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A QUANTITATIVE EASING EXPERIMENT

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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 substitutes for cash and have a constant fundamental value which is not affected by QE in the rational expectations equilibrium. We find that QE raises bond prices above those in the benchmark treatment without QE. Subjects in the benchmark treatment learned to trade the bonds at their fundamental value but those in treatments with QE became more convinced after repeated exposure to the same treatment that QE boosts bond prices. This suggests the possibility of a behavioural channel for the observed effects of actual QE operations on bond yields.

Keywords: Quantitative easing, experimental asset market, expectation dynamics

JEL Code: C90, D84

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1 Introduction

Quantitative easing (QE) has been the biggest monetary policy experiment in modern times. Since 2008, seven major central banks have implemented large scale asset purchase programmes, buying on average assets equivalent to 15% of nominal GDP.[1] They have bought a wide range of assets, including corporate and covered bonds, and asset-backed securities but the core interventions have been in government bond markets. In this most basic form, QE is the purchase of government bonds in exchange for central bank reserves with the intention to retain them for a significant length of time. 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 long-living agents, such a transaction can have no temporary or permanent effects on any macroeconomic variables in 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 being 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 lower 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.

[1] See the report by the Committee on the Global Financial System (2019). These programmes have been extended in many countries in response to the crisis following the outbreak of covid-19.

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

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 is, the more "successful" the instrument is. The central bank is thus an unusual participant in the bond market because it is not 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 no ability to buy enough of the market to become a monopoly seller, such an effect should not exist.

But what if some of these assumptions do not hold, for example, when people's behaviors are better characterized by a level-k type thinking (Nagel, 1995; Camerer et al., 2004)? In such framework, if $k = 0$ players have an instinctive response that the presence of a large external buyer should raise the price, then this will influence the views of $k = 1$ players which together affect the expectations of $k = 2$ players and so on. As long as it is believed that there are enough low k players who believe prices will rise, even a very sophisticated player might be induced to make an offer above the fundamental price. This structure is similar to the guessing game of Ledoux made famous by Nagel (1995).[3] Level-k models can account for many non-equilibrium behaviors observed in the laboratory experiments, including, various types of auctions (see, among others, Crawford and Iriberri, 2007; Crawford et al., 2013),[4] Bertrand price competition (Dufwenberg and Gneezy, 2000; Baye and Morgan, 2004), and the travelers' dilemma game (Capra et al., 1999).[5] Recently, researchers have started to incorporate level-k thinking in analyses of monetary policies. Lovino and Sergeyev (2018) construct a model of level-k thinking applied to QE, and Farhi and Werning (2019) use it, together with incomplete credit market, in explaining the "forward guidance puzzle." We therefore anticipate that many participants will have an instinctive response that the presence of a

[3] See, Buhren et al. (2012) for historical details.

[4] It is well known in the experimental literature on single unit demand auctions that subjects tend to overbid compared with the risk-neutral theoretical predictions in both private and common value auctions of various formats. See, among others, Kagel (1995) and Kagel and Levin (2017) for surveys. The literature suggests several explanations for such observed deviations, including nonstandard preferences, such as 'spite' and the 'joy of winning' (see, for example Cooper and Fang, 2008) or inconsistent beliefs, such as the cursed equilibrium (Eyster and Rabin, 2005) or level-k reasoning (Crawford and Iriberri, 2007). We also note that there are experimental studies pointing out that the level-k model, which relies on the best reply on the wrongly specified belief, cannot account for observed behavior in a private value auction (Kirchkamp and Reiβ, 2011) or in a common value auction (Ivanov et al., 2010).

[5] We thank an anonymous referee for pointing this out.

large external buyer should raise the price.

The main purposes of the experiment presented in this paper are (a) to investigate whether interventions indeed raise the price of bonds, and (b) to investigate whether the observed effect of the interventions disappears with repeated exposure to the same treatment.

The environment which we consider is very simple, and is set out in more detail in Section 2. The experiment is designed to remove as many extraneous sources of uncertainty (such as stochastic dividend payments) and confusion (such as an inability to understand a declining fundamental value) as possible. At the start of the experiment, participants are given bonds and cash, which are essentially identical ways of transferring this endowment to the end of the experiment in the rational expectations equilibrium (REE). The REE – or fundamental – price is constant throughout the experiment. In the Benchmark treatment, participants can trade the bonds for cash among themselves over 11 periods. There is no reason to trade one asset for the other at this fundamental price and the volume of trade should be indeterminate.

In our first QE treatment (called Buy&Hold treatment), the central bank will buy a third of the bonds available in the market before periods four and five, using a discriminatory price auction. This will be described as a QE operation. The central bank holds these bonds until the end of the experiment. However, as this operation changes neither the value of the bonds at maturity nor the equilibrium cash flows, the auctions are competitive and nobody can become a monopoly seller, the market price for bonds in the REE does not change.

In our second QE treatment (called Buy&Sell treatment), the central bank again buys a third of the bonds available in the market before periods four and five, but sells them back again in a reverse discriminatory auction before periods eight and nine. Thus, the participants are back where they started and again there is no change in the fundamental price.

Despite its simplicity, we find statistically significant evidence of mispricing in the Benchmark treatment and in the two QE treatments when participants are first exposed to the experiment. And the degree of mispricing is higher in the two QE treatments in the periods after the first intervention takes place.[6] The participants then repeat the same treatment to which they were originally exposed twice more. By the third round, as shown in the literature following Smith et al. (1988), participants in the Benchmark treatment have clearly realized that prices should not deviate from the fundamental price and the median price is essentially flat across the 11 periods

[6] We also found this in our first set of experiment reported online supplementary appendix I.

of trading at this level (Palan, 2013, Obs.1).[7] By contrast, we find that prices remain statistically significantly above the fundamental price in both the QE treatments. However, there is relatively little to distinguish between the two QE treatment effects except for the last few periods following the reverse intervention.

Throughout the experiment, we collect forecasts of future market prices from the current period onwards from each participant. Thus, we have a rich data set on the beliefs of the participants. We report a very tight link between median forecasts and market prices and between past prices and current forecasts. Forecast dispersion across participants in each group that trades together shrinks very rapidly and although the participants do not know this (others' price forecasts are not revealed to participants), these common priors condition the evolution of future prices.

An interesting feature of both QE treatments is that participants begin to anticipate higher prices from the start, particularly by the third round. Thus, it is not an inability to think forward that prevents the equilibrium price from emerging. Instead, everyone comes to expect that the bonds will be priced high in the auctions.

Our experiment is most similar in motivation to Haruvy et al. (2014). That paper considered share buybacks and share issues in a setup in which the fundamental price of an individual share should be independent of the quantity of outstanding shares. Thus, in REE, the market price should not be affected by these treatment operations. Nevertheless, the authors found that share prices rise after a buyback and fall after an issuance of shares, as we do in our experiment. Haruvy et al. (2014) proposes two possible reasons for this result: (i) the downward sloping nature of the demand schedule for the bonds, and (ii) the change in the traders' beliefs about the intrinsic value of shares owing to the change in the quantity of shares. In our experiment, the market demand schedule is downward sloping by construction, thus the first reason certainly applies. For the traders' beliefs, although we cannot analyze their beliefs about "intrinsic value" of bonds, we do show that the higher the average price paid during the buy operation in Round 1, the higher the period 1 price expectation in Round 2. Thus, the interventions do affect participants expectations about market prices. The latter analysis was made possible through our multiple rounds experiment with forecast elicitation.[8]

[7]See, Palan (2013), Powell and Shestakova (2016), and Nuzzo and Morone (2017) for recent surveys of the literature. The mispricing can reappear, however, when the common experience is broken by a change in the market environment (Hussam et al., 2008) or by inflows of new and inexperienced traders (Dufwenberg et al., 2005; Akiyama et al., 2014; Kirchler et al., 2015).

[8]We thank an anonymous reviewer for pointing this out.

Furthermore, we depart from the approach of Haruvy et al. (2014) in several other ways. Our bonds, unlike their shares, have no intrinsic uncertainty in their payoffs so risk aversion plays no role in determining prices. In addition, we consider a setup in which the fundamental price of the bond should be constant and equal to its maturity value, so there is no risk in our experiment that participants are confused by the idea of an asset that should fall in value, as noted by Kirchler et al. (2012) and Stöckl et al. (2015). Furthermore, in our experiment, market transactions are organized according to a call market, instead of a continuous double auction and, importantly, market interventions take place outside of the usual trading periods, according to an auction rule, with subjects being clearly informed about the exact manner in which interventions will take place. Our experiment setting also focuses on the direct effect of the asset purchases on prices and price forecasts and their interrelationship. The similar effects of interventions observed both in Haruvy et al. (2014) and in our study, despite of all these differences in the experimental setups, suggest that the initial effects (i.e., before the repetition) of interventions are robust to these differences.

The remainder of the paper is organized 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 treatments. Then, we describe each of our three treatments. See online supplementary material (OSM) VI for an English translation of the instructions.

2.1 Basic experimental setup: Market structure

We set up an experimental bond market very similar to Bostian and Holt (2009). A market consists of N traders who hold a portfolio of riskless bonds and cash on deposit. At the start of the experiment, each trader is endowed with eight bonds and 800 ECU 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 on deposit receives a 5% interest rate per period. In this setting, the fundamental value (FV_t) of bond at the beginning of period t is 120 ECU for all $t = 1, ..., T$ in REE.[9]

[9] Consider the beginning of period T. If a trader buys a unit of bond at price P_T, then he or she or she will receive 6+120 ECU at the end of period T. If the trader kept the same amount cash until the end, then it will become

In each period, the participants have the opportunity (but are not obliged) 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 an order by specifying a price–quantity pair. In period t, for example, if trader i wishes to submit a buy order, i must specify the maximum price at which i is willing to buy a unit of bond (bid, b_t^i) and how many units of bonds trader i wishes to purchase (d_t^i). If trader i wishes to submit a sell order in period t, i must specify the minimum price at which i is willing to sell a unit of bond (ask, a_t^i) and how many units of bonds i 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 no order. Neither short-selling nor borrowing of cash is allowed. Thus, in the case where i submits a sell order in period t, i must have at least s_t^i units of bonds in his or her portfolio. Similarly, if i submits a buy order in period t, his or her cash holding has to be no less than $b_t^i d_t^i$. Finally, in the case where i submits both buy and sell orders, we require that $b_t^i \leq a_t^i$.[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.

We have employed a call market structure instead of a continuous double auction to facilitate the forecasting task performed by participants (which will be described in the next subsection). In the call market, because there is only one market-clearing price per period, the prices that participants need to forecast are clearly defined. In any case, 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 setup: Forecasting

By eliciting traders' expectations regarding the current and future period 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

$1.05P_T$ after the interest payment. As 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 P_{T-1}, he or she will have $6 + FV_T = 126$ in fundamental terms at the end of the period. If the same amount of cash is held until the end of period, it will become $1.05P_{T-1}$. As these two have to be equivalent, $1.05FV_{T-1} = 126$, i.e., $FV_{T-1} = 120$. One can do the same thing for all the remaining periods to obtain $FV_t = 120$ for all $t = 1, \ldots, T$.

[10] There was an additional technical constraint in that we only allowed a_t^i and b_t^i to take integer values between 1 and 2,000. This was purely due to the way the experimental software was programmed.

their forecasts of the bond price in the current period as well as in all the remaining periods. That is, at the beginning of period t, subject i submits his or her forecasts for bond prices in periods t, $t+1$, ..., T. This elicitation method allows us to observe the dynamics of subjects' short-run and long-run forecasts, and it has 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 66 forecasts i submitted during 11 periods satisfy this condition, they receive a bonus payment of 33% of their final cash holding.[11]

2.3 Three treatments

We consider three treatments: (T1) Benchmark, (T2) Buy&Hold, and (T3) Buy&Sell. The Benchmark treatment has no central bank intervention and is conducted under the basic setting described above. In both the Buy&Hold and Buy&Sell treatments, participants are told before the experiment begins that the central bank will try to buy a third of the outstanding bonds (by volume) through a discriminatory auction before the beginning of periods 4 and 5 (we call this the buy operation). In the Buy&Sell treatment, it is pre-announced that, before the beginning of periods 8 and 9, the central bank will sell the bonds it has to the market (we call this the sell operation), again using a discriminatory auction.[12]

Many of these features were chosen to mimic the way QE has been implemented. As mentioned in the Introduction, central banks have bought very significant shares of the outstanding volume of bonds. The ECB has set a purchase limit of 1/3 of the outstanding stock of any specific bond and purchases in some jurisdictions have approached this limit. Central banks have also announced their intentions to purchase bonds well before they actually started buying. These announcements have tended to have more effect on bond prices than the actual purchases. To see whether this effect

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

[12]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)."

would be replicated in the lab, we had three periods of market trading before the central bank began purchasing. We also spread the purchases and sales (where applicable) over two periods to have an interim market price. One difference with the way QE was actually implement is that our central bank commits to buy a quantity of bonds rather than a target value of bonds but we do not think this difference is important.

Part of the motivation for choosing a discriminatory auction for the market intervention is the way that the Bank of England implemented its asset purchase scheme.[13]

During the buy operations in T2 and T3, the central bank attempts to buy half of the stock of bonds planned (i.e., a sixth of the outstanding bonds) in both periods 4 and 5. If it fails to buy the bonds planned in period 4, the residual amount is added to its operation in period 5. If it fails to buy its revised target in period 5, the shortfall is ignored.[14]

During each of 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 the submitted offers in ascending order and buys up to the targeted amount, paying the specified price in each case.[15]

In the Buy&Hold treatment, once the central bank completes its buy operation, it will hold the bonds it 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 sells the bonds it has to the market participants during its sell operation before periods 8 and 9.

The sell operation before periods 8 and 9 in the Buy&Sell treatment is conducted in a similar manner to the buy operation. The central bank attempts to sell back half of the targeted amount in period 8 and whatever amount remains in period 9. If it fails to sell back all the units of bonds during these two sell operations, it will simply keep them until the end of period T. During these sell operations, each trader can submit a buy order that specifies a price-quantity pair and the central bank sorts the bids in descending order, and sells up to the targeted amount, in each case receiving the specified price.

Since a primary motivation for our experiment is to see whether QE can work through an entirely

[13]See The Bank of England's Asset Purchase Facility (2017) for an explanation of how the Bank of England conducted QE. It should be noted that not all governments use discriminatory auctions in auctioning off their securities, with many using uniform price auctions. As summarized by Marszalec (2017), the literature, both theoretical and empirical, is inconclusive regarding which method of the two commonly used auction formats is superior in terms of the revenue-raising ability.

[14]Except for two cases to be reported in footnote 21, the central bank always bought or sold its planned amount in each period.

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

behavioural channel, it is important that there is no REE in which the central bank purchases could actually affect the price. Under our set-up there is not. As already mentioned, the central bank's purchases do not in any way affect the maturity value of the bonds, their interim coupon payments or the rate of return on holding deposits. Any bonds not sold to the central bank have a fundamental value of 120 ECU as noted in footnote 9. The only possible cause of price increase is that if traders could expect to make a profit from selling to the central bank. Two elements prevent this. At the fundamental price and given the interest rate, the maximum number of bonds any one participant can accumulate by the end of period 4 is 16. But the central bank will only buy 16 of the 48 bonds in circulation. Thus, it is not possible at the fundamental price for any participant to be certain of selling to the central bank. The possibility of profit thus depends on the behaviour of other traders. The second element is that the auctions are competitive and so any price above the fundamental price cannot be a REE. Even if several participants were to corner the market, each would have an incentive to offer at ϵ less than the price of the other sellers until any alternative equilibrium price would unravel.[16] Furthermore, we can rule out the existence of mixed strategy equilibria *a la* Kaplan and Wettstein (2000) because there is an upper limit for the order price one can submit in our experiment.

2.4 Other aspects of the experiments

In all three cases, the same group of participants repeats the treatment that they were originally assigned three times. We call each sequence of 11 periods a round. We are interested in how subjects learn and adjust their forecasts and trading behavior based on their experience in playing the same treatment. At the end of the final round of the game, one of the three rounds 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 ECU = 1 JPY.

Computerized experiments (with z-Tree, Fischbacher, 2007) were conducted at Waseda University and the University of Tsukuba between January and July 2017. We conducted the whole exercise with two market sizes, $N = 6$ and $N = 12$. This was intended to test whether our earlier results

[16] In our experiment, because prices must be an integer, in addition to everyone bidding FV, there is another equilibrium in which everyone bids 1 ECU above the fundamental value. This is because when everyone bids FV+1, each can expect to obtain 1/3 of ECU per bond, while bidding FV will result in zero profit. Thus, there is no incentive to unilaterally deviate and bid lower. This issue of multiple equilibria due to an integer constraint is also known in p-beauty contest games (López, 2001).

Table 1: Summary of experimental sessions

Treatment	Number of Participants	Number of Markets	Number of Sessions (Participants / sessions)
Baseline $N = 6$	54	9	3 (24, 18, 12)
Baseline $N = 12$	96	8	4 (all 24)
Buy&Hold $N = 6$	48	8	2 (all 24)
Buy&Hold $N = 12$	96	8	4 (all 24)
Buy&Sell $N = 6$	48	8	2 (all 24)
Buy&Sell $N = 12$	96	8	4 (all 24)

based on $N = 6$ (Penalver et al., 2017) were robust to the degree of competition in each market. Because the results were not statistically significantly different between two market sizes, as reported in OSM IV, we combined the two datasets and report pooled results. A total of 438 students were recruited from a variety of disciplines and none had ever participated in similar experiments before. Table 1 provides a summary of the experimental sessions and the number of participants in each treatment. The experiment lasted about 3 hours including the instruction and payment, and subjects earned, on average, 4,350 JPY ($\approx$ 34 EUR during the period when experiments were conducted) including the participation fee.

3 Results

3.1 Price dynamics

Figure 1 illustrates the dynamics of the median observed price in our experiments for the three rounds.[17] The Benchmark is shown in thin blue, the Buy&Hold is in thick red, and the Buy&Sell is in dashed black. The median price path for the Benchmark treatment is slightly above 120 throughout the first round. But in the second and particularly the third rounds, the median price is scarcely different from the fundamental price.

In the Buy&Hold treatment, the median price drifts up from period 4 on (after the first intervention) and it stays high until period 8. The median price starts to decline from period 9 on and as in the Benchmark treatment, it converges back to 120 by period 11. In Round 2 of the Buy&Hold treatment, the action occurs earlier. The median price starts above 120 in period 1, and stays high again until period 8. The median price begins to decline towards the fundamental price in period

[17] The dynamics of observed prices in each market are shown in the OSM II.

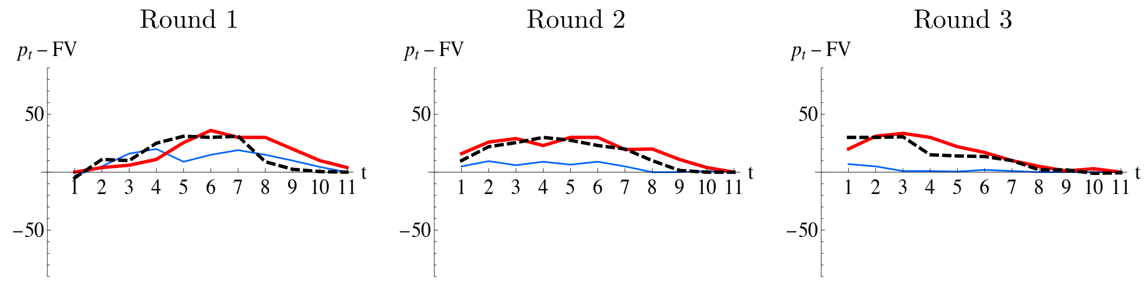


Figure 1: Dynamics of median price deviations from the fundamental value in T1: Benchmark (thin blue), T2: Buy&Hold (thick red), and T3: Buy&Sell (dashed black) over three rounds.

9. By Round 3, in the Buy&Hold treatment, the median price again starts above the fundamental price but it peaks in period 3. The median price converges to the FV by period 9.

The Buy&Sell treatment shows a very similar pattern to the Buy&Hold treatment in Round 1 except for a noticeable drop in the median price for the Buy&Sell treatment when the central bank starts to sell in period 8. The action again begins earlier in Round 2 and the median peaks in period 4. By Round 3, the median price is high initially and then declines after period 3.

3.2 Mispricing

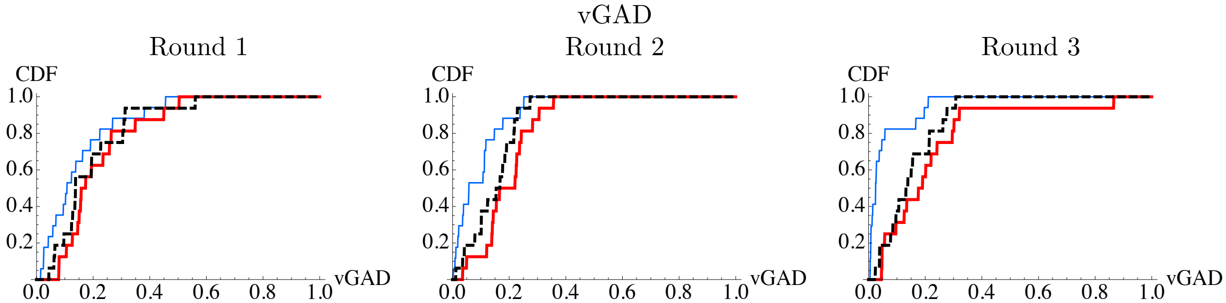
Now, we formally compare the magnitude of mispricing observed in the three treatments over three rounds. Following Powell (2016), we measure the degree of mispricing using the volume-adjusted geometric absolute deviation (vGAD) and the volume-adjusted geometric deviation (vGD).[18] vGAD^m and vGD^m for market m are defined as follows:

$$\text{vGAD}^m \equiv \exp\left(\frac{1}{\sum_{k=1}^{T} v_k^m}\sum_{p=1}^{T} v_p^m \left|\ln\left(\frac{P_p^m}{FV_p}\right)\right|\right) - 1 \quad (1)$$

$$\text{vGD}^m \equiv \exp\left(\frac{1}{\sum_{k=1}^{T} v_k^m}\sum_{p=1}^{T} v_p^m \ln\left(\frac{P_p^m}{FV_p}\right)\right) - 1 \quad (2)$$

where v_t^m and P_t^m are the volume and the realized price observed in period t of market m. $FV_t = 120$ for all t in our experiment, so if $P_t^m = FV_t$ for all t and all m, then vGAD^m =vGD^m $= 0$ for all m. Whereas vGAD measures the absolute magnitude of mispricing, vGD takes into account the direction of mispricing.

[18]The results are robust even if we use other measures of mispricing frequently used in the literature. See OSM III for these additional analyses.



p=0.125 (KW)

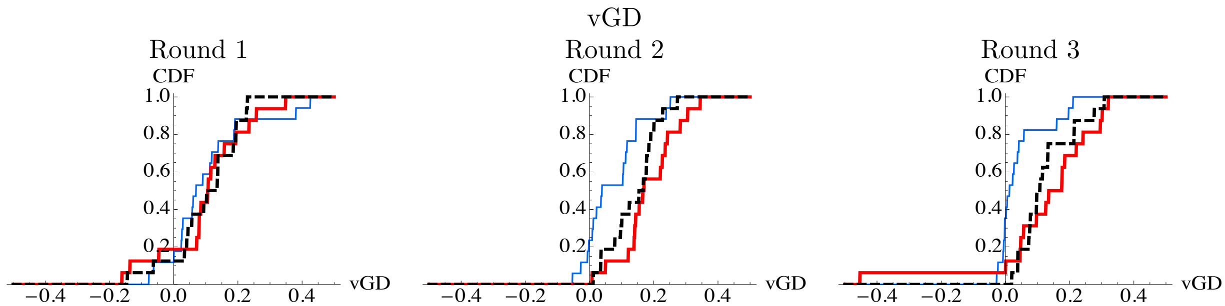
	T2	T3
T1	0.056	0.183
T2		0.386

p=0.007 (KW)

	T2	T3
T1	0.003	0.061
T2		0.132

p<0.001 (KW)

	T2	T3
T1	0.001	0.001
T2		0.327



p=0.749 (KW)

MW	T2	T3
T1	0.517	0.517
T2		0.910

p=0.005 (KW)

MW	T2	T3
T1	0.002	0.031
T2		0.214

p=0.001 (KW)

MW	T2	T3
T1	0.004	0.001
T2		0.451

Figure 2: ECD of vGAD (top) and vGD (bottom) for three rounds. T1: Benchmark (blue), T2: Buy&Hold (red), and T3: Buy&Sell (dashed black). P-values from the KW test for multiple comparisons as well as from the MW tests for pairwise comparisons are reported.

Given variations in the behavior of each market within each treatment and each round, there is a distribution for each measure of mispricing and the respective empirical cumulative distributions (ECDs) are illustrated in Figure 2 (vGADs (top) and vGDs (bottom)). The Benchmark is shown in the thin blue line, Buy&Hold is shown in the thick red line, and Buy&Sell is shown in the thick dashed line. Below each panel, p-values from the Kruskal-Wallis (KW) test of a multiple comparison and Mann-Whitney (MW) tests for pairwise comparisons are reported.

Visually, it is clear that there is very little difference between the cumulative distributions in Round 1 and this is confirmed using the KW test. Pairwise, the degree of mispricing in the benchmark is less than in the Buy&Hold treatment, but this difference is only marginally significant under the vGAD measure and not significant under the vGD measure. The picture changes dramatically in

Rounds 2 and 3. According to both measures, the level of mispricing in the Benchmark treatment is lower than in both the Buy&Hold and the Buy&Sell treatments with a high statistical significance, although there is no significant difference between the latter two treatments over the whole period.

Looking at mis-pricing over the full 11 periods, however, hides some important differences across the three treatments between different sub-periods. The first three periods of trading rounds (periods 1–3) take place before the first buy operation (in Buy&Hold as well as Buy&Sell treatments). So, if participants anticipate some effect of the buy operation, this should show up in these periods in these treatments compared to the benchmark. Trading in periods 5–7 occurs between the buy and the sell operation (in Buy&Sell treatment), thus, if anticipation of the sell operation is to have any effects, they should be visible in these periods in this treatment relative to the Buy&Hold treatment. Finally, trading in the last three periods (periods 9-11) takes place after the sell operation, when traders are only anticipating the maturity of the bonds. Analyzing these three sub-periods separately give us insights into the effects of these interventions.

Figure 3 shows the vGAD for each of the three subperiods, denoted as vGAD_1 (periods 1–3, left), vGAD_2 (periods 5–7, middle), and vGAD_3 (periods 9–11, right) in each round.[19]

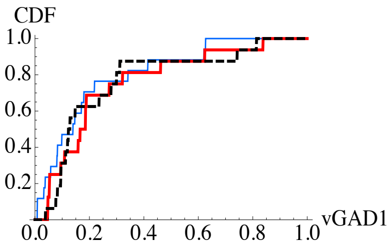
Whereas there was no apparent difference in Round 1 when viewed as a whole, there is now a noticeable, albeit only marginally significant, difference between the distributions during the second subperiod after the central bank purchases but before the sales in the Buy&Sell treatment. The degree of mispricing is markedly higher under the Buy&Hold and the Buy&Sell treatments than under the Benchmark treatment with the difference between the Buy&Sell and the Benchmark being particularly pronounced. The differences become even starker in the third subperiod, although here the main outlier is the Buy&Hold treatment, which is highly statistically significantly different from the other two. The other two are now statistically indistinguishable. To complete the analysis of Round 1, there is no difference between the distributions in the first subperiod. Thus, it is clear that it is the buy operation in the Buy&Hold and the Buy&Sell treatments that drives mispricing relative to the Benchmark in the second subperiod of Round 1, which is largely reversed by the sell operation in the Buy&Sell treatment.

These qualitative differences become more quantitatively significant in Rounds 2 and 3. The

[19]See Appendix A for vGD in these three subperiods, The results are essentially the same as the results that we report based on vGAD in the main text. The Appendix A also reports the summary statistics of vGAD_s and vGD_s and the p-values from various tests. In addition we provide results of analyses where, we include period 4 in the second subperiod and period 8 to the third subperiod, which are in the middle of the operation. The results are qualitatively the same.

Round 1

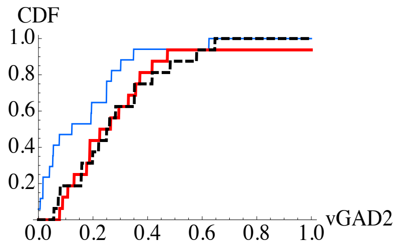
vGAD$_1$



p=0.611 (KW)

MW	T2	T3
T1	0.368	0.428
T2		0.910

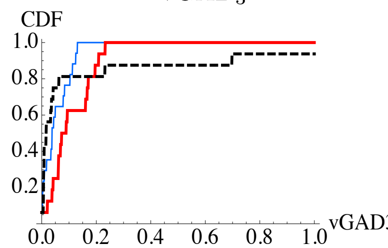
vGAD$_2$



p=0.052 (KW)

MW	T2	T3
T1	0.062	0.026
T2		0.722

vGAD$_3$

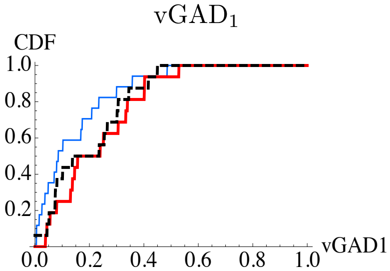


p=0.015 (KW)

MW	T2	T3
T1	0.032	0.326
T2		0.008

Round 2

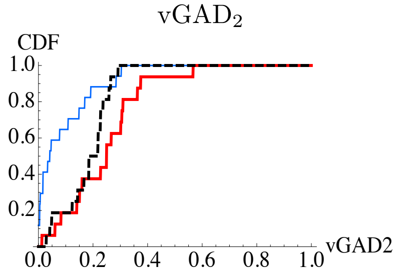
vGAD$_1$



p=0.179 (KW)

MW	T2	T3
T1	0.072	0.207
T2		0.624

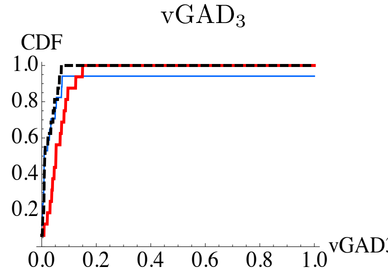
vGAD$_2$



p=0.001 (KW)

MW	T2	T3
T1	0.001	0.007
T2		0.122

vGAD$_3$

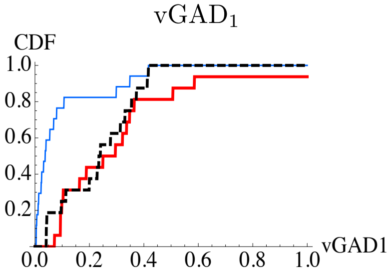


p=0.011 (KW)

MW	T2	T3
T1	0.009	0.534
T2		0.012

Round 3

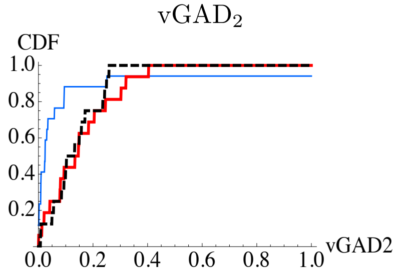
vGAD$_1$



p=0.001 (KW)

MW	T2	T3
T1	0.001	0.002
T2		0.598

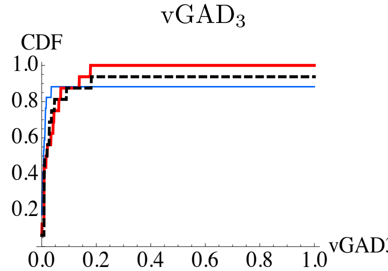
vGAD$_2$



p=0.002 (KW)

MW	T2	T3
T1	0.003	0.002
T2		0.880

vGAD$_3$



p=0.022 (KW)

MW	T2	T3
T1	0.016	0.018
T2		0.797

Figure 3: ECD of vGAD in three subperiods. vGAD$_1$ (periods 1–3). vGAD$_2$ (period 5–7). vGAD$_3$ (period 9-11) for three rounds. T1: Benchmark (blue), T2: Buy&Hold (red), and T3: Buy&Sell (dashed black). P-values from the KW test for multiple comparison as well as MW tests for pairwise comparisons are reported.

pairwise differences between the mispricing in the Benchmark and the two treatments fall below the 5% significance level. Furthermore, in Round 3, the vGAD in the first subperiod is significantly higher in the Buy&Hold and the Buy&Sell treatments than in the Benchmark.

3.3 Market interventions

In this subsection, to better understand the dynamics of prices across periods and rounds in the three treatments, we first summarize the results of the market interventions. Table 2 reports the average prices during the buy operations ($\overline{p_{bo}}$, panel (a)) as well as their differences from the average market prices in the preceding three periods ($\overline{p_{bo}} - \overline{p_{1-3}}$, panel (b)) and sell operations ($\overline{p_{so}}$, panel (c)) and their differences from the average prices in the preceding three periods ($\overline{p_{so}} - \overline{p_{6-8}}$, panel (d)). It also reports the difference between the average transaction prices between the buy and the sell operations (panel (e)).

We observe that, on average, the central bank paid prices substantially above the fundamental value during its buy operations, which may be natural given that the market prices are also higher than the fundamental value. The prices the central bank paid are, however, even higher than the average market prices in the three preceding periods although the difference becomes smaller in later rounds. The prices paid during the buy operations of both the Buy&Hold and Buy&Sell treatments are very similar and do not display any significant differences across three rounds.[20] The sell operation only occurs in the Buy&Sell treatment. Panel (d) of Table 2 reports that the central bank sells for a price below the average market prices in the three periods before the operation, although the difference becomes slightly smaller, in magnitude, in later rounds.

The observed high prices during the buy operation of our experiment, which result from subjects not competing aggressively enough, is very similar to price dispersion observed in Bertrand price competition experiments (called the "Bertrand Paradox", see, Dufwenberg and Gneezy, 2000; Baye and Morgan, 2004) as well as deviation from Nash equilibrium in experiments for the travelers' dilemma game (Capra et al., 1999). What is rather surprising in our data is the absence of significant differences across the three rounds. In Dufwenberg and Gneezy (2000), for example, when number of players is 3 or more, participants quickly learned to compete more aggressively in Bertrand competition experiment. This is not just for the average prices the central bank paid, but even at

[20]The estimated coefficients of the Rounds 2 and 3 dummies on the group fixed effect regressions that regress $\overline{p_{bo}}$ on a constant and these two dummies are not statistically significantly different from zero for the two treatments.

Table 2: Summary of Market Interventions

(a) Average transaction price in buy operations: $\overline{p_{bo}}$

	Mean	SD	Min	Max
T2. R1	149.61^a	18.93	122.06	191.75
T2. R2	162.80^a	34.01	125.00	263.13
T2. R3	151.53^a	21.24	119.94	186.41
T3. R1	148.62^a	20.37	121.09	180.50
T3. R2	154.91^a	17.19	124.69	179.75
T3. R3	145.66^a	16.83	122.19	174.00

(b) Differences from the average market prices in preceding periods: $\overline{p_{bo}} - \overline{p_{1-3}}$

	Mean	SD	Min	Max
T2. R1	25.13^b	25.94	−21.27	77.10
T2. R2	15.93^d	32.86	−21.67	130.79
T2. R3	5.84^d	12.82	−6.76	37.02
T3. R1	26.16^b	22.14	−5.57	69.88
T3. R2	10.89^b	11.98	−5.5	32.08
T3. R3	−1.13	9.90	−20.35	25.23

(c) Average transaction price in sell operations: $\overline{p_{so}}$

	Mean	SD	Min	Max
T3. R1	140.19^a	24.58	116.81	212.81
T3. R2	126.96^a	5.53	115.75	137.38
T3. R3	119.73	11.02	82.69	130.78

(d) Differences from the average market prices in preceding periods: $\overline{p_{so}} - \overline{p_{6-8}}$

	Mean	SD	Min	Max
T3. R1	-10.82^c	15.79	−38.52	26.03
T3. R2	-8.37^b	6.07	−18.58	0.49
T3. R3	-6.82^b	4.33	−15.31	−1.53

(e) Difference between sell and buy operations: $\overline{p_{bo}} - \overline{p_{so}}$

	Mean	SD	Min	Max
T3. R1	8.43	31.67	−78.94	59.69
T3. R2	27.94^b	14.06	0.00	48.38
T3. R3	25.94^b	20.38	3.72	77.25

[a] statistically significantly different from 120 at the 1% level (t-test, two tailed).
[b] statistically significantly different from zero at the 1% level (t-test, two tailed).
[c] statistically significantly different from zero at the 5% level (t-test, two tailed).
[d] statistically significantly different from zero at the 10% level (t-test, two tailed).

individual level.

Figures V.4 to V.7 in OSM V show realized supply schedules during the buy operation for each group in each round. These supply schedules are constructed based on the orders submitted during the operations. In many of the groups, supply schedules become flatter in Rounds 2 and 3 compared to Round 1, suggesting that there are fewer variations in the ask prices submitted by participants during the buy operation, which is consistent with the lower coefficient of variations of the ask prices in later rounds reported in the Table IV.2 in the OSM IV.2. However, it is only in a few groups (within each experimental setting) that we observe convergence toward equilibrium bidding (for example, groups 2 and 3 shown in Figure V.4 demonstrate convergence toward equilibrium bidding). In most of the groups, ask prices decline only slightly from one round to the next. There even exists a case (group 6 of Buy&Hold with 6 traders) where ask prices increased in later rounds.

This absence of convergence toward the equilibrium bidding behavior is in sharp contrast with the convergence to the equilibrium widely observed for the bidding behavior during the sell operations (see, Figures V.8 and V.9 in OSM V).

In a repeated multi-unit auction of Abbink et al. (2006), it takes as many as 25 repetitions for the outcomes (revenue measured relative to the value of the item being auctioned off) to stabilize. Although the slow learning observed in Abbink et al. (2006) may partly be a result of the value of the items being auctioned varying from one auction to another, it is possible that if the experiment had been repeated many more times, participants in our experiment would have learned to bid more competitively during the buy operation. However, the current experiment is not sufficient to study this question.

Panel (e), for convenience, displays the difference in the prices paid and received in the Buy&Sell treatment. The difference is not statistically significantly different from zero in Round 1 but becomes strongly statistically significant in Rounds 2 and 3. As a result, the central bank makes a very large loss and a substantial amount of cash (on average, 20% of the fundamental value of the bonds) was transferred from the central bank to the market participants through these two operations.

Such a large transfer of cash from the central bank to market participants substantially increases the cash-to-asset ratio. Existing studies (see, e.g., Kirchler et al., 2012; Deck et al., 2014) have found that prices can rise when the ratio of cash to assets increases. So one reason why the two buy operations might increase prices is simply the resulting higher cash to assets ratios. To check if the higher cash-to-asset ratio is indeed the main driver of higher mispricing, we conduct the following regression:

$$\Delta\bar{p}^m = b_1 + b_2\overline{p_{bo}}^m + \mu^m \tag{3}$$

where $\overline{p_{bo}}^m$ is the average transaction price per unit of bonds during the buy operation for market m, $\Delta\bar{p}^m \equiv \overline{p_{5-7}}^m - \overline{p_{1-3}}^m$ is the difference in the average prices for the three periods immediately before and after the buy operation for market m (with $\overline{p_{l-k}}^m$ being the average price observed between period l and k for market m).

Regression (3) tests whether the differences in prices in the market before and after the buy operation are related to the average prices paid by the central banks. If the cash-to-asset ratio was an important driver for the price increase after the buy operation, there should be a statistically

Table 3: Dependent Var: $\Delta\overline{p}$

	Round 1	Round 2	Round 3
Const	50.50	-0.234	49.39**
	(43.88)	(16.27)	(21.14)
$\overline{p_{bo}}$	-0.153	-0.003	-0.404***
	(0.292)	(0.101)	(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

significant, positive relationship in regression (3).

The result is reported in Table 3. We do not observe any statistically significant, positive relationship between the change in the market prices before and after the buy operation and the average price paid by the central bank during its buy operation. In Round 3, it is even negative rather than positive.[21] Thus, the cash-in-the-market effect does not seem to be the main driver of our results. More importantly, the cash-in-the-market effect cannot explain the higher mispricing observed in the three periods before the buy operations in the two treatments with intervention compared with the Benchmark in Rounds 2 and 3 that we have seen above (in Figure 3). This is because, in these first three periods, the cash-to-asset ratios are the same in all the treatments.

Indeed, regressing vGD_1 (vGD for periods 1–3)[22] on treatment dummies and the outcome of the buy operations in the previous round (reported in Table 4) shows that the mispricing in the first three periods of the current round is positively and significantly related to the average price that the central bank paid during its buy operation in the previous round.

This suggests that the results of market interventions in a round influenced subjects' price expectations, which in turn influenced the market prices, in the following round. In the next subsection, we will investigate this channel through analyzing the dynamics of subjects' forecasts.

[21] There were two cases in Round 1 (for the market with six traders) where the central bank failed to buy the targeted amount of bonds (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-to-asset ratio caused by the buy operation. We ran the regression (shown in eq. (3)) dropping these two instances, but the result is qualitatively the same. In addition, we ran the regressions separately for the Buy&Hold and Buy&Sell treatments. The results are qualitatively the same as the those presented in the right panel of Table 3 for both treatments.

[22] We use vGD_1, instead of $vGAD_1$ here to take into account the direction of mis-pricing.

Table 4: Mispricing and the previous round buy operation

Dependent Var: vGD$_1$		
	Round 2	Round 3
T2 (Buy&Hold)	0.094*	-0.022
	(0.047)	(0.072)
T3 (Buy&Sell)	0.074	0.063
	(0.046)	(0.064)
Previous round $\overline{p_{bo}}/FV - 1$	0.511***	0.584***
	(0.141)	(0.152)
adf R^2	0.752	0.620
N of Obs.	32	32
$H_0 : T2 == T3$ (p-value)	0.668	0.215

* statistically significant at the 10% level
** statistically significant at the 5% level
*** statistically significant at the 1% level

3.4 Forecasts

To set the scene, we first 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 Round 2 (middle panel), as well as the first four 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. There are many interesting features that we observe in this figure that illustrate results that we demonstrate more formally later.

First, the very first forecasts elicited in period 1 of Round 1, before the participants have any experience of trading, vary widely.[23] However, they vary less at the end than they do at the beginning, suggesting that most participants realized that prices should converge towards the maturity value by period 11.[24] The first realized price, represented by the dot in the first period, is close to the median first-period forecast and very close to the fundamental price. Forecast paths narrow dramatically in period 2 of Round 1 as participants update their beliefs in light of the first period's realized 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

[23] As we show in Appendix B, the initial set of forecasts do not vary across the three treatments. Thus, our inexperienced student subjects initially did not systematically anticipate that different price paths would result from the pre-announced market interventions. This is also reflected in the absence of significant differences in the mispricing observed in the first three periods of round 1 in the three treatments.

[24] One participant with extremely high initial forecasts is excluded to maintain a common scale throughout.

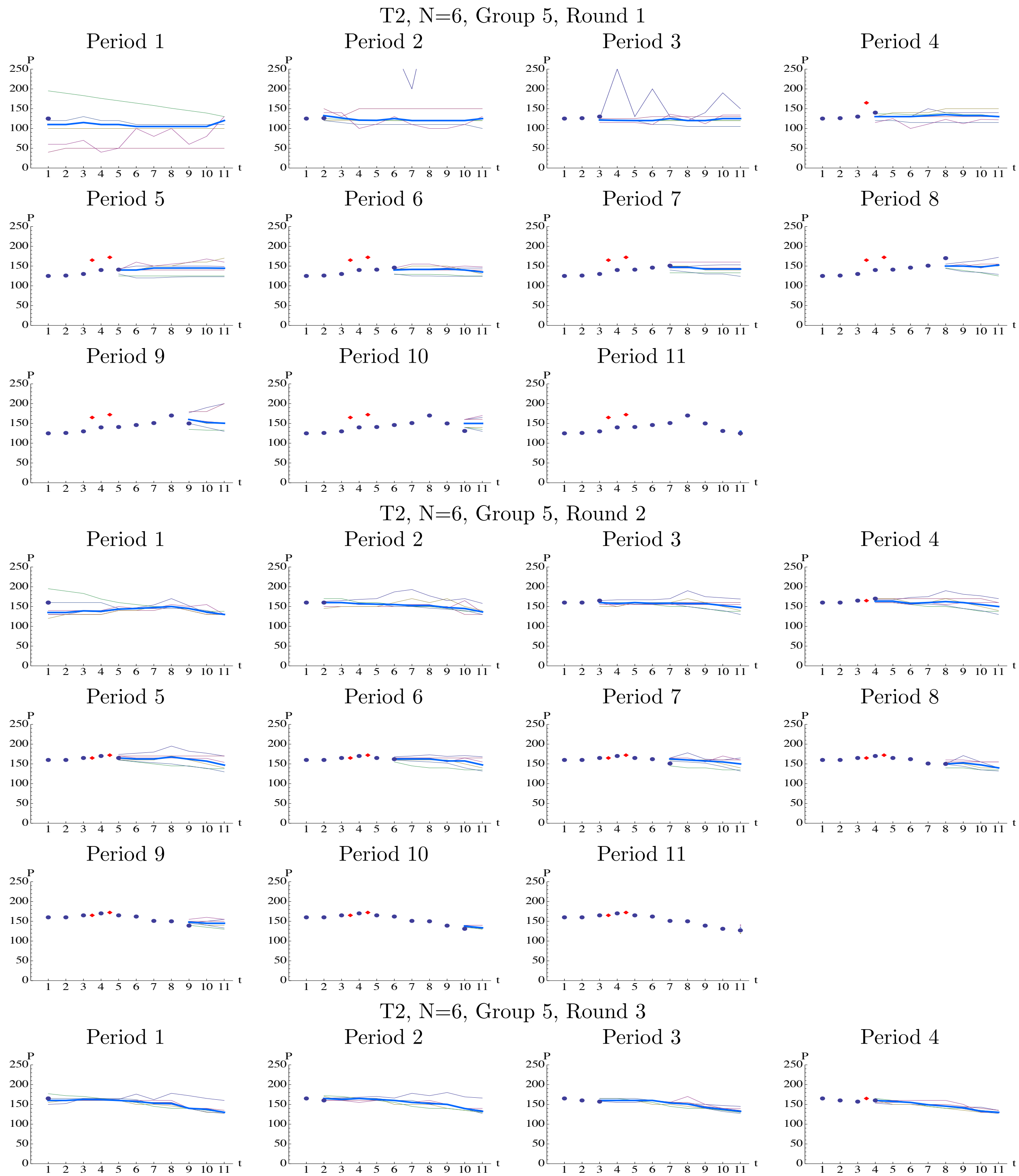


Figure 4: Dynamics of forecasts and price observed in benchmark treatment with six traders per market, Group 1. Top: Round 1. Middle: Round 2. Bottom: the first four periods of Round 3. Thin lines: individual traders. Thick line: Medians. Dots: realized market prices. Red diamonds: average price paid by the central bank.

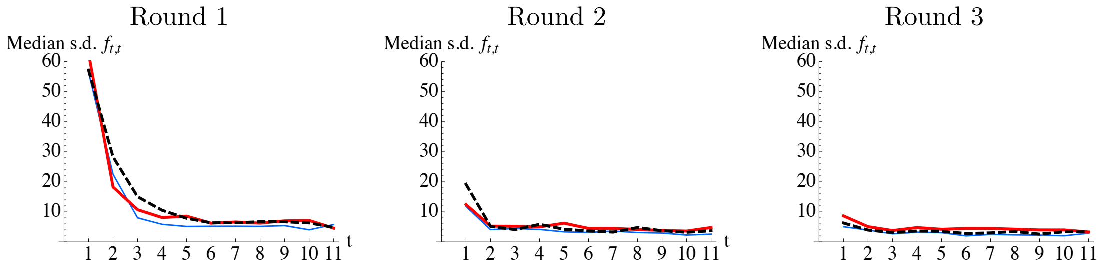


Figure 5: Dynamics of the median within-market standard deviation of the short-term forecasts in three rounds. T1: Benchmark (blue), T2: Buy&Hold (red), and T3: Buy&Sell (dashed black).

immediate impact on price forecasts, although the median is gradually rising in line with realized prices. For this group, prices continue to rise until period 8 and then decline. It is interesting to note that, in periods 8 and 9, two distinct forecast patterns emerge: some who think that prices will continue to rise and a majority who realize that prices ought to be close to the fundamental value by the end.

When the participants start again in period 1 of Round 2, initial forecasts are again relatively dispersed particularly for early periods but converge towards (although they are slightly above) the maturity price in period 11. Importantly, however, the distribution of forecasts has shifted up. Short-term forecasts again narrow dramatically in period 2, centered on the realized price of period 1, which is well above the fundamental value but very close to what the central bank paid in Round 1. What the central bank pays in Round 2 is now squarely in line with previous and future prices. Realized 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 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). Then, prices almost exactly track the initial median path, which is scarcely updated over the first four rounds. (The remaining periods of Round 3 are uninteresting.)

Below, we analyze formally the suggestive evidence of Figure 4. We first show a close relationship between the median short-term forecasts (forecasts for the current period price) and realized prices. We then link how median short-term forecasts in early periods are influenced by market prices and the central bank interventions from the previous round.

We focus on the median short-term forecasts because the short-term forecasts of participants in each market quickly converge around the median, as demonstrated in Figure 4 and more vividly in Figure 5. Figure 5 shows the dynamics of the median within-market standard deviation of the short-term forecasts in the three rounds in each of the three treatments. As one can clearly observe, the variations of short-term forecasts within each market become very small after a few periods in Round 1, and remain small in Rounds 2 and 3, except for a small increase in the first period in Round 2. Thus, we focus on the median instead of individual forecasts, as little insight will be lost. Furthermore, Carle et al. (2019) who re-investigated the data of Haruvy et al. (2007), reported that although short-term forecasts are related to subjects' trading behavior in a statistically significant manner, their long-term forecasts (i.e., forecasts for prices in all the remaining periods of a market) are not. Thus, focusing on short-term forecasts will allow us to understand more clearly the link between the outcomes across rounds.

3.4.1 Median forecasts and prices

The first link in the chain is to demonstrate statistically that market prices are highly correlated with median price forecasts within each market.

Table 5 reports the results of group random effect regressions regressing the current period price P_t on the median short-term forecasts, $\text{Med}f_{t,t}$, for the three treatments and three rounds. The three treatments are considered jointly in a single regression by including two treatment dummies (for T2 and T3) and their interactions with $\text{Med}f_{t,t}$. The regressions show that actual prices follow closely, although not perfectly, the median short-term forecasts from Round 1, and increasingly more so in later rounds. In fact, the estimated coefficients of the $\text{Med}f_{t,t}$ in the two treatments with the central interventions (T2 and T3) are not statistically significantly different from 1.0 in Round 3. The estimated coefficients of the treatment dummies and the interaction terms themselves are not statistically significantly different across three treatments. Such a close link between median forecasts and realized market prices is also reported by Carle et al. (2019).

3.4.2 Initial median forecasts and previous round outcomes

Equipped with this result about a tight link between the realized prices and median short-term forecasts, we now proceed to analyze how median short-term forecasts made in the first period in Rounds 2 and 3 are influenced by outcomes in previous rounds for the same market. We regress the initial median forecast ($\text{Med}f_{1,1}^{R}$) of Round R on the realized first-period price in the previous

Table 5: Current period prices and median short-term forecasts. Dependent variable P_t.

	(1) Round 1	(2) Round 2	(3) Round 3
T2 (Buy&Hold)	13.14	6.766	-10.34
	(7.457)	(7.760)	(9.465)
T3 (Buy&Sell)	14.46**	0.514	-6.071
	(7.105)	(8.863)	(11.47)
Med $f_{t,t}$	0.764***	0.803***	0.855***
	(0.0358)	(0.0426)	(0.0517)
T2 × Med $f_{t,t}$	-0.0823	-0.0382	0.0774
	(0.0541)	(0.0557)	(0.0693)
T3 × Med $f_{t,t}$	-0.101	-0.0197	0.0319
	(0.0523)	(0.0664)	(0.0887)
Constant	31.51***	26.48***	17.89**
	(4.949)	(5.861)	(6.960)
N	539	539	539
P-values for various hypothesis testings;			
H_0: Med$f_{t,t} = 1$	<0.001	<0.001	0.005
H_0: Med$f_{t,t}(1 + T2) = 1$	<0.001	<0.001	0.143
H_0: Med$f_{t,t}(1 + T3) = 1$	<0.001	<0.001	0.118
H_0: T2=T3=0	0.08	0.622	0.550
H_0: T2× Med $f_{t,t}$=T3× Med $f_{t,t}$=0	0.119	0.790	0.531

Standard errors in parentheses

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

round (P_1^{R-1}), the median price paid by the central bank during the buy operation (Medp_{bo}^{R-1}), and a constant.

Table 6 reports the results of separate ordinary least squares (OLS) regressions for each treatment. It is worth noting immediately that the adjusted R^2s for these regressions are very high, particularly for Round 3, implying that these three independent variables explain almost all the variation in median initial price forecasts across the various markets. For all the treatments, the realized price for the same (first) period in the previous round has a large and highly statistically significant effect on the median price forecast for the current round.[25]

Let us turn our attention to those treatments with the interventions. For Round 2, in both

[25] We have checked for potential multicollinearity by computing variance inflation factor (VIF) for T2 and T3 regressions. For both Rounds 2 and 3, the maximum VIF was 1.17 suggesting that the high R^2 is not due to the correlation between P_1^{R-1} and Medp_{bo}^{R-1}.

Table 6: Median short-term first-period forecasts and outcomes in previous round.

	Round 2			Round 3		
	T1	T2	T3	T1	T2	T3
P_1^{R-1}	0.600***	0.534***	0.445***	0.732***	0.899***	0.872***
	(0.105)	(0.055)	(0.098)	(0.0584)	(0.069)	(0.049)
$\text{Med}p_{bo}^{R-1}$		0.214**	0.473**		0.069	0.187***
		(0.098)	(0.194)		(0.050)	(0.052)
Constant	55.80***	36.07**	9.597	34.62***	4.66	-9.64
	(13.12)	(15.26)	(27.35)	(7.89)	(10.17)	(8.40)
Adjusted R^2	0.663	0.872	0.722	0.907	0.933	0.967
Observations	17	16	16	17	16	16
P-values from the hypothesis testing						
H_0: $P_1^{R-1} = 1$	<0.001	<0.001	<0.001	<0.001	0.169	0.021
H_0: $P_1^{R-1} + \text{Med}p_{bo}^{R-1} = 1$		0.034	0.659		0.658	0.320

Standard errors in parentheses

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

the T2 (Buy&Hold) and T3 (Buy&Sell) treatments, the median prices paid by the central bank during the buy operations in Round 1 are positively and significantly related to the initial period price forecast.[26] This is closely linked to the result we have seen Table 4 regarding the positive and significant relationship between the average price during the buy operation in the previous round and the vGD of the first subperiod of the current round. For Round 3, the importance of the result of the intervention in Round 2 diminishes and becomes insignificant in the Buy&Hold treatment. However, the importance of the initial realized price in Round 2 markedly increases.

Drawing these strands together, realized market prices are highly correlated with median expectations, so the forecast formation process is critical. Price forecasts depend strongly on previous experience, but in two distinct steps. In Round 2, price forecasts are strongly influenced by what the central bank paid in Round 1, as well as by what was realized in the same period of Round 1. By Round 3, each market seems to settle on an historical price that coordinates both market prices and the price paid by the central bank. This strong coordination of expectations in the case of the market interventions seems to dominate any possibility that the participants learn that this is not the REE, which they do manage to achieve in the Benchmark case without intervention.

[26] We prefer to use the median price at which central bank bought, instead of the average price, because the latter is sensitive to some extremely low or high prices at which the central bank bought in some sessions. Using the average, however, does not change the qualitative result for T3. For T2, the estimated coefficient for the average price that the central bank paid is not statistically significant in Round 2.

4 Summary and conclusion

In this paper, we have asked whether a large-scale asset purchases by a central bank (a quantitative easing operation) which should be neutral under a rational expectations equilibrium has an impact, and whether such an impact, if exists, survives after participants gaining experience by repeatedly experiencing the same experiment.

It is clear from the repeated Benchmark treatment that participants in our experiment can learn, in line with the results of the literature, that prices should not deviate from the fundamental price in the absence of QE after a couple of repetitions.

In the Buy&Hold treatment, in which the QE operations permanently remove some bonds from the market, prices rise statistically significantly well above the fundamental price and stay there, even after the central bank has stopped buying. In most markets, repeated exposure only strengthens the belief that prices should rise. However, in a minority of cases, the intervention has a 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 learning to compete this effect away, participants come to expect it. Indeed, by Round 3, the price path in the earlier rounds significantly conditions their price expectations. In addition, it was notable 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 are remarkably similar to those in the Buy&Hold treatment, particularly over 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 evidence from this paper seems to suggest that QE could work through a purely behavioural mechanism.

In order to accommodate repeating the experiment three times, we have opted for rather short market horizon of 11 periods. In order to better separate the effect of anticipation of the maturity of bonds and those of the sell interventions, an experiment involving a longer time horizon and thus put sell operation much earlier than bond maturity would be desirable. Indeed, there are papers (for example, Lahav, 2011; Hoshihata et al., 2017) that demonstrate quite different price dynamics in much longer horizon market (200 periods in the former and 100 periods in the latter) compared to short horizon market (of 15 or less periods). We leave this as an interesting avenue for future research.

Of course, the analysis in this paper involves caveats. Abbink et al. (2006) suggested that it may take several repetitions, certainly more than three, for subjects to learn to bid aggressively in a discriminatory multi-unit auction.[27] Thus, it is possible that if we repeat our experiment many more times, subjects will eventually learn to compete more aggressively during the interventions and thus, learn to trade the bond at its fundamental value from the beginning of the market round. Abbink et al. (2006) also showed that subjects learn to bid aggressively much more quickly under a uniform price multi-unit auction than under discriminatory one. Thus, it is possible that we may have observed different results if the intervention had been implemented with a uniform instead of a discriminatory price auction. However, we leave such comparisons to future research.

The experimental paradigm on which we have based our experiment is the one where no trade theorem applies just like many other asset market experiments that follow the paradigm of Smith et al. (1988). It has been recently pointed out, however, that the observed mis-pricing tends to be larger in such an environment compared to those in which participants have intrinsic motives to trade, e.g., to smooth consumption across periods (Asparouhova et al., 2016; Crockett et al., 2019) because of, e.g., participants' desire to do something during the experiment ("active participation hypothesis," Lei et al., 2001) in the absence of alternative activities during the experiment. Thus, it is possible that the effect of market intervention we report in the current paper would be quite different in the environment similar to the one considered by Asparouhova et al. (2016) and Crockett et al. (2019). We believe future research investigating this issue will be of high importance.[28]

Furthermore, professional bond traders are likely to be more strategically sophisticated than undergraduate students exposed to bond trading for the first time and thus, the results reported in this paper may not apply to real bond markets. However, recent research shows that this may not be a serious concern. For example, Weitzel et al. (2020) demonstrated that experimental asset markets consisting of financial professionals result in mispricing, despite its magnitude being smaller than in the case of markets consisting of students. Of course, it would be fruitful to conduct experiments with professionals to check if the mis-pricing caused by a neutral intervention persists as well.

[27] See Kwasnica and Sherstyuk (2013), among others, for a survey of multi-unit auction experiments.

[28] We thank an anonymous reviewer for pointing this out.

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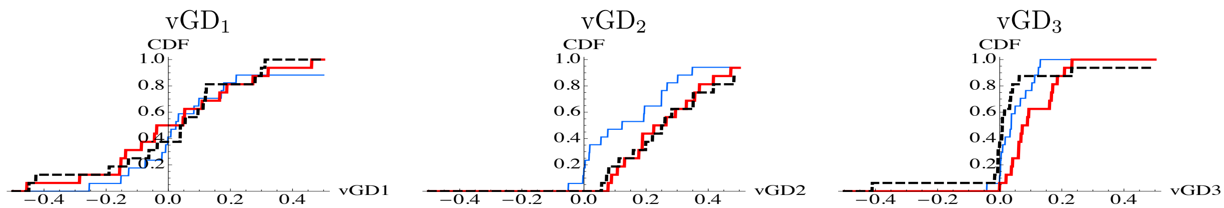
A Subperiods analyses

Figure A shows the ECD of three subperiods, vGD_1 (left), vGD_2 (right), and vGD_3 (right) across the three rounds. The three treatments are represented by different colors: T1: Benchmark (blue), T2: Buy&Hold (red), and T3: Buy&Sell (dashed black). Below the ECD, p-values from KW test for multiple comparison, as well as MW tests for pairwise comparisons are reported.

Round 1



p=0.858 (KW)

MW	T2	T3
T1	0.517	0.914
T2		0.821

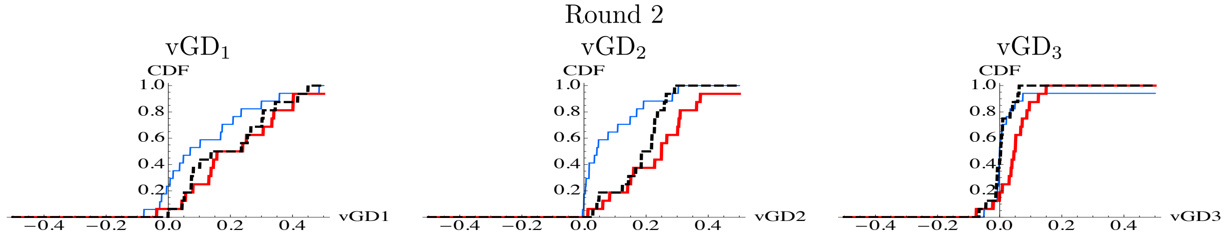
p=0.056 (KW)

MW	T2	T3
T1	0.062	0.028
T2		0.752

p=0.001 (KW)

MW	T2	T3
T1	0.018	0.070
T2		0.001

Round 2



p=0.109 (KW)

MW	T2	T3
T1	0.066	0.084
T2		0.651

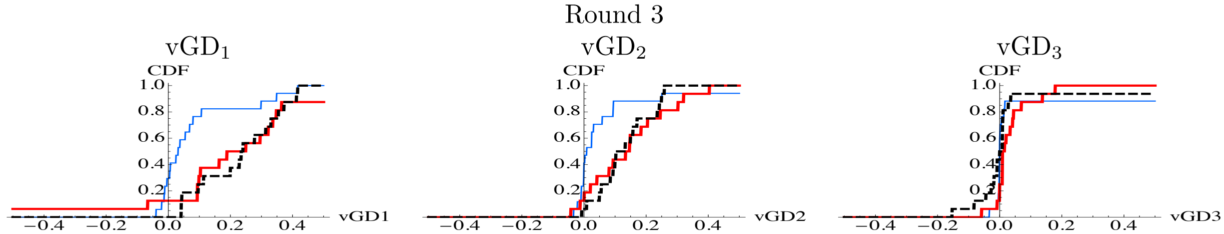
p=0.001 (KW)

MW	T2	T3
T1	0.001	0.007
T2		0.122

p=0.010 (KW)

MW	T2	T3
T1	0.006	0.985
T2		0.012

Round 3



p=0.005 (KW)

MW	T2	T3
T1	0.016	0.002
T2		0.851

p=0.004 (KW)

MW	T2	T3
T1	0.012	0.001
T2		0.970

p=0.013 (KW)

MW	T2	T3
T1	0.007	0.868
T2		0.018

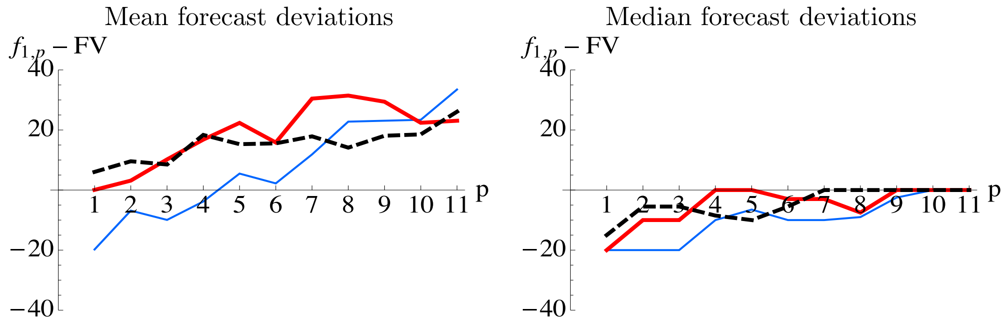
Figure A.1: ECD of vGD in three subperiods. vGD_1 (periods 1–3). vGD_2 (periods 5–7). vGD_3 (periods 9–11) for three rounds. T1: Benchmark (blue), T2: Buy&Hold (red), and T3: Buy&Sell (dashed black). P-values from KW test for multiple comparison, as well as MW tests for pairwise comparisons are reported.

Table A.1 reports the mean and standard deviations of the vGAD, vGD, and TO of the three subperiods, as well as p-values from KW and MW tests. It also reports, for a robustness check, the outcome when we include period 4 in the second subperiods and period 8 included in the third subperiods (shown with $*$). As one can see, the results are qualitatively the same.

Table A.1: Mean (standard deviation) of vGAD, vGD, TO of three subperiods

	Benchmark	Buy&Hold	Buy&Sell	T1=T2=T3^{a}	T1=T2^{b}	T1=T3^{b}	T2=T3^{b}
			Round 1				
vGAD$_1$	0.192 (0.197)	0.238 (0.226)	0.231 (0.229)	p=0.611	p=0.368	p=0.428	p=0.910
vGAD$_2$	0.166 (0.165)	0.246 (0.124)	0.285 (0.177)	p=0.052	p=0.062	p=0.026	p=0.722
vGAD$_3$	0.051 (0.045)	0.105 (0.073)	0.078 (0.181)	p=0.015	p=0.032	p=0.326	p=0.008
vGAD$_2$*	0.170 (0.168)	0.236 (0.119)	0.263 (0.157)	p=0.088	p=0.052	p=0.066	p=0.851
vGAD$_3$*	0.062 (0.055)	0.134 (0.074)	0.090 (0.147)	p=0.008	p=0.008	p=0.777	p=0.008
vGD$_1$	0.084 (0.237)	0.016 (0.236)	0.011 (0.225)	p=0.858	p=0.517	p=0.914	p=0.821
vGD$_2$	0.157 (0.174)	0.246 (0.124)	0.282 (0.179)	p=0.056	p=0.062	p=0.028	p=0.752
vGD$_3$	0.046 (0.050)	0.104 (0.072)	-0.000 (0.128)	p=0.001	p=0.018	p=0.070	p=0.001
vGD$_2$*	0.158 (0.179)	0.236 (0.119)	0.259 (0.161)	p=0.073	p=0.048	p=0.052	p=1.000
vGD$_3$*	0.056 (0.060)	0.134 (0.073)	0.036 (0.138)	p=0.002	p=0.006	p=0.400	p=0.001
TO$_1$	0.240 (0.078)	0.232 (0.055)	0.189 (0.059)	p=0.100	p=0.842	p=0.099	p=0.041
TO$_2$	0.156 (0.066)	0.210 (0.098)	0.247 (0.210)	p=0.151	p=0.069	p=0.144	p=0.734
TO$_3$	0.167 (0.146)	0.197 (0.110)	0.119 (0.124)	p=0.050	p=0.207	p=0.198	p=0.017
TO$_2$*	0.230 (0.089)	0.290 (0.125)	0.315 (0.237)	p=0.295	p=0.121	p=0.296	p=0.734
TO$_3$*	0.215 (0.161)	0.237 (0.120)	0.154 (0.129)	p=0.089	p=0.304	p=0.234	p=0.029
			Round 2				
vGAD$_1$	0.141 (0.138)	0.224 (0.149)	0.196 (0.143)	p=0.179	p=0.072	p=0.207	p=0.624
vGAD$_2$	0.085 (0.100)	0.239 (0.138)	0.179 (0.082)	p=0.001	p=0.001	p=0.007	p=0.122
vGAD$_3$	0.024 (0.026)	0.060 (0.041)	0.025 (0.024)	p=0.011	p=0.009	p=0.534	p=0.012
vGAD$_2$*	0.093 (0.105)	0.243 (0.139)	0.193 (0.091)	p=0.003	p=0.003	p=0.008	p=0.327
vGAD$_3$*	0.025 (0.031)	0.076 (0.053)	0.036 (0.024)	p=0.002	p=0.003	p=0.048	p=0.013
GD$_1$	0.122 (0.155)	0.220 (0.156)	0.196 (0.143)	p=0.109	p=0.066	p=0.084	p=0.651
GD$_2$	0.085 (0.100)	0.239 (0.138)	0.179 (0.082)	p=0.001	p=0.001	p=0.007	p=0.122
GD$_3$	0.006 (0.029)	0.048 (0.055)	0.005 (0.033)	p=0.010	p=0.006	p=0.985	p=0.012
GD$_2$*	0.093 (0.105)	0.243 (0.139)	0.193 (0.091)	p=0.003	p=0.003	p=0.008	p=0.327
GD$_3$*	0.010 (0.033)	0.063 (0.067)	0.021 (0.032)	p=0.009	p=0.006	p=0.280	p=0.022
TO$_1$	0.292 (0.122)	0.248 (0.070)	0.207 (0.091)	p=0.055	p=0.437	p=0.032	p=0.061
TO$_2$	0.167 (0.127)	0.210 (0.117)	0.215 (0.093)	p=0.222	p=0.248	p=0.077	p=0.850
TO$_3$	0.188 (0.141)	0.201 (0.149)	0.122 (0.091)	p=0.236	p=0.971	p=0.139	p=0.145
TO$_2$*	0.218 (0.138)	0.250 (0.111)	0.272 (0.125)	p=0.278	p=0.256	p=0.135	p=0.611
TO$_3$*	0.235 (0.165)	0.243 (0.138)	0.161 (0.108)	p=0.201	p=0.829	p=0.171	p=0.090
			Round 3				
vGAD$_1$	0.092 (0.130)	0.397 (0.589)	0.232 (0.132)	p=0.001	p=0.001	p=0.002	p=0.598
vGAD$_2$	0.041 (0.063)	0.151 (0.119)	0.131 (0.083)	p=0.002	p=0.003	p=0.002	p=0.880
vGAD$_3$	0.008 (0.009)	0.040 (0.051)	0.033 (0.047)	p=0.021	p=0.016	p=0.018	p=0.797
vGAD$_2$*	0.050 (0.073)	0.161 (0.115)	0.146 (0.095)	p=0.001	p=0.003	p=0.001	p=0.880
vGAD$_3$*	0.009 (0.011)	0.045 (0.056)	0.039 (0.045)	p=0.008	p=0.009	p=0.006	p=0.985
vGD$_1$	0.082 (0.137)	0.186 (0.291)	0.232 (0.132)	p=0.005	p=0.016	p=0.002	p=0.851
vGD$_2$	0.032 (0.069)	0.142 (0.129)	0.130 (0.084)	p=0.004	p=0.012	p=0.001	p=0.970
vGD$_3$	-0.001 (0.011)	0.032 (0.057)	-0.016 (0.048)	p=0.013	p=0.007	p=0.868	p=0.018
vGD$_2$*	0.038 (0.080)	0.155 (0.119)	0.145 (0.096)	p=0.001	p=0.002	p=0.001	p=0.970
vGD$_3$*	0.001 (0.011)	0.036 (0.063)	-0.003(0.054)	p=0.050	p=0.011	p=0.859	p=0.109
TO$_1$	0.260 (0.097)	0.242 (0.070)	0.210 (0.057)	p=0.248	p=0.745	p=0.129	p=0.185
TO$_2$	0.124 (0.067)	0.192 (0.102)	0.178 (0.103)	p=0.116	p=0.052	p=0.125	p=0.650
TO$_3$	0.181 (0.187)	0.229 (0.214)	0.137 (0.126)	p=0.238	p=0.312	p=0.448	p=0.100
TO$_2$*	0.178 (0.072)	0.229 (0.114)	0.226 (0.104)	p=0.377	p=0.207	p=0.256	p=0.940
TO$_3$*	0.218 (0.205)	0.257 (0.213)	0.171 (0.137)	p=0.316	p=0.437	p=0.428	p=0.136

a Based on the KW test
b Based on the MW test



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: $H_0 : f_{1,t} = 120$	**0.0002**	0.538	0.058	0.425	0.441	0.592	0.097	**0.005**	**0.002**	**0.008**	**0.001**
T2: $H_0 : f_{1,t} = 120$	0.996	0.723	0.376	0.122	**0.019**	0.120	**0.022**	**0.030**	0.06	0.087	0.115
T3: $H_0 : f_{1,t} = 120$	0.647	0.381	0.418	0.196	0.078	0.142	0.060	0.090	0.091	0.096	0.981
$H_0 : T1 = T2 = T3$	0.084	0.567	0.125	0.103	0.333	0.277	0.446	0.525	0.828	0.938	0.814

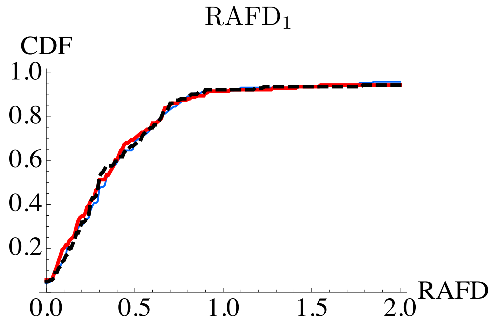
Figure B.1: The average (left) and the median (right) initial forecasts deviations from FV for 11 periods in three treatments. T1: Benchmark (thin blue), T2: Buy&Hold (thick red), and T3: Buy&Sell (black dashed)

B Initial forecasts

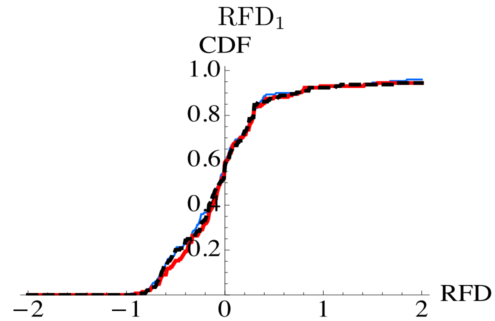
Here we analyze the initial set of forecasts submitted by the subjects to investigate whether the announced large-scale intervention had any impact on the future price expectations of *inexperienced* subjects. The deviations of the mean and median paths from FV are presented in Figure B.1 (T1: Benchmark (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 for 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 equal to the 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.

Figure B.1 shows the p-values for testing whether, for each treatment, the forecast for the period p price is different from the FV, as well as whether the forecasts for the period p price are different across the three treatments. Those periods in which the test rejects the null hypothesis at the 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.

$$f^i_{1,p} = \alpha_1 D^i_{T1} + \alpha_2 D^i_{T2} + \alpha_3 D^i_{T3} + \epsilon^i_p \tag{B.1}$$



Mean (Std. Dev.)		
T1	T2	T3
0.503	0.546	0.543
(0.676)	(0.908)	(0.838)
p=0.807		



Mean (Std. Dev).		
T1	T2	T3
0.062	0.155	0.127
(0.821)	(1.03)	(0.983)
p=0.538		

Figure B.2: Empirical CDF of $RAFD_1$ and RFD_1. T1: Benchmark (thin blue), T2: Buy&Hold (thick red), and T3: Buy&Sell (black dashed)

where $f^i_{1,p}$ is subject i's forecast for the period p price elicited at the beginning of period 1 and D^i_xs are dummy variables that take a value of one if i has participated in treatment $x \in \{T1, T2, T3\}$. The standard errors are corrected for a potential within-group clustering effect. We have chosen this test to control for possible correlation among subjects within a group.[29] Overall, we do not observe a significant effect of the announced differences in treatments on the initial forecasts.

To further check that the policy announcement did not influence subjects' initial forecasts, we measured the deviation of price forecasts from FVs using 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 at the beginning of period t, $RAFD^i_t$ and RFD^i_t are defined as:

$$\text{RAFD}^i_t = \frac{1}{11 - t + 1} \sum_{p=t}^{T} \frac{|f^i_{t,p} - 120|}{120} \tag{B.2}$$

$$\text{RFD}^i_t = \frac{1}{11 - t + 1} \sum_{p=t}^{T} \frac{f^i_{t,p} - 120}{120} \tag{B.3}$$

where $f^i_{t,p}$ is the forecast asset price in period p submitted by subject i at the beginning of period t.

Figure B.2 shows the empirical cumulative distribution (ECD) of $RAFD^i_1$ (left) and RFD^i_1

[29] However, note that because this is the first set of forecasts submitted by the subjects without observing the past realized prices, the effect of such a correlation should be very limited. Not correcting for the clustering effect does not change the result qualitatively.

(right) for the three treatments: T1: Benchmark (thin blue), T2: Buy&Hold (thick red), and T3: Buy&Sell (black dashed). It also reports the mean, standard error, and the p-values for treatment comparison.[30]

The absence of treatment effects in $RAFD_1$ and RFD_1 confirms the earlier finding. The announcement of a large intervention does not influence the subjects' initial expectations.[31]

[30] Just as we have done for the forecasts for the period p price, the test of equality among the three treatments is done by running OLS regressions (and correcting for the clustering effect) of the form $Y^i = a + b_1 D_{T1} + b_2 D_{T2} + b_3 D_{T3} + \mu^i$ (where Y^i is either $RAFD_1^i$ or RFD_1^i. D_x is a dummy variable that takes a value of one if the treatment is x.) and testing whether the estimated coefficients of the treatment dummies are equal, that is if $H_0 : b_1 = b_2 = b_3$, to control for the possible correlation among subjects within a group.

[31] Furthermore, the nonparametric KW test provides the same conclusion: p=0.867 for RAFD and p=0.836 for RDF.

Online Supplementary Material

The supplementary material is organized as follows:

I. Summary of results of the experiment reported in Panelvar et al. (2007)

II. Price dynamics in Individual Markets

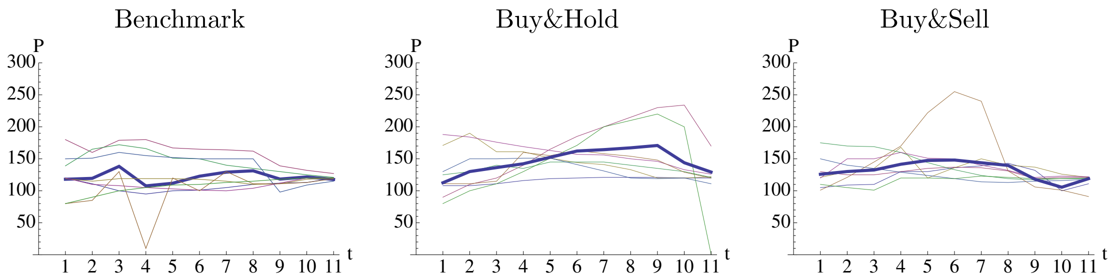
III. Other measures of market outcomes

IV. Comparison between outcomes of two market sizes

V. Supply and demand schedules during central bank operations

VI. Instructions

I Summary of results in Panelvar et al. (2007)



Note: Thin lines are the realization of each of the 8 markets. The thick line is the volume weighted average price across the 8 markets.

Figure I.1: Price dynamics in three treatments

Here we report the main results of our first set of experiments reported in earlier version of our paper (Penalver et al., 2017) for completeness. The three treatments (Benchmark, Buy&Hold, Buy&Sell) are the same as those described in the main text. However, unlike the experiment reported in the main text where participants repeated the same treatment three times, here in each session, participants participated in all the three treatments, but according to one of the 6 possible orders. Here, we report the outcome of the first treatment participants are exposed to.

Computerized experiments were carried out between June and July 2016 at Waseda University in Japan. 144 students were recruited from across the campus and each student participated in only one experimental session. Each experimental session consisted of 24 subjects. Each session was further divided into 4 groups of 6 students who played the game together. Thus 8 groups were exposed to the benchmark treatment first, 8 groups were exposed to the Buy&Hold treatment first, and 8 groups were exposed to the Buy&Sell treatment first.

Figure I.1 illustrates the price paths over the 11 periods in three treatments: Benchmark (left), Buy&Hold (middle), and Buy&Sell (left). In each panel. the price paths for each of the 8 markets alongside the volume-weighted average price are shown.

The dynamics of prices observed in Benchmark treatment confirm, especially for individual markets, previous results in the literature that prices can deviate quite substantially from the fundamental price (see, for example, Smith et al., 1988; Bostian and Holt, 2009). However, in our experiment, unlike the previous finding in the literature, the average price path exhibits no obvious pattern and is not statistically significantly different from the fundamental price as one can see from the result of statistical tests reported in the top panel of Table I.1. There is initially some variance in prices

Table I.1: Dynamics of average prices (unweighted and weighted) in three treatments

Benchmark treatment

	1	2	3	4	5	6	7	8	9	10	11
Unweighted	124	123	134	117	128	124	127	125	116	119	120
P-value	0.78	0.77	0.28	0.87	0.43	0.65	0.41	0.56	0.45	0.65	0.84
Weighted	118	119	138	108	112	123	129	131	118	122	118
P-value	0.85	0.96	0.14	0.52	0.21	0.75	0.16	0.12	0.67	0.55	0.13

Buy&Hold treatment

	1	2	3	4	5	6	7	8	9	10	11
Unweighted	125	135	136	145	150	153	157	155	155	148	111
P-value	0.70	0.26	0.12	0.01***	0.00***	0.00***	0.01***	0.03**	0.06*	0.11	0.63
Weighted	113	130	136	142	152	162	164	167	171	144	129
P-value	0.48	0.31	0.03**	0.00***	0.00***	0.00***	0.00***	0.01**	0.02**	0.15	0.21

Buy&Sell treatment

	1	2	3	4	5	6	7	8	9	10	11
Unweighted	127	131	134	146	143	148	146	129	121	116	115
P-value	0.49	0.18	0.12	0.01***	0.09*	0.12	0.11	0.05**	0.83	0.25	0.25
Weighted	126	130	133	142	147	148	144	140	118	106	119
P-value	0.48	0.24	0.11	0.01**	0.04**	0.05**	0.08*	0.00***	0.61	0.00***	0.15

Note: P-values are the probability that the sample is drawn from a distribution with a mean equal to the fundamental value of 120 using a two-sided Student's t-test with 7 degrees of freedom. ***$\leq$ 0.01, **$\leq$ 0.05, *$\leq$ 0.1.

but these converge very close to the fundamental price by period 11 in all 8 markets.

The middle panel of Figure I.1 illustrates the results of the Buy&Hold treatment. This shows a quite different profile to the Benchmark and if nothing else indicates that central bank actions can disturb the price determination process. In one market, the market price scarcely deviated from the fundamental price and in two others, prices dropped initially and then rose dramatically before collapsing in a path resembling a bubble. Prices remained at or above the fundamental price in all 8 markets until round 10.[1] Nevertheless, prices in almost all markets converged towards the fundamental price by period 11.[2] Average prices are statistically significantly above the fundamental price from periods 4 to 9 (reported in the middle panel of Table I.1).

The top panel of Table I.2 presents simple comparison of means tests which confirm the visual impression that average prices are statistically significantly higher over periods 5 to 9 when the

[1] With the exception of 1 price in one period at 119.
[2] No trading takes place at the extremely low price in period 11 in one of the games.

Table I.2: Comparison of means

Benchmark vs Buy&Hold

	1	2	3	4	5	6	7	8	9	10	11
Unweighted											
Buy&Hold	125	135	136	145	150	153	157	155	155	148	111
Benchmark	124	123	134	117	128	124	127	125	116	119	120
P-value	0.92	0.50	0.89	0.20	0.07*	0.04**	0.06*	0.08*	0.05*	0.10	0.62
Weighted											
Buy&Hold	113	130	136	142	152	162	164	167	171	144	129
Benchmark	118	119	138	108	112	123	129	131	118	122	118
P-value	0.71	0.46	0.88	0.11	0.00***	0.01***	0.02**	0.05**	0.02**	0.19	0.14

Buy&Hold vs Buy&Sell

	1	2	3	4	5	6	7	8	9	10	11
Unweighted											
Buy&Hold	125	135	136	145	150	153	157	155	155	148	111
Buy&Sell	127	131	134	146	143	148	146	129	121	116	115
P-value	0.95	0.79	0.89	0.95	0.62	0.78	0.56	0.09*	0.07*	0.08*	0.83
Weighted											
Buy&Hold	113	130	136	142	152	162	164	167	171	144	129
Buy&Sell	126	130	133	142	147	148	144	140	118	106	119
P-value	0.33	1.00	0.69	0.93	0.68	0.33	0.24	0.09*	0.02**	0.04**	0.17

Note: P-values using a two-sided Student's t-test with 7 degrees of freedom. ***≤ 0.01, **≤ 0.05, *≤ 0.1.

central bank undertakes QE than when it doesn't.

The left panel of Figure I.1 illustrates the results of the Buy&Sell treatment. As reported in the bottom panel of Table I.1, average prices in this treatment were statistically significantly above fundamentals in periods 4 to 8 in the weighted-average case and periods 4, 5 and 8 in the unweighted case.[3] Prices were then statistically significantly *below* fundamentals in the weighted-average case in period 10. Despite these fluctuating dynamics, prices converged to fundamentals in the final period.

The bottom panel of Table I.2 reports a comparison of means between Buy&Hold and Buy&Sell treatments, and it is evident that behaviour before, during and immediately after the common buy operation are indistinguishable. But prices fall in the case where the central bank subsequent sells and are statistically significantly below the Buy&Hold in periods 8, 9 and 10.

It is clear, therefore, that in these experiments QE does make a significant difference for bond prices and that the two QE treatments have starkly different effects.

[3]Periods 6 and 7 were quite close to the 10% significance threshold.

II Price dynamics in Individual Markets

Figure II.1 illustrates the observed price dynamics in our experiments. The columns indicate, respectively, the Benchmark treatment, the Buy&Hold treatment, and the Buy&Sell treatment. The rows show the first, second and third rounds for each treatment. In each panel, a thin line represents the observations from one market, whereas a thick line represents their median.[4] We observe substantial variations across markets within each treatment.[5]

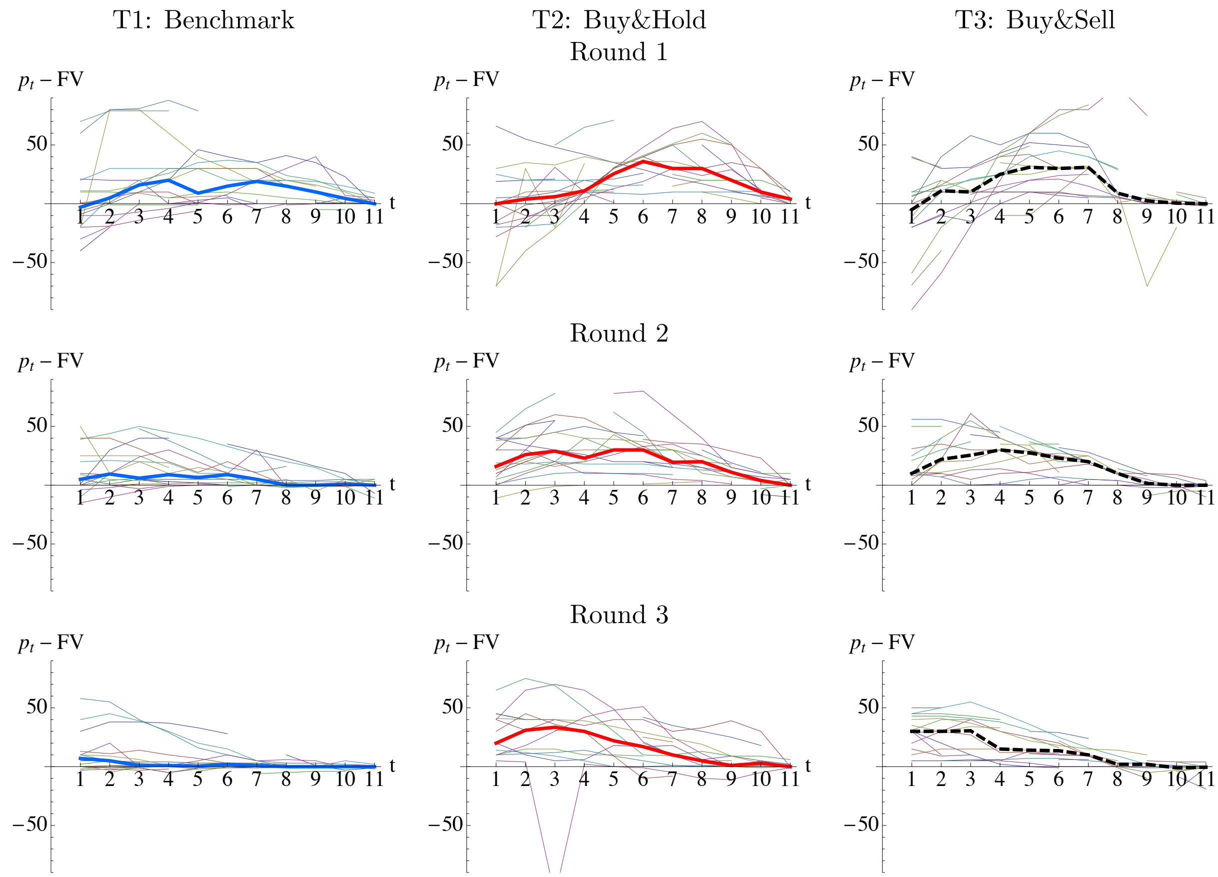


Figure II.1: Dynamics of price deviations in T1: Benchmark (left), T2: Buy&Hold (center), and T3: Buy&Sell (right) over three rounds. The medians across markets are shown using thick lines.

[4]We have eliminated all prices in the periods in which no trading took place, which is why there are some gaps in the series. No transaction is possible when the maximum submitted bid is below the minimum submitted ask or when the quantity demanded or supplied or both are zero.

[5]The literature suggests that these variations can be due to variations in the characteristics of market participants, such as their cognitive ability (Bosch-Rosa et al., 2018; Breaban and Noussair, 2015), their risk preferences (Breaban and Noussair, 2015), and their tendency to speculate (Janssen et al., 2019). We have not gathered data for these individual characteristics, and thus we are not able to further investigate the reason behind the variations within treatment.

III Other measures of market outcomes

Table III.1: Definitions of the measures of mispricing

Relative absolute deviation (RAD)	$\frac{1}{T}\sum_{p=1}^{T}\frac{\lvert P_p - FV_p\rvert}{\lvert\overline{FV}\rvert}$
Relative deviation (RD)	$\frac{1}{T}\sum_{p=1}^{T}\frac{P_p - FV_p}{\lvert\overline{FV}\rvert}$
Geometric absolute deviation (GAD)	$\exp\left(\frac{1}{T}\sum_{p=1}^{T}\left\lvert\ln\left(\frac{P_p}{FV_p}\right)\right\rvert\right) - 1$
Geometric deviation (GD)	$\exp\left(\frac{1}{T}\sum_{p=1}^{T}\ln\left(\frac{P_p}{FV_p}\right)\right) - 1$
Volatility (Vol)	$\text{Vol} = \frac{1}{T-1}\sum_{p=2}^{T}\lvert(P_p - FV_p) - (P_{p-1} - FV_{p-1})\rvert$
Turnover (TO)	$\sum_{p=1}^{T} v_p/OS_p$
Volume-adjusted relative absolute deviation (vRAD)	$\frac{1}{\sum_{p=1}^{T} v_p}\sum_{p=1}^{T} v_p\frac{\lvert P_p - FV_p\rvert}{\lvert\overline{FV}\rvert}$
Volume-adjusted relative deviation (vRD)	$\frac{1}{\sum_{p=1}^{T} v_p}\sum_{p=1}^{T} v_p\frac{P_p - FV_p}{\lvert\overline{FV}\rvert}$
Volume-adjusted geometric absolute deviation (vGAD)	$\exp\left(\frac{1}{\sum_k v_k}\sum_{p=1}^{T} v_p\left\lvert\ln\left(\frac{P_p}{FV_p}\right)\right\rvert\right) - 1$
volume-adjusted geometric deviation (vGD)	$\exp\left(\frac{1}{\sum_k v_k}\sum_{p=1}^{T} v_p\ln\left(\frac{P_p}{FV_p}\right)\right) - 1$

In addition to the vGAD and vGD presented in the main text, we have computed various measures proposed in the literature to characterize market outcomes, as summarized in Table III.1. Furthermore, we consider two measures of the concentration of market activities to a few traders. One measure considers the concentration of transactions, and the other concerns the concentration of a few traders being marginal price setters, which captures the degree to which market prices are determined by a few traders.

To measure the degree of concentration of transactions, we compute, for each market, the normalized Herfindahl index (HIST) based on the share of transactions. We use the normalized index to enable comparisons between markets with two different sizes. Namely, for each subject i in market m, we compute his or her share of transactions s_m^i as:

$$s_m^i = \frac{\sum_{t=1}^{T}\lvert q_t^i\rvert}{\sum_{j\in m}\sum_{t=1}^{T}\lvert q_t^j\rvert} \tag{III.1}$$

where $\lvert q_t^i\rvert$ is the quantity subject i has transacted in period t and $j \in m$ represents subject j in market m. Then, the normalized Herfindahl index for the share of transactions in market m is:

$$HIST_m = \frac{\sum_{i\in m}(s_m^i)^2 - 1/N}{1 - 1/N} \tag{III.2}$$

where N is number of traders in m.

To measure the degree of concentration of subjects being a marginal price setter, we compute, for each market, the normalized Herfindahl index for the share of frequencies for subjects being a marginal price setter. We refer to this as $HIFPS_m$ for market m. We identify the marginal price setter as the buyer (or buyers) who has (have) submitted the buy order with a bid equal to, or the closest bid above, the market-clearing price, and the seller (or sellers) who has (have) submitted the sell order with the ask equal to, or the closest ask below, the market price. In the case where there is no transaction, given the way our price determination algorithm operates, it is the buyer who has submitted the buy order with a bid just below the price, as well as the seller who has submitted the sell order with an ask just above the market price. Note that because, in general, the marginal price-setting buyer and the marginal price-setting seller are different, we have more than one marginal price setter in each period.

Table III.2 reports the means and standard deviations of these measures for each treatment separately for three rounds. It also reports the p-values for treatment comparisons. The treatment comparisons reported in Table III.2 confirm that the differences in the magnitude of mispricing across the three treatments that we have reported in the main text are robust even if we use other mispricing measures. At the same time, Table III.2 shows that the three measures that are not related to non-mispricing – turnover (TO), HIST, and HIFPS – are not significantly different across the three treatments. This suggests that differences in the magnitude of mispricing across the three treatments are not caused by differences in the volume or degree of market concentrations across the treatments.

Table III.2: Mean (standard deviation) of various measures of market outcomes

	Benchmark	Buy&Hold	Buy&Sell	T1=T2=T3[a]	T1=T2[b]	T1=T3[b]	T2=T3[b]
				Round 1			
RAD	0.137 (0.115)	0.178 (0.073)	0.182 (0.111)	p=0.201	p=0.105	p=0.150	p=0.880
RD	0.108 (0.120)	0.139 (0.086)	0.121 (0.096)	p=0.498	p=0.235	p=0.471	p=0.720
GAD	0.133 (0.107)	0.180 (0.075)	0.193 (0.135)	p=0.159	p=0.098	p=0.105	p=0.821
GD	0.099 (0.110)	0.125 (0.089)	0.098 (0.094)	p=0.562	p=0.313	p=0.719	p=0.451
TO	0.684 (0.275)	0.759 (0.218)	0.658 (0.351)	p=0.160	p=0.207	p=0.678	p=0.052
VOL	6.600 (4.733)	10.08 (5.966)	10.92 (7.244)	p=0.069	p=0.048	p=0.048	p=0.970
vRAD	0.148 (0.133)	0.197 (0.090)	0.180 (0.115)	p=0.157	p=0.084	p=0.171	p=0.407
vRD	0.113 (0.143)	0.120 (0.115)	0.120 (0.114)	p=0.664	p=0.471	p=0.407	p=0.940
vGAD	0.146 (0.126)	0.214 (0.125)	0.189 (0.132)	p=0.125	p=0.056	p=0.183	p=0.386
vGD	0.104 (0.135)	0.101 (0.133)	0.100 (0.104)	p=0.749	p=0.517	p=0.517	p=0.910
HIST	0.048 (0.032)	0.067 (0.051)	0.044 (0.018)	p=0.734	p=0.494	p=0.692	p=0.572
HIFPS	0.036 (0.021)	0.060 (0.042)	0.053 (0.024)	p=0.134	p=0.098	p=0.078	p=0.792
				Round 2			
RAD	0.080 (0.079)	0.187 (0.091)	0.138 (0.073)	p=0.004	p=0.002	p=0.031	p=0.147
RD	0.072 (0.084)	0.171 (0.093)	0.132 (0.072)	p=0.008	p=0.005	p=0.022	p=0.250
GAD	0.078 (0.076)	0.215 (0.186)	0.133 (0.069)	p=0.003	p=0.002	p=0.026	p=0.142
GD	0.069 (0.082)	0.144 (0.135)	0.127 (0.069)	p=0.016	p=0.013	p=0.021	p=0.327
TO	0.745 (0.352)	0.741 (0.211)	0.640 (0.273)	p=0.412	p=0.601	p=0.540	p=0.152
VOL	4.041 (3.248)	7.769 (7.328)	5.775 (3.166)	p=0.094	p=0.042	p=0.109	p=0.611
vRAD	0.092 (0.082)	0.196 (0.092)	0.149 (0.080)	p=0.008	p=0.003	p=0.056	p=0.152
vRD	0.077 (0.092)	0.191 (0.094)	0.145 (0.078)	p=0.006	p=0.002	p=0.037	p=0.200
vGAD	0.089 (0.079)	0.190 (0.088)	0.144 (0.077)	p=0.007	p=0.003	p=0.061	p=0.132
vGD	0.073 (0.089)	0.184 (0.089)	0.140 (0.075)	p=0.005	p=0.002	p=0.031	p=0.214
HIST	0.072 (0.066)	0.061 (0.042)	0.057 (0.026)	p=0.869	p=0.885	p=0.564	p=0.792
HIFPS	0.061 (0.034)	0.054 (0.020)	0.053 (0.025)	p=0.808	p=1.000	p=0.505	p=0.651
				Round 3			
RAD	0.051 (0.059)	0.152 (0.085)	0.131 (0.091)	p<0.001	p<0.001	p=0.002	p=0.366
RD	0.029 (0.072)	0.133 (0.107)	0.101 (0.066)	p=0.001	p=0.002	p=0.002	p=0.274
GAD	0.076 (0.134)	0.158 (0.088)	0.169 (0.236)	p=0.001	p=0.001	p=0.004	p=0.228
GD	0.012 (0.112)	0.119 (0.122)	0.075 (0.117)	p=0.001	p=0.001	p=0.006	p=0.228
TO	0.656 (0.253)	0.727 (0.323)	0.607 (0.223)	p=0.549	p=0.540	p=0.577	p=0.291
VOL	3.659 (5.564)	6.838 (5.585)	5.731 (6.687)	p=0.018	p=0.004	p=0.135	p=0.235
vRAD	0.054 (0.072)	0.178 (0.100)	0.148 (0.089)	p<0.001	p<0.001	p=0.001	p=0.327
vRD	0.043 (0.078)	0.143 (0.143)	0.132 (0.086)	p=0.002	p=0.004	p=0.001	p=0.429
vGAD	0.052 (0.069)	0.210 (0.198)	0.145 (0.088)	p<0.001	p<0.001	p=0.001	p=0.327
vGD	0.012 (0.074)	0.123 (0.182)	0.126 (0.085)	p=0.001	p=0.004	p=0.001	p=0.451
HIST	0.068 (0.058)	0.054 (0.037)	0.063 (0.037)	p=0.665	p=0.666	p=0.692	p=0.346
HIFPS	0.051 (0.017)	0.050 (0.024)	0.047 (0.025)	p=0.668	p=0.957	p=0.313	p=0.624

a Based on the KW test
b Based on the MW test

IV Comparison between outcomes of two market sizes

We compare the outcomes for markets with six and 12 players, based on various measures of market outcomes (subsection IV.1), outcomes of the interventions (subsection IV.2), and forecast deviations (subsection IV.3)

IV.1 Market characteristics

Table IV.1 reports, for each round and each treatment, means and the standard deviations of various measures of market outcomes presented in Appendix III separately for markets with six traders/market experiment and 12 traders/market experiment. The p-values from two-sample permutation tests (two-tailed) are also reported.

For the Benchmark and Buy&Hold treatments, except for HIST or HIFPS in Rounds 1 and 2, we do not observe any statistically significant difference in all the measures that we consider between the sessions with six traders and 12 traders in any of the three rounds. In the Buy&Sell treatment, we observe many measures of mispricing to be marginally significantly different between the two market sizes in Rounds 1 and 2. Among them, however, only vGAD in Round 1, and RD and GD in Round 2 are significantly different at the 5% level.

IV.2 Outcomes of Buy&Sell operations

We compare the outcomes in the buy as well as the sell operations between two market sizes. We analyse (a) the share of traders participating in, i.e., submitting bids or asks, these operations (sAsk_t and sBid_t for buy and sell operations in period t, respectively), (b) the coefficient of variation in the bids or asks submitted (cvAsk_t and cvBid_t for buy and sell operations in period t, respectively), (c) the degree of concentration of the transactions during the operation measured by the normalized Herfindahl index (HISTB_t and HISTS_t for buy and sell operations in period t, and HIST_B and HIST_S for buy operations and sell operations over two periods), (d) the average price paid for a unit of bonds by the central bank in their buy operations (avePB_t for period t, and aveP_B over two periods), and (d) the average price received by the central bank for a unit of bonds in their sell operation (avePS_t for period t, and aveP_S over two periods).

Table IV.2 shows the results. We observe statistically significant difference in the two market sizes in the degree of concentrations of transactions in buy operation (HIST_B) in Rounds 1 and 2 of

Table IV.1: Comparison between six 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)	0.747	0.061 (0.069)	0.040 (0.048)	0.481
RD	0.117 (0.160)	0.098 (0.060)	0.769	0.060 (0.092)	0.085 (0.078)	0.541	0.024 (0.089)	0.036 (0.051)	0.737
GAD	0.155 (0.136)	0.108 (0.061)	0.390	0.072 (0.081)	0.084 (0.075)	0.762	0.110 (0.177)	0.038 (0.046)	0.333
GD	0.102 (0.145)	0.095 (0.060)	0.901	0.057 (0.089)	0.082 (0.076)	0.531	-0.008 (0.149)	0.034 (0.049)	0.532
TO	0.604 (0.210)	0.775 (0.323)	0.221	0.711 (0.358)	0.784 (0.366)	0.681	0.648 (0.313)	0.665 (0.184)	0.894
VOL	8.011 (5.821)	5.013 (2.655)	0.202	3.989 (3.295)	4.050 (3.421)	0.940	4.756 (7.458)	2.425 (1.972)	0.581
vRAD	0.179 (0.175)	0.114 (0.054)	0.349	0.084 (0.088)	0.100 (0.080)	0.687	0.056 (0.082)	0.051 (0.065)	0.975
vRD	0.123 (0.196)	0.103 (0.053)	0.777	0.058 (0.103)	0.098 (0.080)	0.384	0.041 (0.090)	0.047 (0.068)	0.887
vGAD	0.176 (0.164)	0.112 (0.054)	0.327	0.082 (0.084)	0.097 (0.077)	0.691	0.054 (0.077)	0.049 (0.062)	0.979
vGD	0.109 (0.184)	0.099 (0.053)	0.885	0.054 (0.098)	0.095 (0.077)	0.359	0.038 (0.085)	0.045 (0.065)	0.872
HIST	0.062 (0.036)	0.033 (0.019)	**0.050**	0.094 (0.083)	0.047 (0.028)	0.160	0.083 (0.072)	0.050 (0.032)	0.246
HIFPS	0.042 (0.025)	0.030 (0.014)	0.223	0.063 (0.039)	0.058 (0.031)	0.768	0.055 (0.020)	0.047 (0.014)	0.370

	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)	0.187	0.185 (0.100)	0.188 (0.088)	0.949	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
GAD	0.154 (0.072)	0.205 (0.073)	0.182	0.249 (0.255)	0.182 (0.083)	0.650	0.186 (0.083)	0.130 (0.090)	0.217
GD	0.115 (0.096)	0.135 (0.088)	0.676	0.108 (0.171)	0.181 (0.083)	0.318	0.112 (0.153)	0.126 (0.092)	0.854
TO	0.749 (0.265)	0.768 (0.178)	0.865	0.752 (0.248)	0.730 (0.184)	0.851	0.723 (0.433)	0.732 (0.192)	0.972
VOL	10.625 (6.233)	9.525 (6.059)	0.738	9.012 (9.670)	6.525 (4.247)	0.649	8.338 (7.051)	5.338 (3.462)	0.346
vRAD	0.178 (0.102)	0.216 (0.078)	0.412	0.199 (0.109)	0.201 (0.079)	0.832	0.200 (0.097)	0.156 (0.106)	0.392
vRD	0.115 (0.124)	0.124 (0.114)	0.875	0.181 (0.111)	0.201 (0.079)	0.684	0.134 (0.181)	0.153 (0.104)	0.806
vGAD	0.195 (0.135)	0.233 (0.121)	0.556	0.186 (0.104)	0.194 (0.074)	0.848	0.270 (0.257)	0.151 (0.100)	0.252
vGD	0.100 (0.142)	0.102 (0.133)	0.979	0.174 (0.107)	0.194 (0.074)	0.657	0.099 (0.245)	0.148 (0.099)	0.713
HIST	0.099 (0.053)	0.035 (0.020)	**0.006**	0.076 (0.051)	0.045 (0.025)	0.145	0.060 (0.044)	0.048 (0.030)	0.617
HIFPS	0.082 (0.050)	0.038 (0.015)	**0.036**	0.064 (0.023)	0.043 (0.008)	**0.022**	0.044 (0.023)	0.055 (0.025)	0.385

	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)	**0.064**	0.172 (0.057)	0.104 (0.074)	**0.060**	0.159 (0.103)	0.103 (0.073)	0.234
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
GAD	0.254 (0.144)	0.132 (0.099)	**0.054**	0.165 (0.054)	0.101 (0.071)	**0.059**	0.238 (0.322)	0.100 (0.070)	0.223
GD	0.115 (0.114)	0.081 (0.082)	0.481	0.160 (0.058)	0.093 (0.064)	**0.046**	0.057 (0.155)	0.092 (0.069)	0.684
TO	0.726 (0.498)	0.591 (0.075)	0.462	0.614 (0.374)	0.666 (0.135)	0.750	0.603 (0.281)	0.612 (0.165)	0.936
VOL	13.313 (7.239)	8.525 (6.853)	0.207	6.700 (2.934)	4.850 (3.305)	0.260	8.350 (8.610)	3.113 (2.450)	**0.053**
vRAD	0.240 (0.116)	0.121 (0.081)	**0.054**	0.182 (0.061)	0.115 (0.086)	**0.096**	0.173 (0.082)	0.123 (0.095)	0.273
vRD	0.164 (0.133)	0.076 (0.074)	0.127	0.180 (0.062)	0.110 (0.081)	**0.074**	0.147 (0.081)	0.118 (0.094)	0.522
vGAD	0.257 (0.141)	0.122 (0.084)	**0.025**	0.175 (0.059)	0.113 (0.083)	0.104	0.170 (0.082)	0.120 (0.092)	0.264
vGD	0.135 (0.126)	0.065 (0.066)	0.188	0.173 (0.060)	0.106 (0.077)	**0.076**	0.138 (0.082)	0.114 (0.091)	0.587
HIST	0.054 (0.021)	0.034 (0.008)	**0.028**	0.070 (0.027)	0.045 (0.018)	**0.045**	0.078 (0.044)	0.047 (0.022)	0.100
HIFPS	0.052 (0.033)	0.054 (0.015)	0.903	0.064 (0.030)	0.041 (0.011)	**0.057**	0.053 (0.034)	0.042 (0.014)	0.385

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

both the Buy&Hold and the Buy&Sell treatments, as well as in the sell operations (HIST_S) in Round 2. In the Buy&Sell treatment, we also observe statistically significant difference in the coefficient of variation of asks in Round 1 as well as average price the central bank bought and sold in Round 2. Apart from these, there are no statistically significant differences between the two market sizes in the measures we have considered.

IV.3 Forecasts deviations

Figures IV.1, IV.2, and IV.3 show the dynamics of the average $RAFD_t$ and RFD_t for six traders/session (solid) and 12 traders/ session (dashed) in the benchmark, the Buy&Hold, and the Buy&Sell treatment, respectively. It also shows the p-values of the market size effect. Note that we are simply taking the 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, which correct for the clustering effect (at group level), of the form $Y = \alpha + \beta D_{12}$, where Y is either $RAFD$ or RFD and D_{12} takes a value of one for 12 traders/session and zero for six traders/session, and testing whether β is significantly different from zero.

$RAFD_t$ and RFD_t are not statistically significantly different (at the 10% level) between the two market sizes in any of the periods in the benchmark treatment. Similarly, for the Buy&Hold treatment, except for the $RAFD_t$ in period 10 of Round 1, they are not statistically significantly different at the 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 the 10% level between the two market sizes. Nevertheless, for most of the periods, they are not statistically significantly different.

Table IV.2: Market interventions. Comparison between six traders/market sessions and 12 traders/market sessions

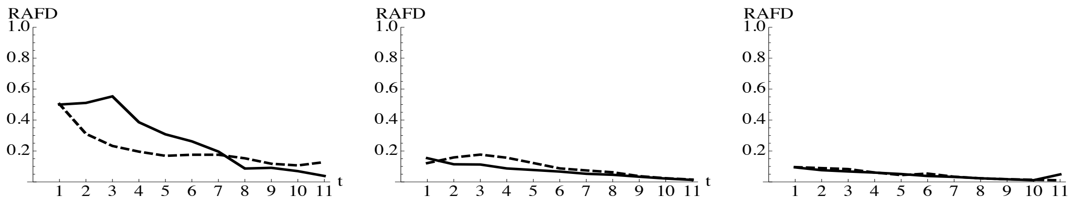
	Buy&Hold Round 1			Buy&Hold Round 2			Buy&Hold Round 3		
	6 traders	12 traders	p-value	6 traders	12 traders	p-value	6 traders	12 traders	p-value
$sAsk_4$	0.875 (0.077)	0.792 (0.100)	0.138	0.854 (0.165)	0.927 (0.053)	0.189	0.854 (0.165)	0.885 (0.088)	0.750
$sAsk_5$	0.833 (0.089)	0.802 (0.099)	0.655	0.854 (0.107)	0.802 (0.109)	0.452	0.854 (0.188)	0.792 (0.118)	0.515
$cvAsk_4$	0.724 (0.473)	0.623 (0.381)	0.635	0.328 (0.418)	0.315 (0.475)	0.956	0.168 (0.328)	0.262 (0.527)	0.546
$cvAsk_5$	0.276 (0.408)	0.378 (0.319)	0.594	0.341 (0.490)	0.268 (0.520)	0.565	0.226 (0.376)	0.067 (0.042)	0.201
$HISTB_4$	0.564 (0.311)	0.257 (0.100)	**0.014**	0.663 (0.366)	0.251 (0.989)	**0.01**	0.545 (0.304)	0.369 (0.135)	0.174
$HISTB_5$	0.452 (0.297)	0.249 (0.150)	0.107	0.531 (0.321)	0.373 (0.293)	0.315	0.508 (0.299)	0.498 (0.273)	0.947
$avePB_4$	140.9 (20.63)	146.3 (16.91)	0.571	180.0 (65.09)	154.6 (16.29)	0.358	155.4 (25.05)	152.5 (17.98)	0.792
$avePB_5$	161.7 (40.57)	149.5 (9.91)	0.460	160.0 (30.10)	156.7 (20.28)	0.797	151.2 (25.04)	147.1 (20.94)	0.722
$HIST_B$	0.338 (0.180)	0.156 (0.087)	**0.020**	0.256 (0.114)	0.123 (0.065)	**0.015**	0.223 (0.120)	0.202 (0.047)	0.664
$aveP_B$	151.3 (24.70)	147.9 (12.29)	0.731	170.0 (45.79)	155.4 (16.28)	0.464	153.3 (24.20)	149.8 (19.34)	0.748

	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
$sAsk_4$	0.917 (0.126)	0.896 (0.124)	0.873	0.896 (0.177)	0.875 (0.109)	0.898	0.917 (0.089)	0.938 (0.059)	0.423
$sAsk_5$	0.771 (0.177)	0.865 (0.147)	0.217	0.792 (0.214)	0.844 (0.094)	0.546	0.875 (0.148)	0.885 (0.062)	0.779
$cvAsk_4$	0.397 (0.444)	1.062 (0.617)	**0.028**	0.251 (0.470)	0.333 (0.594)	0.568	0.066 (0.051)	0.422 (0.682)	0.222
$cvAsk_5$	0.108 (0.078)	0.382 (0.576)	**0.083**	0.067 (0.069)	0.229 (0.424)	0.349	0.061 (0.057)	0.237 (0.519)	0.616
$HISTS_4$	0.484 (0.377)	0.308 (0.223)	0.273	0.545 (0.390)	0.169 (0.066)	**0.009**	0.419 (0.189)	0.375 (0.170)	0.624
$HISTS_5$	0.258 (0.193)	0.205 (0.132)	0.528	0.475 (0.293)	0.354 (0.197)	0.345	0.611 (0.335)	0.379 (0.278)	0.139
$avePB_4$	148.8 (27.36)	136.7 (19.80)	0.317	165.5 (14.72)	146.0 (19.83)	**0.045**	153.8 (13.80)	143.1 (20.27)	0.274
$avePB_5$	162.8 (17.00)	146.4 (17.71)	**0.080**	163.0 (10.42)	145.1 (15.25)	**0.018**	148.8 (14.57)	137.9 (17.20)	0.193
$HIST_B$	0.531 (0.164)	0.377 (0.139)	**0.064**	0.646 (0.357)	0.336 (0.104)	**0.023**	0.658 (0.207)	0.459 (0.262)	0.118
$aveP_B$	155.7 (20.95)	141.5 (18.32)	0.165	164.3 (12.00)	145.6 (17.02)	**0.026**	150.8 (14.07)	140.5 (18.67)	0.232
$sBid_8$	0.875 (0.118)	0.927 (0.083)	0.243	0.917 (0.126)	0.917 (0.077)	1.000	0.896 (0.124)	0.865 (0.133)	0.742
$sBid_9$	0.854 (0.107)	0.885 (0.109)	0.559	0.875 (0.173)	0.823 (0.129)	0.595	0.854 (0.107)	0.854 (0.118)	0.911
$cvBid_8$	0.220 (0.128)	0.340 (0.188)	0.156	0.163 (0.177)	0.101 (0.078)	0.463	0.203 (0.197)	0.097 (0.099)	0.199
$cvBid_9$	0.218 (0.142)	0.203 (0.137)	0.836	0.141 (0.152)	0.097 (0.119)	0.512	0.261 (0.373)	0.101 (0.113)	0.328
$HISTS_8$	0.269 (0.127)	0.221 (0.137)	0.482	0.503 (0.278)	0.256 (0.210)	**0.068**	0.376 (0.200)	0.210 (0.096)	**0.050**
$HISTS_9$	0.489 (0.276)	0.250 (0.208)	**0.068**	0.409 (0.158)	0.281 (0.252)	0.254	0.637 (0.362)	0.400 (0.310)	0.174
$avePS_8$	147.6 (37.21)	143.7 (19.56)	0.801	131.3 (9.57)	126.1 (3.53)	0.171	124.3 (12.05)	124.7 (5.45)	0.931
$avePS_9$	136.8 (29.19)	132.6 (16.03)	0.773	127.5 (6.90)	123.1 (3.27)	0.128	109.7 (28.46)	121.7 (3.62)	0.179
$HIST_S$	0.604 (0.257)	0.391 (0.234)	0.109	0.787 (0.206)	0.369 (0.129)	**0.001**	0.756 (0.345)	0.485 (0.162)	**0.060**
$aveP_S$	142.2 (31.48)	138.1 (17.15)	0.796	129.4 (6.72)	124.6 (2.70)	**0.084**	116.3 (14.66)	123.2 (4.24)	0.215

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

Dynamics of the average RAFD_t in the Benchmark

Round 1 Round 2 Round 3

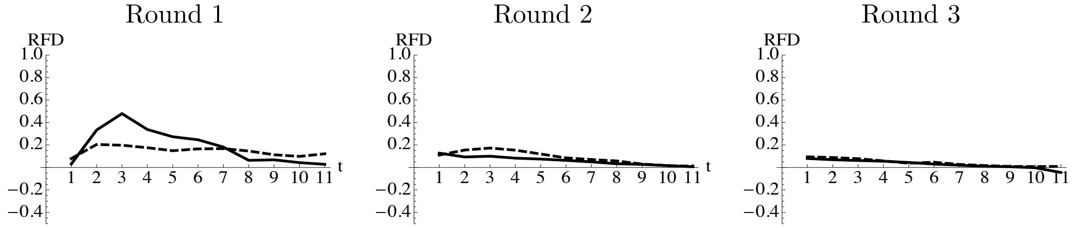


P-values for the treatment difference

	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11
Round 1	0.974	0.186	0.152	0.146	0.174	0.396	0.796	0.153	0.577	0.450	0.293
Round 2	0.546	0.440	0.172	0.193	0.306	0.539	0.458	0.536	0.831	0.860	0.697
Round 3	0.966	0.764	0.725	0.985	0.823	0.569	0.942	0.998	0.929	0.570	0.293

Dynamics of the average RFD_t in the Benchmark

Round 1 Round 2 Round 3

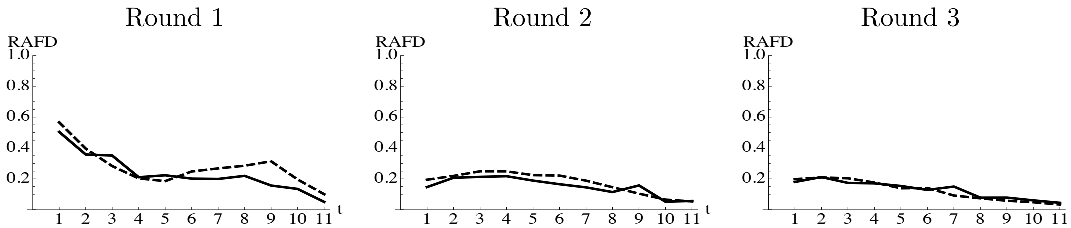


P-values for the treatment difference

	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11
Round 1	0.621	0.401	0.242	0.256	0.264	0.444	0.862	0.087	0.355	0.267	0.276
Round 2	0.772	0.312	0.135	0.185	0.302	0.507	0.481	0.357	0.863	0.927	0.371
Round 3	0.743	0.671	0.721	0.936	0.823	0.545	0.731	0.534	0.641	0.067	0.146

Figure IV.1: Dynamics of the average RAFD_t (top) and the average RFD_t (bottom) over 10 periods in three rounds of the Benchmark treatment for sessions with six traders (solid) and 12 traders (dashed).

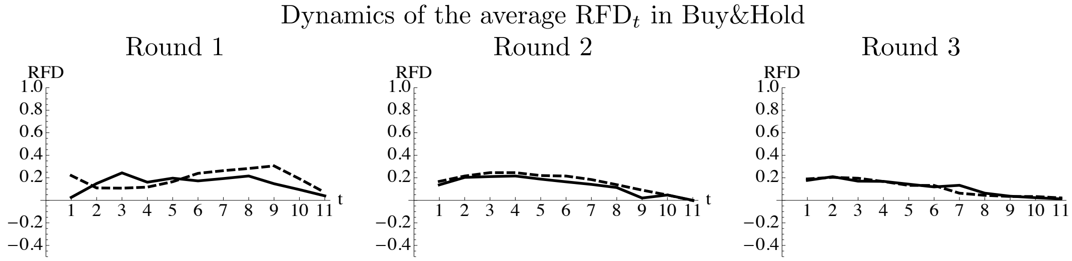
Dynamics of the average RAFD_t in Buy&Hold



P-values for the treatment difference

	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11
Round 1	0.580	0.625	0.629	0.886	0.447	0.529	0.358	0.452	0.161	0.275	**0.057**
Round 2	0.224	0.840	0.610	0.671	0.586	0.362	0.406	0.433	0.439	0.573	0.912
Round 3	0.716	0.975	0.631	0.922	0.756	0.770	0.232	0.892	0.485	0.667	0.599

Dynamics of the average RFD_t in Buy&Hold



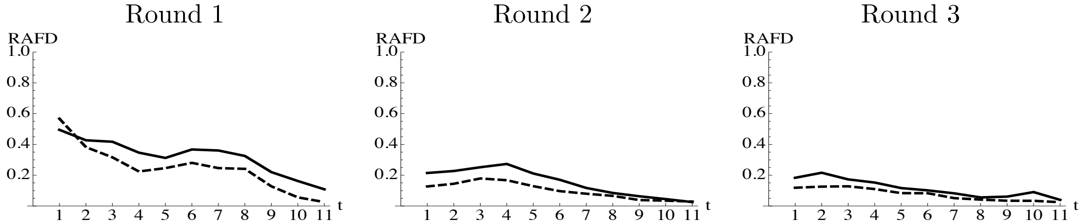
P-values for the treatment difference

	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11
Round 1	0.220	0.798	0.307	0.516	0.566	0.399	0.343	0.445	0.145	0.143	0.335
Round 2	0.490	0.840	0.628	0.688	0.625	0.410	0.417	0.519	0.394	0.997	0.950
Round 3	0.801	0.938	0.685	0.981	0.835	0.785	0.190	0.625	0.955	0.780	0.748

Figure IV.2: Dynamics of the average RAFD_t (top) and the average RFD_t (bottom) over 10 periods in three rounds of the Buy&Hold treatment for sessions with six traders (solid) and 12 traders (dashed).

Dynamics of the average RAFD_t in Buy&Sell

Round 1 Round 2 Round 3

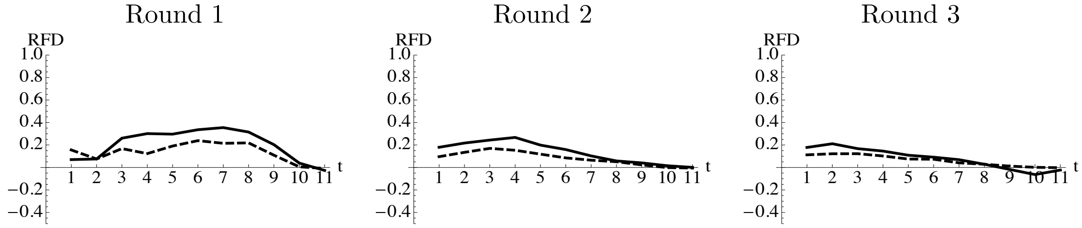


P-values for the treatment difference

	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11
Round 1	0.624	0.534	0.406	0.070	0.556	0.545	0.416	0.455	0.438	0.111	**0.037**
Round 2	**0.052**	0.174	0.392	0.252	**0.040**	**0.019**	**0.099**	0.283	0.199	0.486	0.723
Round 3	**0.062**	**0.063**	0.271	0.265	0.243	0.496	**0.059**	0.306	0.282	0.308	0.275

Dynamics of the average RFD_t in Buy&Sell

Round 1 Round 2 Round 3



P-values for the treatment difference

	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9	t=10	t=11
Round 1	0.595	0.999	0.379	0.057	0.409	0.540	0.344	0.410	0.449	0.690	0.572
Round 2	**0.092**	0.197	0.390	0.219	**0.039**	**0.016**	0.144	0.736	0.396	0.461	0.716
Round 3	**0.056**	**0.063**	0.270	0.245	0.239	0.501	0.121	0.997	0.343	0.299	0.313

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

V Supply and demand schedules during central bank operations

Figures V.4 to V.7 show the supply schedules constructed from orders submitted during the buy operations for each group and treatment. Red line is for the operation between periods 3 and 4, and blue dashed line is for the one between periods 4 and 5. The equilibrium supply schedule is shown in gray solid line while the quantity to be purchased is shown in gray dashed vertical line. For each group, the outcomes from three rounds are displayed.

Figures V.8 and V.9 show the demand schedules constructed from orders submitted during the sell operation for each group and treatment. Just as for the supply schedules shown in Figures V.4 to V.7, red line is for the operation between periods 7 and 8, and blue dashed line is for the one between periods 8 and 9. The equilibrium demand schedule is shown in gray solid line while the quantity to be sold is shown in gray dashed vertical line. For each group, the outcomes from three rounds are displayed. Unlike the supply schedules for the buy operations, convergence to the equilibrium is observed by Round 3 in many of the groups shown in Figures V.8 and V.9.

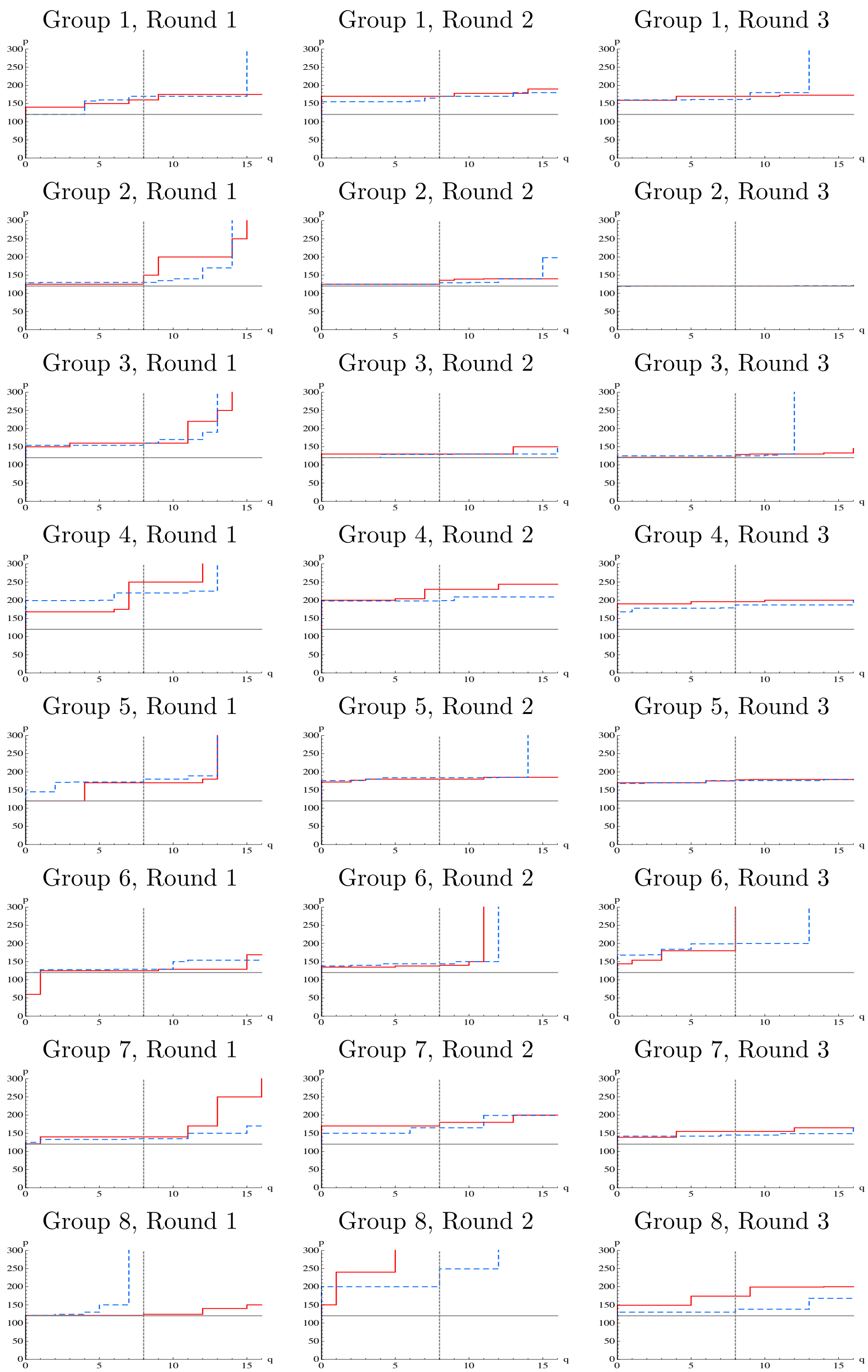


Figure V.4: Supply schedule during Buy operation. The one between periods 3 and 4 is shown in red, and the one between periods 4 and 5 is shown in blue dashed. Buy & Hold. N=6

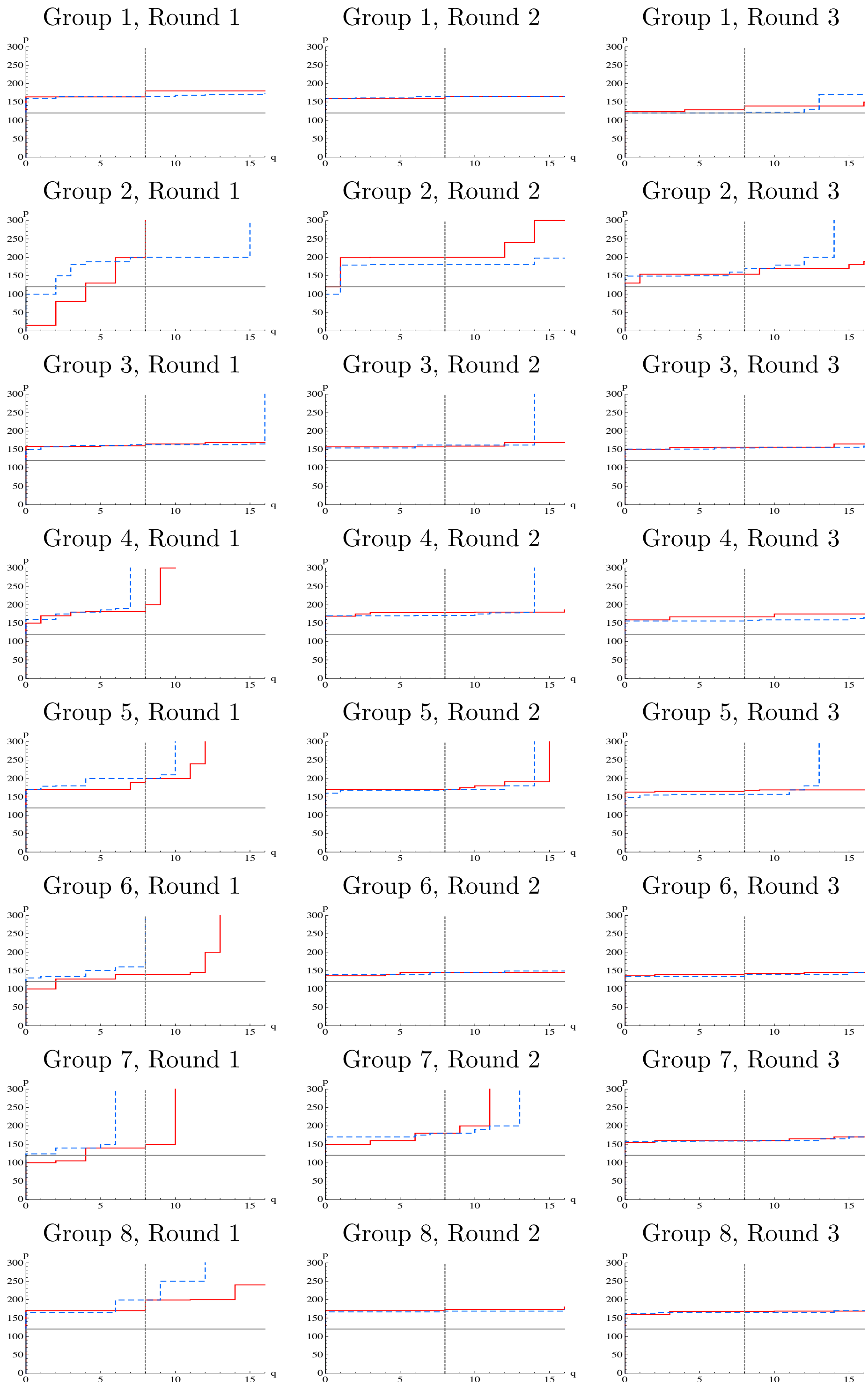


Figure V.5: Supply schedule during Buy operation. The one between periods 3 and 4 is shown in red, and the one between periods 4 and 5 is shown in blue dashed. Buy & Sell. N=6

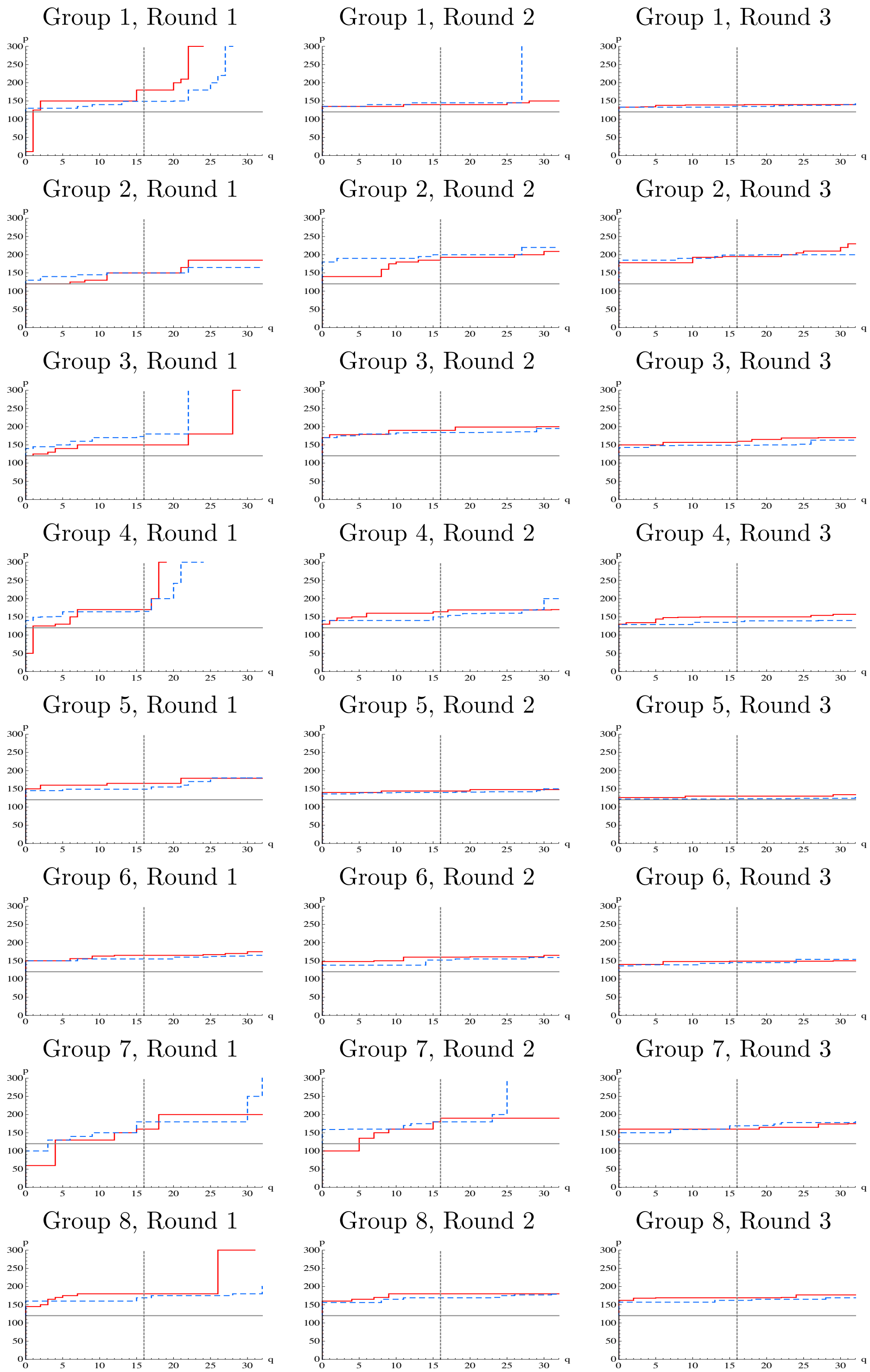


Figure V.6: Supply schedule during Buy operation. The one between periods 3 and 4 is shown in red, and the one between periods 4 and 5 is shown in blue dashed. Buy & Hold. N=12

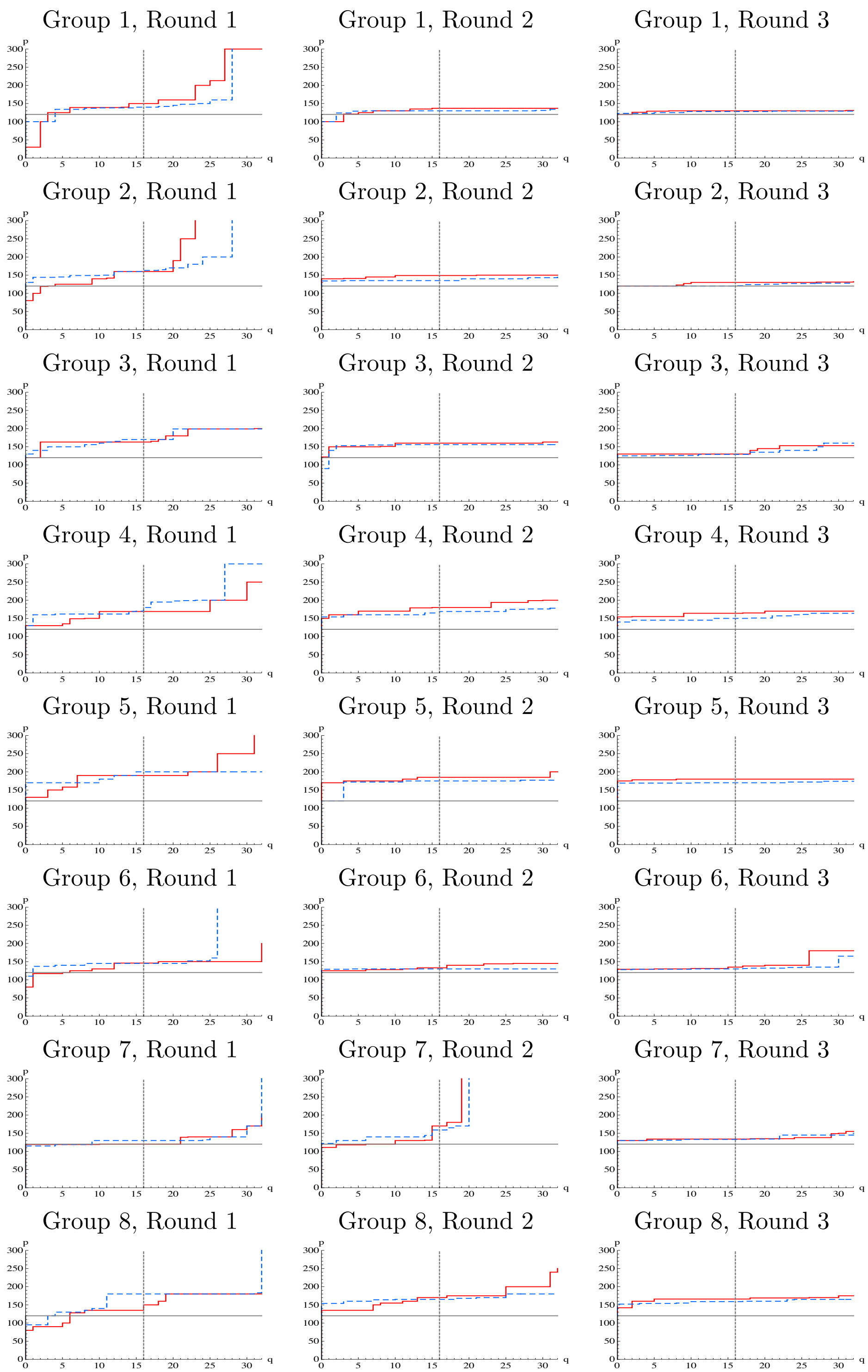


Figure V.7: Supply schedule during Buy operation. The one between periods 3 and 4 is shown in red, and the one between periods 4 and 5 is shown in blue dashed. Buy & Sell. N=12

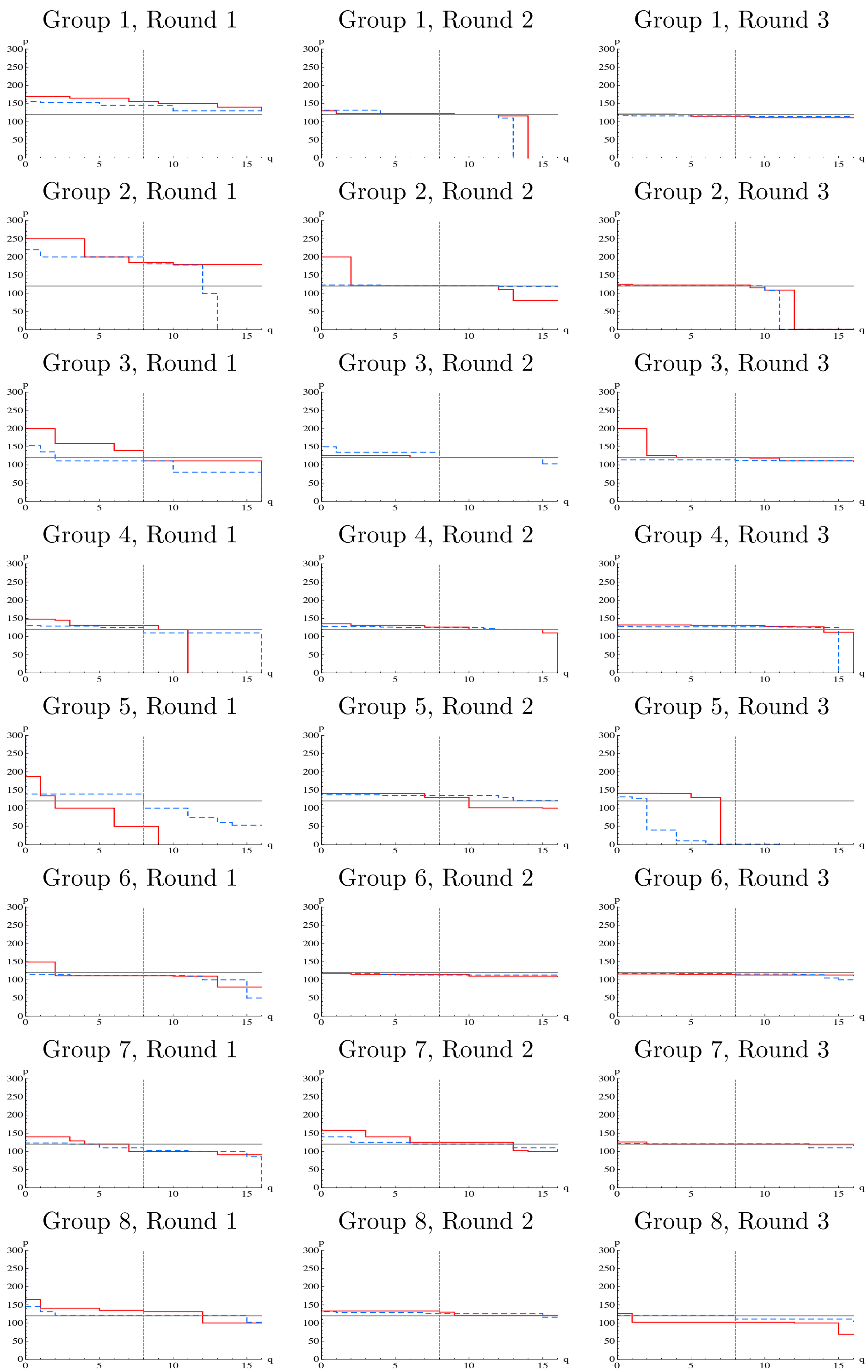


Figure V.8: Demand schedule during Sell operation. The one between periods 7 and 8 is shown in red, and the one between periods 8 and 9 is shown in blue dashed. Buy & Sell. N=6

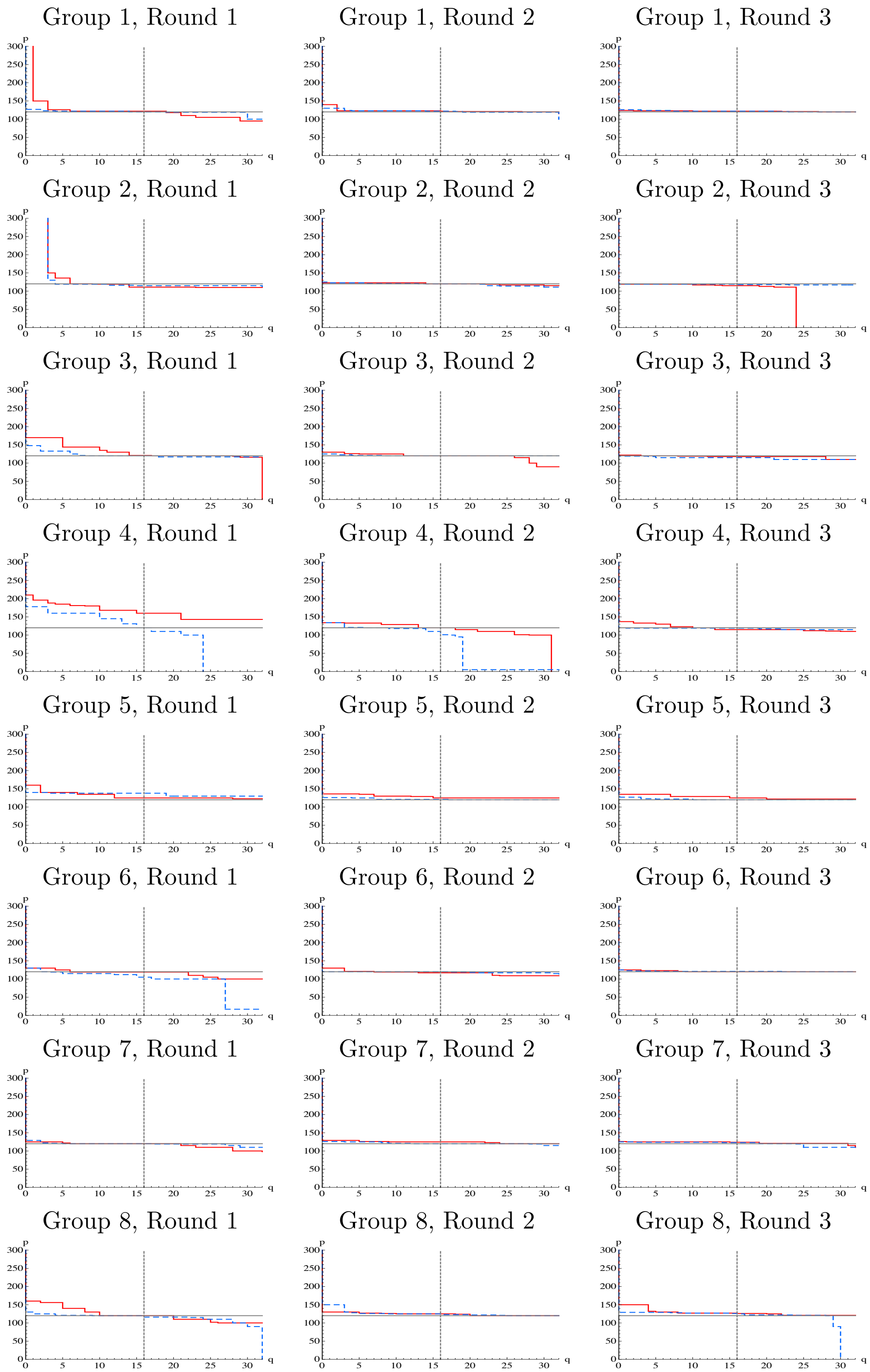


Figure V.9: Demand schedule during Sell operation. The one between periods 7 and 8 is shown in red, and the one between periods 8 and 9 is shown in blue dashed. Buy & Sell. N=12

VI 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.

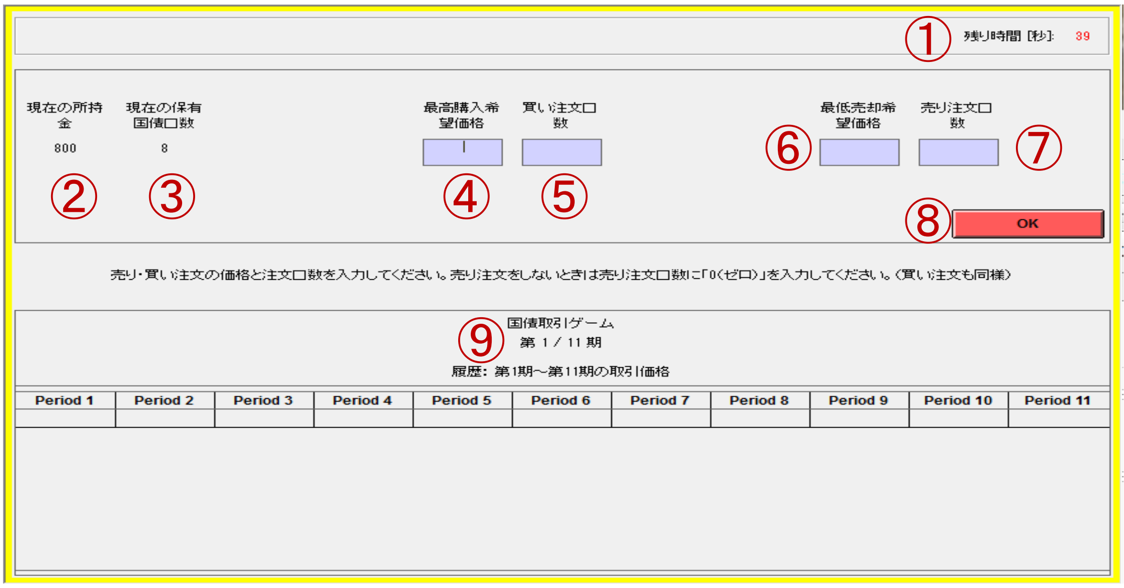
[Earning a profit margin]

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 (selling price) - 100 (purchase price) = 20 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 (selling price) - 100 (purchase price) = 20 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.



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) × (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.

- <u>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.</u>
- <u>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.</u>
- 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 <u>to equate the number of buy orders and the number of sell orders</u>.

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.

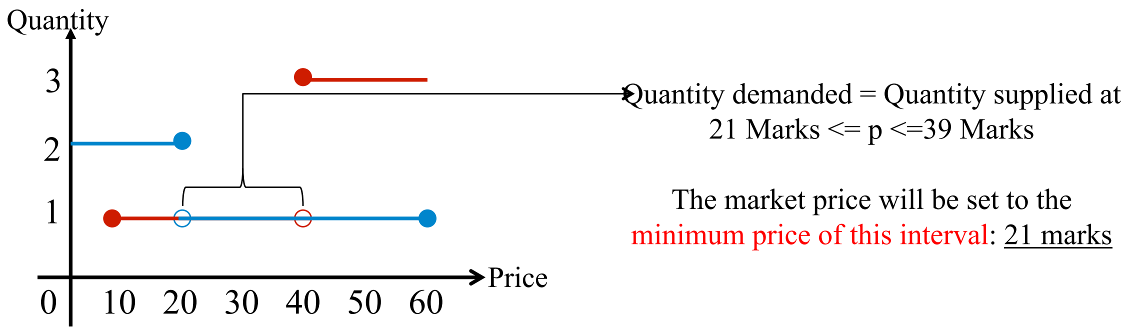
—Trader 1: One sell order, which can be executed at 10 Marks or higher

—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

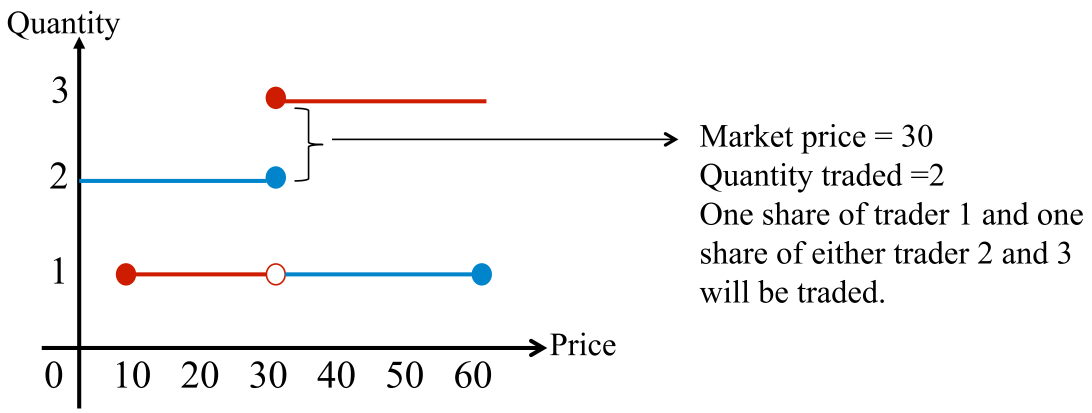
—Trader 2: One sell order, which can be executed at 30 Marks or higher

—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.

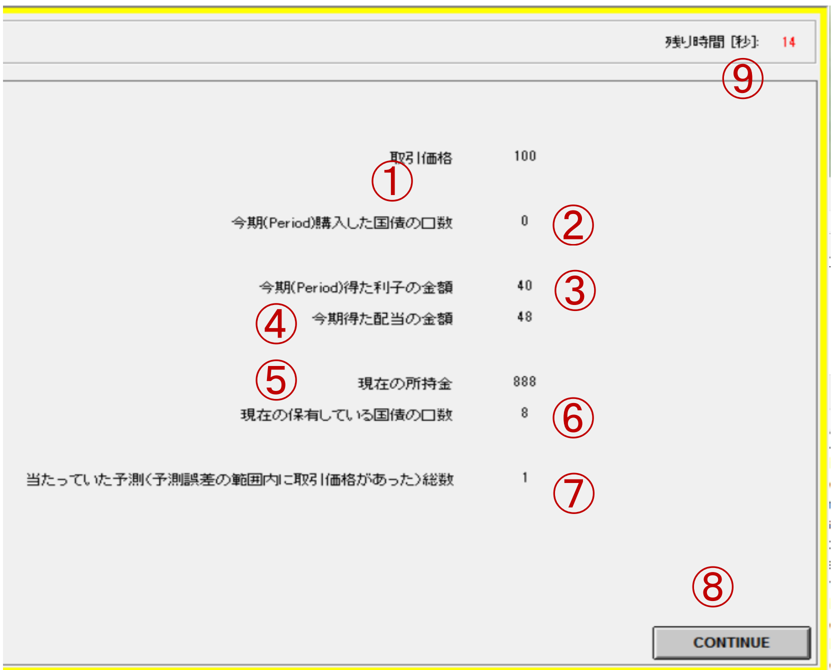


As shown above, only one bond is supplied at 10 Marks as in the previous example. If the price rises to 30 Marks, the number of bonds that are supplied increases to three. However, there is only one bond demanded at 60 Marks. If the price falls to 30 Marks, the quantity demanded increases to two. As 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.



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 <u>for the bonds you hold at the end of each period</u>. 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.

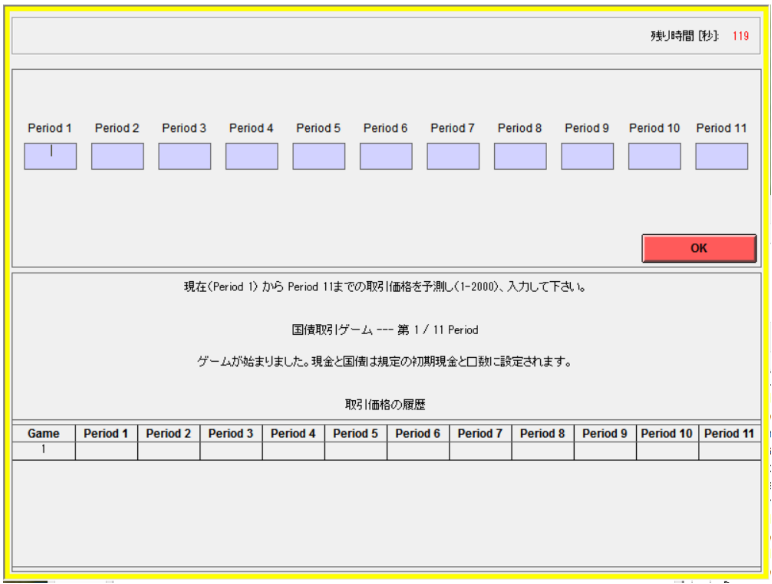
Please turn to the next page.

[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".



[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) x 0.5% x (the number of accurate predictions). The maximum bonus percentage is 0.5% x 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]

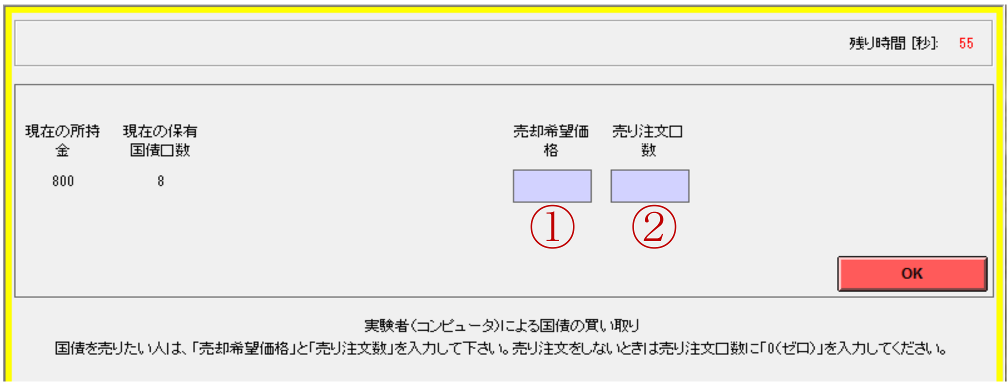
During this game, the computer will buy bonds you hold. The buying operation will be conducted before the beginning of the 4^{th} and 5^{th} periods. During these two operations, you will be asked to submit a sell order. The computer will buy bonds in ascending order of the prices submitted by the market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



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. 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.

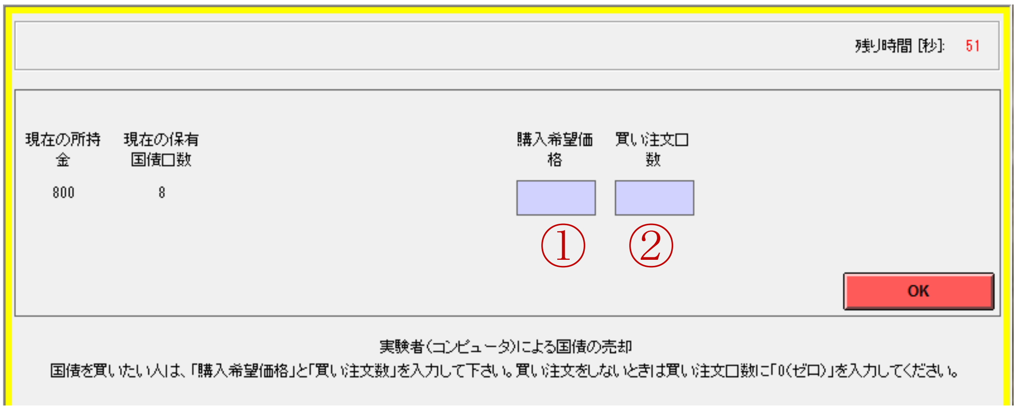
Even if fewer than 16 bonds are sold during the two selling operations, there is no additional selling operation.

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.



[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.

The screen displayed after the selling operations is similar.

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.