Managing bubbles in experimental asset markets with monetary policy

Myrna Hennequin[a,b] and Cars Hommes[a,b*]

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[a] *CeNDEF, Amsterdam School of Economics, University of Amsterdam*
[b] *Tinbergen Institute, Amsterdam*

Abstract

We study the effect of a "leaning against the wind" monetary policy on asset price bubbles in a learning-to-forecast experiment, where prices are driven by the expectations of participants in the market. We find that a strong interest rate response is successful in preventing or deflating large price bubbles, while a weak response is not. Giving information about the interest rate changes and communicating the goal of the policy increases coordination of expectations and works stabilizing. When the steady state fundamental price is unknown and the interest rate rule is based on a proxy instead, the policy is less effective.

JEL codes: C92, D84, E52, G12, G41
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1 Introduction

Since the burst of the US housing bubble in 2007 and the following financial crisis, the consensus view that monetary policy should not respond to asset price bubbles no longer holds. Prominent policymakers such as Trichet (2005) and Bernanke (2010) have called to carefully monitor asset prices and remain open to using monetary policy as a supplementary tool to address bubbles, while keeping in mind the difficulties and dangers of that approach.[1] But aside from the difficulty of identifying a bubble and the danger of harming other parts of the economy, the relationship between monetary policy and asset price bubbles is not yet clear.

In this paper, we examine this relationship in a learning-to-forecast experiment (LtFE) where the only task of participants is to submit asset price forecasts. Previous laboratory experiments of this type have shown that large price bubbles frequently occur in these asset markets, caused by coordination on trend-following expectations (Hommes et al. (2005, 2008, 2018), Bao et al. (forthcoming)).[2] By introducing monetary policy in this controlled environment, we can study the interaction between individual expectations, asset price bubbles and interest rate policy.

A "leaning against the wind" policy reacts to asset price bubbles by increasing the interest rate. Theoretically, this policy can mitigate bubbles by reducing asset prices via the discount rate effect.[3] However, asset prices are not only determined by fundamentals, but also by return expectations. The way in which expectations are formed is therefore crucial for the transmission of monetary policy. For example, if the asset market is having a "rational bubble", the price grows at a rate proportional to the interest rate, so increasing the interest rate leads to faster price growth and works destabilizing. Boundedly rational agents might display trend-following behavior that is too strong for monetary policy to be effective, despite the downward pressure of the interest rate on the price. Yet, it could also be that interest rate policy is able to prevent or manage coordination on expectations that

[1] A recent study by Cieslak and Vissing-Jorgensen (2017) suggests that the Federal Reserve already reacts to stock market declines with interest rate cuts, but they do not find a response to stock market rises.

[2] Trend extrapolation by investors is widely documented in the empirical literature (see e.g. Shleifer and Summers (1990); Hirshleifer (2001); Shiller (2002); Barberis and Thaler (2003); Greenwood and Shleifer (2014); Barberis et al. (2018)), suggesting that this is an important factor in real-world asset markets as well.

[3] Several empirical studies find that asset prices indeed fall after an increase in the interest rate (see e.g. Bernanke and Kuttner (2005); Gürkaynak et al. (2005); Ioannidis and Kontonikas (2008); Rigobon and Sack (2004)). Both the discount rate effect and the effect on expectations seem to play a role. However, Galí and Gambetti (2015) challenge the view that a "leaning against the wind" policy can reduce bubbles and provide empirical evidence that the opposite effect could also occur.

cause bubbles.[4]

The appropriate monetary policy response to asset price bubbles is heavily debated in the theoretical literature. Most prominently, Bernanke and Gertler (1999, 2001) show that inflation-targeting can achieve both general macroeconomic stability and financial stability in their New Keynesian model with a financial accelerator and an exogenous bubble process. Therefore, they recommended against a systematic response of interest rates to asset price bubbles. These results have been challenged by Cecchetti et al. (2000, 2002), who use a similar model but reach the opposite conclusion. Recent models that depart from assuming rationality on asset markets and make bubble formation endogenous also lead to opposing views. Winkler (forthcoming) constructs a model in which agents learn about asset prices and finds that a monetary policy response to asset prices increases welfare under learning, but not under rational expectations. Boehl (2017) introduces speculative asset traders and concludes that only a very moderate monetary policy response to asset prices has the potential to increase macroeconomic stability, but it is unlikely that this has a positive effect on welfare. A different modelling approach is taken by Galí (2014, 2017), who assumes that bubbles are rational so that raising the interest rate increases the volatility of asset prices and the size of bubbles.

Although theoretical models give insight in the possible effects of monetary policy, the policy conclusions are conflicting and depend crucially on the modeling assumptions. Both rational and behavioral models make assumptions about the behavior of economic agents that might not be realistic. An experimental study allows for potentially nonrational and heterogeneous expectations and can therefore complement the theoretical and empirical literature. Our experiment sheds light on the ambiguous effect of a "leaning against the wind" policy and the interaction with individual expectations and asset prices.

We follow the experimental design of Hommes et al. (2008) and add a "leaning against the wind" policy rule.[5] The Taylor-type rule in our experiment sets the interest rate in response to relative deviations from the steady state fundamental price. We compare a weak and a strong interest rate rule to study the effect of the policy on market stability. To find out how subjects respond to information about interest rate changes, we consider two additional treatments with a strong

[4]Experiments in a New Keynesian framework show that monetary policy rules that react aggressively to inflation can avoid coordination on destabilizing trend-following expectations by reducing the degree of positive feedback in the system (Pfajfar and Žakelj (2016); Assenza et al. (2018)). Experimental asset markets with a lower degree of feedback throughout the whole experiment are also more stable and show faster convergence (Sonnemans and Tuinstra (2010); Bao and Hommes (forthcoming)).

[5]A related experiment of Hommes et al. (2005) includes a stabilizing force in the form of fundamental robot traders whose share increases when the price deviates more from the fundamental, but the implementation is ad hoc and cannot be interpreted as a policy rule.

interest rate rule. First, we take away the information about current and past interest rates and only tell participants that the target rate is 5%. Second, we give participants extra information by including the goal of the interest rate policy in the instructions. Finally, we conduct a treatment where we account for the possibility that the central bank does not know the steady state price and uses the sample average price as a proxy to set the interest rate.

Our results indicate that a weak interest rate response is not able to prevent the formation of large bubbles. By contrast, bubbles are absent or remain smaller in markets with a strong interest rate response. When participants do not get any information about the interest rate changes, the price patterns are more irregular and coordination is less strong then when they know the current and past interest rates. Communicating the goal of the policy works even more stabilizing. When the interest rate rule is based on the sample average price instead of the steady state price, the policy is less effective.

So far, there is little experimental work on monetary policy and asset price bubbles, with three notable exceptions.[6] Simultaneously but independently, Bao and Zong (2018) investigate the impact of an interest rate change on asset price bubbles in a learning-to-forecast experiment. They use a simple policy rule that substantially raises or cuts the interest rate when the asset price reaches a certain threshold, and find that this policy effectively stabilizes prices. Instead of having sudden shocks in the interest rate, our Taylor-type policy rule smoothly responds to asset price movements. In addition, we consider three scenarios with different information about the policy, and a scenario in which the central bank uses a proxy for the steady state fundamental price.

Fenig et al. (2018) combine a production economy with an asset market. Participants submit labor supply, output demand and asset trading decisions. A "leaning against the wind" policy unintendedly gives rise to bubbles at first, but rapidly increasing interest rates are successful at quickly deflating bubbles and stabilizing asset prices. The policy does not seem to have large negative effects on production. The authors focus on the behavior of the aggregate economy, rather than the behavior of individual participants. Our experimental design is simpler and therefore allows us to analyze individual behavior in more detail. Specifically, we study expectation formation because this is a crucial element of many economic models.

Fischbacher et al. (2013) study a partial equilibrium economy that extends the

[6]Most experiments with monetary policy use a New Keynesian framework and do not include asset markets, such as Arifovic and Petersen (2017); Assenza et al. (2018); Cornand and M'baye (2016); Hommes et al. (2019b,a); Kryvtsov and Petersen (2015); Petersen (2015); Pfajfar and Žakelj (2016); Noussair et al. (forthcoming).

classical design of Smith et al. (1988). Participants can trade in both a risky stock and an interest bearing bond. They find that increasing the interest rate in response to stock price bubbles has only a limited effect in reducing bubbles. Furthermore, explaining the purpose of the interest rate policy in the instructions does not increase policy effectiveness. An issue with the design of Fischbacher et al. (2013) is that the fundamental price is declining even without increasing the interest rate. Asset markets with declining fundamentals have been associated with larger bubble formation (Noussair et al., 2001; Kirchler et al., 2012; Giusti et al., 2016). In our setting, the fundamental price is constant in absence of interest rate policy, and the steady state price always remains constant. Another main advantage of our asset pricing LtFE is that we separate expectation formation from trading decisions, which provides clean data on expectations.

This paper is organized as follows. Section 2 explains the experimental design in detail. Next, the experimental results are discussed: Section 3 focuses on market prices, Section 4 on interest rates and Section 5 on individual expectations. Finally, Section 6 concludes.

2 Experimental design

2.1 Asset pricing framework with interest rate rule

Our experimental design is based on Hommes et al. (2008). The novel aspect is that we let the risk-free interest rate be variable instead of fixed, so that we can implement an interest rate rule. A detailed description of the asset pricing framework is given in Appendix A. In short, the framework is as follows. Consider an asset market with I traders with heterogeneous price expectations. At the beginning of each period, traders can choose to invest in a risk-free asset paying an interest rate r_t, or a risky asset paying an i.i.d. dividend with mean $\bar{y} = 3$. The interest rate r_t is variable, but it is known at the time of the investment decision and therefore risk-free. Traders calculate their demand for shares using myopic mean-variance optimization. Equilibrium between demand and supply then gives the market price of the risky asset:

$$p_t = \frac{1}{1+r_t}\left[\frac{1}{I}\sum_{i=1}^{I} p^e_{i,t+1} + \bar{y}\right], \tag{1}$$

where $E_{it}(p_{t+1}) = p^e_{i,t+1}$ denotes the prediction by trader i in period t for the price in period $t+1$. The price of the risky asset depends on the average price forecast of all traders in the market, so there is positive expectations feedback. When the interest rate is low, expectations are almost self-fulfilling, while increasing the interest rate reduces the strength of the positive feedback. This discount rate effect brings down the price of the risky asset.

We include a "leaning against the wind" policy rule that increases the interest rate in response to asset price bubbles. The interest rate is set according to a Taylor-type rule with a zero lower bound (ZLB):

$$r_t = \max\left\{r^* + \phi\left(\frac{p_{t-1} - p^*}{p^*}\right), 0\right\}, \tag{2}$$

where the target interest rate is $r^* = 5\%$ and the target price is $p^* = 60$, in line with the asset pricing model with a fixed interest rate of Hommes et al. (2008).[7] The parameter ϕ determines the strength of the rule: the interest rate is increased by ϕ percentage-points for a one percentage-point rise in the asset price relative to the steady state value.

Taylor-type rules that endogenously set the interest rate in response to deviations from steady state values are often used in other macroeconomic settings, such as New Keynesian models. The rule gives a smooth interest rate response to asset price bubbles. Moreover, this policy has been inspired by the influential paper of Bernanke and Gertler (1999). We use a version of their policy rule that is adapted to our setting: we abstract from inflation and output in our asset pricing model, and we do not use log differences to approximate the percentage deviation from the steady state, since this approximation is only appropriate for small deviations.

Equations (1) and (2) form a dynamical system with $r^* = 5\%$ and $p^* = 60$ as the unique steady state equilibrium.[8] Under rational expectations, the steady state is a saddle point for the values of ϕ that we consider in the experiment. In addition, there is a continuum of rational bubble solutions with prices and interest rates that keep growing faster. We also consider the dynamics under a number of well-known homogeneous expectation rules. For relevant values of ϕ, the system is stable and there is monotonic convergence to the steady state under adaptive or weak trend-following expectations. Under anchoring and adjustment, convergence is oscillatory. However, a strong trend-following rule gives an unstable steady state and leads to oscillations in prices and interest rates. Derivations and details about the properties of the dynamical system can be found in Appendix A.

[7] Note that the interest rate rule is based on the most recent observation of the asset price, p_{t-1}. It is not possible to implement a contemporaneous rule using p_t instead, because p_t depends on p^e_{t+1}. When these expectations are formed in period t, the interest rate r_t for that period should be known, otherwise there is no risk-free investment. Hence, r_t cannot depend on p_t.

[8] With a constant interest rate of 5%, the fundamental price of the asset is $p^f = \bar{y}/r = 60$. But with a varying interest rate, the fundamental price depends on interest rate expectations. Hence, $p^* = 60$ cannot be called the fundamental, but it still is the steady state rational expectations equilibrium. See Appendix A for details.

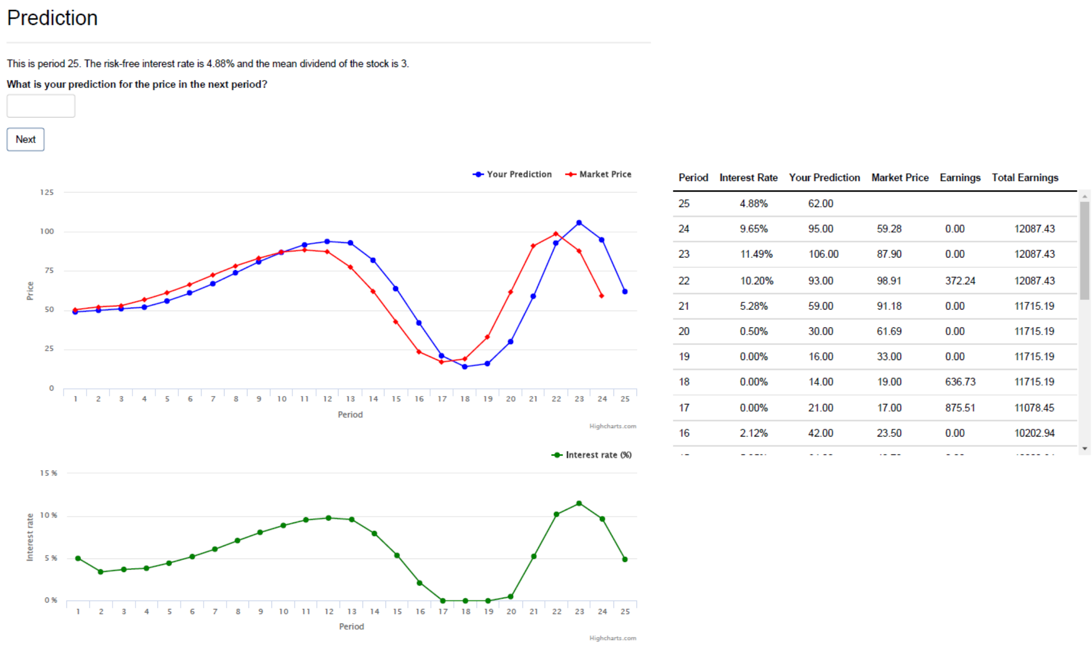

Figure 1: Screenshot of the experiment
Notes: This screen is seen by participants in all but the No Information treatment. In that treatment, the current interest rate is replaced by the target interest rate of 5%, the graph of past interest rates is removed and the column in the table with the past interest rates is not shown.

2.2 General design

The experimental asset markets consist of six participants each. They have the role of advisors to a large pension fund, and their only task is to submit two-period-ahead forecasts of the price of the risky asset for 51 periods. The pension fund calculates its optimal demand for the asset based on the price forecast, so trading is computerized. The market price follows from Equations (1) and (2). Participants are paid for their prediction accuracy: $e_{it} = \max\left\{1300 - \frac{1300}{49}(p_t - p^e_{it})^2, 0\right\}$. A lower quadratic forecast error results in higher earnings. The experimental points e_{it} are converted into euros using an exchange rate of €0.5 per 1300 points.

The instructions for the experiment are largely the same as in Hommes et al. (2008), except for the parts about the interest rate (see Appendix B). Participants receive only qualitative information about the asset market. They are informed that there is a risky asset with a mean dividend of $\bar{y} = 3$ and a risk-free asset with a variable interest rate that starts at 5%. This gives participants enough information to calculate the steady state price, assuming that the interest rate does not change: $p^* = 3/0.05 = 60$. They can also infer that there is positive expectations feedback. As in Hommes et al. (2008), there is an upper bound on predictions of 1000, but that is not known beforehand. Participants receive a message about the upper bound when they try to enter a prediction higher than 1000. It is important to

Table 1: Overview of treatments

Treatment	Interest rate rule	Strength	Information for participants
Weak Rule (WR)	Known p^* (Eq. (2))	$\phi = 0.001$	Current and past interest rates
Strong Rule (SR)	Known p^* (Eq. (2))	$\phi = 0.1$	Current and past interest rates
No Information (NI)	Known p^* (Eq. (2))	$\phi = 0.1$	Only target rate of 5%
Communication (C)	Known p^* (Eq. (2))	$\phi = 0.1$	Goal of policy
Sample Average (SA)	Unknown p^* (Eq. (3))	$\phi = 0.1$	Current and past interest rates

note that participants are not informed about the market pricing equation or the interest rate rule.

At the beginning of the experiment, instructions are provided both on screen and on paper. To ensure understanding of the instructions, participants have to correctly answer a number of control questions before they can proceed with the experiment. The main task consists of a series of 51 price predictions. In the first two periods, participants only know that the interest rate is 5% and that it is very likely that the price will be between 0 and 100. After submitting two price predictions, the first price becomes known, earnings are calculated and the interest rate may change. Subsequently, in each period t, subjects have to predict the price for period $t + 1$ knowing only prices up to period $t - 1$. Furthermore, participants have information on their own past predictions up to period t, current and past interest rates up to period t, and period and total earnings up to period $t - 1$. Figure 1 gives an example of the computer screen, showing graphs of past prices, predictions and interest rates, and a table with all the available information. The current interest rate r_t and the mean dividend $\bar{y} = 3$ are also indicated separately. After completing the prediction task, subjects fill in a short questionnaire, which includes open questions about their prediction strategy.

2.3 Treatments

We conduct five different experimental treatments to study the effects of monetary policy under various scenarios. These treatments differ in the interest rate rule that is used, the strength of the rule that is implemented, and the information that is given to participants. We explain the treatments below and give an overview in Table 1.

First, we consider a baseline treatment with a weak interest rate response to asset price bubbles. In this Weak Rule treatment, we set the strength of the rule in Equation (2) to $\phi = 0.001$, to ensure that the interest rate changes are very small and the interest rate stays close to 5%. With such a weak policy response, we expect that large bubbles are still present in the market. We compare this with a Strong Rule treatment with $\phi = 0.1$, to see if this policy is able to stabilize the asset markets.[9] In both treatments, participants receive information about the current and past interest rates as described in Section 2.2.

When the interest rate is increased, this lowers the price via the discount rate effect in Equation (1). But it might also lower predictions by giving a signal to participants that the price of the asset is too high. In the Strong Rule treatment, we are not able to tell these two effects apart. To disentangle the effects, we run a No Information treatment with a strong interest rate rule ($\phi = 0.1$), where we do not give participants any information about the interest rate changes. The instructions tell them that the target interest rate is 5% and that the pension fund knows the current interest rate. During the prediction task, participants do not see the current and past interest rates in the graph and table on their computer screen. Hence, an interest rate change has no signaling effect. By comparing this treatment to the Strong Rule treatment, we can find out if participants respond to the information about interest rate changes.

Instead of giving less information, the central bank can also choose to give more information about the interest rate policy and be transparent about its goal. This might increase policy effectiveness. We test this in a Communication treatment with a strong interest rate rule ($\phi = 0.1$) where we add a sentence to the instructions: "The policy of the central bank is to raise the interest rate above 5% when it considers the asset price to be too high, and to cut the interest rate below 5% when it considers the asset price to be too low." Comprehension of this statement is also tested in a control question. When participants observe the current and past interest rates (as in Figure 1), it should thus be clear what the interest rate changes mean. We compare the Communication treatment with the Strong Rule treatment to examine the effect of communicating the goal of the policy.

In reality, it could be difficult to determine whether there is an asset price bubble, because the central bank might not know the steady state fundamental price. To account for this possibility, we study a policy rule where the sample average price p_{t-1}^{av} is used as a proxy for p^*:

$$r_t = \max \left\{ r^* + \phi \left(\frac{p_{t-1} - p_{t-1}^{av}}{p_{t-1}^{av}} \right), 0 \right\}, \tag{3}$$

[9] A behavioral heuristics switching model captures the price patterns in previous asset pricing experiments quite well (Anufriev and Hommes (2012), Bao et al. (forthcoming)). Simulations with this model guided the policy choices for the experiment. The simulations suggest that bubbles are still large for $\phi = 0.001$, whereas the market is quite stable with only small oscillations around the steady state price for $\phi = 0.1$. Moreover, $\phi = 0.1$ is the parameter value that is used in Bernanke and Gertler (1999).

where $p^{av}_{t-1} = \frac{1}{t-1}\sum_{i=1}^{t-1} p_i$. We again consider a strong policy response ($\phi = 0.1$) and compare this Sample Average treatment to the Strong Rule treatment.

2.4 Implementation

The experiment was run in the CREED laboratory at the University of Amsterdam in May 2017 and September 2017. We conducted eight markets of each treatment with six subjects per market, giving a total of 240 subjects. No subject participated in more than one session. A session lasted about 1.5 hours in total. Earnings, including a €10 lump-sum payment, ranged from €10.70 to €34.10 and averaged €17.73.[10] The experiment was programmed in oTree (Chen et al., 2016).

3 Aggregate results

3.1 Price dynamics

Figure 2 shows the realized market prices and interest rates in all markets, plotted per treatment. In Appendix C, summary statistics are given and prices, predictions and interest rates are plotted for each market separately. It is immediately clear that large bubbles, with prices approaching the upper limit of 1000, only occur in the Weak Rule treatment. All four versions of the strong interest rate rule are successful in preventing or deflating large bubbles.

In treatment Weak Rule, five markets display large bubbles, while the other three markets are stable or have small oscillations around the steady state price. The results of this treatment are very similar to related experiments without monetary policy (Hommes et al. (2008, 2018), Bao et al. (forthcoming)), except that there are relatively more stable groups in our experiment.

There are some differences among the four treatments with a strong interest rate rule as well. In the Strong Rule treatment, seven markets exhibit small price oscillations that are persistent throughout the experiment. Prices are below 200, except for one outlier in group 7. Only one market is stable and converges to the steady state.

In treatment No Information, the price patterns seem to be more erratic. Five markets have more or less regular price oscillations, except for an outlier in group 1.

[10] For the sessions that we ran on the first day (group 1–4 of the Weak Rule treatment and group 1–4 of the Strong Rule treatment), we paid participants €15 whenever their earnings in the experiment were below this amount. Since this occurred more often than we expected (namely for 46 out of 48 subjects), we decided to change this practice. From the second day onwards, we paid a lump-sum of €10 on top of the earnings in the experiment. In both cases, the participants did not know about the extra payments in advance, so the incentives during the experiment were the same in all sessions.

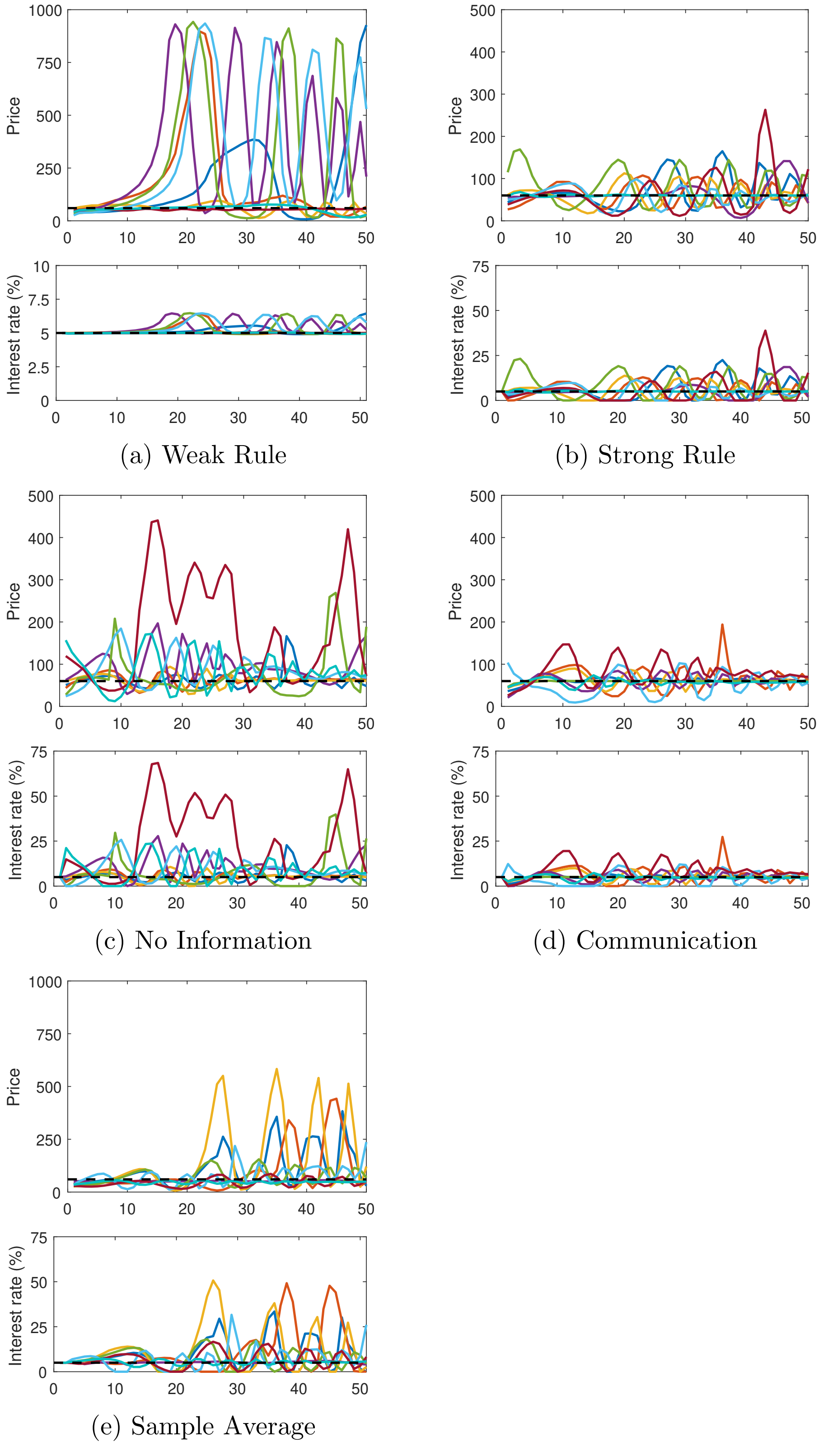

Figure 2: Market prices and interest rates in all treatments
Notes: The dashed lines indicate the steady state price of 60 and the steady state interest rate of 5%. Note that the scale of the vertical axis may differ per treatment.

However, three markets exhibit quite irregular price patterns, with sudden jumps or drifts in the price. In group 7, there is even a medium sized bubble with prices above 400. None of the markets is stable.

The Communication treatment looks somewhat more stable than the Strong Rule treatment. The price oscillations are generally slightly smaller and are dampening or even converging in three groups. There are also three markets that are stable, with only very small oscillations in two cases and full convergence within 25 periods in one case. This is the only market in our experiment that fully converged to the steady state.

The results of the Sample Average treatment vary greatly per group. In three markets, multiple medium sized bubbles with prices up to 600 form in the second half of the experiment. There are small, persistent oscillations around the steady state in another three groups. Two markets are stable, but prices remain slightly below the steady state of 60.

3.2 Quantifying mispricing and overvaluation

The figures suggest that mispricing is largest in treatment Weak Rule, followed by Sample Average, No Information, Strong Rule and Communication. We quantify the bubble size in our markets with the Relative Absolute Deviation (RAD) and the Relative Deviation (RD) from the steady state price $p^* = 60$, adapting the definitions of Stöckl et al. (2010):

$$\mathrm{RAD} = \frac{1}{50}\sum_{t=1}^{50} \frac{|p_t - p^*|}{p^*}, \tag{4}$$

$$\mathrm{RD} = \frac{1}{50}\sum_{t=1}^{50} \frac{p_t - p^*}{p^*}. \tag{5}$$

For example, RAD $= 0.5$ indicates that the price differs on average 50% from the steady state, while RD $= 0.5$ means that the price is on average overvalued by 50%.

Figure 3 shows the empirical cumulative distribution functions of RAD and RD for each treatment. In addition, Table 4 in Appendix C includes the values of RAD and RD for each group and the averages per treatment. The above ordering of treatments is confirmed by our measure of mispricing, the RAD. RD is always smaller than RAD, indicating that there are periods of undervaluation in each market, although the asset is on average overvalued (RD > 0) in 30 out of 40 markets. Undervaluation is relatively larger and more common in the Sample Average treatment, where RD < -0.1 in three groups (against one group each in

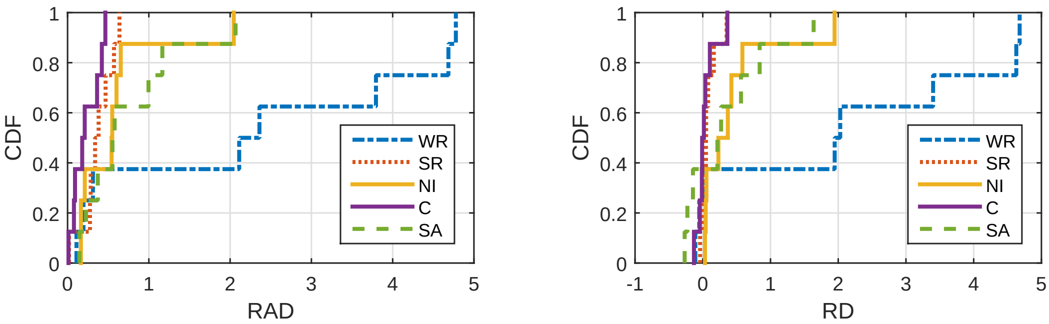

Figure 3: Empirical cumulative distribution functions of RAD and RD

Table 2: p-values of pairwise two-sided MWW tests for RAD and RD

Pairwise MWW tests for RAD					Pairwise MWW tests for RD				
	SR	NI	C	SA		SR	NI	C	SA
WR	0.195	0.195	0.038**	0.279	WR	0.279	0.442	0.130	0.083*
SR		0.574	0.161	0.279	SR		0.065*	0.279	0.574
NI			0.050**	0.574	NI			0.010**	0.645
C				0.021**	C				0.574

Notes: ** and * indicate significance at the 5% and 10% level, respectively.

treatments Weak Rule and Communication and zero in the other two treatments).

We test if the treatment differences are significant using pairwise two-sided Mann-Whitney-Wilcoxon tests at the 5% level. The null hypothesis is that the RAD or RD of the two groups have the same distribution. Table 2 presents the p-value of all pairwise MWW tests.

Despite the fact that RAD and RD are on average much larger for treatment Weak Rule, the difference in mispricing (as measured by RAD) is only significant compared with treatment Communication. This result suggests that simply implementing a strong interest rate rule is not enough to significantly reduce mispricing, but including communication about the rule is. Comparing the four treatments with a strong interest rate rule, the MWW test indicates that including communication leads to significantly less mispricing than giving no information or using the sample average. However, the differences between treatment Strong Rule and the other treatments are not significant, even though the RAD is on average higher in treatments No Information and Sample Average, and lower in treatment Communication. The low significance of the results could be due to the small sample size (eight markets per treatment) and the heterogeneity in market realizations within treatments, particularly in treatment Weak Rule.

In terms of overpricing (as measured by RD), the only difference that is significant at the 5% level is found between treatments No Information and Communication. Since many markets oscillate around the steady state price, RD is close to zero in these markets. Therefore, no significant differences in overpricing can be detected between the other treatments.

4 Interest rates

4.1 Interest rate dynamics

In treatment Weak Rule, the interest rate does not get higher than 6.5%. Clearly, this increase is not big enough to prevent large price bubbles. In the three treatments using the strong steady state rule (Equation (2) with $\phi = 0.1$), the highest realized interest rate is 68.4%. However, rates this high are uncommon: in 96% of the periods, the interest rate is below 20%. Most of the time, an increase to this level is enough to reverse an upward trend and deflate a bubble. Similarly, in the Sample Average treatment (Equation (3) with $\phi = 0.1$), the highest realized rate is 50.7%, but the interest rate is below 20% in 93% of the periods. Only in the three markets with medium bubbles, the interest rate is above this level for multiple periods, preventing the bubbles from growing larger.

The interest rate is closely related to the feedback strength: $\lambda_t = \frac{1}{1+r_t}$. The higher the interest rate r_t, the lower the feedback strength λ_t, so the weaker the expectations feedback and the more high prices are being pushed down. In related market experiments, Sonnemans and Tuinstra (2010) and Bao and Hommes (forthcoming) found that markets with a feedback strength of $\lambda = 0.95$ (i.e. $r = 5\%$) are unstable, markets with $\lambda = 0.86$ (i.e. $r = 16\%$) are relatively stable but do not converge, and markets with $\lambda = 0.71$ (i.e. $r = 40\%$) or higher are stable and converge quickly. Our results are in line with these findings. We observe that higher interest rates and therefore lower feedback strengths can dampen bubbles and make the market less unstable. However, this does not always lead to convergence because the interest rate is not kept at a high level. In many markets, there still seems to be coordination on destabilizing trend-following expectations, causing persistent price oscillations. This is in line with the findings of Sonnemans and Tuinstra (2010), who conclude that coordination of expectations appears to be independent of the feedback strength, but convergence is mainly due to the prices being pushed more towards the fundamental value when the feedback strength is low.

By construction, the interest rate can only become zero in the four treatments with a strong interest rate rule.[11] The ZLB is reached in 125 out of 1600 periods

[11] Of course, we cannot know exactly what prices would have been without a ZLB in place. Nevertheless, we can calculate what the negative interest rate and the corresponding price would

(8%). There are differences both across and within treatments. With the steady state rule, the ZLB is hit when the price drops below 30. This happens most often in treatment Strong Rule (in total 47 times in seven markets), because most markets oscillate around the steady state. In the other two treatments, No Information and Communication, the ZLB is reached less often because there is either mostly overpricing or the price oscillations are smaller, so that the price is above 30 most of the time. In treatment Sample Average, the ZLB is hit when the price is 50% lower than the sample average price. This happens in total 43 times in six markets, caused by relatively large oscillations and regular low prices.

4.2 Performance of the sample average rule

The sample average rule performs worse than the steady state rule, simply because the sample average price is generally not a good proxy for the steady state price. As a result, the interest rate can increase above 5% even though the price is below the steady state, and vice versa. The sample average price starts out too low in all groups of the Sample Average treatment and stays too low in three groups, while it becomes too high in the other five groups. When the sample average price is too low, the sample average rule can reinforce the underpricing by setting an interest rate that is higher than it should be. This often happens in group 4 and 8, where the price consistently stays below $p^* = 60$. Nevertheless, the sample average rule pushes the price down when there is overpricing. If preventing large bubbles is the main goal of the monetary policy, the sample average rule might be a useful alternative if the steady state price is not known.

5 Individual expectations

5.1 Expectation dynamics

Plots of individual predictions in all markets can be found in Appendix C. At first glance, predictions are quite close to each other most of the time, indicating that there is coordination of expectations. Many participants seem to use trend-following prediction strategies.[12] This leads to some large bubbles in the Weak Rule

have been, assuming that predictions would not have changed. This exercise shows that on average, the negative interest rate would have been -1.6%, and the lowest rate would have been -4.0%. This would have given prices that are on average 0.5 units and at most 4.3 units higher than the realized prices in the experiment, and the differences of more than one unit are all in the Sample Average treatment. We believe that these minor differences would not have changed the price dynamics in the experiment.

[12]This observation is supported by the questionnaire, in which more than half of the participants describe their strategy as some form of trend following.

treatment, but bubbles are dampened in the four treatments with a strong interest rate rule. In stable markets, predictions seem to follow adaptive or naive strategies. Naturally, in markets with higher coordination and more stability, forecasting performance and therefore earnings are also better.

Most markets with a strong interest rate response exhibit small price oscillations, typically with the following dynamics. The price displays an upward trend in the beginning and increases above the steady state, so the interest rate is increased above 5%. This pushes the price down and thus flattens the upward trend. Participants lower their predictions in the next period(s) in response, which ultimately reverses the trend. The process repeats itself with both upward and downward trends. The amplitude of the oscillations usually becomes smaller because participants learn to anticipate the trend reversals. Large bubbles are thus prevented, not only because of the direct effect of the interest rate on the price, but also because of the indirect effect on expectations. It seems that trend extrapolation becomes less strong, although it continues to cause price oscillations.

While there is generally consensus about future prices, there are also subjects who submit so-called "spoilers": sudden large and erratic deviations in individual predictions (Sonnemans and Tuinstra, 2010). In markets of six, predictions of a single participant have a substantial effect on the price, so these spoilers can change the price dynamics in the experiment. In treatment Weak Rule, three participants in different groups try to bring down the price by submitting a very low prediction. These attempts are unsuccessful in two cases, but two other bubbles in group 1 and 2 remained smaller due to these low predictions. Treatment Strong Rule, No Information and Communication all have one market where a single spoiler leads to a sudden jump in the price, followed by a jump in predictions of the other subjects in the market, which temporarily destabilizes the market. A small typo in a stable market can also lead to destabilization, which probably happened in group 8 of treatment Weak Rule and group 4 of treatment Strong Rule. Lastly, there are some participants that submit repeated spoilers and therefore have a great effect on the price dynamics. In the No Information treatment, one subject in group 5 and two subjects in group 7 cause erratic price patterns with their spoilers. In the Sample Average treatment, repeated spoilers in group 1, 2 and 6 lead to price peaks and irregular oscillations. However, the general upward trend in group 1 and 2 suggests that the medium bubbles also would have formed without those outliers, as was the case in group 3.

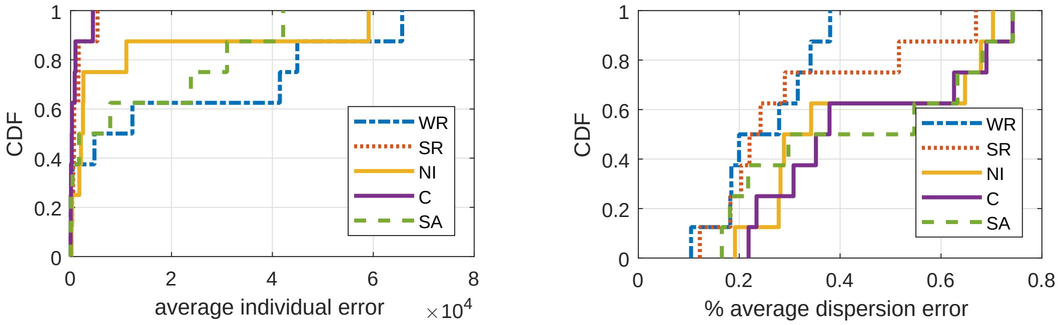

Figure 4: Empirical cumulative distribution functions of average individual quadratic forecast errors (left) and percentages of average dispersion error (right)

5.2 Quantifying coordination

Coordination and average forecasting performance can be quantified by splitting up the quadratic forecast error, averaged over time and individuals:

$$\frac{1}{45}\cdot\frac{1}{6}\sum_{t=6}^{50}\sum_{i=1}^{6}(p_{it}^e - p_t)^2 = \frac{1}{45}\cdot\frac{1}{6}\sum_{t=6}^{50}\sum_{i=1}^{6}(p_{it}^e - \bar{p}_t^e)^2 + \frac{1}{45}\sum_{t=6}^{50}(\bar{p}_t^e - p_t)^2, \qquad (6)$$

where $\bar{p}_t^e = \frac{1}{6}\sum_{i=1}^{6} p_{it}^e$ is the average prediction for period t. The first five periods are omitted to allow for some learning. The first term is called the average dispersion error, which is relatively small if there is coordination of expectations. The second term is called the average common error, which is relatively small if expectations are approximately correct in the aggregate, in line with Muth's (1961) formulation of the rational expectations hypothesis.

Figure 4 plots the empirical cumulative distribution functions of the average individual quadratic forecast error and the percentage of the average dispersion error for each treatment. Obviously, errors are larger in markets with large or medium bubbles, and spoilers also lead to more errors. This is directly reflected in the earnings of the participants, since these are based on the quadratic forecast error as well. In terms of percentages, the average dispersion error is usually lower than the average common error. This indicates that there is coordination, despite being on the wrong price. Forecast errors generally do not cancel out at the aggregate level, so expectations cannot be called rational in the sense of Muth (1961).

The average dispersion error in absolute terms is on average higher in the No Information treatment than in the Strong Rule treatment. On the other hand, treatment Strong Rule and Communication are comparable in terms of average dispersion errors. These results suggest that coordination is less strong without providing information about interest rate changes, but providing communication

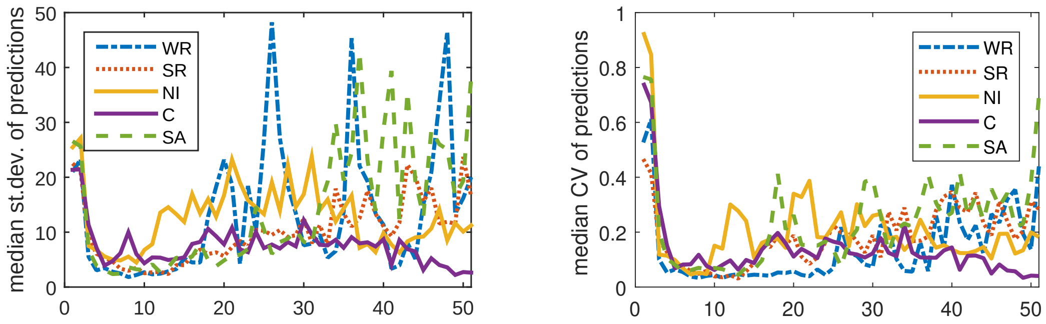

Figure 5: Time series of median standard deviation of predictions (left) and median coefficient of variation of predictions (right)

about the interest rate rule does not make coordination stronger. However, pairwise MWW tests indicate that only the difference between treatment No Information and Communication is statistically significant (p-value $= 0.028$), not the differences with treatment Strong Rule.

Note that the average dispersion error is equal to the population variance of individual predictions, averaged over time. We take a closer look at coordination by instead considering the sample standard deviation of predictions in each period of each market. This measure is expressed in the same units as the predictions and gives us insight into the dynamics of coordination. The time series of the median standard deviation of predictions in each treatment is shown in the left panel of Figure 5.

All treatments show a sharp drop in heterogeneity of expectations after the first two periods, indicating that participants use the market price as a coordination device. Coordination is generally strong in the beginning, but breaks when large or medium bubbles form or when spoilers are submitted. For this reason, heterogeneity is often larger in treatment Weak Rule, No Information and Sample Average. In the Strong Rule treatment, the median standard deviation of predictions increases towards the end of the experiment, which reflects the persistent oscillations in most markets of this treatment. By contrast, heterogeneity decreases over time in the Communication treatment, reflecting the dampening oscillations or convergence in this treatment.

The right panel of Figure 5 displays the median coefficient of variation (CV) of predictions over time. The CV is defined as the ratio of the standard deviation to the mean of predictions and can thus be interpreted as a measure for the relative heterogeneity in expectations. The time series of the CV also illustrate the sharp drop in heterogeneity in the beginning of all treatments. The Weak Rule treatment shows a relatively low value of the CV, especially in the first half of the experiment. This suggests that the first large bubbles in these markets are caused by relatively strong coordination of expectations. In the Strong Rule, No Information and Sample Average treatments, heterogeneity is relatively high, reflecting that expectations and prices do not completely stabilize in most markets. The CV again reveals an increase in coordination towards the end in the Communication treatment.

Looking at both mispricing and coordination and comparing the three treatments with differences in information for participants, it seems that giving more information is helpful. We observe that markets are less stable and coordination is less strong in treatment No Information, where there is no signaling effect of the interest rate. On the other hand, markets are slightly more stable in treatment Communication, where the signaling effect is more pronounced because of the extra information about the policy. The signal given by the interest rate thus seems to aid coordination and stabilization, although the results are somewhat noisy.

5.3 Estimating prediction strategies

To further analyze the prediction strategies that participants use, we start by estimating a general specification for each individual i:[13]

$$p^e_{i,t+1} = \alpha + \sum_{k=1}^{4} \beta_k p_{t-k} + \sum_{l=0}^{3} \gamma_l p^e_{i,t-l} + u_t. \tag{7}$$

We regress the individual predictions on a constant, the last four observations of the market price and the last four own predictions. To allow for a short learning phase, the forecasting rule is estimated from period $t = 5$. We then delete the least significant regressors one by one, until all remaining regressors are significant at the 5% level. We call the estimation successful if there is no autocorrelation in the residuals of the final rule (Breusch-Godfrey test, two lags).

Table 3 presents the main estimation results per treatment and overall: the percentage of successful rules, the mean value of the adjusted R^2, the percentage of subjects using each regressor, and the mean value of all nonzero coefficients for each regressor. The full estimation results can be found in Tables 5–9 in Appendix D. In total, 214 out of 240 rules (89%) are successfully estimated. Of those successful estimations, the adjusted R^2 is generally quite high, indicating that the estimated forecasting rules provide a good fit.

In all treatments, the last observation of the market price (p_{t-1}) is the most im-

[13]The forecasting rule is estimated after removing outliers, i.e. predictions that differ substantially from what would be expected from the general pattern. A total of 13 outliers, all for different participants, were removed by linear interpolation (0.1% of all predictions).

Table 3: Main results of estimated forecasting rules

	WR	SR	NI	C	SA	Overall
% successful	96%	85%	94%	81%	90%	89%
mean adjusted R^2	0.87	0.76	0.68	0.69	0.73	0.75
% used (nonzero coeff.)						
β_1	89%	83%	89%	79%	79%	84%
β_2	76%	68%	76%	79%	60%	72%
β_3	46%	46%	58%	54%	42%	49%
β_4	28%	37%	40%	54%	35%	38%
γ_0	41%	39%	29%	46%	53%	42%
γ_1	35%	32%	24%	28%	28%	29%
γ_2	33%	24%	16%	21%	9%	21%
γ_3	24%	29%	13%	10%	28%	21%
mean coefficient						
α	38.88	22.75	23.56	26.05	20.60	26.56
β_1	1.88	1.69	1.76	1.51	1.65	1.71
β_2	-1.39	-1.33	-1.22	-1.21	-1.23	-1.28
β_3	0.68	0.58	-0.02	0.65	0.37	0.43
β_4	-0.48	-0.56	0.35	-0.36	-0.05	-0.20
γ_0	0.32	0.36	0.31	0.59	0.46	0.42
γ_1	-0.46	-0.40	-0.34	-0.25	-0.44	-0.39
γ_2	0.07	0.31	0.56	0.03	-0.02	0.19
γ_3	0.27	0.09	-0.45	0.00	0.02	0.03

portant regressor: 79–89% of the participants use this variable in their forecasting rule. A large majority (60–79%) also considers p_{t-2}. The corresponding coefficient β_2 is almost always negative (with just four exceptions), indicating trend-following behavior. The last own prediction (p^e_t) is also an important regressor, used by 29–53% of the subjects. These three regressors form the basis of benchmark heuristics, such as adaptive, trend-following and anchoring and adjustment rules. The estimation results confirm the key role of these variables, but also indicate that many participants use more sophisticated forecasting rules, involving higher lags of prices and predictions.

The effect of the interest rate on predictions cannot be easily identified, since the interest rate rule makes r_t perfectly correlated with p_{t-1}. Recall that participants in treatment No Information do not know anything about the interest rate changes. We can compare this treatment to the Strong Rule treatment, where participants do know the current and past interest rates, and to the Communication treatment, where participants additionally receive information about the goal of the policy. Pairwise MWW tests only find a significant difference in γ_0 between treatments

No Information and Communication (p-value = 0.040). The insignificance of the differences in coefficients suggests that participants do not change their prediction strategy if they know about the interest rate changes. However, this conclusion is not in line with the questionnaire, where 122 out of 192 participants (64%) state that the interest rate affected their strategy in some way. While a few participants correctly interpret an interest rate above 5% as a signal that the price is too high, the questionnaire also reveals several misunderstandings of the interest rate rule. For example, 17 participants indicate that they increased their predictions after an interest rate increase. This is not the desired response, as it reinforces trend chasing and works destabilizing.

6 Conclusion

We study the effect of monetary policy on asset price bubbles in a learning-to-forecast experiment, where prices are driven by the expectations of participants in the asset market. Our "leaning against the wind" Taylor-type policy rule sets the interest rate in response to relative deviations from the steady state price. The success of the policy crucially depends on individual expectations: a rational bubble grows faster after an interest rate increase, but bubbles caused by boundedly rational expectations might be managed or even prevented.

We find that a weak policy response is not able to prevent large price bubbles, since destabilizing trend-following expectations are too strong. By contrast, large bubbles do not occur in any of our four treatments with a strong interest rate response. Most of the time, an interest rate increase up to 20% is enough to stop the formation of a bubble. Yet, most markets are not completely stabilized. While an interest rate increase pushes the price down and thus dampens a bubble, there is often still coordination on trend-following expectations, causing persistent price oscillations.

In our baseline setting, current and past interest rates are known. To remove the signaling effect of the interest rate, we conduct a treatment where we do not inform participants about the interest rate changes. Price patterns are more erratic and the absence of the signaling effect seems to decrease coordination. On the other hand, when we communicate the goal of the policy, markets are slightly more stable.

The steady state fundamental price of an asset may be unknown. When we base the interest rate on the sample average price instead, the results are mixed: markets exhibit medium sized bubbles, small price oscillations or persistent underpricing. The policy is less effective because the sample average price is usually not a good proxy for the steady state. As a result, underpricing can be reinforced. Nonetheless, the sample average rule pushes the price down in a bubble and might therefore be a useful alternative for the steady state rule.

The bubbles in our experiment are not based on rational expectations. Regressions show that many participants use the last two observations of the market price and the last own prediction to form new predictions. This is in line with benchmark heuristics, such as adaptive, trend-following and anchoring and adjustment rules. Many prediction strategies have a trend-following component. Most participants pay attention to the interest rate changes, but they do not seem to adapt their strategies in a significant way.

Our experimental results suggest that a strong interest rate rule is successful in deflating large price bubbles. Even though the policy cannot always prevent coordination on destabilizing trend-following expectations, it can substantially dampen price oscillations. Communicating the goal of the policy is necessary to significantly decrease mispricing and increase coordination. There seems to be room for improvement by explaining the policy to market participants more carefully, so that interest rate changes are not misunderstood and expectations can be managed even more. It would also be interesting to study whether adding communication to a weak rule or a sample average rule would help to stabilize markets.

An argument that is often raised against a monetary policy response to asset prices is that deflating a bubble is likely to have negative side-effects on the economy. Our partial equilibrium asset pricing model disregards important economic variables such as inflation and output. It is possible that an interest rate policy successfully stabilizes asset markets, but harms other parts of the economy. Embedding an asset market in a New Keynesian framework to experimentally study the effects of monetary policy on bubbles in a more realistic setting is an important topic for future work. Our present experiment is a first step in gaining insight in how individual expectations and asset prices interact with interest rate policy in a simple environment.

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Appendix

A Asset pricing model with variable interest rate

A.1 Derivation of the market equilibrium price

The experiment is based on an asset pricing model with heterogeneous beliefs, as in Campbell et al. (1997) and Brock and Hommes (1998). The asset market consists of I traders. At the beginning of each period, trader i can choose to invest in a risk-free asset or a risky asset. The risk-free asset (e.g. a savings account) pays a variable interest rate r_t over period t, which is known at the time of the investment decision.[14] The infinitely lived risky asset has a price p_t and pays an uncertain dividend y_t that is independently and identically distributed with mean $\bar{y}$. The number of shares z_{it} purchased by trader i in period t cost $(1 + r_t)p_t$ and yield a payoff $p_{t+1} + y_{t+1}$. The realized wealth of the trader at the beginning of period $t + 1$ is thus given by

$$W_{i,t+1} = R_t W_{i,t} + (p_{t+1} + y_{t+1} - R_t p_t) z_{it}, \tag{8}$$

where $R_t = 1 + r_t$ is the gross rate of return of the risk-free asset in period t.

Traders differ in their beliefs about the conditional mean of the evolution of wealth, $E_{it}(W_{i,t+1})$. It is assumed that traders believe that the conditional variance of excess returns is constant and equal to σ^2. Traders are myopic mean-variance optimizers, so the demand for shares z_{it} corresponds to the solution of

$$\max_{z_{it}} \left\{ E_{it}(W_{i,t+1}) - \frac{1}{2} a V_{it}(W_{i,t+1}) \right\} = \max_{z_{it}} \left\{ z_{it} E_{it}(p_{t+1} + y_{t+1} - R_t p_t) - \frac{1}{2} a \sigma^2 z_{it}^2 \right\},$$

where a measures the degree of risk aversion. Assume that the outside supply of shares z^s is zero. The market equilibrium condition then becomes

$$\sum_{i=1}^{I} z_{it} = \frac{1}{a\sigma^2} \sum_{i=1}^{I} E_{it}(p_{t+1} + y_{t+1} - R_t p_t) = z^s = 0. \tag{9}$$

Using that $E_{it}(y_{t+1}) = \bar{y}$ for all i and all t, the market equilibrium price is given by

$$p_t = \frac{1}{1 + r_t} \left[\frac{1}{I} \sum_{i=1}^{I} p^e_{i,t+1} + \bar{y} \right], \tag{10}$$

where $E_{it}(p_{t+1}) = p^e_{i,t+1}$ denotes the prediction by trader i in period t for the price in

[14] This is the only extra assumption that is necessary to derive the market price when the interest rate is variable instead of fixed. It implies the interest rate can be taken out of the expectations operator. This is a standard assumption in macroeconomics (see e.g. Bernanke et al. (1999)). The payoff of the risk-free asset between period t and period $t + 1$ can be either defined as r_t or r_{t+1}, which is set by the central bank at the beginning of period t. These two equivalent forms of notation are both used in the literature.

period $t+1$.

A.2 Fundamental value of the risky asset

The fundamental value of the risky asset is the discounted sum of all future dividend payments. With a constant interest rate $r_t = r$, the fundamental is simply $p^f = \bar{y}/r$. This simplification can no longer be made when the interest rate is variable. To find the fundamental value, we iterate the market equilibrium price (10) K steps forward and apply the law of iterated expectations:

$$p_t = E_{it}\left[\prod_{k=0}^{K}\frac{1}{1+r_{t+k}}\left(\frac{1}{I}\sum_{i=1}^{I}E_{it}[p_{t+k+1}]\right)\right] + E_{it}\left[\sum_{j=0}^{K}\prod_{k=0}^{j}\frac{1}{1+r_{t+k}}\bar{y}\right]. \tag{11}$$

The transversality condition imposes that the first term in Equation (11) goes to zero, so that the fundamental price is given by

$$p^f_{it} = E_{it}\left[\sum_{j=0}^{\infty}\prod_{k=0}^{j}\frac{1}{1+r_{t+k}}\bar{y}\right]. \tag{12}$$

With a time-varying interest rate, the fundamental value is time-varying and depends on individual expectations of future interest rates.

A.3 Interest rate rule and zero lower bound

The interest rate is set according to a Taylor-type rule:

$$r_t = r^* + \phi\left(\frac{p_{t-1} - p^*}{p^*}\right), \tag{13}$$

where the target interest rate is $r^* = 0.05$ and the target price is $p^* = 60$, in line with the asset pricing model with a fixed interest rate.

With the interest rate rule in Equation (13), the interest rate becomes negative if $p_{t-1} < -\frac{3}{\phi} + 60$. This is only problematic for $\phi > 0.05$, since the condition is never satisfied for smaller values of ϕ. Hence, a zero lower bound (ZLB) on the interest rate must be implemented if $\phi > 0.05$. In our experiment, we use $\phi = 0.1$, so that means that the ZLB is reached when the price drops below 30. However, this does not have a large effect on the dynamics of the system. When the price is lower than 30, the interest rate without implementing the ZLB would be negative but relatively close to zero, so that the difference in the realized market price with or without implementing the ZLB is usually very small. In simulations with homogeneous expectations or a heuristics switching model, the difference in prices with or without a ZLB is barely visible and the dynamics are virtually the same. For our other parameter value, $\phi = 0.001$, the ZLB does not play a role. Hence, to ease the derivations in this appendix, the interest rate rule in Equation (13) is taken without the ZLB.

A.4 Rational expectations equilibrium

Substituting the interest rate rule (Eq. (13)) into the market equilibrium price (Eq. (10)), we obtain

$$p_t = \frac{60}{63 + \phi(p_{t-1} - 60)} \left[\frac{1}{I} \sum_{i=1}^{I} p^e_{i,t+1} + 3 \right]. \tag{14}$$

It is easy to verify that $p^* = 60$ and $r^* = 0.05$ form a steady state equilibrium, just as in the asset pricing model with a fixed interest rate. This is the only feasible steady state of the model.[15]

Any rational expectations (RE) solution must satisfy $p_t = p^e_{it}$, for all traders i and all periods t. Replacing the average price prediction in Equation (14) with p_{t+1} and rewriting the system in deviations from the steady state price, with $x_t = p_t - 60$, we obtain a first-order 2-D system:

$$\begin{aligned} x_{t+1} &= 1.05 x_t + \frac{\phi}{60} x_t y_t + \phi y_t, \\ y_{t+1} &= x_t. \end{aligned} \tag{15}$$

This system describes all RE or perfect foresight solutions. The steady state $(x^*, y^*) = (0, 0)$ of this system is a saddle point for $0 \leq \phi < 2.05$ and an unstable node for $\phi > 2.05$. For the values of ϕ we consider in the experiment, $0 \leq \phi \leq 0.1$, the unique steady state is thus saddle-path stable.

Given two initial values $x_1, y_1 > 0$, the price in deviation from the steady state keeps growing. In the absence of monetary policy ($\phi = 0$), this "rational bubble" has a growth rate of $1 + r^* = 1.05$. When monetary policy is implemented ($\phi > 0$), the growth rate gets even larger and also increases over time, since the interest rate keeps increasing as well. The rational bubbles are illustrated in Figure 6.

A.5 Dynamics under homogenous expectations

To get an intuition for the dynamics of the asset pricing model, we investigate the stability of the system under homogeneous expectations, i.e. when $p^e_{i,t+1} = p^e_{t+1}$ for all i.

Adaptive expectations are given by

$$p^e_{t+1} = w p_{t-1} + (1 - w) p^e_t = p^e_t + w(p_{t-1} - p^e_t), \tag{16}$$

with weight $w \in [0, 1]$. Naive expectations are a special case of this rule, obtained for $w = 1$. For $0 < w \leq 1$, the steady state is a stable node for $\phi < \frac{w-42}{20w-40}$. For $w = 0$, it is a

[15] Another steady state is $p = -\frac{3}{\phi}$ and $r = -\phi$, but this is not feasible since $\phi \geq 0$ and prices cannot be negative.

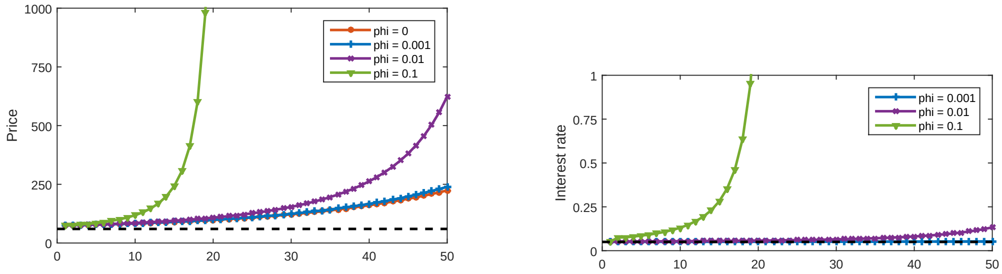
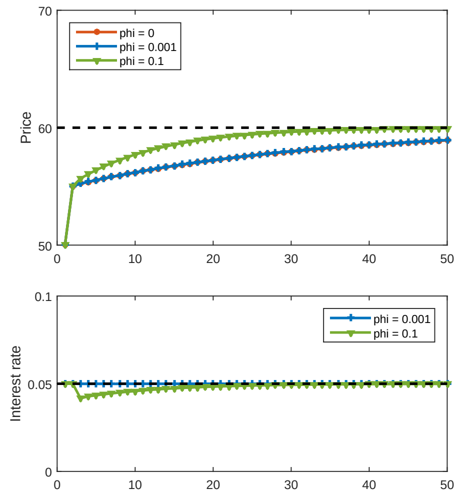
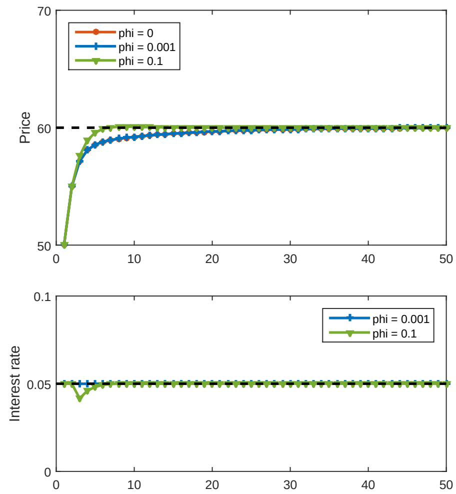


Figure 6: Simulations of rational bubbles

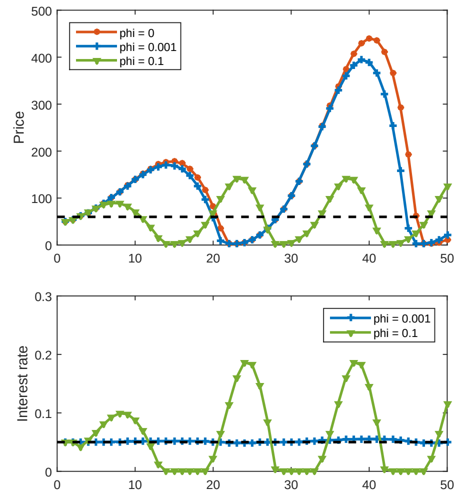
Notes: Initialization of the simulations: $x_1 = 15.75$ and $y_1 = 15$. The dashed lines indicate the steady state of $p^* = 60$ and $r^* = 0.05$.



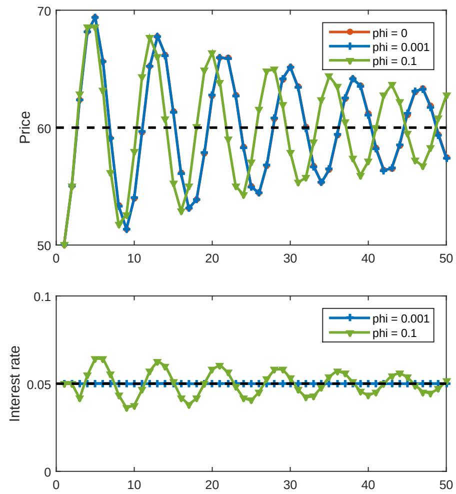
(a) Adaptive expectations



(b) Weak trend extrapolation



(c) Strong trend extrapolation



(d) Anchoring and adjustment

Figure 7: Simulations with homogeneous expectations

Notes: Initialization of the simulations: $p_1 = 50$, $p_2 = 55$ and $p_3^e = 55$. The simulations implement the ZLB. The dashed lines indicate the steady state of $p^* = 60$ and $r^* = 0.05$. Note that the scale of the vertical axis differs in the four figures.

saddle point for $0 \leq \phi < 1.05$. So for our parameter values, $0 \leq \phi \leq 0.1$, prices converge monotonically to the steady state (unless $w = 0$). This is illustrated in Figure 7a, which shows prices for adaptive expectations with $w = 0.65$.

Under trend-following expectations, we have

$$p^e_{t+1} = p_{t-1} + \gamma(p_{t-1} - p_{t-2}), \tag{17}$$

with extrapolation coefficient $\gamma > 0$. The dynamics of this system change for different combinations of ϕ and γ. For a weak trend-following rule with $\gamma = 0.4$ and $0 \leq \phi \leq 0.1$, the eigenvalues are real and inside the unit circle. The steady state is a stable node and there is monotonic convergence of the price, as illustrated in Figure 7b. For a strong trend-following rule with $\gamma = 1.3$ and $0 \leq \phi \leq 0.1$, the eigenvalues are complex and outside the unit circle, so the steady state is an unstable focus. The simulations (including ZLB) in Figure 7c shows that prices and interest rates oscillate and converge to cycles.

Under anchoring and adjustment, expectations are given by

$$p^e_{t+1} = 0.5(p^* + p_{t-1}) + (p_{t-1} - p_{t-2}). \tag{18}$$

Again, the dynamics depend on the value of ϕ. For $0 \leq \phi \leq 0.1$, the eigenvalues are complex and inside the unit circle, so the steady state is a stable focus. Convergence is oscillatory, as can be seen from the simulations in Figure 7d.

B Instructions experiment

The instructions below are used for the Weak Rule, Strong Rule and Sample Average treatments.

For the No Information treatment, "a known interest rate" is replaced by "an interest rate that is known to the pension fund" and the interest rate is not mentioned in the information about the forecasting task of the financial advisor. Furthermore, the second sentence of the information about the investment strategies of the pension funds is changed into "The bank account of the risk-free investment pays a target interest rate of 5% each time period" and the following three sentences about the interest rate are removed.

For the Communication treatment, a sentence is added after the fourth sentence of the information about the investment strategies of the pension funds: "The policy of the central bank is to raise the interest rate above 5% when it considers the stock price to be too high, and to cut the interest rate below 5% when it considers the stock price to be too low."

Instructions

General information

You are a **financial advisor** to a pension fund that wants to optimally invest a large amount of money. The pension fund has two investment options: a risk-free investment and a risky investment. The risk-free investment is putting all money on a bank account paying a known interest rate. The alternative risky investment is an investment in the stock market with uncertain return. In each time period the pension fund has to decide which fraction of its money to put on the bank account and which fraction of its money to spend on buying stocks. In order to make an optimal investment decision the pension fund needs an accurate prediction of the price of the stock. As their financial advisor, you have to predict the stock market price during 51 subsequent time periods. Your earnings during the experiment depend upon your forecasting accuracy. The smaller your forecasting errors in each period, the higher your total earnings.

Forecasting task of the financial advisor

The only task of the financial advisors in this experiment is to forecast the stock market index in each time period as accurate as possible. The stock price has to be predicted two time periods ahead. At the beginning of the experiment, you have to predict the stock price in the first two periods, given the risk-free interest rate. It is very likely that the stock price will be between 0 and 100 in the first two periods. After all participants have given their predictions for the first two periods, the stock market price for the first period will be revealed and, based upon your forecasting error, your earnings for period

1 will be given. After that you have to give your prediction for the stock market index in the third period, given the risk-free interest rate. After all participants have given their predictions for period 3, the stock market index in the second period will be revealed and, based upon your forecasting error, your earnings for period 2 will be given. This process continues for 51 time periods.

The available information in period t for forecasting the stock price for period $t+1$ consists of

- the current interest rate for period t and all past interest rates,
- all past prices up to period $t-1$, and
- all past predictions up to period t, and
- total earnings up to period $t-1$.

Information about the stock market

The stock market price is determined by equilibrium between demand and supply of stocks. The stock market price in period t will be that price for which aggregate demand equals supply. The supply of stocks is fixed during the experiment. The demand for stocks is determined by the aggregate demand of a number of large pension funds active. Each pension fund is advised by a participant of the experiment.

Information about the investment strategies of the pension funds

The precise investment strategy of the pension fund that you are advising and the investment strategies of the other pension funds are unknown. The bank account of the risk-free investment pays a known interest rate each time period. The interest rate is initially set at 5% per period, but it is variable. This means that it is possible, but not certain, that the interest rate will change in later periods. The current interest rate will be given in each period. The holder of the stock receives a dividend payment in each time period. These dividend payments are uncertain however and vary over time. Economic experts of the pension funds have computed that the average dividend payments are 3 euro per time period. The return of the stock market per time period is uncertain and depends upon (unknown) dividend payments as well as upon price changes of the stock. As the financial advisor of a pension fund you are **not** asked to forecast dividends, but you are only asked to forecast the price of the stock in each time period. Based upon your stock market price forecast, your pension fund will make an optimal investment decision. The higher your price forecast is, the larger will be the fraction of money invested by your pension fund in the stock market, so the larger will be their demand for stocks.

Earnings

Your earnings depend only on the accuracy of your predictions. The earnings shown on the computer screen will be in points. If your prediction is p_t^e and the price turns out to be p_t in period t, your earnings are determined by the following equation:

$$earnings_t = \max\{1300 - \frac{1300}{49}(p_t^e - p_t)^2, 0\},$$

The maximum possible points you can earn for each period (if you make no prediction error) is 1300, and the larger your prediction error is, the fewer points you earn. You will earn 0 points if your prediction error is larger than 7. The earnings table below shows the number of points you earn for different prediction errors. At the end of the experiment, your total earnings in points will be converted into euros, at an exchange rate of **0.5 euro for 1300 points**.

Earnings table
1300 points equal 0.5 euro

error	points	error	points	error	points	error	points	error	points
0.1	1300	1.5	1240	2.9	1077	4.3	809	5.7	438
0.15	1299	1.55	1236	2.95	1069	4.35	798	5.75	423
0.2	1299	1.6	1232	3	1061	4.4	786	5.8	408
0.25	1298	1.65	1228	3.05	1053	4.45	775	5.85	392
0.3	1298	1.7	1223	3.1	1045	4.5	763	5.9	376
0.35	1297	1.75	1219	3.15	1037	4.55	751	5.95	361
0.4	1296	1.8	1214	3.2	1028	4.6	739	6	345
0.45	1295	1.85	1209	3.25	1020	4.65	726	6.05	329
0.5	1293	1.9	1204	3.3	1011	4.7	714	6.1	313
0.55	1292	1.95	1199	3.35	1002	4.75	701	6.15	297
0.6	1290	2	1194	3.4	993	4.8	689	6.2	280
0.65	1289	2.05	1189	3.45	984	4.85	676	6.25	264
0.7	1287	2.1	1183	3.5	975	4.9	663	6.3	247
0.75	1285	2.15	1177	3.55	966	4.95	650	6.35	230
0.8	1283	2.2	1172	3.6	956	5	637	6.4	213
0.85	1281	2.25	1166	3.65	947	5.05	623	6.45	196
0.9	1279	2.3	1160	3.7	937	5.1	610	6.5	179
0.95	1276	2.35	1153	3.75	927	5.15	596	6.55	162
1	1273	2.4	1147	3.8	917	5.2	583	6.6	144
1.05	1271	2.45	1141	3.85	907	5.25	569	6.65	127
1.1	1268	2.5	1134	3.9	896	5.3	555	6.7	109
1.15	1265	2.55	1127	3.95	886	5.35	541	6.75	91
1.2	1262	2.6	1121	4	876	5.4	526	6.8	73
1.25	1259	2.65	1114	4.05	865	5.45	512	6.85	55
1.3	1255	2.7	1107	4.1	854	5.5	497	6.9	37
1.35	1252	2.75	1099	4.15	843	5.55	483	6.95	19
1.4	1248	2.8	1092	4.2	832	5.6	468	error ≥ 7	0
1.45	1244	2.85	1085	4.25	821	5.65	453		

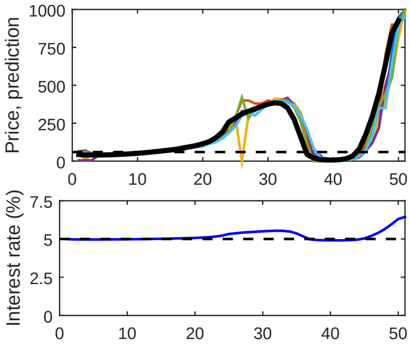
Control questions

- Suppose in one period, your prediction for the market price is 45.5, and the market price turns out to be 45.75. How many points do you earn for the forecasting task in this period (round it to the nearest integer)? *(Answer: 1298)*
- Suppose a financial advisor predicts that the stock price goes up in period 10, and goes down in period 20, and the pension fund acts according to this prediction. In which period does the pension fund increase its demand for stocks, period 9 or period 19? *(Answer: period 9)*
- In which of the following cases will the stock price go up?
  A. When advisors think the price will go down and the pension funds buy very little.
  B. When advisors think the price will go up and the pension funds buy a lot.
  (Answer: B)
- *NOT for treatment No Information:*
  Which of the following statements is true?
  A. The current interest rate is known, so the bank account is always a risk-free investment.
  B. The interest rate is variable, so the bank account and the stock are both risky investments.
  (Answer: A)
- *ONLY for treatment Communication:*
  Suppose the current interest rate is 10%. Does this mean that the central bank considers the stock price to be too high or too low? *(Answer: Too high)*
- Suppose by the end of the experiment you have earned 26,000 points, how much is this worth in euros? *(Answer: 10 euro)*

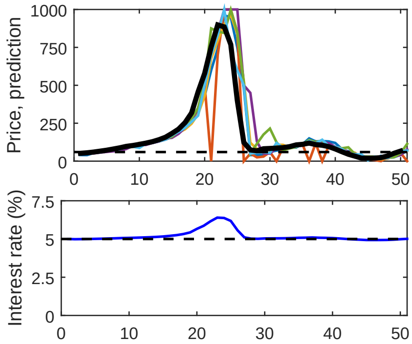
C Experimental results per market

Table 4: Summary statistics

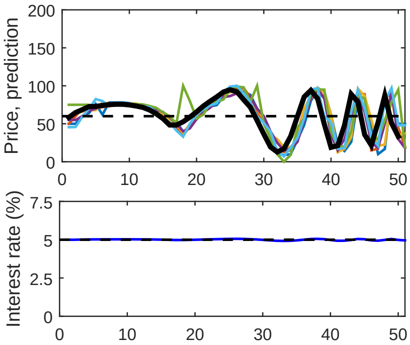
	Prices						Interest rates (%)			
	mean	st.dev.	min	max	RAD	RD	mean	st.dev.	min	max
Weak Rule										
Average	**184.11**	**173.32**	**22.09**	**607.74**	**2.29**	**2.07**	**5.20**	**0.29**	**4.94**	**5.91**
Group 1	181.78	205.97	7.27	926.88	2.36	2.03	5.20	0.34	4.91	6.44
Group 2	176.87	222.75	19.58	898.36	2.11	1.95	5.19	0.37	4.93	6.40
Group 3	61.45	22.55	12.85	94.80	0.31	0.02	5.00	0.04	4.92	5.06
Group 4	337.74	288.66	35.86	930.62	4.69	4.63	5.45	0.48	4.96	6.45
Group 5	264.05	317.40	12.23	942.35	3.79	3.40	5.33	0.53	4.92	6.47
Group 6	340.72	310.28	26.19	934.73	4.78	4.68	5.46	0.52	4.94	6.46
Group 7	53.43	2.53	46.83	57.30	0.11	-0.11	4.99	0.00	4.98	5.00
Group 8	56.87	16.39	15.93	76.91	0.20	-0.05	4.99	0.03	4.93	5.03
Strong Rule										
Average	**65.07**	**29.13**	**23.04**	**140.64**	**0.37**	**0.08**	**5.99**	**4.61**	**0.55**	**18.44**
Group 1	69.82	38.19	22.30	164.8	0.47	0.16	6.72	6.18	0	22.47
Group 2	64.79	25.87	26.92	107.39	0.38	0.08	5.81	4.23	0	12.90
Group 3	61.12	24.89	17.63	112.52	0.34	0.02	5.31	3.90	0	13.75
Group 4	62.83	27.81	6.70	141.48	0.28	0.05	5.74	4.12	0	18.58
Group 5	81.12	42.82	25.17	169.08	0.64	0.35	8.49	7.04	0	23.18
Group 6	57.64	21.16	17.38	98.87	0.28	-0.04	4.76	3.24	0	11.48
Group 7	62.98	50.44	11.66	262.92	0.57	0.05	6.02	7.86	0	38.82
Group 8	60.22	1.86	56.57	68.02	0.02	0.00	5.04	0.31	4.43	6.34
No Information										
Average	**87.62**	**42.50**	**28.12**	**201.07**	**0.62**	**0.46**	**9.55**	**7.00**	**0.33**	**28.51**
Group 1	62.58	21.76	40.45	166.42	0.21	0.04	5.42	3.59	1.74	22.74
Group 2	63.21	12.33	32.06	85.85	0.16	0.05	5.52	2.04	0.34	9.31
Group 3	61.95	13.94	29.26	94.03	0.16	0.03	5.32	2.30	0	10.67
Group 4	95.09	36.92	29.43	196.75	0.65	0.58	10.74	6.14	0	27.79
Group 5	73.84	54.68	24.08	268.94	0.55	0.23	7.33	8.97	0	39.82
Group 6	85.35	36.21	23.98	184.41	0.54	0.42	9.16	5.97	0	25.73
Group 7	176.77	122.88	33.47	440.50	2.04	1.95	24.08	20.46	0.58	68.42
Group 8	82.19	41.31	12.23	171.69	0.60	0.37	8.82	6.55	0	23.61
Communication										
Average	**62.44**	**16.59**	**29.47**	**103.07**	**0.23**	**0.04**	**5.48**	**2.63**	**0.75**	**12.18**
Group 1	60.99	6.76	36.19	70.50	0.08	0.02	5.16	1.12	1.03	6.75
Group 2	66.28	29.14	24.20	193.99	0.36	0.10	6.09	4.72	0	27.33
Group 3	62.25	14.31	34.66	89.59	0.18	0.04	5.37	2.36	0.78	9.93
Group 4	59.21	15.28	20.79	85.34	0.21	-0.01	4.90	2.45	0	9.22
Group 5	59.43	2.22	46.35	60.77	0.01	-0.01	4.91	0.37	2.72	5.13
Group 6	52.19	28.63	9.16	103.69	0.42	-0.13	4.29	4.01	0	12.28
Group 7	81.79	29.63	25.66	146.98	0.47	0.36	8.57	4.89	0	19.50
Group 8	57.41	6.79	38.72	73.73	0.09	-0.04	4.58	1.12	1.45	7.29
Sample Average										
Average	**81.67**	**60.91**	**18.04**	**249.68**	**0.76**	**0.36**	**7.98**	**6.58**	**0.80**	**26.60**
Group 1	110.4	93.04	8.56	383.03	1.17	0.84	9.51	8.85	0	33.46
Group 2	93.89	107.43	7.10	442.09	1.00	0.56	10.63	12.93	0	49.19
Group 3	158.2	173.94	6.00	583.00	2.07	1.64	11.85	13.06	0	50.70
Group 4	51.29	2.64	43.29	56.26	0.15	-0.15	5.17	0.47	3.74	5.97
Group 5	72.96	38.64	18.59	154.97	0.55	0.22	7.34	5.27	0	18.06
Group 6	76.25	45.75	11.27	236.81	0.58	0.27	7.43	6.26	0	31.63
Group 7	43.96	19.94	15.16	85.97	0.37	-0.27	6.61	4.64	0	16.65
Group 8	46.37	5.87	34.32	55.32	0.23	-0.23	5.29	1.19	2.63	7.16



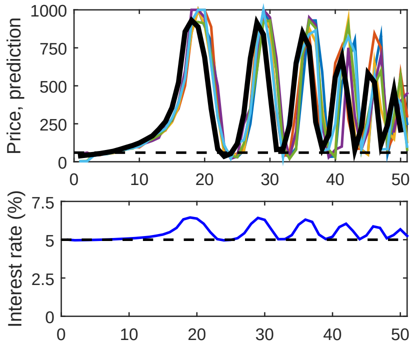
(a) Group 1



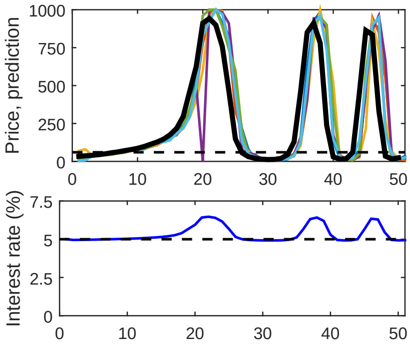
(b) Group 2



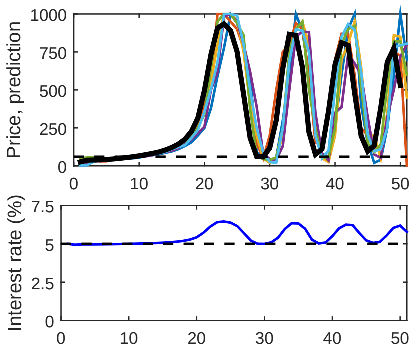
(c) Group 3



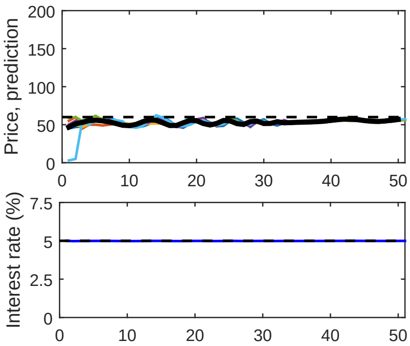
(d) Group 4



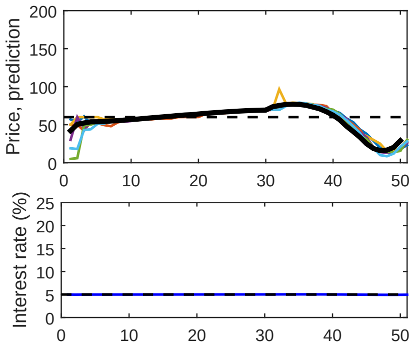
(e) Group 5



(f) Group 6



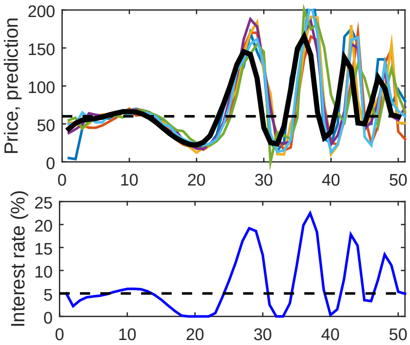
(g) Group 7



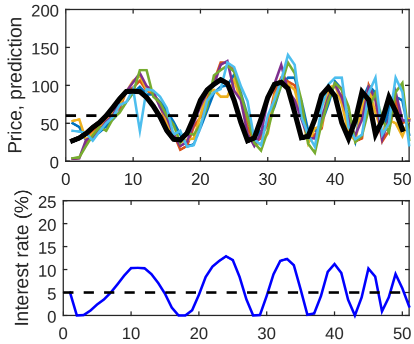
(h) Group 8

Figure 8: Market prices, predictions and interest rates in treatment Weak Rule

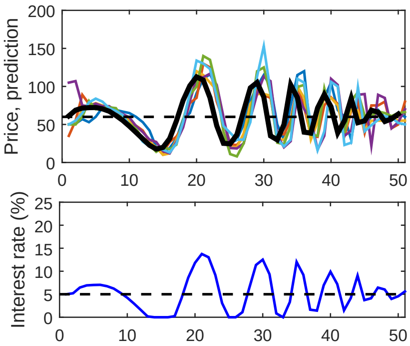
Notes: The dashed lines indicate the steady state price of 60 and the steady state interest rate of 5%. Note that the scale of the vertical axis may differ per group.



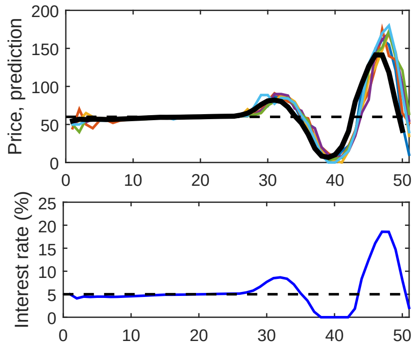
(a) Group 1



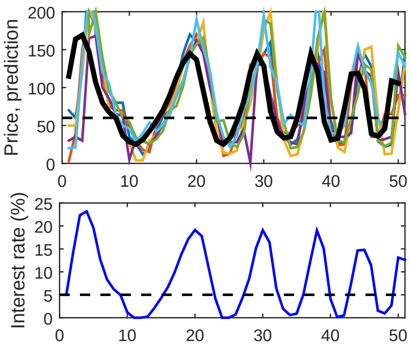
(b) Group 2



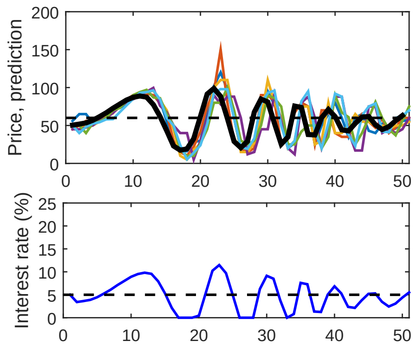
(c) Group 3



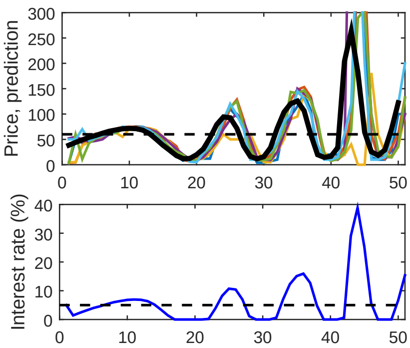
(d) Group 4



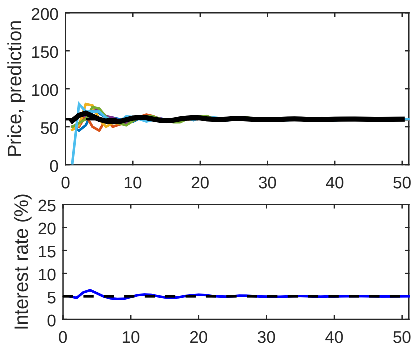
(e) Group 5



(f) Group 6



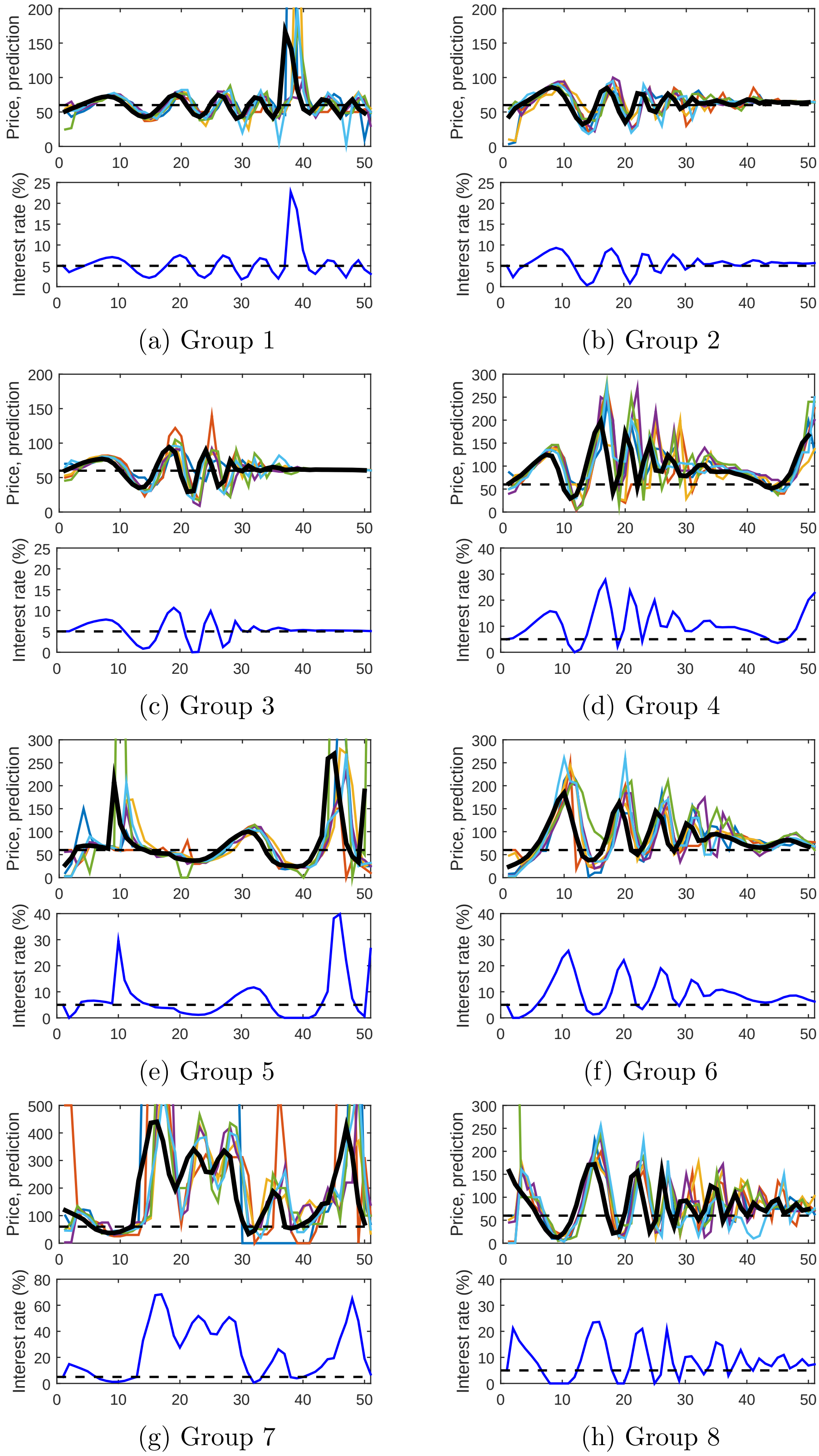
(g) Group 7



(h) Group 8

Figure 9: Market prices, predictions and interest rates in treatment Strong Rule

Notes: The dashed lines indicate the steady state price of 60 and the steady state interest rate of 5%. Note that the scale of the vertical axis may differ per group.



(a) Group 1 (b) Group 2

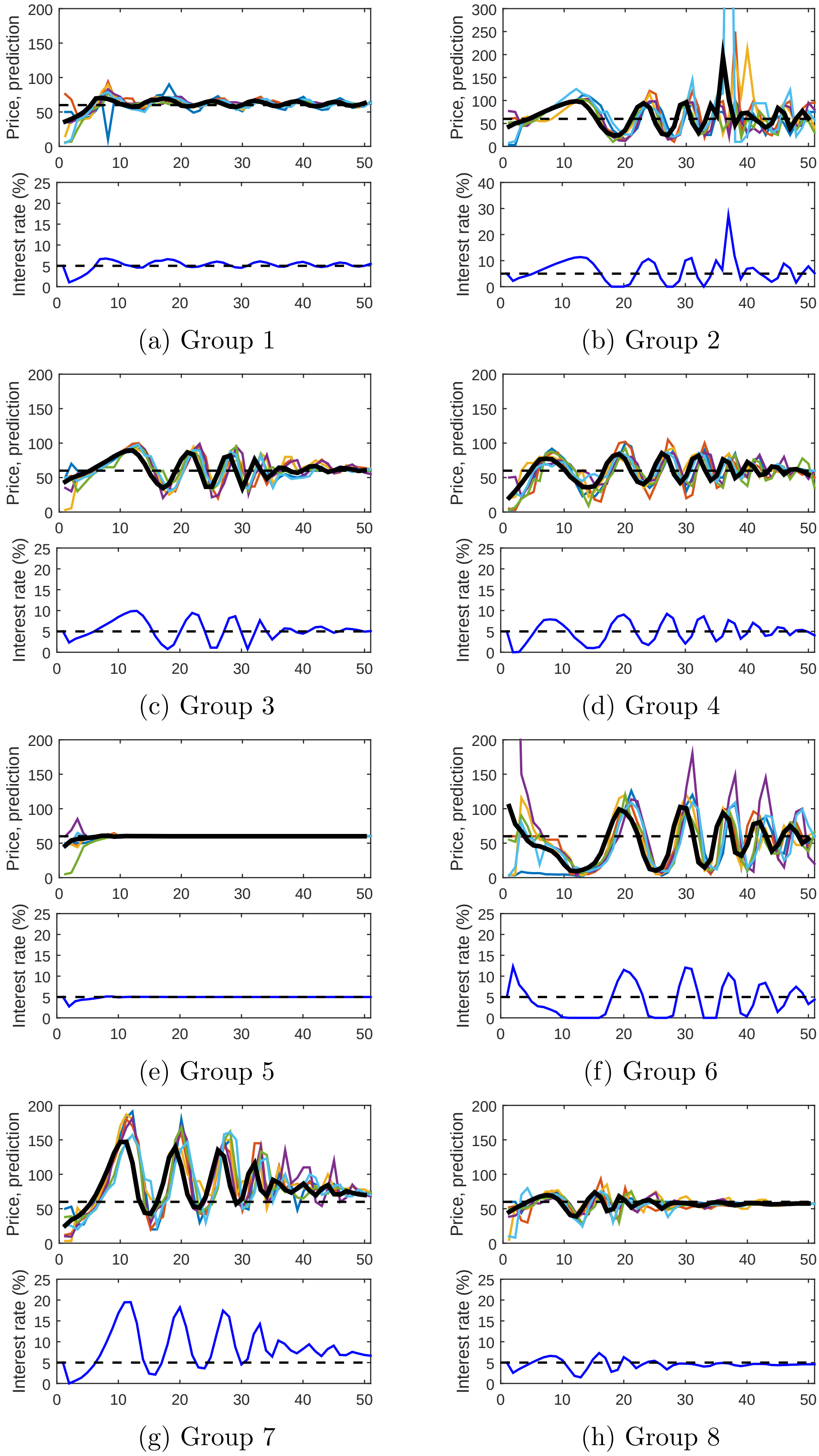
(c) Group 3 (d) Group 4

(e) Group 5 (f) Group 6

(g) Group 7 (h) Group 8

Figure 10: Market prices, predictions and interest rates in treatment No Information

Notes: The dashed lines indicate the steady state price of 60 and the steady state interest rate of 5%. Note that the scale of the vertical axis may differ per group.



(a) Group 1 (b) Group 2

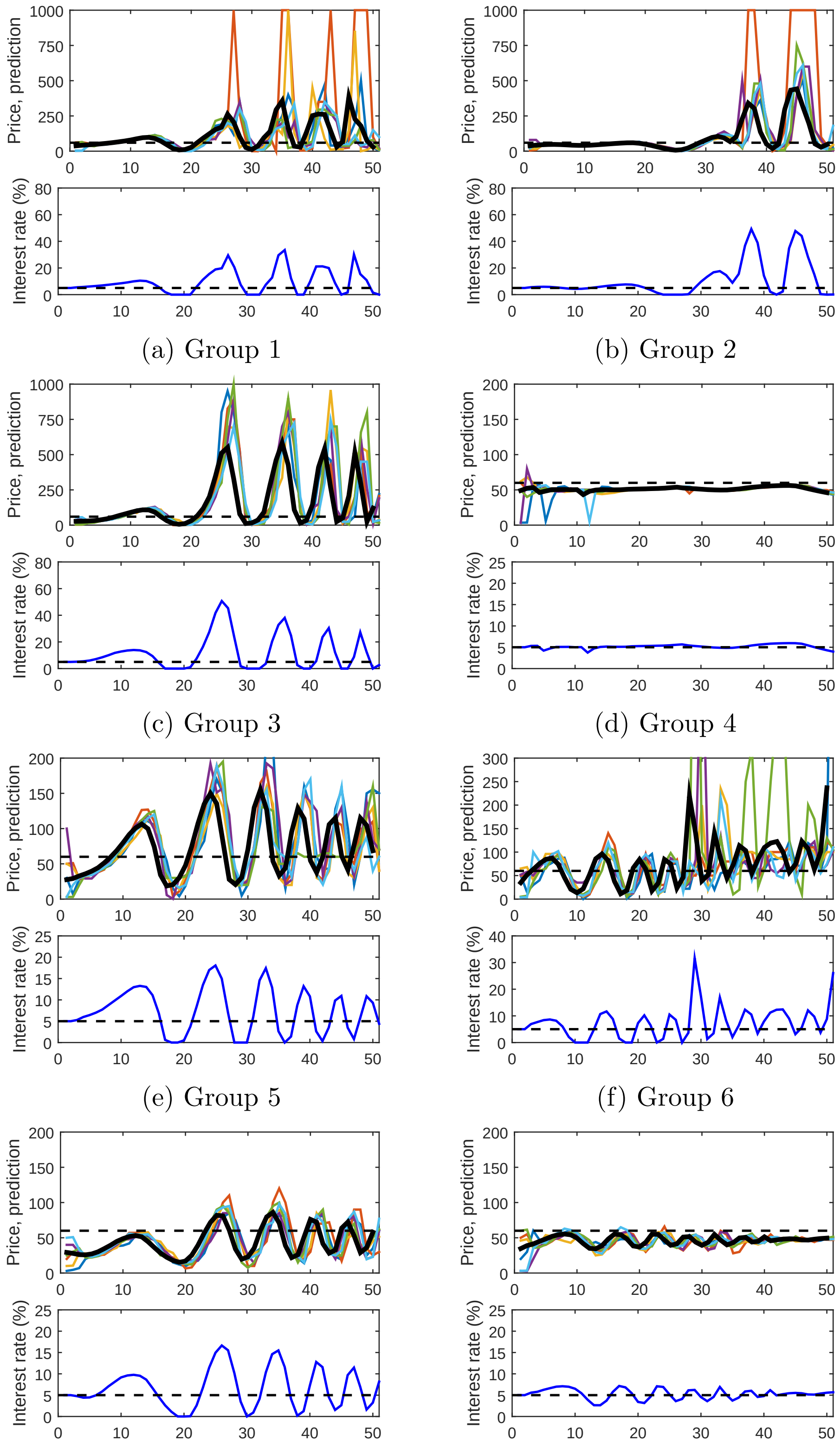
(c) Group 3 (d) Group 4

(e) Group 5 (f) Group 6

(g) Group 7 (h) Group 8

Figure 11: Market prices, predictions and interest rates in treatment Communication

Notes: The dashed lines indicate the steady state price of 60 and the steady state interest rate of 5%. Note that the scale of the vertical axis may differ per group.



(a) Group 1 (b) Group 2 (c) Group 3 (d) Group 4 (e) Group 5 (f) Group 6 (g) Group 7 (h) Group 8

Figure 12: Market prices, predictions and interest rates in treatment Sample Average

Notes: The dashed lines indicate the steady state price of 60 and the steady state interest rate of 5%. Note that the scale of the vertical axis may differ per group.

D Estimated prediction strategies

Table 5: Estimated forecasting rules for treatment Weak Rule

G	S	α	β_1	β_2	β_3	β_4	γ_0	γ_1	γ_2	γ_3	R^2	BG
1	1	-2.3	3.947	-1.277	0.684	0	-1.037	-1.175	0	0	0.986	0.701
1	2	14.1	2.074	-0.642	0	0	0.628	-1.011	0	0	0.961	0.926
1	3	6.1	1.994	-1.208	0	0	0	0	0.222	0	0.994	0.856
1	4	0.3	2.130	-1.420	1.066	0	0	0	-0.695	0	0.988	0.219
1	5	14.5	2.652	-2.089	0	0	0	0	0	0.354	0.978	0.705
1	6	6.9	2.190	-1.726	0	-0.436	0	0	0.948	0	0.986	0.528
2	1	17.2	1.797	-2.039	3.013	-1.844	0.837	-1.077	-0.772	1.014	0.987	0.361
2	2	-4.7	3.019	0	-1.204	0	-0.671	-0.750	0	0.510	0.898	0.016**
2	3	7.7	2.038	-1.380	0.354	0	0	0	0	0	0.973	0.164
2	4	8.9	1.328	0	-0.224	0	0	0	0	0	0.924	0.091
2	5	10.8	2.120	-2.403	0.876	0	0.433	0	0	0	0.949	0.229
2	6	8.5	3.149	-2.377	2.872	0	0	-0.662	-1.561	-0.426	0.973	0.332
3	1	2.9	2.290	-1.633	0	0	-0.710	0.980	0	0	0.876	0.123
3	2	18.6	2.386	-1.926	1.035	-0.681	0	-1.012	0.902	0	0.860	0.232
3	3	22.5	2.469	-2.158	0.742	0	-0.784	0.823	0	-0.441	0.818	0.480
3	4	12.2	1.421	-1.238	1.724	0	0	0	-1.156	0	0.715	0.105
3	5	12.1	1.685	-1.340	0.485	0	0	0	0	0	0.754	0.383
3	6	35.2	0	-1.772	0	-0.385	1.326	0	1.266	0	0.660	0.180
4	1	90.9	2.236	0	-0.993	0	-1.054	0	0.762	-0.131	0.916	0.433
4	2	130.6	0	0	0.346	0	1.200	-0.867	0	0	0.677	0.988
4	3	134.2	1.384	0	0	-0.935	0	-0.771	0	0.933	0.685	0.915
4	4	131.8	1.479	-1.562	0	0	0	0.730	0	0	0.814	0.591
4	5	135.9	2.611	-1.436	0.993	-1.464	-0.939	0	0	0.900	0.772	0.814
4	6	189.3	0	0	0	0	0.959	-0.454	0	0	0.524	0.638
5	1	99.7	0	-0.675	0	0	1.307	0	0	0	0.815	0.124
5	2	88.4	1.546	-0.798	0	0	0	0	0	0	0.833	0.451
5	3	47.6	1.767	-1.351	0	-0.290	0	0	0.703	0	0.897	0.889
5	4	80.5	1.594	-0.790	0	0	0	0	0	0	0.863	0.717
5	5	98.4	1.563	-0.819	0	0	0	0	0	0	0.807	0.060
5	6	74.6	1.826	-1.468	0	0	0	0	0.406	0	0.809	0.749
6	1	40.2	1.553	0	0	0	0	-0.736	0	0	0.936	0.469
6	2	52.0	0	-0.824	0	0.347	1.279	0	0	0	0.825	0.299
6	3	39.8	2.126	-1.680	0.484	0	0	0	0	0	0.912	0.533
6	4	13.7	1.542	-0.697	0	0.125	0	0	0	0	0.948	0.176
6	5	50.4	2.205	-1.602	0	0	0	0	0	0.299	0.899	0.508
6	6	30.7	2.059	-1.330	0	0	0	0	0	0.247	0.934	0.508
7	1	5.6	1.531	0	0	-0.340	0	-0.733	0.431	0	0.865	0.686
7	2	15.8	0.550	-0.816	0	0	0.449	0	0.525	0	0.671	0.956
7	3	8.2	0.543	-0.929	0.665	-0.436	0.609	0	0	0.396	0.647	0.574
7	4	8.3	1.840	-1.516	0.520	0	0	0	0	0	0.732	0.179
7	5	41.0	0	0	0	0	0.811	-0.578	0	0	0.546	0.032**
7	6	15.2	1.834	-1.827	1.828	-0.612	0	0	-0.504	0	0.679	0.632
8	1	2.8	1.340	0	-0.376	0	0	0	0	0	0.999	0.465
8	2	1.4	1.366	-0.518	0	0	0.655	-0.537	0	0	0.988	0.962
8	3	8.2	1.061	0	-0.535	0	0.683	-0.336	0	0	0.988	0.817
8	4	-3.4	2.326	0	0	0	-0.485	-0.577	0	-0.216	0.995	0.477
8	5	1.8	2.352	-1.383	0	0	0	0	0	0	0.994	0.472
8	6	-0.7	1.326	0	-1.315	0.745	0.647	0	-0.393	0	0.997	0.942

Notes: 'G' indicates the number of the group, 'S' indicates the number of the subject. The column 'BG' reports p-values of the Breusch-Godfrey test, ** indicates significance at the 5% level.

Table 6: Estimated forecasting rules for treatment Strong Rule

G	S	α	β_1	β_2	β_3	β_4	γ_0	γ_1	γ_2	γ_3	R^2	BG
1	1	22.0	2.054	-1.671	0	0	0	0	0	0.423	0.688	0.621
1	2	0.5	1.739	-0.903	0	0	0	0	0	0.147	0.882	0.777
1	3	-16.3	2.449	0	0.429	0	-0.685	-0.856	0	0	0.788	0.509
1	4	8.5	1.918	-1.490	0.517	0	0	0	0	0	0.752	0.617
1	5	4.3	1.016	0	0	0	0	0	0	0	0.715	0.333
1	6	5.8	3.146	0	-1.130	0	-1.195	-0.596	0.718	0	0.887	0.996
2	1	3.1	1.793	-1.666	1.344	-1.299	0	0	0	0.794	0.797	0.284
2	2	56.5	1.613	-2.217	0	-0.606	0	0.616	0.728	0	0.809	0.201
2	3	34.3	0	0	0	0	1.067	-0.591	0	0	0.623	0.326
2	4	58.4	0	-1.528	1.152	-0.682	1.180	0	0	0	0.755	0.234
2	5	7.8	1.786	-1.787	1.551	-0.615	0.419	-0.438	0	0	0.902	0.146
2	6	12.1	2.153	-2.135	1.239	0	0	0	0	-0.338	0.834	0.812
3	1	19.1	1.516	-1.313	0.756	-0.737	0	0	0	0.51	0.678	0.078
3	2	31.8	0.957	0	0	0	0	-0.479	0	0	0.480	0.446
3	3	33.6	0	-0.501	0	0	0.940	0	0	0	0.557	0.353
3	4	12.3	1.716	0	-0.930	0	-0.565	0	0.571	0	0.819	0.682
3	5	34.3	0	0	0	0	1.032	-0.585	0	0	0.604	0.239
3	6	31.3	1.462	-0.633	-0.943	0	0	0	0.599	0	0.717	0.112
4	1	15.3	3.164	-2.494	0	0	-0.508	0.580	0	0	0.972	0.211
4	2	34.8	0.718	0	1.962	-1.573	0	0	-0.696	0	0.962	0.005**
4	3	3.2	1.552	0	0	0	0	-0.359	0	-0.243	0.989	0.012**
4	4	17.5	0	2.012	-1.130	0	0.359	0	-0.518	0	0.978	0.241
4	5	18.6	0.784	0	0	-0.566	0.477	0	0	0	0.969	0.164
4	6	19.5	1.371	-1.405	1.063	-1.015	0.841	-0.658	0.483	0	0.984	0.733
5	1	24.5	1.532	-0.810	0	0	0	0	0	0	0.739	0.299
5	2	42.5	0.777	-0.811	0	0	0.502	0	0	0	0.675	0.504
5	3	18.3	1.531	0	-1.065	0	0	0	0.332	0	0.924	0.773
5	4	27.2	1.206	-0.624	0	0	0	0	0	0	0.570	0.661
5	5	2.1	1.485	0	-0.937	0.529	0	0	0	0	0.825	0.806
5	6	35.4	1.612	0	0	0.629	0	-0.914	0	-0.395	0.649	0.128
6	1	29.9	2.064	-2.504	1.720	-0.783	0	0	0	0	0.755	0.850
6	2	44.2	1.815	-2.429	1.739	-0.870	0	0	0	0	0.459	0.612
6	3	18.2	2.346	-2.900	2.246	-1.009	0	0	0	0	0.813	0.538
6	4	0.7	1.156	0	0	0	0	-0.373	0	0.194	0.743	0.458
6	5	9.8	1.361	-0.546	0	0	0	0	0	0	0.796	0.160
6	6	9.7	1.803	-1.183	0	0	0	0	0	0.242	0.839	0.441
7	1	-8.2	2.232	-1.499	0	0.787	0	0	0	-0.388	0.938	0.278
7	2	2.0	2.193	-1.042	-1.362	0.795	0	0.363	0.284	-0.167	0.976	0.007**
7	3	37.9	0	0	0.546	-0.627	0.347	0	0	0	0.524	0.005**
7	4	4.9	2.059	-1.233	0	0	0	0	0.186	0	0.874	0.515
7	5	10.0	1.474	-1.261	0	0.529	0.505	0	0	-0.342	0.958	0.040**
7	6	13.9	2.479	-3.509	0	0.630	0.273	0.692	0.459	-0.212	0.945	0.001**
8	1	23.7	0.742	-0.500	0	0	0.674	-0.407	0.339	-0.242	0.798	0.223
8	2	47.4	1.287	0	-1.076	0	-0.069	0.068	0	0	0.956	0.012**
8	3	103.2	0	-1.275	1.609	-1.319	0.736	-0.472	0	0	0.816	0.073
8	4	44.3	1.297	-2.317	1.702	-0.921	0.503	0	0	0	0.854	0.208
8	5	6.9	1.884	-0.837	0	0	0	0	0	-0.16	0.893	0.255
8	6	65.1	0	0	0	0	0	0	-0.330	0.244	0.171	0.273

Notes: 'G' indicates the number of the group, 'S' indicates the number of the subject. The column 'BG' reports p-values of the Breusch-Godfrey test, ** indicates significance at the 5% level.

Table 7: Estimated forecasting rules for treatment No Information

G	S	α	β_1	β_2	β_3	β_4	γ_0	γ_1	γ_2	γ_3	R^2	BG
1	1	35.2	0.381	0	0	0	0	0	0	0	0.344	0.200
1	2	27.5	0.248	0	-0.401	0.303	0.634	0	0	-0.262	0.764	0.646
1	3	-37.2	3.007	-2.206	0.856	0	0	0	0	0	0.929	0.158
1	4	38.3	0	0.399	-0.536	0.370	0.776	-0.645	0	0	0.596	0.32
1	5	10.7	1.177	-0.298	0.301	0	0	-0.374	0	0	0.880	0.259
1	6	28.7	1.306	-0.779	0	0	0	0	0	0	0.781	0.955
2	1	44.2	1.546	-1.721	1.158	-0.640	0	0	0	0	0.617	0.397
2	2	2.1	2.125	-1.767	0.605	0	0	0	0	0	0.804	0.316
2	3	7.5	1.423	-1.266	0.745	0	0	0	0	0	0.642	0.793
2	4	15.4	2.042	-1.915	1.297	-0.661	0	0	0	0	0.805	0.212
2	5	39.5	0	-0.370	0	0	0.757	0	0	0	0.401	0.597
2	6	37.1	2.127	-2.379	1.288	-0.646	0	0	0	0	0.703	0.955
3	1	14.9	0.664	-0.584	0.266	-0.200	0.625	0	0	0	0.890	0.097
3	2	-1.5	2.045	-0.952	0	0	0	-0.480	0.467	0	0.700	0.707
3	3	53.6	1.204	-1.173	0	0	0	0	0.463	-0.373	0.573	0.697
3	4	19.8	0.896	-0.628	0	0	0.636	-0.536	0.290	0	0.796	0.407
3	5	2.4	2.601	0	0	0	-1.136	-0.530	0	0	0.827	0.190
3	6	63.4	0	-1.405	1.168	-0.696	0.904	0	0	0	0.563	0.509
4	1	47.3	1.351	-1.190	0.897	0	0	0	0	-0.437	0.578	0.038**
4	2	56.6	1.538	-1.737	1.056	-0.841	0.389	0	0	0	0.736	0.020**
4	3	30.1	1.570	-1.449	0.594	0	0	0	0	0	0.761	0.977
4	4	45.7	2.232	-2.736	1.354	-0.726	0	0.494	0	0	0.794	0.011**
4	5	72.5	1.914	-2.352	2.083	-1.265	0	0	0	0	0.508	0.108
4	6	45.1	1.352	-1.130	1.047	-0.637	0	0	0	0	0.426	0.679
5	1	7.5	1.278	-0.735	0	0	0.347	0	0	0	0.798	0.864
5	2	30.7	0	-0.292	0.295	-0.233	0.742	0	0	0	0.460	0.985
5	3	4.5	0.872	0.239	0	-0.129	0	0	0	0	0.968	0.466
5	4	17.1	0.678	0	-0.449	0	0	0.492	0	0	0.885	0.253
5	5	-251.4	13.632	-2.890	-18.129	14.434	-1.779	0	2.662	-1.705	0.301	0.508
5	6	25.2	0.854	0	-0.238	0	0	0	0	0	0.822	0.715
6	1	28.9	1.614	-0.916	0	0	0	0	0	0	0.606	0.164
6	2	77.5	1.787	-2.394	1.755	-1.061	0	0	0	0	0.580	0.275
6	3	19.9	2.263	-2.439	1.421	0	0	0	0	-0.360	0.739	0.353
6	4	0.4	1.463	0	0	0	0	-0.408	0	0	0.888	0.261
6	5	-8.9	1.938	-1.912	0.959	0	0.311	0	0	0	0.792	0.716
6	6	33.6	2.480	-2.152	0	-0.369	0	0	0.689	0	0.805	0.284
7	1	66.0	0	0	0	0	0.842	0	0	0	0.701	0.407
7	2	69.5	1.057	0	0	0	0.418	0	-0.418	0	0.493	0.465
7	3	45.3	1.149	0	0	0	0	-0.315	0	0	0.789	0.124
7	4	23.7	1.308	0	0	0	0	0	-0.260	0	0.706	0.612
7	5	8.7	1.326	0.643	0	0	0	-0.826	0	0	0.854	0.394
7	6	5.1	1.720	-0.605	0	-0.424	0	0	0	0.336	0.945	0.234
8	1	56.6	1.150	-1.040	0.534	0	0	0	0	-0.326	0.513	0.638
8	2	56.5	1.368	-1.402	0.860	-0.475	0	0	0	0	0.672	0.492
8	3	60.3	1.038	-0.636	0	0	0	0	0	0	0.554	0.883
8	4	67.7	1.295	-1.196	0.798	-0.638	0	0	0	0	0.500	0.633
8	5	9.7	1.159	0	0.425	0	0	-0.551	0	0	0.512	0.401
8	6	56.8	1.311	-1.611	0.766	-0.681	0	0.479	0	0	0.449	0.374

Notes: 'G' indicates the number of the group, 'S' indicates the number of the subject. The column 'BG' reports p-values of the Breusch-Godfrey test, ** indicates significance at the 5% level.

Table 8: Estimated forecasting rules for treatment Communication

G	S	α	β_1	β_2	β_3	β_4	γ_0	γ_1	γ_2	γ_3	R^2	BG
1	1	45.7	0	0	0	0	0.687	0	-0.427	0	0.621	0.583
1	2	9.1	2.272	-1.683	0	0	0	0	0.285	0	0.703	0.870
1	3	33.5	1.710	-2.634	1.374	-0.536	0.548	0	0	0	0.853	0.006**
1	4	18.6	0.924	-0.780	0.511	0	0.457	0	-0.387	0	0.709	0.419
1	5	35.4	0.581	-0.423	0	0	0.275	0	0	0	0.420	0.257
1	6	34.9	1.464	-0.711	0	-0.312	0	0	0	0	0.845	0.211
2	1	13.2	0.539	-0.350	0	0	0.780	-0.424	0.237	0	0.684	0.438
2	2	15.1	1.456	-0.860	0.243	0	0	0	0	0	0.814	0.033**
2	3	26.1	0.497	-0.722	1.057	-0.498	0.592	0	-0.281	0	0.609	0.245
2	4	28.8	0.572	-0.602	0	0	0.564	0	0	0	0.592	0.064
2	5	38.4	0	-0.515	0.389	-0.237	0.758	0	0	0	0.414	0.289
2	6	51.0	0	0	0	0	0.663	-0.403	0	0	0.318	0.647
3	1	16.9	1.962	-2.134	1.420	-0.530	0	0	0	0	0.777	0.066
3	2	13.7	2.023	-1.952	1.474	-0.743	0	0	0	0	0.772	0.108
3	3	17.4	1.577	-2.229	1.352	-0.451	0.493	0	0	0	0.837	0.113
3	4	28.6	1.828	-1.492	0.736	-0.498	0	0	0	0	0.777	0.614
3	5	27.1	1.426	-1.370	0.527	0	0	0	0	0	0.549	0.010**
3	6	4.5	2.072	-2.332	1.623	-0.450	0	0	0	0	0.675	0.018**
4	1	11.5	2.099	-1.959	1.293	-0.624	0	0	0	0	0.825	0.747
4	2	-10.9	2.161	-1.283	1.209	0	0	-0.546	0	-0.421	0.793	0.582
4	3	56.8	0	-0.946	0.867	-0.603	0.748	0	0	0	0.447	0.475
4	4	30.0	1.198	-0.656	0	0	0	0	0	0	0.828	0.527
4	5	-5.5	1.833	-1.449	0.658	0	0	0	0	0	0.660	0.809
4	6	57.5	0.493	0	0	-0.413	0.477	-0.896	0	0.422	0.629	0.077
5	1	9.0	-0.432	1.092	-0.321	0	1.096	-0.548	-0.290	0.253	0.997	0.000**
5	2	-9.1	3.791	-1.046	-0.751	-0.594	-1.184	0.378	0.434	0.123	0.993	0.541
5	3	20.2	1.729	-0.429	0.444	-0.554	-0.673	0.147	0	0	0.819	0.005**
5	4	251.1	-0.913	-1.948	0	0.591	-0.457	0	-0.200	-0.257	0.951	0.000**
5	5	-8.1	0.706	0	0.267	0	0.394	-0.299	0.026	0.040	0.996	0.000**
5	6	34.0	-0.272	0	-0.557	0.343	0.778	0.469	-0.191	-0.136	0.726	0.744
6	1	9.0	1.342	-0.907	0	-0.264	0.540	-0.438	0.561	0	0.927	0.280
6	2	24.3	0	0	0	0	1.032	-0.513	0	0	0.586	0.909
6	3	24.9	0	0	0	0	1.061	-0.540	0	0	0.614	0.951
6	4	-7.0	1.796	0	-1.46	0.898	0	0	0	0	0.901	0.598
6	5	10.4	1.350	0	-0.545	0.507	0	-0.597	0	0	0.697	0.244
6	6	3.5	1.543	-0.615	0	0	0	0	0	0	0.896	0.898
7	1	25.4	2.137	-1.885	0.977	-0.484	0	0	0	0	0.798	0.678
7	2	34.3	2.200	-2.363	1.404	-0.595	0	0	0	0	0.729	0.076
7	3	67.0	0	-1.018	0.85	-0.617	0.995	0	0	0	0.586	0.402
7	4	15.9	2.208	-2.062	0.745	0	0	0	0	0	0.722	0.676
7	5	19.6	1.573	-0.773	0	0	0	0	0	0	0.833	0.369
7	6	6.0	1.432	-0.446	0	0	0	0	0	0	0.865	0.236
8	1	52.0	0	-0.546	0	-0.234	0.880	0	0	0	0.584	0.087
8	2	79.9	1.263	-2.054	1.18	-0.813	0	0	0	0	0.457	0.854
8	3	27.0	1.227	-0.657	0	0	0	0	0	0	0.539	0.883
8	4	50.9	0.918	-1.081	1.184	-0.461	0	0	-0.448	0	0.473	0.037**
8	5	11.4	1.773	-1.689	0	0	0	0.715	0	0	0.849	0.687
8	6	70.3	1.293	-1.639	0.808	-0.710	0	0	0	0	0.510	0.191

Notes: 'G' indicates the number of the group, 'S' indicates the number of the subject. The column 'BG' reports p-values of the Breusch-Godfrey test, ** indicates significance at the 5% level.

Table 9: Estimated forecasting rules for treatment Sample Average

G	S	α	β_1	β_2	β_3	β_4	γ_0	γ_1	γ_2	γ_3	R^2	BG
1	1	36.1	1.450	-1.362	0.611	0	0.414	-0.359	0	0	0.797	0.269
1	2	72.0	2.486	0	0	-2.820	0	0	0	0.928	0.464	0.843
1	3	116.4	0	0	0	0	0	0	0	0	0.000	0.000**
1	4	35.2	0.436	-0.367	0	0	0.559	0	0	0	0.513	0.875
1	5	46.1	0.427	-0.466	0	0	0.594	0	0	0	0.518	0.194
1	6	31.6	0.491	0	0	0	0.483	-0.301	0	0	0.595	0.568
2	1	14.3	1.184	0	-1.085	0.653	0	0	0	0	0.924	0.232
2	2	-134.4	4.212	0	0	0.997	0	-0.815	0	0	0.650	0.842
2	3	5.0	1.293	0	-0.834	0.461	0	0	0	0	0.966	0.272
2	4	20.3	1.330	0	-0.365	0	0	0	0	0	0.749	0.69
2	5	0.3	2.627	-0.777	0	0	-0.331	-0.395	0	0	0.951	0.587
2	6	-3.0	1.661	0	-1.992	2.109	0	0	0	-0.564	0.926	0.478
3	1	80.0	0	0	-0.446	0.885	0.781	0	0	-0.521	0.563	0.264
3	2	113.6	0	-0.601	0	0	0.953	0	0	0	0.547	0.344
3	3	34.0	2.131	-1.603	0	0	0	0	0.452	0	0.810	0.272
3	4	44.8	1.564	-0.963	0	1.759	0	0	0	-1.151	0.660	0.025**
3	5	37.3	2.313	-1.552	0	0	0	0	0.288	0	0.852	0.224
3	6	29.4	1.904	-1.516	1.102	-1.214	0	0	0	0.587	0.911	0.317
4	1	12.7	1.458	-0.751	0	0	0.155	-0.110	0	0	0.841	0.000**
4	2	9.3	0.815	0	0	0	0	0	0	0	0.616	0.780
4	3	2.4	0.529	0	0	-0.254	0.967	-0.293	0	0	0.900	0.524
4	4	6.2	0.656	0	0	-0.257	0.480	0	0	0	0.892	0.349
4	5	6.6	0.754	-0.273	-0.227	0	0.757	0	0	-0.142	0.924	0.719
4	6	12.7	0.569	0	0	0	0.568	-0.227	0	-0.156	0.823	0.099
5	1	6.1	2.155	-1.441	0	0	0	0	0.301	0	0.851	0.441
5	2	27.1	2.145	-2.133	2.378	-1.487	0	0	-1.107	0.914	0.776	0.331
5	3	31.6	2.799	-1.131	0	0	-1.170	0	0	0	0.857	0.357
5	4	29.9	1.816	-2.330	1.364	-0.560	0.384	0	0	0	0.828	0.286
5	5	37.0	0	0	0	0	1.114	-0.604	0	0	0.621	0.143
5	6	19.7	1.697	-1.406	0.483	0	0	0	0	0	0.646	0.245
6	1	30.1	0	0	0	0	0.550	0	0	0	0.237	0.033**
6	2	37.9	0	-0.250	0	0	0.732	0	0	0	0.384	0.049**
6	3	2.9	0.829	-0.902	0.506	0.445	0.377	0	0	-0.271	0.713	0.210
6	4	2.9	2.048	-1.504	0.750	0	0	0	0	-0.320	0.579	0.337
6	5	33.1	0	0	0	0	0.762	-0.415	0	0.323	0.467	0.858
6	6	50.9	0	0	0	0.554	0.296	-0.284	0	-0.363	0.341	0.096
7	1	-8.5	2.088	-0.790	0	0.322	-0.428	0	0	0	0.925	0.182
7	2	-1.1	1.842	-0.752	0	0	0	0	0	0	0.900	0.377
7	3	13.4	2.101	-2.42	1.674	-0.637	0	0	0	0	0.797	0.481
7	4	1.2	2.139	-1.652	0.961	0	0	-0.480	0	0	0.881	0.326
7	5	33.0	0	-0.817	0	0	1.093	0	0	0	0.754	0.329
7	6	3.2	3.096	-2.283	0.767	0	-0.588	0	0	0	0.821	0.091
8	1	26.5	0	0	0	0	0.436	0	0	0	0.169	0.126
8	2	17.5	1.567	-0.974	0	0	0	0	0	0	0.717	0.357
8	3	32.1	0	0	0	0	0.891	-0.600	0	0	0.565	0.906
8	4	22.2	1.329	-0.797	0	0	0	0	0	0	0.761	0.436
8	5	14.2	1.332	-1.131	0.479	0	0	0	0	0	0.489	0.680
8	6	35.9	0	-0.936	0.569	0	1.271	-0.508	0	-0.159	0.833	0.958

Notes: 'G' indicates the number of the group, 'S' indicates the number of the subject. The column 'BG' reports p-values of the Breusch-Godfrey test, ** indicates significance at the 5% level.