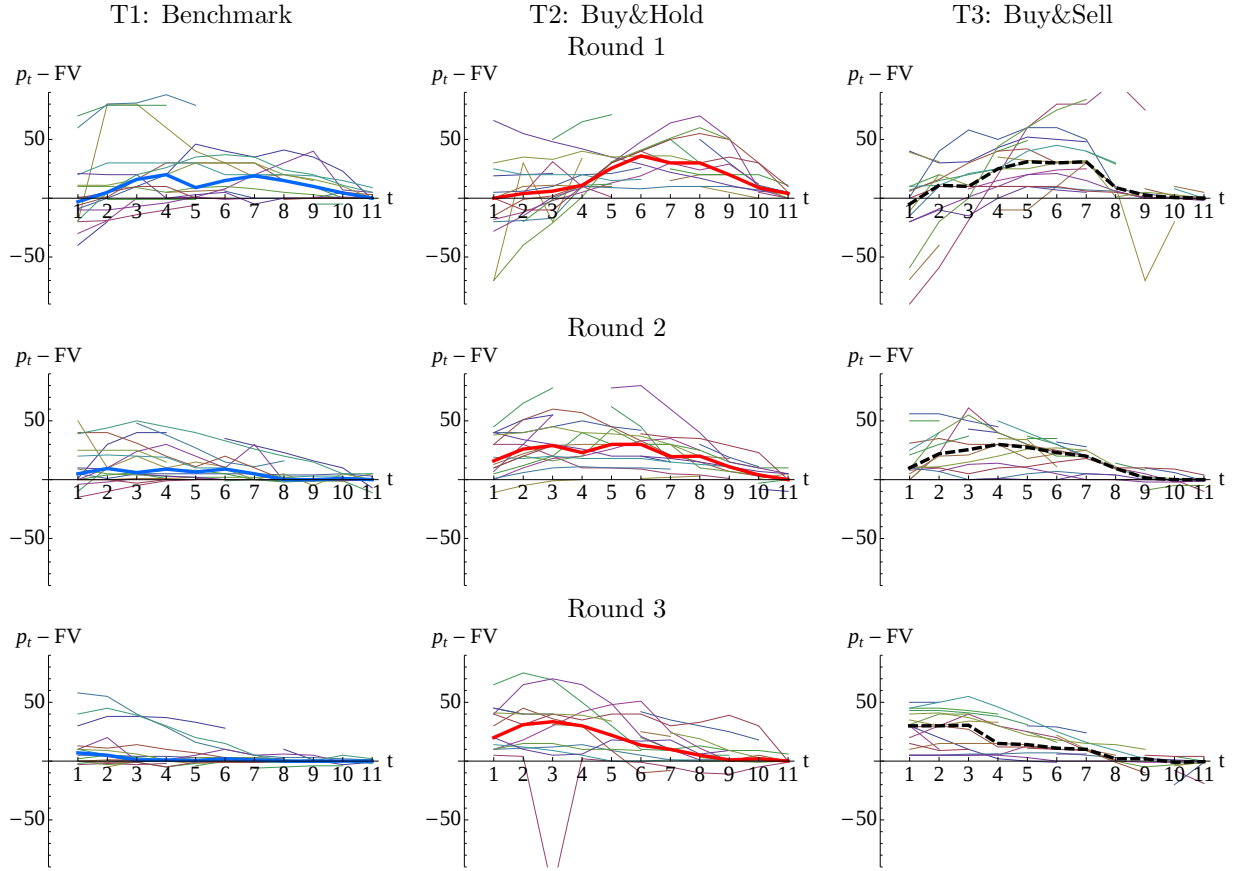


Figure 2: Dynamics of price deviations in T1: Benchmark (left), T2: Buy&Hold (center), and T3: Buy&Sell (right) over three rounds. The median across markets are shown in thick lines.

variations across markets within each treatment.¹⁹

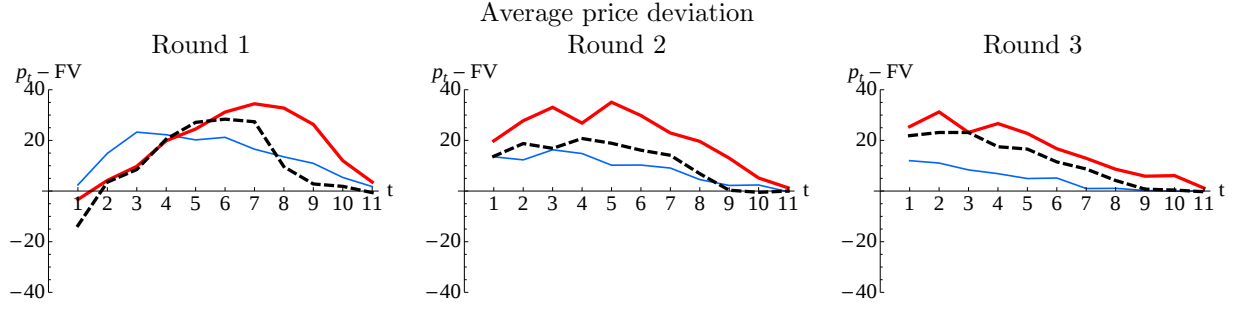
There are a number of interesting results here. The median price path for the Benchmark treatment in the first round is slightly above 120 but many are clustered around the fundamental value. A few markets have wildly high prices at the beginning and a few others rise and then fall. By the second and particularly the third round, the median price is scarcely different from the fundamental price. Fewer and fewer markets show any deviation.

In the Buy&Hold treatment, period 1 prices in round 1 are highly dispersed. But prices generally drift up and between periods 6 and 8 (after the central bank has stopped buying) and prices in every single one of the 16 markets is above the fundamental price. Prices converge back to 120 by period 11. In round 2 of the Buy&Hold treatment, the action moves earlier. Almost all markets start with prices well above 120. And with the notable exception of one market in which they have collectively realised the rational expectations solution, all markets have prices above the fundamental price from periods 2 to 7. Prices begin to gradually converge towards the fundamental price from period 6. By round 3, markets in the Buy&Hold treatment again almost all start above the fundamental price but the median price peaks in period 3. Median prices have converged to fundamentals by period 9.

The Buy&Sell treatment shows quite a similar pattern to the Buy&Hold treatment. Prices in period 1 of round 1 are highly dispersed but again rise so that almost all prices are above the fundamental price in periods 4 to 7. There is, however, a noticeable drop in prices as the central bank starts to sell in periods 8 and 9. The action again moves earlier in round 2 and the median peaks in period 4. By round 3, prices in all markets jump initially and then generally monotonically decrease after period 3.

Figure 3 presents the same price paths using averages and reports a number of simple statistical tests of hypotheses of differences in behaviour. Our three treatments are shown in each panel, T1: Benchmark (thin blue), T2: Buy&Hold (thick red), and T3: Buy&Sell (black dashed). The table below the three panels reports p-values from various tests. Those p-values less than 0.05 are shown in bold. Several observations can be made. In round 1, bonds are overvalued in all treatments, including the benchmark. There is little difference between the three treatments before period 6. In period 7, however, the average prices in two treatments with QE is statistically significantly higher than that in the benchmark. The two QE treatments become noticeably and statistically

¹⁹It is not the case that trades occurs among only a few specific traders in the market, nor the prices are determined by some specific minority of traders in each market. See Subsections A.1.2 and A.1.3 of Appendix for the analyses done separately for two market sizes.



Round 1. P-values											
	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11
T1: $H_0 : p_t = 120^*$	0.748	0.087	0.012	0.006	0.005	0.002	0.001	0.002	0.007	0.008	0.050
T2: $H_0 : p_t = 120^*$	0.726	0.524	0.104	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.018
T3: $H_0 : p_t = 120^*$	0.223	0.549	0.042	<0.001	<0.001	<0.001	<0.001	0.056	0.840	0.731	0.878
$H_0 : T1 = T2 = T3^{**}$	0.826	0.820	0.618	0.509	0.176	0.114	0.029	0.016	0.006	0.008	0.081
$H_0 : T1 = T2^{***}$	0.635	0.326	0.181	0.795	0.591	0.184	0.008	0.006	0.012	0.052	0.263
$H_0 : T1 = T3^{***}$	0.253	0.348	0.319	0.850	0.162	0.137	0.020	0.537	0.466	0.115	0.134
$H_0 : T2 = T3^{***}$	0.543	0.999	0.712	0.534	0.315	0.707	0.967	0.252	0.072	0.001	0.025

Round 2. P-values											
	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11
T1: $H_0 : p_t = 120^*$	0.022	0.006	0.002	0.002	0.007	0.004	0.016	0.049	0.191	0.022	0.804
T2: $H_0 : p_t = 120^*$	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.031	0.426
T3: $H_0 : p_t = 120^*$	0.002	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.215	0.949	0.668
$H_0 : T1 = T2 = T3^{**}$	0.354	0.033	0.090	0.072	0.013	0.028	0.026	0.005	0.001	0.050	0.560
$H_0 : T1 = T2^{***}$	0.376	0.017	0.020	0.068	<0.001	0.001	0.013	0.001	0.001	0.248	0.441
$H_0 : T1 = T3^{***}$	0.509	0.057	0.140	0.049	0.011	0.017	0.093	0.258	0.930	0.120	0.961
$H_0 : T2 = T3^{***}$	0.839	0.570	0.506	0.947	0.075	0.109	0.261	0.002	0.002	0.040	0.374

Round 3. P-values											
	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11
T1: $H_0 : p_t = 120^*$	0.019	0.022	0.037	0.070	0.065	0.035	0.244	0.275	0.706	0.899	0.785
T2: $H_0 : p_t = 120^*$	<0.001	<0.001	0.065	<0.001	<0.001	0.004	0.003	0.028	0.080	0.100	0.089
T3: $H_0 : p_t = 120^*$	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.001	0.035	0.740	0.277	0.267
$H_0 : T1 = T2 = T3^{**}$	0.016	0.004	0.001	0.001	0.002	0.053	0.001	0.059	0.177	0.096	0.044
$H_0 : T1 = T2^{***}$	0.050	0.012	0.192	0.005	0.003	0.036	0.003	0.038	0.088	0.049	0.188
$H_0 : T1 = T3^{***}$	0.016	0.017	0.006	0.023	0.005	0.025	<0.001	0.119	0.817	0.334	0.293
$H_0 : T2 = T3^{***}$	0.763	0.546	0.863	0.398	0.398	0.552	0.568	0.315	0.292	0.035	0.053

* P-values based on t-test (two-tailed).

** P-values based on Kruskal-Wallis test.

*** P-values based on Fisher-Pitman permutation test (two-tailed).

Those p-values < 0.05 are shown in bold.

Figure 3: Dynamics of the average price deviations from the FV over three rounds in T1: Benchmark (thin blue), T2: Buy&Hold (thick red), and T3: Buy&Sell (black dashed). P-values for various hypothesis tests are also reported.

significantly different from the benchmark treatment - evidence of a non-fundamental channel for QE - in rounds 2 and 3. Treatments Buy&Hold and Buy&Sell are statistically indistinguishable until periods 8 and 10. In these periods, prices in the Buy&Sell treatment are statistically significantly lower than the Buy&Hold treatment, strong evidence that the sell-operation had a systematic effect on prices.

Observation 2 *The large scale buy-operation (quantitative easing) raises the bond price significantly. This price effect remains even as subjects repeat the experiment. Experienced subjects (Round 2 and 3), start to anticipate price increases.*

Observation 3 *The sell-operation that follows the buy-operation significantly lowers the bond price only immediately after its completion. It does not lower the prices before the operation takes place.*

3.2.1 Central bank operations

Table 1 report the average prices per unit of bond with which the central bank bought (top panel) and sold (middle panel) during its operation. It also reports the difference between the average transaction prices between two operations (bottom panel). We observe that, on average, the central bank paid a price substantially higher than the FV during its buy operations. In the Buy&Sell treatment, although the central bank also sold at prices significantly higher than FV during its sell operation (except in Round 3), on average, it was not as high as the prices it paid for a unit of bond during the buy operation (except in Round 1). As a result, substantial amount of cash (on average, 20% of FV per unit of bond) has been transferred from the central bank to the market participants through these two operations.

Existing studies (see, e.g., Kirchler et al., 2012; Haruvy et al., 2014; Deck et al., 2014) of similar types of experimental asset markets find that prices can rise when the ratio of cash to assets increases. It is possible that participants in those experiments thought they needed to put “idle cash to work”. The two QE buy operations in our experiments are an exchange of bonds for cash and thus substantially increase this ratio. Some readers might wonder whether the subsequent strength of prices is simply a result of this effect. We test this hypothesis by running the following regression:

$$\Delta \bar{p}^m = b_1 + b_2 \bar{p}_{bo}^m + \mu^m \quad (2)$$

Table 1: Summary of Central Bank Operation

Average transaction price in buy operation : $\overline{p_{bo}}$				
	Mean	SD	Min	Max
T2. Round 1	149.61 ^a	18.93	122.06	191.75
T2. Round 2	162.80 ^a	34.01	125.00	263.13
T2. Round 3	151.53 ^a	21.24	119.94	186.41
T3. Round 1	148.62 ^a	20.37	121.09	180.50
T3. Round 2	154.91 ^a	17.19	124.69	179.75
T3. Round 3	145.66 ^a	16.83	122.19	174.00

Average transaction price in sell operation : $\overline{p_{so}}$				
	Mean	SD	Min	Max
T3. Round 1	140.19 ^a	24.58	116.81	212.81
T3. Round 2	126.96 ^a	5.53	115.75	137.38
T3. Round 3	119.73	11.02	82.69	130.78

Difference between sell and buy operation: $\overline{p_{bo}} - \overline{p_{so}}$				
	Mean	SD	Min	Max
T3. Round 1	8.43	31.67	-78.94	59.69
T3. Round 2	27.94 ^b	14.06	0.00	48.38
T3. Round 3	25.94 ^b	20.38	3.72	77.25

^a statistically significantly different from 120 at 1% level.
(t-test, 2 tailed)

^b statistically significantly different from 0 at 1% level.
(t-test, 2 tailed)

where $\overline{p_{bo}}^m$ is the average transaction price per unit of bond during the buy operation for market m , and $\Delta \overline{p}^m \equiv \overline{p_{5-7}}^m - \overline{p_{1-3}}^m$ is the difference in the average prices for the three periods immediately before and after the buy-operation for market m .

Regression 2 tests whether the difference in prices in the market before and after the central bank buy operation are related to the average price paid by the central bank.²⁰ If the cash/asset ratio was an important driver for the price increase after the buy-operation, these should be a statistically significant positive relationship. Table 2 shows that this is clearly not the case. In rounds 1 and 2, the effect is negligible and in round 3 it is negative rather than positive.

The top panel of Table 3 compares the average prices paid by the central to the average prices

²⁰There were two cases in Round 1 (for the market with 6 traders) where the central bank failed to buy the targeted amount of bond (instead of 16, it bought 14 or 15) for these two instances, the $\overline{p_{bo}}$ is not a precise measure of the change in the cash/asset ratio caused by the buy operation compared to others markets where target is met. We have run the regression (shown in eq. (2)) dropping these two instances, but the result is qualitatively the same. We have also run the regressions separately for Buy&Hold and Buy&Sell treatments. The results are qualitatively the same as the one presented in Table 2 for both treatments.

Table 2: Relationships between the change in average market prices and the buy operation

	Dependent Var: $\Delta \bar{p}$		
	Round 1	Round 2	Round 3
Const	50.50 (43.88)	-0.234 (16.27)	49.39** (21.14)
$\bar{p}_{bo}$	-0.153 (0.292)	-0.003 (0.101)	-0.404*** (0.141)
R^2	0.009	0.000	0.214
N of Obs.	32	32	32

** statistically significant at 5% level

*** statistically significant at 1% level

in the three periods beforehand. In round 1, the central bank pays around 25 ECUs more than the previous average market price in both treatments. This gap narrows until it is negligible in round 3. By contrast, the bottom panel shows that the central bank on average sells at below the price prevailing in the periods beforehand.

Observation 4 *The central bank pays significantly more than the fundamental price for the bonds it buys. Initially, it pays more than the prior market prices but in later rounds, these coincide. When the central bank subsequently sells bonds it makes a substantial loss relative to what it paid. This transfer of cash to the market, however, has no systematic effect on prices.*

3.3 Forecast dynamics

To set the scene, for our discussion of the joint evolution of prices and forecasts, we provide a comprehensive description of the paths of forecasts and prices across the three rounds for one group. Figure 4 shows, for each period of Round 1 (Top panel) and 2 (Middle panel) as well as the first 4 periods of Round 3 (bottom panel), the complete path of individual forecasts (thin lines), their medians (thick lines), and realized prices (dots) for one group of six subjects in the Buy&Hold treatment.²¹ There are many interesting features that we observe in this figure that illustrate results that we demonstrate more formally later in the paper. First of all, the very first forecasts elicited in period 1 of round 1 before the participants have any experience of trading vary widely. But they vary less at the end than they do at the beginning, suggesting that most participants realise

²¹This group was not chosen at random. It is the one that most neatly illustrates behaviour observed in general across the experiment.

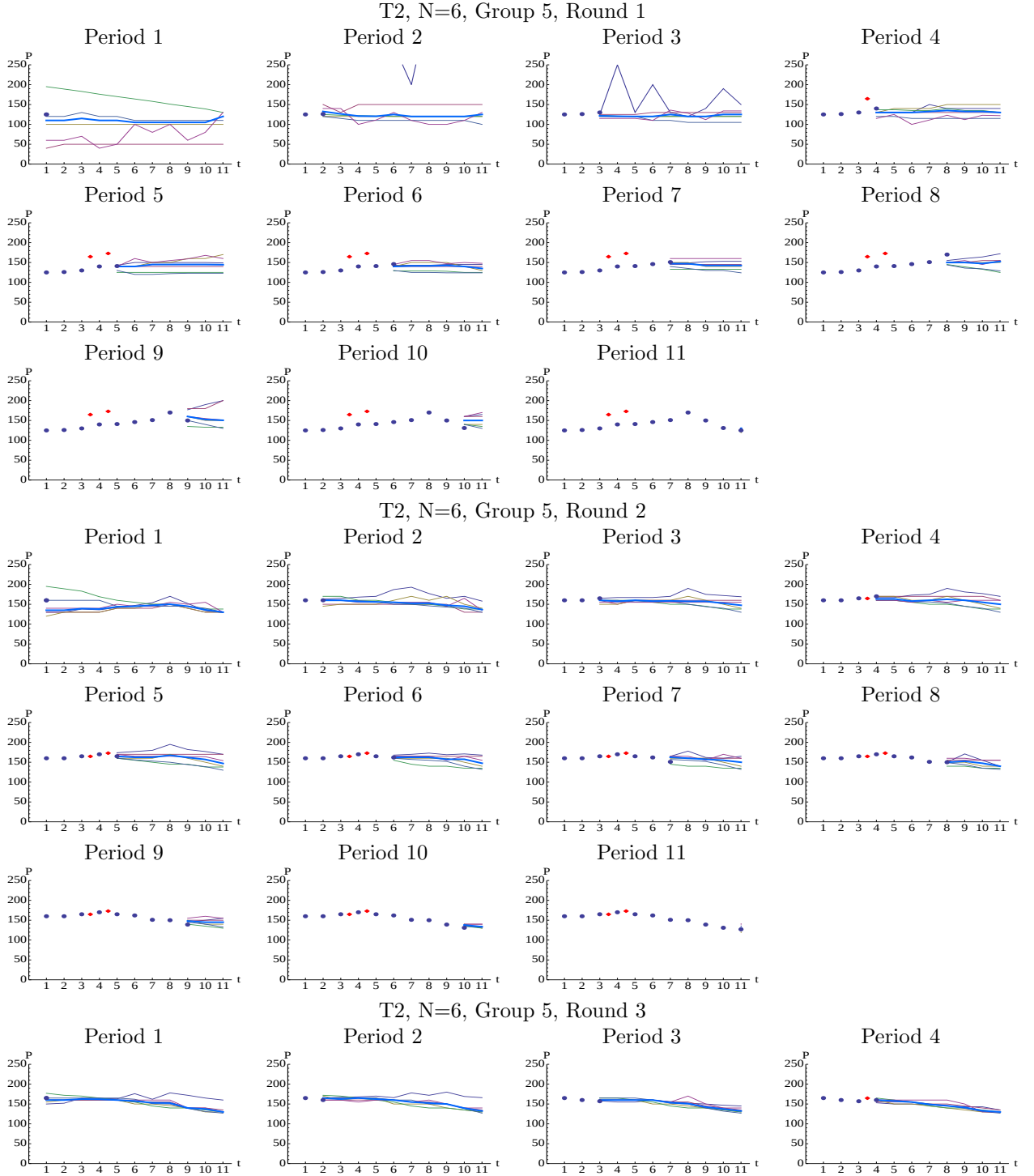


Figure 4: Dynamics of forecasts and price observed in Benchmark treatment with 6 traders/market, Group 1. Top: Round 1. Middle: Round 2. Bottom: the first four periods of Round 3. Thin lines: individual traders. Thick line: Median. Dots realized prices

Table 3: Central bank operation and the market prices

	$\overline{p_{bo}} - \overline{p_{1-3}}$		Min	Max
	Mean	SD		
T2. Round 1	25.13***	25.94	-21.27	77.10
T2. Round 2	15.93	32.86	-21.67	130.79
T2. Round 3	5.84	12.82	-6.76	37.04
T3. Round 1	26.16***	22.14	-5.57	69.88
T3. Round 2	10.89***	11.98	-5.5	32.08
T3. Round 3	-1.13	9.90	-20.35	25.23

	$\overline{p_{so}} - \overline{p_{5-7}}$		Min	Max
	Mean	SD		
T3. Round 1	-13.96**	19.00	-55.85	21.36
T3. Round 2	-13.87**	8.10	-23.83	-0.98
T3. Round 3	-14.13***	14.84	-64.98	-1.90

*** statistically significantly different from 0 at 1% level.
(t-test, two-tailed)

** statistically significantly different from 0 at 5% level.
(t-test, two-tailed)

that prices should converge towards the maturity value by period 11.²² The first realised price, represented by the dot in the first period, is close to the median first period forecast and very close to FV. Forecast paths narrow dramatically in period 2 of round 1 as participants update their beliefs in light of the first period's realised price. The distribution of price forecasts across horizons is now much flatter. What the central bank pays in periods 4 and 5 (illustrated by the red diamond) is well above the previous market prices and above the subsequent market prices in those periods. There is no obvious immediate impact on price forecasts, although the median is gradually rising in line with realised prices. For this group, prices continue to rise until period 8 and then decline. When the participants start again in period 1 of round 2, initial forecasts are again relatively dispersed particularly for early periods but converge towards (slightly above) the maturity price in period 11. Notably, the distribution of forecasts has shifted up. Short-term forecasts again narrow dramatically in period 2, centered on the realised price of period 1 which is well above the fundamental value. What the central bank pays in round 2 is now squarely in line with previous and future prices. Realised market prices in round 2 fall fairly monotonically thereafter but are still slightly above the maturity value in period 11. By the time the participants start again in period 1 of round 3, initial forecasts are virtually indistinguishable. There is a near universal belief that prices will initially

²²One participant has extremely high forecasts initially and is excluded to keep a common scale throughout.

Table 4: Current period prices and median short-term forecasts. Dependent variable P_t .

	Round 1			Round 2			Round 3		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
Median $f_{t,t}$	0.687*** (0.0357)	0.737*** (0.0397)	0.787*** (0.0372)	0.705*** (0.0419)	0.705*** (0.0486)	0.715*** (0.0305)	0.866*** (0.0660)	0.902*** (0.0527)	0.687*** (0.0733)
Period	-1.613*** (0.307)	-1.277*** (0.330)	-1.255*** (0.350)	-0.660*** (0.182)	-1.474*** (0.330)	-1.231*** (0.174)	-0.202 (0.245)	-0.274 (0.310)	-1.478*** (0.391)
Constant	52.53*** (4.906)	44.75*** (5.083)	35.84*** (5.194)	41.12*** (5.914)	50.45*** (7.668)	45.83*** (4.711)	15.71 (9.019)	13.42 (8.410)	49.27*** (11.41)
N	187	176	176	187	176	176	187	176	176

Standard errors in parentheses

** $p < 0.05$, *** $p < 0.01$

jump to the price expected to prevail in periods 4 and 5 (for which there is complete consensus that prices will be equal to what the central bank paid in round 2). Prices then track almost exactly the initial median path which is scarcely updated over the first four rounds. (The remaining periods of round 3 are uninteresting.)

For the further analyses, it is convenient to distinguish short-term and long-term forecasts as have been done by recent studies (Carle et al., 2017; Hanaki et al., 2018a). Short-term forecast is the forecast for the current period price, while long-term forecasts are forecasts for all the future periods not including the current period. In this paper, we focus on the relationship between the short-term forecasts and realized prices, as well as their dynamics, because as found in Carle et al. (2017) and Hanaki et al. (2018a) the relationships between the dynamics of long-term forecasts and realized prices are not very clear.

We have conducted regression analyses in order to investigate more systematically the relationships between the median short-run forecasts among market participants and the realized current period prices, as well as the individual short-run forecasts and the past-realized prices.

Table 4 reports, the results of group random effect regression for the three treatments and three rounds. The dependent variable is the current period price P_t . In Table 4, we show that the median short-term forecasts, Median $f_{t,t}$, is always highly significant and generally increases in importance in later rounds.

Table 5 describes in statistical terms how the participants made their short-term price forecasts $f_{t,t}$ across the three treatment groups. It does so in two steps. In the top panel, the explanatory variables for the price forecasts are a constant, the previous forecast ($f_{t-1,t}$), the lagged price (P_{t-1}), and a time trend. The first three explanatory variables can be thought of as the fundamental, the

Table 5: Short-term forecasts and previous periods prices. Dependent variable: $f_{t,t}$

	Round 1			Round 2			Round 3		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
P_{t-1}	0.950*** (0.0338)	0.826*** (0.103)	0.793*** (0.0419)	0.716*** (0.0776)	0.825*** (0.0774)	0.754*** (0.0539)	0.898*** (0.0392)	0.339*** (0.130)	0.453*** (0.0461)
$f_{t-1,t}$	0.0301 (0.0323)	0.175 (0.110)	0.187*** (0.0400)	0.170*** (0.0613)	0.0533 (0.0421)	0.194*** (0.0308)	0.0124 (0.0111)	0.494*** (0.0674)	0.415*** (0.0600)
Period	-0.611** (0.299)	-0.923** (0.462)	-1.309*** (0.356)	-0.832* (0.486)	-1.042*** (0.277)	-1.018*** (0.260)	-0.330* (0.190)	-0.954** (0.400)	-0.674** (0.304)
Constant	9.112** (3.744)	6.270 (4.520)	12.40*** (3.852)	21.13 (13.00)	23.21*** (8.838)	12.95*** (4.249)	14.34*** (5.128)	29.03** (13.49)	21.74*** (7.342)
N	1350	1296	1296	1350	1296	1296	1350	1296	1296
adj. R^2									

Standard errors corrected for within group correlations in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

	Round 1			Round 2			Round 3		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
P_{t-1}	0.967*** (0.0337)	0.978*** (0.0418)	0.933*** (0.0352)	0.871*** (0.0627)	0.877*** (0.115)	1.037*** (0.0809)	0.494*** (0.117)	0.619*** (0.127)	0.526*** (0.0698)
Period	-0.339 (0.243)	-0.880*** (0.333)	-1.286*** (0.449)	-0.829* (0.442)	-1.148*** (0.264)	-0.715*** (0.156)	-0.0918 (0.150)	-1.192* (0.613)	-0.536** (0.217)
P_t^{R-1}				-0.0126 (0.0266)	-0.00752 (0.0684)	-0.0885*** (0.0343)	0.355*** (0.0869)	0.152*** (0.0284)	0.336*** (0.0729)
Constant	9.699** (3.996)	9.367* (5.168)	19.55*** (4.584)	25.21* (13.25)	24.91*** (8.625)	11.36 (6.953)	19.20*** (6.910)	39.10* (20.37)	21.60*** (5.761)
N	1500	1440	1440	1500	1440	1440	1500	1440	1440
adj. R^2									

Standard errors corrected for within group correlations in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

prior, and the news, respectively. This panel clearly shows that participants almost entirely relied on the lagged price to guide their forecasts during the first round. This is most marked in the case of the benchmark treatment but is also present in the other two cases. The prior ($f_{t-1,t}$) is only statistically significant for the Buy&Sell treatment. By round 3, lagged prices are less important in terms of magnitude and has about the same weight as the prior for the two QE treatments. The value of the fundamental has also increased in importance and significance. (Round 2 is roughly in between.)

The bottom panel repeats the same regressions but replaces the prior ($f_{t-1,t}$) with the market price observed in the same period the round before.²³ By Round 3, the previous round's price is highly statistically significant. The participants are starting to think that prices should follow a pattern - recall the round 3 initial forecasts in Figure 4.

4 Insights and conclusion

This paper has presented experimental evidence that quantitative easing can work even if bonds and central bank cash are perfect substitutes by comparing the data gathered from a controlled laboratory bond market experiment with three treatments: the benchmark treatment without QE and two treatments with QE.

In the benchmark treatment without QE, although there was an upward mis-pricing in the first round of the experiment, as subjects gained experience, they quickly learned to trade the bonds at its fundamental value. This shows that there is nothing inherently biased in our set-up that would cause bond prices to rise.

In the Buy&Hold treatment in which the central bank permanently removes some bonds from the market, prices rise statistically significantly well above the fundamental price as well as prices in the benchmark treatment and stay there, even after the central bank has stopped buying. In most markets, repeated exposure only strengthens the belief that prices should rise. In a minority of cases, though, QE has limited effect. We find that the central bank considerably overpays relative to the fundamental price and the most recent market price in round 1. Rather than compete this effect away (as rational expectations would imply), participants come to expect it. Indeed, by round 3 the price path in the earlier rounds significantly conditioned their price expectations. It was noticeable

²³As might be expected from the results, the previous round's price is highly significant in explaining the prior (not separately reported).

also that the peak price effect occurs earlier in the later rounds as participants start to anticipate higher prices from the beginning.

Price dynamics in the Buy&Sell treatment is remarkably similar to that in the Buy&Hold treatment, particularly over the periods 1 to 7. The main difference occurs thereafter, as prices tend to drop to the fundamental price as the central bank sells. Overall, the central bank makes considerable losses.

What insights do these results offer for the conduct of QE? If we take the results at face value, the first result is a positive one: QE can work even if bonds are completely substitutable with cash. All that is required is that enough traders believe that enough other traders believe that others will bid a higher price. Indeed it is even conceivable that each trader in isolation believes that QE should not work in principle but believes that enough other traders do believe it will work (or believes that others believe that it will work etc) to offer at a higher price. Accepting that shifts in beliefs could be part of the explanation for the effect of QE on bond prices does not affect any aspects of the transmission mechanism from bond yields to economic activity and ultimately inflation. This belief-driven channel also does not exclude the alternative explanations of imperfect substitutability between bonds and cash or the reinforcement of forward guidance.

If QE can work even when bonds and cash are very close substitutes, then this suggests that central banks can buy quite short-term maturity debt. This is consistent with the evolution of QE across several central banks. The Bank of England began its QE programme in March 2009 with a minimum residual maturity of 5 years that was subsequently reduced to 3 years. The European Central Bank began with a minimum residual maturity of 2 years and reduced this to 1 year in December 2016.

A more speculative conclusion one could draw is that central banks need to make QE dominate other potential factors in the minds of traders. For this to occur, QE programmes need to be large and long. Central banks also need to focus their communication on the assets purchased rather than the money created. This might seem trivial but it is notable that the original QE by the Bank of Japan, widely regarded at the time as ineffective, concentrated on the expansion of the money supply and not on the counterpart asset purchases. It might also be important to maintain a large stock of assets yet to be purchased.

It is also likely that the central bank must be prepared to “lose whatever it takes” for it to be fully effective. The belief that prices will rise above fundamentals is directly linked to how much

the central bank is expected to overpay. The average student made a profit from the central bank of over 10% of their initial bond portfolio. And these central bank losses were higher in the case that the central bank bought and then sold. Thus it is crucial that central banks communicate that they are focused solely on the macroeconomic outcomes of the policy rather than the impact on the central bank balance sheet (see Bean, 2009).

QE can have a sustained effect on prices even after it has stopped buying despite the absence of any fundamental channel. In a situation of high strategic uncertainty, participants used the history of market prices as a strong guide for future prices. QE can have lasting effects because they change the frame through which traders view the market. This does, however, suggest that QE can work when it is the dominant market “narrative” but could lose traction in the event of significant other shocks.

Of course, all this analysis comes with a large health warning. This is only a single experiment and it remains to be seen whether the results are replicated in future experiments. Bond traders are also likely to be more strategically sophisticated than undergraduate students exposed to bond trading for the first time. For example, Thoma et al. (2015) reports that professional traders have higher score in Cognitive Reflection Test (CRT, Frederick, 2005) which is positively correlated with the profits subjects make in various asset market experiments (see, among others, Breaban and Noussair, 2015; Corgnet et al., 2015, 2018) than bankers, non-financial professionals, or average students. Furthermore, Breaban and Noussair (2015) and Bosch-Rosa et al. (2018) show a negative correlation between the magnitude of mis-pricing observed in the experimental asset market and the average degree of sophistication (measured, for example, by the average CRT scores) of market participants. So there is some danger in extrapolating the finding of the current experiment to the real world.²⁴ That said, the world is considerably more complex than this environment and so these experiments can still offer lessons provided they approximate the thought processes and strategies of actual professional traders.

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²⁴A similar problem applies in extrapolating from rational expectations models too.

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A Comparisons between two market sizes

In this appendix, we provide the result of comparing outcomes between sessions with 6 traders / market and those with 12 traders / market.

A.1 Market level outcomes

A.1.1 Magnitude of mis-pricing and trading volume

We measure degree of mis-pricing, RAD and RD, volume of trade, TO, and volume weighted RAD and RD, vRAD and vRD.

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

$$RD^m = \frac{1}{T} \sum_{p=1}^T \frac{P_p^m - FV_p}{|\overline{FV}|}, \quad (\text{A.2})$$

$$TO^m = \sum_{p=1}^T \frac{Q_p^m}{S_p^m}, \quad (\text{A.3})$$

where S_p^m is the number of outstanding bond in market m in period p . Note that this is initially 8N (where N is the number of traders in the market), but change during 11 periods as a result of central bank operations.

We consider vRAD and vRD here as well because in a few cases with 6 traders/market, there are large price deviations from FV (price equal to 1) without any transactions. In market with 12 traders, such outcomes are not observed. vRAD and vRD are defined as

$$vRAD^m = \frac{1}{T} \sum_{p=1}^T \frac{Q_p^m |P_p^m - FV_p|}{S_p^m |\overline{FV}|} \quad (\text{A.4})$$

$$vRD^m = \frac{1}{T} \sum_{p=1}^T \frac{Q_p^m (P_p^m - FV_p)}{S_p^m |\overline{FV}|} \quad (\text{A.5})$$

A.1.2 Degree of concentration of transactions

We compute the share of the number of market transactions over 11 periods for each trader in each market. Because we are interested in whether transactions are concentrated among a few traders in

the market, we compute, for each market, normalized Herfindahl index. We use normalized index to be able to compare between markets with two different sizes.

Namely, we compute for each subject i in market m , his share of transactions s_m^i as

$$s_m^i = \frac{\sum_{t=1}^{11} |q_t^i|}{\sum_{j \in m} \sum_{t=1}^{11} |q_t^j|} \quad (\text{A.6})$$

where $|q_t^i|$ is the quantity subject i has transacted in period t and $j \in m$ represents subject j in market m . Then, the normalized Hefindahl index for the share of transaction in market m is

$$HIST_m = \frac{\sum_{i \in m} s_m^i}{1 - 1/N} \quad (\text{A.7})$$

where N is number of traders in m .

A.1.3 Degree of concentration of being a price setter

We also compute the relative frequencies with which a trader has been the marginal price setter over 11 periods. Because we are interested in whether market prices are determined by a few traders in the market or not, we computer, for each market, normalized Herfindal index, just as we do for concentration of the share of market transactions, for the share of frequencies of being the marginal price setter. We call it $HIFPS_m$ for market m .

We identify the marginal price setter to be the buyer who has submitted the buy or sell order with a bid or an ask equal to the market clearing price. In case there is no transaction, given the way our price determination algorithm, it is the buyer who has submitted the buy order with a bid just below the market price.

Table A.1 reports, for each round and each treatment, means and the standard deviations of RAD, RD, TO, vRAD, vRD, HIST, and HIFPS, separately for 6 traders/market experiment and 12 traders/market experiment. The p-values from two-sample permutation test (two-tailed) are also reported.

For the benchmark treatment, we do not observe any statistically significant difference for the five measures we consider between 6 traders and 12 traders sessions in any of the three rounds. For the Buy&Hold treatment, only vRAD in Round 1 is significantly different (at 10% level). Finally, in Buy&Sell treatment, we observe RAD in Round 1 and 2 (at 10% level), and RD in Round 2 (at

Table A.1: Comparison between 6 traders/market sessions and 12 traders/market sessions

Benchmark Round 1				Benchmark Round 2				Benchmark Round 3			
6 traders	12 traders	p-value		6 traders	12 traders	p-value		6 traders	12 traders	p-value	
RAD	0.161 (0.148)	0.110 (0.062)	0.384	0.074 (0.084)	0.087 (0.078)	0.753		0.061 (0.069)	0.040 (0.048)	0.483	
RD	0.117 (0.160)	0.098 (0.060)	0.764	0.060 (0.092)	0.085 (0.078)	0.541		0.024 (0.089)	0.036 (0.051)	0.737	
TO	0.569 (0.188)	0.770 (0.324)	0.150	0.688 (0.369)	0.766 (0.371)	0.660		0.613 (0.265)	0.661 (0.182)	0.665	
vRAD	0.009 (0.009)	0.008 (0.005)	0.740	0.005 (0.006)	0.007 (0.007)	0.514		0.003 (0.006)	0.004 (0.006)	0.926	
vRD	0.006 (0.009)	0.006 (0.004)	0.887	0.004 (0.007)	0.007 (0.007)	0.402		0.003 (0.006)	0.003 (0.006)	0.877	
HIST	0.049 (0.026)	0.032 (0.022)	0.175	0.083 (0.071)	0.043 (0.032)	0.195		0.089 (0.067)	0.049 (0.032)	0.145	
HIFPS	0.091 (0.061)	0.042 (0.017)	0.038	0.073 (0.044)	0.070 (0.028)	0.871		0.082 (0.032)	0.057 (0.016)	0.058	

Buy&Hold Round 1				Buy&Hold Round 2				Buy&Hold Round 3			
6 traders	12 traders	p-value		6 traders	12 traders	p-value		6 traders	12 traders	p-value	
RAD	0.154 (0.077)	0.203 (0.065)	0.186	0.185 (0.100)	0.188 (0.088)	0.944		0.169 (0.076)	0.136 (0.095)	0.438	
RD	0.126 (0.094)	0.152 (0.081)	0.550	0.155 (0.100)	0.188 (0.088)	0.494		0.134 (0.123)	0.131 (0.096)	0.960	
TO	0.737 (0.276)	0.763 (0.183)	0.831	0.726 (0.230)	0.721 (0.189)	0.969		0.707 (0.402)	0.701 (0.217)	0.977	
vRAD	0.009 (0.004)	0.014 (0.006)	0.092	0.011 (0.006)	0.012 (0.007)	0.641		0.011 (0.006)	0.009 (0.007)	0.548	
vRD	0.007 (0.005)	0.009 (0.008)	0.398	0.011 (0.006)	0.012 (0.007)	0.610		0.008 (0.010)	0.008 (0.007)	0.927	
HIST	0.092 (0.045)	0.034 (0.018)	0.003	0.068 (0.049)	0.045 (0.026)	0.261		0.055 (0.047)	0.040 (0.030)	0.516	
HIFPS	0.141 (0.104)	0.063 (0.035)	0.062	0.110 (0.049)	0.054 (0.014)	0.001		0.066 (0.032)	0.059 (0.028)	0.640	

Buy&Sell Round 1				Buy&Sell Round 2				Buy&Sell Round 3			
6 traders	12 traders	p-value		6 traders	12 traders	p-value		6 traders	12 traders	p-value	
RAD	0.232 (0.105)	0.132 (0.097)	0.063	0.172 (0.057)	0.104 (0.074)	0.061		0.159 (0.103)	0.103 (0.073)	0.237	
RD	0.149 (0.106)	0.093 (0.081)	0.244	0.168 (0.060)	0.097 (0.069)	0.048		0.106 (0.063)	0.096 (0.073)	0.782	
TO	0.694 (0.445)	0.590 (0.073)	0.508	0.605 (0.367)	0.665 (0.135)	0.709		0.586 (0.280)	0.608 (0.162)	0.849	
vRAD	0.018 (0.019)	0.007 (0.005)	0.108	0.010 (0.007)	0.007 (0.006)	0.375		0.007 (0.003)	0.007 (0.006)	0.847	
vRD	0.014 (0.017)	0.005 (0.004)	0.185	0.010 (0.007)	0.007 (0.006)	0.378		0.007 (0.003)	0.007 (0.006)	0.855	
HIST	0.050 (0.018)	0.034 (0.007)	0.035	0.069 (0.022)	0.043 (0.016)	0.014		0.075 (0.040)	0.043 (0.020)	0.061	
HIFPS	0.107 (0.039)	0.079 (0.050)	0.228	0.097 (0.082)	0.057 (0.018)	0.175		0.094 (0.067)	0.052 (0.020)	0.108	

Means (standard deviations) as well as p-values from two-sample permutation tests are reported.

5% level) are significantly different, but once we take volume of transactions into account (vRAD) they are no longer statistically significantly different.

The normalized Herfindal indices for share of trades as well as frequencies of being a price setter are both low suggesting that trades are not concentrated among a few traders, nor it is the case that prices are driven by a few specific traders. Between two market sizes, the degree of concentration is higher, in some cases statistically significantly so, for the smaller market which is not too surprising.

A.2 Forecasts deviations

We measure the deviation of price forecasts from FV by the two measures proposed by Akiyama et al. (2014, 2017), the relative absolute forecast deviations (RAFD) and the relative forecast deviation (RFD). For the set of forecasts submitted by subject i in the beginning of period t , $RAFD_t^i$ and RFD_t^i are defined as:

$$RAFD_t^i = \frac{1}{11 - t + 1} \sum_{p=t}^T \frac{|f_{t,p}^i - 120|}{120} \quad (\text{A.8})$$

$$RFD_t^i = \frac{1}{11 - t + 1} \sum_{p=t}^T \frac{f_{t,p}^i - 120}{120} \quad (\text{A.9})$$

where $f_{t,p}^i$ is the forecast of asset price in period p submitted by subject i in the beginning of period t . We compare the average $RAFD_t$ and RFD_t between 6 traders and 12 traders sessions for each round in each treatment.

Figure A.1, A.2, and A.3 show the dynamics of average $RAFD_t$ and RFD_t for 6 traders session (solid) and 12 traders session (dashed) in Benchmark, Buy&Hold, and Buy&Sell treatment, respectively. It also shows the p-values of the market size effect. Note that we are simply taking average across subjects for the plot, but for the statistical test, we correct for within group correlation. Namely, these p-values are obtained by running linear regressions that correct for clustering effect (at group level) of the form $Y = \alpha + \beta D_{12}$ where Y is either $RAFD$ or RFD and D_{12} takes value of 1 for 12 traders session and zero for 6 traders session, and testing whether β is significantly different from zero.

$RAFD_t$ and RFD_t are not statistically significantly different (at 10% level) between two market sizes in none of the periods in the Benchmark treatment. Similarly, for the Buy&Hold treatment, except for the $RAFD_t$ of Period 10 of Round 1, they are not statistically significantly different at

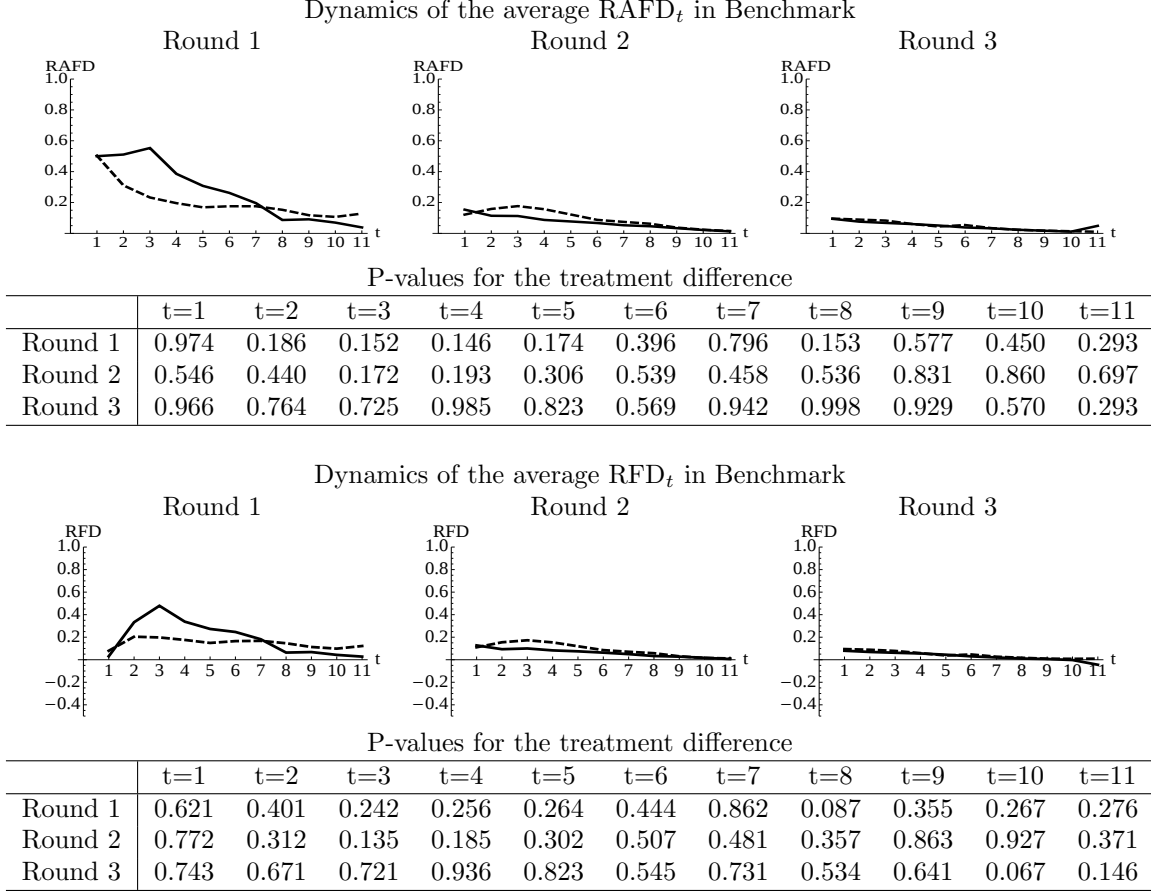


Figure A.1: Dynamics of the average $RAFD_t$ (top) and the average RFD_t (bottom) over 10 periods in 3 rounds of Benchmark treatment for 6 traders sessions (solid) and 12 traders sessions (dashed).

10% level between two market sizes. For Buy&Sell treatments, there are more periods where $RAFD_t$ and RFD_t are statistically significantly different at 10% level between the two market sizes, but for most of the periods, they are not.

A.3 Outcomes of Buy&Sell operations

We compare the average price paid for a unit of bond by the CB in their buy operations, and average price received by the CB for a unit of bond in their sell operation between two market sizes.

Table A.2 shows the result. The average prices for a unit of bond paid by CB in her buy operation tend to be higher in smaller markets although they are not statistically significantly different between the two market size except for Round 2 in Buy&Sell treatment, according to the two-sample permutation test (two-tailed). The same is true for the average prices for a unit of bond

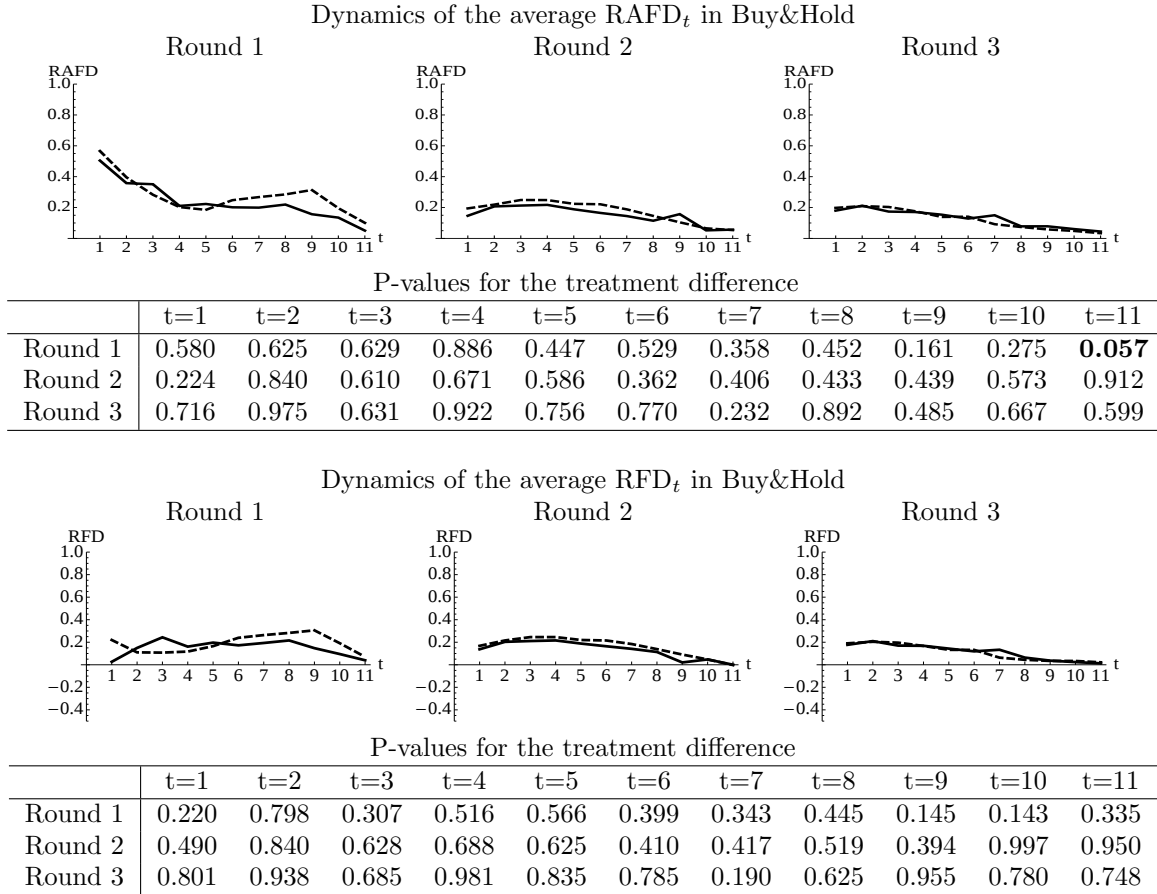


Figure A.2: Dynamics of the average $RAFD_t$ (top) and the average RFD_t (bottom) over 10 periods in 3 rounds of Buy&Hold treatment for 6 traders sessions (solid) and 12 traders sessions (dashed).

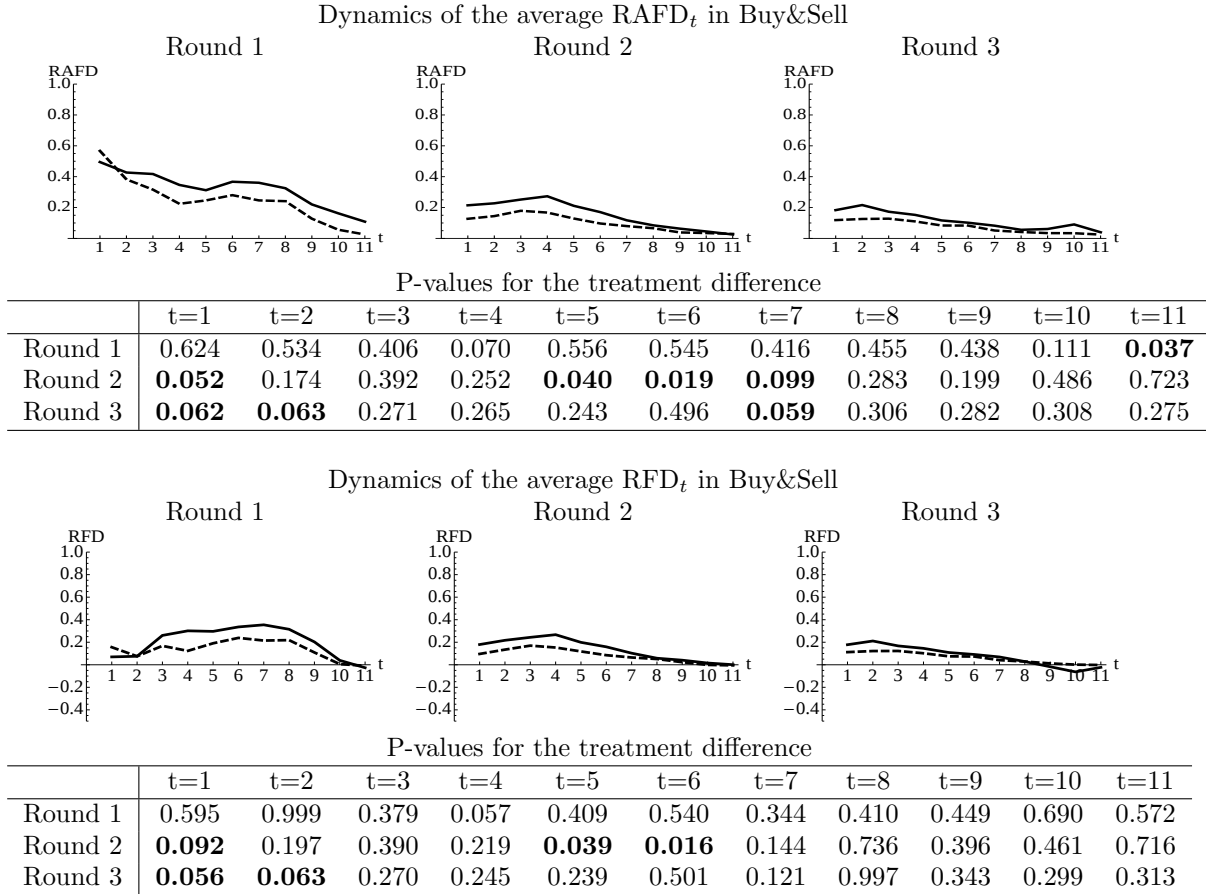


Figure A.3: Dynamics of the average $RAFD_t$ (top) and the average RFD_t (bottom) over 10 periods in 3 rounds of Buy&Sell treatment for 6 traders sessions (solid) and 12 traders sessions (dashed).

Table A.2: Average price per unit of bond paid by CB and received by CB

	Buy&Hold			Buy&Sell		
	Average price paid for a unit of bond			Average price paid for a unit of bond		
	6 traders	12 traders	p-values	6 traders	12 traders	p-values
Round 1	151.3 (24.70)	147.9 (12.29)	0.731	155.7 (20.95)	141.5 (18.32)	0.165
Round 2	170.0 (45.79)	155.4 (16.28)	0.464	164.3 (12.00)	145.6 (17.02)	0.026
Round 3	153.3 (24.20)	149.8 (19.34)	0.748	150.8 (14.07)	140.5 (18.67)	0.232
Average price received for a unit of bond						
	6 traders	12 traders	p-values			
Round 1				142.2 (31.48)	138.1 (17.15)	0.796
Round 2				129.4 (6.72)	124.6 (2.70)	0.084
Round 3				116.3 (14.66)	123.2 (4.24)	0.215

received by CB in her sell operation. They are not statistically significantly different between the two market sizes except in Round 2.

B English translation of the instruction

The instructions for the three treatments begin with information common to all three treatments. The common part of the instructions is for the baseline treatment. After a practice round, the instructions for each treatment are presented as follows. For the buy and hold treatment, an explanation of the buying operation is added after the common information. For the buy and sell treatment, an explanation of the selling operation is added after the instructions for the buy and hold treatment. Below is the instruction for market with six traders. For those with 12 traders, numbers are replaced accordingly.

The handout of the instruction below is distributed to the participants, and the instruction is explained by the movie with the sound that a computer reads out the sentences. Both the movie and sentences to be read out are identical to the instruction below.

Instructions for Today's Experiment

Let's start today's experiment. The experiment is explained in the handout in front of you.

Please turn to the next page.

We first explain the instructions for today's game. There is a practice period for the game so that you may familiarize yourself with the computer interface before the real experiment. The experiment consists of three games, each of which has 11 periods. After completing the games, we will ask you to respond to a questionnaire and take some quizzes. Your earnings will be paid in cash at the conclusion of the experiment.

Your earnings will consist of a participation fee of 500 yen, and an amount that depends on the results of the games. The questionnaire and quizzes will not impact your earnings. The three games are independent of each other, so that the result of one game does not affect the other games. You will have a short bathroom break before the game begins.

[Today's experiment]

You will participate in a bond trading game in which you trade national bonds in an artificial market. Please listen to the instructions carefully. If you do not understand any part of an instruction, ask for clarification by raising your hand. Moreover, if you have any questions during the experiment, raise your hand and an instructor will come to you and answer your question privately.

Throughout the experiment, please respect the following rules.

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

Please turn to the next page.

[Outline of bond trading game]

You will be divided into several groups. You will not know the identities of the members of each group. Each group will consist of six subjects. You will play the bond trading game with the other five people in the group to which you belong.

[Objectives of the game]

Your objective in this game is to make as much profit as you can. There are two ways of making a profit:

- First, you can realize a profit margin through buying and selling bonds, from dividends on your bond holdings, and from interest on your cash holdings.
- Second, you can make a profit by accurately predicting the future prices of the bonds.

We use Marks as the currency for the experiment. At the end of the experiment, your profit will be converted into Yen (1 Mark = 1 Yen) and paid out to you.

Please turn to the next page.

[Earning a profit margin]

You will be given eight bonds and 800 Marks at the beginning of the game. To earn a profit margin by trading, you need to buy bonds at a low price and sell them at a higher price. For example, suppose that you buy a bond for 100 Marks, and that the price of the bond then increases to 120 Marks. If you sell the bond, you earn $120 \text{ (selling price)} - 100 \text{ (purchase price)} = \underline{20 \text{ Marks profit}}$. In contrast, suppose that you buy a bond for 100 Marks, and that the price of the bond then decreases to 80 Marks. If you sell the bond, you will make $80 \text{ (selling price)} - 100 \text{ (purchase price)} = \underline{20 \text{ Marks loss}}$. We explain later how the prices are determined.

We now explain how to use the program interface.

[Order entry screen]

The following screen is used to enter your orders for each period.

残り時間 [秒] 39

現在の所持金 800 現在の保有国債口数 8

最高購入希望価格 1 買い注文口数 1

最低売却希望価格 売り注文口数

OK

売り・買い注文の価格と注文口数を入力してください。売り注文をしないときは売り注文口数に「0(ゼロ)」を入力してください。(買い注文も同様)

国債取引ゲーム
第 1 / 11 期
履歴: 第1期～第11期の取引価格

Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11

- ① This shows the time remaining for entering your orders. The time limit for entering your orders is 60 seconds. When the time has elapsed, a red warning message will flash in the top-right corner of your screen. A period ends once everyone has pressed “OK”; note that this could be within the 60-second time limit.
- ② This indicates your cash balance or the amount of money at your disposal; you may buy bonds up to this amount.
- ③ This shows the number of bonds you have. You may sell a maximum of this number of bonds.
- ④ This is where you enter the maximum price you are willing to pay to buy a bond in this period. You must enter a whole number between 1 and 2000.
- ⑤ This is where you enter the maximum number of bonds that you want to buy in this period. If you do not want to purchase any bonds, enter 0. The product of ④ and ⑤ must be no greater than your cash balance shown in ②. An error message will appear if (the number of bonds you wish to buy) $\times$ (the maximum price you are prepared to pay for these) exceeds your cash balance.

In practice, the price you actually pay for a bond may not be the same as the maximum price you are willing to pay. This is because the market price depends on all the orders placed by the market participants. If the market price is greater than the maximum you are willing to pay, then your order will not be processed. This will be further clarified at a later stage.

Please turn to the next page.

- ⑥ This is where you enter the minimum price at which you are willing to sell your bonds in this period. You must enter a whole number between 1 and 2000. The price you enter here should

not be greater than that given in ④.

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

In practice, the price at which you sell a bond may not be the same as the minimum price at which you are willing to sell. This is because the market price depends on all the orders placed by the market participants. If the market price is lower than your minimum price, then your order will not be processed. This will be further clarified at a later stage.

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

The most important points for buying and selling bonds are summarized below.

- You can simultaneously place buy and sell orders, or you can place only a buy order or only a sell order. It is also possible to not submit any order.
- If you do not want to submit a buy order, please enter 0 as the quantity to buy. If you do not want to submit a sell order, please enter 0 as the quantity to sell.
- The screen displays an error message if any of the following conditions are violated.
 1. The maximum quantity to sell must be less than or equal to the number of units you hold.
 2. The maximum purchase price multiplied by the quantity to buy must be less than or equal to the cash you have available.
 3. If you simultaneously place buy and sell orders, the maximum purchase price must be less than or equal to the minimum selling price.

Please turn to the next page.

[End of each period screen]

① Market prices

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

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

[Example 1: how the market price is determined]

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

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

A graph summarizing these orders is shown below.



A seller is willing to sell at the price requested or higher. A buyer is willing to buy at the price specified or lower. As shown above, there is only one bond supplied at 10 Marks. If the price rises to 40 Marks, the number of bonds supplied increases to three. However, only one bond is demanded at 60 Marks. If the price falls to 20 Marks, the quantity demanded increases to two. Therefore, the quantity demanded is equal to the quantity supplied at prices between 21 Marks and 39 Marks. The market price is set at the minimum price in this interval; that is, 21 Marks.

Next we consider the second example.

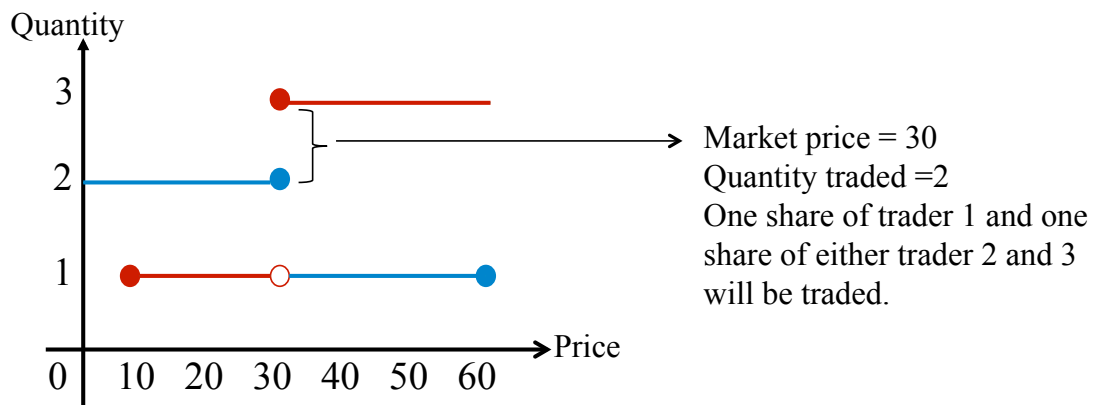
Please turn to the next page.

[Example 2: how the market price is determined]

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

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

A graph summarizing these orders is shown below.



As shown above, only one bond is supplied at 10 Marks as in the previous example. If the price rises to 30 Marks, the number of bonds that are supplied increases to three. However, there is only one bond demanded at 60 Marks. If the price falls to 30 Marks, the quantity demanded increases to two. As a result, two transactions can be completed at 30 Marks. In this case, the market price is set at 30 Marks. The orders that are fulfilled are determined as follows.

Priority is given to Trader 1, because he/she requested a price less than the market price. In addition to the order of Trader 1, the order of either Trader 2 or Trader 3 is fulfilled. The choice between Trader 2 and Trader 3 is determined randomly by a computer.

[End of each period screen]

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

残り時間 [秒]: 14

⑨

取引価格	100
①	
今期(Period)購入した国債の口数	0
	②
今期(Period)得た利子の金額	40
④ 今期得た配当の金額	48
③	
⑤ 現在の所持金	888
現在の保有している国債の口数	8
	⑥
当たっていた予測(予測誤差の範囲内)に取引価格があった総数	1
	⑦

⑧

CONTINUE

The details in the green sentences will be explained later.

- ① This shows the market price as explained previously.
 - ② A positive value indicates the number of bonds you purchased in the current period, while a negative value indicates the number of bonds you sold in the current period.
 - ③ This shows the interest payments for the current period.
 - ④ This shows the dividend payments for the current period.
 - ⑤ This shows your cash holdings after the transactions, the interest payments and the dividend payments have been processed for the current period.
 - ⑥ This is the number of bonds you currently hold.
 - ⑦ This is the number of market prices that you have predicted correctly.
 - ⑧ By clicking the “Continue” button, you move to the next period.
 - ⑨ The remaining time (maximum of 20 seconds) that this screen will be visible is displayed here.
- After observing the information on the screen, press the “Continue” button ⑧. Once all of the participants have pressed this button, the computer will display the next screen.

Please turn to the next page.

[Earning interest from cash holdings]

In each game, there are 11 periods in which you can submit buy/sell orders and trade with other traders in your market. You will be paid interest of 5% on the amount of cash you hold at the end of each period.

The interest earned is rounded up to a whole number. For instance, suppose that at the end of the 5th period your cash holdings are 90 Marks and you have two bonds. You are paid interest of 5% on the cash holdings of 90 Marks. The interest of 4.5 Marks is rounded to 5 Marks, so your cash holdings are 95 Marks after adding the interest.

Likewise, dividends from bonds are added to your cash holdings when you hold bonds. This is explained below.

[Earning dividends from bonds]

You will be paid a dividend of 6 Marks per bond for the bonds you hold at the end of each period. The dividend income at the end of each period is calculated as: 6 Marks × (number of bonds you hold).

In the example above, 12 Marks (= 6 Marks * 2 bonds) is added to your cash holdings of 95 Marks after adding the interests. Thus you start the 6th period with 107 Marks and two bonds.

If you hold bonds at the end of the game (after the 11th period), the bonds you hold are bought for 120 Marks each after any dividend payments.

Please turn to the next page.

[Earning a profit by predicting future prices correctly]

Before each period begins, you will be asked to predict the market prices in the remaining periods. The following screen will appear.

The time limit for predicting the market prices is (number of periods remaining) x (20 seconds). Before the beginning of the first period, the time limit is 220 seconds. After that, the time limit decreases by 20 seconds each period. The time limit before the 11th period is 20 seconds.

When the time limit is reached, a warning message to complete your prediction will flash in red in the upper right corner of your screen. The next period begins when everyone has finished entering their price predictions and has pressed “OK”.

Game	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11
1											

[Prediction of future prices]

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

That is:

- before the beginning of period 1, there are 11 periods remaining so you must predict 11 prices;
- before the beginning of period 2, there are 10 periods remaining so you must predict 10 prices;

. . .

- before the beginning of period 11, only one period remains so you must predict one price.

Thus, you will make a total of 66 predictions of market prices.

Please turn to the next page.

[Earning a profit by predicting future prices]

The computer keeps a record of the number of accurate predictions (that is, when the market price realized is between 90% and 110% of your predicted price for the corresponding period).

At the end of each game, you will be paid a bonus based on the number of accurate predictions according to the following formula: (your final cash balance) $\times$ 0.5% $\times$ (the number of accurate predictions). The maximum bonus percentage is $0.5\% \times 66 = 33\%$. Please be aware that your final cash balance depends on earnings made from profit margins, interest and dividends, so the size of your bonus decreases as your earnings from profit margins, interest and dividends decrease.

[Summary of ways to make a profit]

There are two ways of making a profit: (1) earning a profit margin, earning returns from dividends and earning interest on cash holdings, and (2) predicting market prices of bonds.

The computer randomly chooses one of three games. At the end of the experiment, your final cash holdings from the game will be converted at a rate of 1 Mark to 1 Yen and paid out to you. In addition to the aforementioned rewards, you will be offered 500 yen as payment for participating in the experiment.

After the instructions, we will announce the practice round.

[Practice]

We start with a practice round so that you can familiarize yourself with the software. In particular, you will learn how to enter the required information. The first screen displayed is for predicting future prices. Press the “OK” button after you have entered all your price forecasts. The computer will display the order entry screen once everyone has pressed “OK”.

The practice round ends when everyone has entered their orders and pressed the “OK” button. The results of the practice round will not be displayed. Rewards do NOT take the practice round into consideration.

Let us start the practice round.

[Finish the practice round]

Before starting the game, we will announce the following:

Let's start the game.

- There are six people in the market.
- All the people in the market are in this room.
- You will be given eight bonds and 800 Marks at the beginning of the game.

(The instructions for the baseline treatment finish here.)

[Instructions for buying operation]

During this game, the computer will buy bonds you hold. The buying operation will be conducted before the beginning of the 4th and 5th periods. During these two operations, you will be asked to submit a sell order. The computer will buy bonds in ascending order of the prices submitted by the market participants.

The target quantity for the first buying operation is eight bonds, and a total of 16 bonds are to be bought in the two operations. If fewer than eight bonds are purchased in the first buying operation, then the shortfall will be added to the second buying operation at the beginning of the 5th period. For instance, suppose that the computer purchases only six bonds in the first buying operation, which is two units short of the target. Then the target quantity for purchasing in the second buying operation is 10 bonds.

Even if fewer than 16 bonds are purchased during the two buying operations, there is no additional buying operation.

For the buying operations, the following screen is displayed.

If you want to sell the bonds you hold, you need to enter a selling price and the maximum number of bonds to sell in ① and ②, respectively. Otherwise, please leave ① blank, and enter 0 in ②.

The screenshot shows a software interface for an experiment. At the top right, a red box displays '残り時間 [秒]: 55'. The main area contains a table with the following information:

現在の所持金	現在の保有国債口数	売却希望価格	売り注文口数
800	8		

Below the table, the input fields for '売却希望価格' and '売り注文口数' are labeled with red circled numbers ① and ② respectively. An 'OK' button is located at the bottom right of the main area. At the bottom of the window, there is a small text box with the following Japanese text:

実験者(コンピュータ)による国債の買い取り
国債を売りたい人は、「売却希望価格」と「売り注文数」を入力して下さい。売り注文をしないときは売り注文口数に「0(ゼロ)」を入力して下さい。

Please turn to the next page.

[How the computer purchases bonds during the buying operation]

The sales prices submitted by the market participants are ordered from lowest to highest. The computer will purchase bonds in ascending order of the specified price until the target quantity is reached. If there are orders with identical selling prices, and meeting all of them will exceed the target quantity, then the computer will randomly choose which orders to meet (some orders may be partially met).

After the buying operations, neither interest nor dividends will be offered for cash and bond holdings.

(The instructions for the buying operation finish here.)

[Instructions for selling operation]

In this game, the computer will also sell the bonds it purchases during the two buying operations. The selling operations will be conducted before the beginning of the 8th and 9th periods. You will be asked to submit a buy order prior to these selling operations. The computer will sell the bonds in descending order of the prices submitted by the market participants.

The target quantity for the first selling operation is eight bonds, and a total of 16 bonds are to be sold in the two operations. If fewer than eight bonds are sold in the first selling operation, then the unsold bonds are added to the second selling operation before the beginning of the 9th period. For instance, suppose that the computer sells only five bonds in the first selling operation, so that there are three unsold bonds. Then there are 11 bonds available for the second selling operation.

Even if fewer than 16 bonds are sold during the two selling operations, there is no additional selling operation.

Please turn to the next page.

[How to buy the bonds]

During the selling operations, the following screen is displayed.

When you want to buy the bonds, you need to enter a buying price and the maximum number of bonds that you want to buy in ① and ②, respectively. Otherwise, please leave ① blank, and enter 0 in ②.

残り時間 [秒]: 51

現在の所持金	現在の保有国債口数	購入希望価格	買い注文口数
800	8		

① ②

OK

実験者(コンピュータ)による国債の売却
国債を買いいたい人は、「購入希望価格」と「買い注文口数」を入力して下さい。買い注文しないときは買い注文口数に「0(ゼロ)」を入力して下さい。

[How the computer sells the bonds]

The buying prices submitted by the market participants are ordered from highest to lowest.

The computer will sell the bonds in descending order of the specified prices until the target quantity is reached. If there are orders with identical buying prices, and meeting all of them will exceed the target quantity, then the computer randomly chooses which orders to meet (some orders may be partially met).

After the selling operations, neither interest nor dividends will be offered for cash and bond holdings.

(The instructions for the buying & selling operations finish here.)

Additional Information for readers:

After the round with the first buying operation, the following screen is displayed. The left part of the screen shows the following.

- ① How many bonds the computer has bought during the buying operation.
- ② Explanation of the information displayed in the center of the screen.
- ③ How many bonds you sold to the computer, and the payment received (Marks) from the trade.
- ④ The number of bonds and the amount of cash (Marks) you hold after the buying operation.

The center of the screen shows the prices, in ascending order, at which the bonds were bought by the computer. After the second buying operation, the list of prices appears on the right of the screen while the center disappears.

実験者が買い取った国債の総数 8 ① 実験者が買い取った国債の価格: ※ 安値から右のパネルに表示されます ※ 正の数値の部分が買い取った価格です ※ 「-1」が表示されている部分は取引に無関係です ② あなたが今回 ..売った国債の口数は 2 口です ③ ..得た現金の総額は 400 です 現在保有している国債の口数 6 ④ 現在の所持金 1477 OK		<table> <tr><td>国債 1</td><td>100</td></tr> <tr><td>国債 2</td><td>200</td></tr> <tr><td>国債 3</td><td>200</td></tr> <tr><td>国債 4</td><td>300</td></tr> <tr><td>国債 5</td><td>300</td></tr> <tr><td>国債 6</td><td>300</td></tr> <tr><td>国債 7</td><td>400</td></tr> <tr><td>国債 8</td><td>400</td></tr> </table>	国債 1	100	国債 2	200	国債 3	200	国債 4	300	国債 5	300	国債 6	300	国債 7	400	国債 8	400
国債 1	100																	
国債 2	200																	
国債 3	200																	
国債 4	300																	
国債 5	300																	
国債 6	300																	
国債 7	400																	
国債 8	400																	

The screen displayed after the selling operations is similar.

		残り時間 [秒] 16																
実験者が売却した国債の総数 8 ⑤ 実験者が売却した国債の価格: ※ 高値から右のパネルに表示されます ※ 正の数値の部分が実験者の売却価格です ⑥ ※ 「-1」が表示されている部分は取引に無関係です あなたが今回 ..購入した国債の口数は 1 口です ⑦ ..支払った現金の総額は 300 です 現在保有している国債の口数 5 ⑧ 現在の所持金 2076 OK		<table> <tr><td>国債 1</td><td>500</td></tr> <tr><td>国債 2</td><td>500</td></tr> <tr><td>国債 3</td><td>500</td></tr> <tr><td>国債 4</td><td>500</td></tr> <tr><td>国債 5</td><td>400</td></tr> <tr><td>国債 6</td><td>400</td></tr> <tr><td>国債 7</td><td>400</td></tr> <tr><td>国債 8</td><td>300</td></tr> </table>	国債 1	500	国債 2	500	国債 3	500	国債 4	500	国債 5	400	国債 6	400	国債 7	400	国債 8	300
国債 1	500																	
国債 2	500																	
国債 3	500																	
国債 4	500																	
国債 5	400																	
国債 6	400																	
国債 7	400																	
国債 8	300																	

The left part of the screen shows the following.

- ⑤ How many bonds the computer sold during the selling operation.
- ⑥ Explanation of the information displayed in the center of the screen.

- ⑦ How many bonds you bought from the computer, and the amount paid (Marks) for the trade.
- ⑧ The number of bonds and the amount of cash (Marks) you hold after the selling operation.

The center of the screen shows the prices, in descending order, at which the bonds were sold by the computer. After the second selling operation, the list of prices appears on the right of the screen while the center disappears.

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