Expectations and Monetary Policy: Experimental Evidence

Oleksiy Kryvtsov*
Bank of Canada

Luba Petersen†
Simon Fraser University

This version: April 15, 2015
First version: November 2013

Abstract

The effectiveness of monetary policy depends, to a large extent, on market expectations of its future actions. In a standard New Keynesian business-cycle model with rational expectations, systematic monetary policy reduces the variance of inflation and the output gap by at least two-thirds. These stabilization benefits can be substantially smaller if expectations are non-rational. We design an economic experiment that identifies the contribution of expectations to macroeconomic stabilization achieved by systematic monetary policy. We find that, despite some non-rational component in expectations formed by experiment participants, monetary policy is quite potent in providing stabilization, reducing macroeconomic variance by roughly half.

JEL classifications: C9, D84, E3, E52
Keywords: Expectations, Monetary Policy, Inflation, Laboratory Experiment, Experimental Macroeconomics.

---

*Bank of Canada, email: okryvtsov@bank-banque-canada.ca.

†Department of Economics, Simon Fraser University, e-mail: luba_petersen@sfu.ca. We thank Claude Montmarquette and Jim Engle-Warnick for providing us with access to CIRANO experimental lab facilities. We are especially grateful to Jean Boivin for inspiring us to work on this project and for numerous helpful discussions. We thank Bob Amano, Jasmina Arifovic, Janet (Hua) Jiang, Bruce Preston, Malik Shukayev, seminar participants at the Bank of Canada, University of Melbourne, University of New South Wales, University of Monash, Queensland University of Technology, Canadian Economic Association meetings in Montréal, International Conference on Computing in Economics and Finance in Vancouver, and Theoretical and Experimental Macroeconomics conference in Barcelona for useful comments and suggestions. Boyan Bejanov provided superb research assistance, and Natalie Viennot provided excellent lab assistance. We thank Glen Keenleyside for extremely helpful editorial assistance. The views expressed here are ours, and they do not necessarily reflect the views of the Bank of Canada. All remaining errors are our own.

1 Introduction

The modern economy is a complex and inherently uncertain environment. To make optimal decisions in such an environment, households and firms in the economy must take into account a possible unravelling of future events. For instance, a household's decision to buy a house will depend on the expectations of its future income, future interest rates and future changes in house value. A retailer's decision to set new prices for its merchandise will be affected by its expectations of future inflation. The importance of expectations for economic decisions underscores their major role for macroeconomic fluctuations.

Monetary policy, mandated to ensure a stable macroeconomic environment, is naturally concerned with how private expectations affect the economy. The key challenge for a central banker is to understand not only how expectations affect the economy and which policy actions they elicit, but also how the stance of monetary policy affects expectations. Managing market expectations is an important tool of monetary policy that central banks often use to stabilize the economy both in normal and extraordinary times.[1] The goal of this paper is to use experimental evidence to measure the degree of macroeconomic stabilization achieved by monetary policy through its effect on expectations.

Despite the central role that expectations play in macroeconomic fluctuations, our understanding of how they are formed and what they imply for policy is far from satisfactory. The vast majority of modern macroeconomic models assume rational expectations, according to which households and firms take into account all information available; have a complete understanding of the workings of the economy, including future consequences

[1]Woodford (2003), Galí (2008) and Boivin, Kiley and Mishkin (2010) emphasize the importance of the management of expectations by monetary policy. Boivin (2011) highlights the importance of studying expectations formation for monetary policy design. The importance of forward guidance by central banks during the period of historically low interest rates has been stressed by Carney (2012) and Woodford (2012, 2013).

of their actions; and make optimal decisions that are consistent with this understanding. Despite its tractability and theoretical appeal, the assumption of rational expectations implies aspects of decision making that are often not consistent with how people think in reality.[2] Moreover, model-based inference of expectations formation faces the difficult task of identifying model restrictions stemming from assumed expectations formation vis-à-vis other model restrictions.

In this paper, we employ an alternative approach that uses economic experiments to obtain direct evidence on how expectations are formed and allows us to quantify their role in macroeconomic stabilization. The key advantage of this approach stems from a more precise control of conditions in which participants in the experiment form their forecasts.[3] Our approach consists of four main parts. First, we introduce a measure of the expectations channel of monetary policy in a standard New Keynesian business-cycle model and demonstrate how stabilization achieved by monetary policy depends on the way expectations are formed. Second, we implement this model in an experimental setting, in which expectations of inflation and the output gap are repeatedly provided by experiment participants. Third, we use experimental data to measure the strength and robustness of the expectations channel, which we then compare to measures obtained in a theoretical setting. Finally, we study individual forecasting behaviour, and how subjects utilize available information to form their expectations.

We begin our analysis by developing a theoretical framework based on a standard New Keynesian business-cycle model à la Woodford (2003) and augmented with a flexible specification for expectations formation. To quantify the strength of the expectations channel, we first derive the responses of inflation and the output gap to the natural-rate-of-interest impulse that occurs in the absence of future responses of nominal inter-

[2] Boivin (2011) provides an overview of studies of non-rational behaviour.

[3] Duffy (2008), Hommes (2011), and Chakravarty et al. (2011) review the literature on experimental macroeconomics. Surveys of households or professional forecasters are another source of direct evidence on expectations formation. See Mankiw, Reis and Wolfers (2004) and Coibion and Gorodnichenko (2012) for recent studies of expectations using survey-of-forecasters data.

est rates. We then document how much these counterfactual responses are reduced in equilibrium with countercyclical nominal interest rate responses. Our measure of the expectations channel is therefore based on the fraction of conditional variances of inflation and the output gap that are decreased by the systematic monetary policy response over the quarters following the quarter of the shock.

For empirically plausible parameterizations of the model, we find that, under rational expectations, monetary policy reduces the conditional variance of inflation and the output gap by at least *two-thirds*. In contrast, when expectations are non-rational, the decrease in the variance due to monetary policy can be substantially smaller. For example, in versions of the model with adaptive expectations, where expectations rely heavily on past output and inflation realizations, the reduction of macroeconomic volatility by monetary policy is less than one-third and can be as low as zero.

We then design an experiment that implements this model in a learning-to-forecast setting, in which expectations of inflation and the output gap are repeatedly provided by experiment participants. There are two novel features in our experimental design. First, we provide full information about the only exogenous shock process (for the natural-rate-of-interest disturbance), as well as complete information about the underlying model. This set-up allows us to estimate aggregate and individual forecasts as functions of observed shock history, which we then use to quantify the contribution of expectations to macroeconomic stabilization. Second, we provide, at a small time cost, information about the histories of past outcomes and shocks, and a detailed model description. This allows us to monitor how information is used, and whether it improves forecast accuracy.

In the experiment, inflation and the output gap predominantly exhibit stable cyclical behaviour, with the peak-to-trough time ranging between 3.9 and 7.5 quarters in the Benchmark treatment, which is within the range of 3 to 20 quarters predicted by our baseline model under various expectations formations. Subjects quickly converge to their stationary behaviour, and experimental outcomes do not seem to be driven by factors outside the data-generating process, such as sunspots or strategic behaviour.

Our main finding is that, in the experiment, monetary policy provides a substantial degree of macroeconomic stabilization via its effect on subjects' expectations. In the Benchmark treatment, the fraction of conditional variance of inflation and the output gap, reduced by the anticipated response of nominal interest rates, is 0.51 and 0.45, respectively. Our theoretical model predicts that the reduction in the variance should range between 0.73 for inflation (0.65 for the output gap) under rational expectations and virtually zero under strong forms of adaptive expectations. Therefore, despite falling somewhat short of the stabilization that could be achieved if agents behaved rationally, monetary policy is quite potent, reducing roughly half of the variance of inflation and the output gap.

We show that a version of the theoretical model with a weak form of adaptive expectations, which puts significant weight on the last-period output and inflation realizations, fits best both the magnitude and the timing of aggregate fluctuations in the experiment. For example, in the model with this form of adaptive expectations, the standard deviations of inflation, the output gap and their forecasts are between 0.70 and 1.24 times those documented for the sessions in the Benchmark treatment (versus 0.36 to 0.74 for the model with rational expectations). Correlations between the experimental and model time series range between 0.76 and 0.89 (versus 0.55 to 0.71 for the model with rational expectations).

We check the robustness of our findings by introducing variation in key features of our experimental design. Our model predicts that two such features are the persistence of macroeconomic fluctuations and the elasticity of the nominal interest rate response to these fluctuations. We therefore conduct two alternative experimental treatments with more-persistent shocks and with more-aggressive monetary policy. We find that, in accordance with the model's predictions, monetary policy in both treatments provides *more* stabilization than in the Benchmark treatment, reducing the variance of inflation (the output gap) by 0.95 (0.96) in the High-Persistence treatment and by 0.72 (0.56) in the Aggressive Monetary Policy treatment. We also extend the Benchmark treatment by adding an explicit announcement of the expected path of future nominal interest rates. Such information has the potential to improve participants' expectations of monetary policy and enable them to form relatively more stable expectations. The supplementary information leads to *less* stabilization, leading to a reduction in the variance of inflation (the output gap) by 0.14 (0.10). This is a result of highly bipolar outcomes, with half the sessions behaving comparably to the Benchmark treatment while the other half experiencing significantly greater macroeconomic volatility and weaker estimated expectations channel.

This paper is most closely related to recent experimental studies of expectations formations and their impact on the effectiveness of monetary policy interventions in the context of New Keynesian models.[4] These studies typically find some form of adaptive expectations, which rely heavily on the past history of inflation or the output gap. Adam (2007) finds that sluggish expectations can account for considerable persistence of output and inflation. Assenza et al. (2012) find that monetary policy must be significantly aggressive to changes in inflation from target levels to maintain macroeconomic stability. Pfajfar and Zakelj (2012, 2013) study the stabilizing role of various Taylor rule specifications in a forward-looking New Keynesian model. The consensus of this literature is that expectations play a major role in business-cycle fluctuations, and that they underline the effectiveness of monetary policy in stabilizing those fluctuations.

The main contribution of our paper is in developing the methodology that identifies the degree of stabilization provided by monetary policy via its effect on expectations.

[4] Recent studies include Adam (2007); Assenza et al. (2012); Pfajfar and Zakelj (2012, 2013). Typically, these studies use learning-to-forecast experiments, in which subjects participate as private forecasters. Subjects are paid based on the forecast accuracy alone and are imperfectly informed about the underlying data-generating process. They are provided with all past information on inflation and output, and are asked to provide one- and sometimes two-step-ahead forecasts repeated for at least 40 periods. The average forecast of a group of subjects is used in the calculation of current inflation and output. Expectations formation is inferred from estimating the forecasting rules used by subjects.

Of central importance to this methodology is the experimental design that enables the estimation of expectations as functions of the observed shock history. These functions are used to quantify the counterfactual decrease in the variance of inflation and the output gap due to the systematic response of monetary policy to an exogenous economic disturbance. Our main finding is that, despite a non-rational component in expectations formation, monetary policy is quite potent in providing stabilization, accounting for roughly half of the business-cycle stabilization.

The rest of the paper proceeds as follows. Section 2 develops the theoretical framework that is used to set up artificial macroeconomic simulation in the experimental setting, described in section 3. Section 4 reports the main results of the experiment concerning the behaviour of average expectations as well as the dynamics of the output gap, inflation and the interest rate. Section 5 characterizes differences in how individual expectations are formed, and how subjects use available information. Finally, section 6 concludes.

2 Theoretical Framework

2.1 Model outline

Our theoretical framework is based on a standard New Keynesian business-cycle model, in which private expectations of future economic outcomes and policy actions play a key role in determining current outcomes.[5] In the model, a unit measure of households consume a basket of differentiated goods, save in one-period nominal bonds and supply working hours to productive firms. Let Y_t^n denote the level of output in this model in the case of fully flexible prices, or the natural rate of output. As Woodford (2003) shows, this concept is convenient for summarizing the effects of shocks on the real marginal cost. Define the output gap, x_t, as the difference between the level of output

[5]See Woodford (2003) for detailed assumptions and derivations of equilibrium conditions in the model under rational expectations. Clarida et al. (2000) provide closely related analysis.

and the natural rate of output, $x_t = Y_t - Y_t^n$. Households' intertemporal optimization of consumption expenditures implies that, in equilibrium, the level of output (relative to the natural rate of output) must satisfy the Euler equation (written in terms of a log-linear approximation around a deterministic steady state):

$$x_t = E_t^* x_{t+1} - \sigma^{-1} \left(i_t - E_t^* \pi_{t+1} - r_t^n \right) \ , \tag{1}$$

where σ is the coefficient of risk aversion; i_t is the risk-free one-period nominal interest rate, controlled by the central bank; π_t is the inflation rate, and r_t^n is the deviation of the natural rate of interest.[6] We will assume that r_t^n follows an AR(1) process:

$$r_t^n = \rho_r r_{t-1}^n + \varepsilon_{rt} \ , \tag{2}$$

where ε_{rt} are i.i.d. draws from $N\left(0, \sigma_r^2\right)$.

Terms $E_t^* x_{t+1}$ and $E_t^* \pi_{t+1}$ denote households' expected values of the next period's the output gap and inflation, respectively. Equation (1) says that, in equilibrium, the real aggregate demand (relative to its natural level) depends on the real interest rate (relative to its natural level). For example, if the real interest rate is high (say, if the nominal interest rate is higher than implied by the natural rate of return), households discount future consumption at a higher rate, which means that they need to save more (consume less) in the present in order to ensure their preferred level of consumption in the future.

A continuum of monopolistic firms use labour supplied by households to produce goods of a particular variety. They face constraints on how often they can adjust their prices, but commit to satisfy all demand at the price that they have at any point in

[6] The natural rate of interest may be defined as the equilibrium real rate of return in the case with fully flexible prices. It is the real rate of interest required to keep aggregate demand to be equal to the natural rate of output, Y_t^n, at all times. Its fluctuations may stem from disturbances to government purchases, households' propensity to consume or willingness to work, and to firms' productivity. See Woodford (2003, Chapter 4) for details.

time. Under standard assumptions on the demand for goods and on firms' technology, firms' intertemporal optimization leads to an aggregate supply equation that relates the inflation rate to the level of real activity, also known as the New Keynesian Phillips curve, or (in log deviations):

$$\pi_t = \kappa x_t + \beta E_t^* \pi_{t+1} \ . \tag{3}$$

Equation (3) says that a higher level of real activity is associated with a higher marginal cost of production, leading to higher new prices and inflation rates. Since the price set by a given firm may last for many periods in the future, it has to take into account the entire future path of its marginal costs, captured by the term proportional to firms' expected future rate of inflation, $E_t^* \pi_{t+1}$. From the point of view of the policy-maker, equation (3) represents a trade-off between inflation and the output gap. For example, permanently reducing the inflation rate by 1 percentage point is associated with a permanent reduction of the output gap by $\frac{1-\beta}{\kappa}$ per cent. Coefficient κ that governs this trade-off is a function of the parameters that determine the frequency and size of firms' price changes.[7] Note that we assume that households have identical information sets, and that their expectations (of inflation and the output gap) are identical functions of the state history. Under these assumptions, equilibrium equations (1) and (3) have the same form as in Woodford (2003) under rational expectations.[8]

Finally, monetary policy sets the path of short-term nominal interest rates i_t according to a Taylor interest rate rule (in log deviations):

$$i_t = \phi_\pi E_{t-1}^* \pi_t + \phi_x E_{t-1}^* x_t \ , \tag{4}$$

where i_t is an exogenous term reflecting variations in the interest rate target (stemming

[7] See Chapters 3 and 5 in Woodford (2003) for examples of strategic pricing complementarities.

[8] Preston (2006) studies implications of heterogeneity of information across households in New-Keynesian set-up and finds that targeting private sector expectations can be important if a central bank's inflation forecasts differ from those of the private sector.

from nominal demand disturbances or imperfect control of the nominal interest rate by the central bank), and ϕ_π, ϕ_x are the coefficients in front of the expected inflation rate and the output gap, respectively.[9] According to this specification, the monetary authority sets its period-t interest rate in response to deviations of period-t inflation and the output gap expected in period $t-1$.[10] We assume that the monetary authority has the same information and forecasting functions as the private sector. An important implication of the Taylor rule (4) is that monetary policy responds to fluctuations in the economy with a one-period lag. This assumption captures important timing restrictions commonly made in the monetary policy literature, and will also be useful in the experimental set-up.[11]

The model is closed by specifying how the expected values $E_t^* x_{t+1}$ and $E_t^* \pi_{t+1}$ are determined as functions of the state history. We define these functions by imposing the following general specification for ex ante one-period-ahead forecast errors:

$$E_t \left(\begin{bmatrix} \pi_{t+1} \\ x_{t+1} \end{bmatrix} - E_t^* \begin{bmatrix} \pi_{t+1} \\ x_{t+1} \end{bmatrix} \right) = \sigma^{-1} \rho_r \sum_{s=0}^{\infty} \begin{bmatrix} \kappa L_{s\pi} \\ L_{sx} \end{bmatrix} r_{t-s}^n \ , \qquad (5)$$

where E_t denotes the mean conditional on state history through period t, and $L_{s\pi}$, L_{sx} are real numbers representing the elasticity of ex ante forecast errors for inflation and the output gap with respect to shock realizations in periods $t, t-1, \ldots$. Under rational

[9] It is common in the literature to include in the Taylor rule an exogenous term, ι_t, reflecting variations in the interest rate target (stemming from nominal demand disturbances or imperfect control of the nominal interest rate by the central bank); e.g.,

$$i_t = \iota_t + \phi_\pi E_{t-1}^* \pi_t + \phi_x E_{t-1}^* x_t \ .$$

Since the effects of ι_t on the output gap and inflation in our set-up are identical to those of the r_t^n shock, we will abstract from it here.

[10] A number of papers in the literature argue in favour of a specification of the Taylor rule in which the central bank responds to deviations in the *expected* – as opposed to current – inflation rate. See Clarida et al. (2000); Bernanke and Boivin (2003). We find that expressing the Taylor rule in terms of inflation and output gap realizations does not alter the key conclusions of our paper.

[11] In our experiment, subjects observe the shocks and the interest rate before making their forecasts. Since the forecasts determine current period inflation and output, the observed interest rate can only depend on past inflation and output gap realizations.

expectations, ex ante forecast errors are always zero, so that $L_{s\pi} = L_{sx} = 0$ for all s. Hence, according to (5), non-rational expectations imply that ex ante forecast errors correlate with current or past shock realizations.[12]

Specification of expectations (5) possesses several features that are important for our study. First, it is sufficiently general to allow us to study alternative expectations formations. Second, non-rational behaviour can be identified by estimating conditional correlations of expectations with past shock realizations (i.e., coefficients $L_{s\pi}$, L_{sx}). We show later in this section that to estimate expectations as functions of the shock history is sufficient to quantify their contribution to the stabilization achieved by monetary policy.[13] Finally, we do not need to know the exact nature of departures from rational expectations in order to quantify their role in the expectations channel of monetary policy.[14]

The equilibrium in this model is defined as the sequences of the output gap, $\{x_t\}_{t=0}^{\infty}$, inflation, $\{\pi_t\}_{t=0}^{\infty}$ and the nominal interest rate, $\{i_t\}_{t=0}^{\infty}$, that, given expectation functions (5) and sequences of exogenous disturbances, $\{r_t^n\}_{t=0}^{\infty}$, satisfy the system of equilibrium equations (1)–(4).

This model incorporates one of the main channels through which monetary policy affects the real economy. According to the Euler equation (1), the effect of a given change in the nominal interest rate on inflation depends not only on its effect on nominal savings (and hence, nominal consumption expenditures), but also on its effect on *real* consumption expenditures. This effect is dictated by households' preferences to smooth

[12]Notice that, under non-rational expectations defined by (5), the law of iterated expectations, in general, does not hold; e.g., $E_t^* E_{t+s}^* \pi_{t+1+s} \neq E_t^* \pi_{t+s+1}$ for a given $s = 1, 2, ...$

[13]We assume in the model that non-rational behaviour affects only agents' expectations, and that otherwise they behave optimally, under full information about the underlying model and the fundamental shock. Our experimental design is set up to implement these assumptions as closely as possible. In particular, we will assume that experiment participants observe realizations of the only shock in the model.

[14]Such departures may be due to information rigidities (Woodford, 2001; Mankiw and Reis, 2010; Veldkamp, 2011), adaptive behaviour (Preston, 2006), and cognitive biases (Chakravarty et al. 2011; Boivin, 2011).

their real consumption over time: real consumption expenditures today depend on the current real rate of interest, given by $i_t - E_t^* \pi_{t+1}$, as well the expected path of all future real rates of interest, given by the term $E_t^* x_{t+1}$. Quantitatively, the effect on real consumption depends on the trade-off between inflation and the real aggregate supply of goods needed to satisfy consumption demand.

Hence, when prices are sticky, the trade-off between inflation and the output gap, given by the aggregate supply equation (3), implies that the central bank can control inflation not only by setting its short-term nominal interest rate, but also by committing to an entire future path of nominal interest rates. This second way in which the stance of monetary policy affects current economic outcomes is often referred to as the "expectations channel" of monetary policy. The primary goal of our paper is to quantify the strength of this channel by using experimental evidence.

2.2 Model dynamics under rational and non-rational expectations

Under rational expectations, $L_{s\pi} = L_{sx} = 0$ for all s in (5), so that $E_t^* x_{t+1}$ and $E_t^* \pi_{t+1}$ are respective statistical means over distributions of x_{t+1} and π_{t+1} conditional on state history through period t. As is common in the literature, we will denote period-t expected values by an operator E_t. The rational-expectations solution of the equilibrium system implies that period-t expected values of inflation and the output gap are functions of only period-t realization of the real interest rate shock:[15]

$$E_t \begin{bmatrix} \pi_{t+1} \\ x_{t+1} \end{bmatrix} = \begin{bmatrix} \Phi_\pi \\ \Phi_x \end{bmatrix} \rho_r r_t^n \ , \tag{6}$$

where Φ_π, Φ_x are real numbers that depend on model parameters.

We adopt the model with rational expectations as our baseline, and parameterize it to match the salient features of inflation and the output-gap fluctuations in Canada. We use the Bank of Canada measures of inflation and the output-gap deviations; see the

[15] Details of the model solution under various expectations formations are provided in the appendix.

appendix for details. Standard deviation and serial correlation of the r_t^n shock process, σ_r and ρ_r, and the slope of the New Keynesian Phillips curve, κ, are calibrated to match the following three moments in the Canadian data: standard deviation and serial correlation of inflation deviations (0.44 per cent and 0.4, respectively), and the ratio of standard deviations of the output gap and inflation (4.4). This gives us $\sigma_r = 1.13$ per cent, $\rho_r = 0.57$ and $\kappa = 0.13$. The remaining three parameters are assigned values commonly used in the literature. The discount factor, β, is $0.96^{1/4}$; intertemporal elasticity of substitution, σ^{-1}, is one; and the Taylor-rule coefficients in front of the expected inflation and expected the output-gap terms are 1.5 and 0.5, respectively, implying that the interest rate responds more than one-for-one to the long-run changes in inflation.

For non-rational expectations, we first consider specification (5), in which ex ante forecast errors are positively correlated with recent state history. For concreteness, we consider the case with $L_{0\pi} > 0, L_{0x} > 0$ and $L_{s\pi} = L_{sx} = 0,\ s = 1, 2, \ldots$. This case implies that period-$(t+1)$ forecast errors are negatively correlated with period-t shocks. For example, if in period t there is a positive shock to the real interest rate, $r_t^n > 0$, then agents' forecasts tend to be more elastic with respect to rational forecasts. For this reason, we term such expectations formation *sensitive expectations*.

If, instead, the deviation from the rational expectations goes in the opposite direction (i.e., if $L_{0\pi} < 0$ and $L_{0x} < 0$), then period-$(t+1)$ forecast errors are *positively* correlated with period-t shocks. For example, if in period t there is a positive shock to the real interest rate, $r_t^n > 0$, then agents' forecasts tend to be *less* elastic than rational forecasts. We therefore term these expectations *static expectations*.[16] For example, if $L_{0\pi} = L_{0x} = -1$, expectations do not move at all; i.e., $E_t^* x_{t+1} = E_t^* \pi_{t+1} = 0$.[17]

[16] We show in the appendix that, under sensitive (static) expectations, agents' forecasts are identical to rational forecasts under a more- (less-) persistent shock. Hence, despite the full knowledge of the underlying shock, agents form sensitive (static) expectations as if they perceive the fundamental shock to be more (less) persistent than it is.

[17] We do not find significant effects from adding one or two lags to the formation of sensitive and static expectations.

So far, we have considered deviations from rational expectations that imply that agents' forecast errors do no persist for a long period of time. In particular, we considered the case of (5), in which forecast errors systematically differ from zero only over the first two periods after the shock. To study the implications of forecast errors that persist for a long time, we examine another specification of non-rational expectations. For convenience, we substitute specification (5) with an equivalent specification, in which the expected values of inflation and the output gap are functions of past realizations of inflation and the output gap.[18] Specifically, we assume that ex ante forecast errors are

$$E_t \left(\begin{bmatrix} \pi_{t+1} \\ x_{t+1} \end{bmatrix} - E_t^* \begin{bmatrix} \pi_{t+1} \\ x_{t+1} \end{bmatrix} \right) = -\omega \left(\begin{bmatrix} \pi_{t-l} \\ x_{t-l} \end{bmatrix} - E_t \begin{bmatrix} \pi_{t+1} \\ x_{t+1} \end{bmatrix} \right) . \tag{7}$$

Therefore, in period t, agents use a period $t-l$ realization of inflation (the output gap) to form expectations of period-$(t+1)$ inflation (the output gap). For example, if realized inflation in period $t-l$ are high (low), then agents' forecasts of inflation tend to be higher (lower) than would be implied under rational expectations. We therefore term such expectations *adaptive(l) expectations*, where the value in parentheses provides the lag in (7). One important implication of adaptive expectations is that, unlike in the case of static or sensitive expectations, agents' forecast errors persist forever; see the appendix.[19]

How does the model economy respond to a one-standard-deviation innovation to the r_t^n shock? According to the IS equation (1), the increase in the real interest rate increases the rate at which households discount consumption over time, hence increasing the demand for current consumption, leading to a higher output gap. The response of the output gap, however, is 1.6 times higher than implied by the direct effect of the real

[18]Such specification is commonly used in the literature on adaptive expectations. See, for example, Arifovic et al. (2013) and references therein. Hommes and Lux (2013) demonstrate that AR(1) forecasting rules can have a simple behavioural interpretation.

[19]Throughout the paper we assume that $\omega = 0.5$.

interest rate increase. This endogenous component of the output-gap response is the result of two effects. First, the persistence of the shock implies positive effects on future consumption, which, due to consumption smoothing, has a positive effect on the current consumption and the output gap. Second, future positive the output gaps imply higher future inflation. Since the response of the nominal interest rate is zero at the time of the shock, the real interest rate is below the shock on impact. Furthermore, if future responses of the nominal interest rate are not large enough (i.e., if ϕ_π and ϕ_x are not too large), future real interest rates are also not large enough to offset the future levels of r_t^n.

To illustrate the role that expectations play in the ability of monetary policy to stabilize such fluctuations, Figure 1 compares impulse responses of inflation for different expectations formations. Sensitive expectations imply more volatile expected values of inflation and the output gap, leading to more volatile inflation. In contrast, static expectations lead to muted responses of expected values and, hence, smaller responses of inflation. Under adaptive(1) expectations, the impulse response is hump-shaped and takes about three years to fully dissipate. Such strong endogenous persistence under adaptive expectations implies that the stabilization of such expectations by monetary policy responses following the shock is smaller.

2.3 Measuring the importance of expectations

Since the goal of this paper is to understand how macroeconomic stabilization by monetary policy depends on the formation of expectations, the key to our analysis is to find a statistic that quantifies such stabilization. When inflation or the output gap are destabilized after a shock or a series of shocks, the countercyclical response of the entire path of future nominal interest rates implies that those deviations will be reduced. The expectation of reduced future deviations of inflation and the output gap, in turn, limits their deviations at the time of the shock.

Identifying such a mechanism is confounded by the dynamic nature of inflation and the output gap, as well as by the endogeneity of monetary policy and expectations. Namely: (i) since the fundamental shock process is persistent, innovation to that shock at any period will have effects in future periods; (ii) since monetary policy has an endogenous component, its response depends on the history of inflation and the output gap, as well as their future expected paths; (iii) expectations of inflation and the output gap may be correlated with shock realizations; and finally, (iv) concurrent countercyclical responses of the nominal interest rate provide stabilization that should be distinguished from that via the expectations channel.

To properly identify and measure the effect of the expectations channel, we propose a statistic that is based on counterfactual responses of inflation and the output gap to an innovation to r_t^n, conditional on zero future responses of nominal interest rates. Such counterfactual responses can be constructed using the following steps. Denote by $s = 0, 1, 2, ...$ the number of periods after the impulse ε_{r0} to the natural-rate-of-interest deviation, so that its impulse response is $r_s^n = \rho_r^s \varepsilon_{r0}$. Let x_s, π_s and i_s denote the equilibrium impulse responses of the output gap, inflation and interest rate, respectively.

To construct counterfactual responses of the output gap $\tilde{x}_s$ and inflation $\tilde{\pi}_s$, we assume that expectations of inflation and the output gap converge sufficiently close to the steady state after T periods after the impulse, so that we can assume $E_T^* \tilde{x}_{T+1} = E_T^* \tilde{\pi}_{T+1} = 0$. We then use equations (1) and (3) to solve recursively for the output gap and inflation for $s = T, T-1, ..., 0$ under the assumption that nominal interest rate responses are zero in all periods. Denote those paths by $\tilde{x}_s^*$ and inflation $\tilde{\pi}_s^*$:

$$\tilde{x}_T^* = \sigma^{-1} r_T^n, \quad \tilde{\pi}_T^* = \kappa \sigma^{-1} r_T^n \ ,$$

$$...$$

$$
\begin{aligned}
\tilde{x}_s^* &= \sigma^{-1} r_s^n + E_s^* \tilde{x}_{s+1}^* + \sigma^{-1} E_s^* \tilde{\pi}_{s+1}^*, \qquad s = 1, ..., T-1 \ , \\
\tilde{\pi}_s^* &= \kappa\sigma^{-1} r_s^n + \kappa E_s^* \tilde{x}_{s+1}^* + \left(\beta + \kappa\sigma^{-1}\right) E_s^* \tilde{\pi}_{s+1}^*, \qquad s = 1, ..., T-1 \ , \\
& ... \\
\tilde{x}_0^* &= \sigma^{-1} r_0^n + E_0^* \tilde{x}_1^* + \sigma^{-1} E_0^* \tilde{\pi}_1^* \ , \\
\tilde{\pi}_0^* &= \kappa\sigma^{-1} r_0^n + \kappa E_0^* \tilde{x}_1^* + \left(\beta + \kappa\sigma^{-1}\right) E_0^* \tilde{\pi}_1^* \ .
\end{aligned}
$$

Note that the differences between $\tilde{x}_s^*, \tilde{\pi}_s^*$ and equilibrium responses x_s, π_s are due to shutting down the countercyclical response of the nominal interest rate to the shock. Since we want to focus only on the effect of *future* responses of the nominal interest rate, we also need to account for the concurrent effects of the nominal interest rate by adding $-\sigma^{-1} i_s$ to $\tilde{x}_s^*$, and $-\kappa\sigma^{-1} i_s$ to $\tilde{\pi}_s^*$, obtaining the following counterfactual responses of inflation and the output gap:

$$
\begin{aligned}
\tilde{x}_s &= \tilde{x}_s^* - \sigma^{-1} i_s, \qquad s = 0, ..., T \ , \\
\tilde{\pi}_s &= \tilde{\pi}_s^* - \kappa\sigma^{-1} i_s, \qquad s = 0, ..., T \ .
\end{aligned}
$$

In computing $\tilde{\pi}_s$ and $\tilde{x}_s$, we assume that agents perfectly observe fundamental shock realizations and are able to forecast the next-period shock rationally, which implies that $E_s^* \tilde{x}_{s+1}^* = \tilde{x}_{s+1}^*$ and $E_s^* \tilde{\pi}_{s+1}^* = \tilde{\pi}_{s+1}^*$. Therefore, by construction, counterfactual responses $\tilde{\pi}_s$ and $\tilde{x}_s$ do not depend on the form of expectations. We incorporate this convenient feature in our experimental design by allowing the subjects to observe both shock realizations and their rational forecasts.

Figure 2 compares impulse responses of inflation in the model with rational and adaptive(1) expectations. Since the response of the nominal interest rate is countercyclical, the counterfactual response is larger than both of the equilibrium responses. The degree of the stabilizing effect of the anticipated monetary policy response is indicated by the decrease in the total response of inflation. The greater the decrease, the stronger is the expectations channel of monetary policy. Specifically, we summarize the strength of the expectations channel by computing the decrease in the cumulative absolute response due to future responses in nominal interest rates; i.e., we compute

$$\Xi_\pi = \frac{\sum_{s=0}^{T} |\tilde{\pi}_s| - \sum_{s=0}^{T} |\pi_s|}{\sum_{s=0}^{T} |\tilde{\pi}_s|} , \quad \text{and} \quad \Xi_x = \frac{\sum_{s=0}^{T} |\tilde{x}_s| - \sum_{s=0}^{T} |x_s|}{\sum_{s=0}^{T} |\tilde{x}_s|} .$$

2.4 Model predictions for the expectations channel

How much does monetary policy stabilize the economy after a shock via its effect on expectations? Table 1 shows that, in the baseline model expectations play a substantial role in the ability of monetary policy to stabilize fluctuations in the the output gap and inflation. The shares of the conditional variance of inflation and the output gap that decreased due to the expectations channel, Ξ_π and Ξ_x, are 0.73 and 0.65, respectively.

To gain further intuition regarding the workings of the expectations channel, we compute Ξ_π and Ξ_x for different parameter values in the model with rational expectations.[20] We show that Ξ_π and Ξ_x are monotonically increasing in ρ_r, κ, σ^{-1} and ϕ_π, and can even take on negative values. Higher shock persistence, ρ_r, extends the horizon over which future nominal interest rates stay high, therefore increasing the stabilizing effect of the expectations channel. Table 1 shows that increasing ρ_r from 0.57 to 0.80 raises stabilization from 0.73 to 0.97 for inflation, and from 0.65 to 0.98 for the output gap.

For a shock of given magnitude, κ and σ^{-1} increase the elasticities of inflation and the output gap with respect to the current increase in the nominal interest rate. This would allow future increases in the nominal interest rate to be more efficient in offsetting deviations in inflation and the output gap, increasing the importance of the expectations channel. Doubling each of these parameters increases the effect of policy on conditional variance to over 0.8 for both inflation and the output gap (see Table 1).

[20] Ξ_π and Ξ_x are computed for the range of each of these parameters, keeping other parameters fixed at the Benchmark levels. Figures A.2 and A.3 in the appendix provide Ξ_π for a range of parameter values and for alternative expectations formations.

An increase in the elasticity of the nominal interest rate to expected inflation and the output-gap fluctuations increases the aggressiveness of future nominal rate increases with respect to inflation and the output-gap deviations, thus increasing the effect of expectations on current outcomes. Doubling the elasticity of the policy response increases the fraction of variance explained by the expectations channel from 0.73 to 0.82 for inflation and from 0.65 to 0.75 for the output gap.[21]

We also consider alternative specifications of the policy rule (4). First, we compute Ξ_π and Ξ_x for the model in which the terms on the right-hand side of the Taylor rule are $\phi_\pi \pi_t + \phi_x x_t$, instead of $\phi_\pi E^*_{t-1}\pi_t + \phi_x E^*_{t-1} x_t$ in our baseline model. Without a policy lag, the contribution of expectations to stabilization is marginally larger, increasing from 0.73 to 0.76 for inflation.

Turning to the degree of stabilization under non-rational expectations, rows 1 and 2 of Table 2 show that, when expectations are sensitive (static), monetary policy is able to stabilize respective outcomes less (more). For sensitive expectations, the decrease in conditional variance due to the expectations channel of monetary policy is lower than under rational expectations, 0.55 and 0.54 for inflation and output gap, respectively. For static expectations, the decrease is larger, 0.89 and 0.74, respectively.

Rows 3, 4 and 5 of Table 2 show moments for equilibrium dynamics for adaptive(0), adaptive(1) and adaptive(2) expectations, respectively. In all cases, the contribution of future nominal interest rate responses to the stabilization of inflation and the output-gap deviations is lower than under rational expectations, 0.55, 0.20 and -0.14, respectively, for inflation, and 0.51, 0.32 and 0.35 for the output gap. The intuition is similar to the case of sensitive expectations: the positive realization of the period-t real interest rate shock implies higher expected future values of the output gap and inflation. Unlike sensitive expectations, for which such effects last a finite number of periods, period-t shock realization has long-lasting effects on agents' forecast errors. These results demonstrate

[21] In this exercise, we change ϕ_π, ϕ_x proportionally, so that $\phi_\pi/\phi_x = 3$.

that, under non-rational expectations, the stabilization benefits of monetary policy can be substantially smaller, or even none.[22]

The above exercises demonstrate that the relative rankings of the importance of expectations for inflation variance under alternative expectations formations are not sensitive to a particular parameterization of the model. We conclude that our metric, in theory, provides a reliable measure of the importance of expectations for inflation and the output-gap stabilization by monetary policy.

3 Experimental Design

The experiment was conducted at CIRANO's Experimental Economics Laboratory in Montréal, Quebec. This lab has access to a large subject pool with a large number of non-student participants. Subjects were invited to participate in sessions that involved 30 minutes of instructions and 90 minutes of game participation. Each session involved nine subjects interacting together in a single group. Earnings, including a $10 fee for showing up, ranged from $18 to $45, and averaged $36 for 2 hours.

3.1 Procedures

Participants were provided with detailed instructions before the experiment began. Using clear, non-technical language, we explained, both verbally and via their computer screens, how the the output gap, inflation and interest rate would evolve given their expectations, monetary policy and shocks.[23] The participants' task was to submit forecasts for the next period's inflation and the output gap. We explained that their period score depended only on the accuracy of their two forecasts submitted for that period. In particular, subject i's score in period t was determined by the following function of

[22]We show in the appendix (Figure A.3) that the relative rankings of the contributions of future terms implied by alternative expectations are invariant across all combinations of model parameters. We also provide additional robustness checks for alternative calibrations of σ_r, ρ_r and κ.

[23]In the experiment, we used the term "output" to denote the output gap, for simplicity.

absolute forecast errors: $S_{i,t} = R_0 \left(e^{-\alpha\left|E^*_{i,t-1}\pi_t - \pi_t\right|} + e^{-\alpha\left|E^*_{i,t-1}x_t - x_t\right|}\right)$, where $R_0 = 0.3$, $\alpha = 0.01$ and $E^*_{i,t-1}\pi_t$, $E^*_{i,t-1}x_t$ are subject i's forecasts submitted in period $t-1$. This scoring rule implied that subjects could earn over $70 for the entire experiment if they made accurate forecasts. Another key feature of the scoring rule is that it provided an incentive to make accurate forecasts: for every additional error of 100 basis points for both inflation and the output gap forecasts, the subjects' score in that period would decrease by half.

While the written and verbal instructions, provided prior to the experiment, included a qualitative description of the IS and Phillips curves as well as the central bank's policy function, they did not explain functional forms or calibrations of the model economy. Subjects were informed that a shock to the the output gap would occur each period, that it would gradually dissipate with persistence parameter ρ, and that its size would be randomly drawn from a normal distribution, with mean zero and variance σ^2_r. In each period, the average forecasts, $E^*_{t-1}\pi_t$ and $E^*_{t-1}x_t$, appearing in the IS curve, the Phillips curve, and the Taylor rule, were computed as medians across subjects' individual forecasts, $E^*_{i,t-1}\pi_t$ and $E^*_{i,t-1}x_t$.[24] Subjects never directly observed other subjects' forecasts or the average forecasts.

In each experimental session, subjects participated in four practice rounds before commencing two multi-round sequences, or "repetitions." Each repetition was initiated at the long-run steady state of zero inflation, the output gap and interest rate. The historical graphs and tables available to subjects showed the time horizon beginning at period –5 with all values at their long-run values through to period 0. The purpose of this design feature was to emphasize to subjects that the economy had been fully reset. Subjects were informed that each sequence would end randomly between 45 and

[24] Median forecasts are a better measure of central tendency as they are less sensitive to extreme individual entries. While it may be more difficult for participants to understand how their forecasts influence aggregate expectations, the usage of median rather than average forecasts reduces the ability of individual subjects ability to manipulate aggregate forecasts.

55 periods. Periods lasted up to 75 seconds in the first 10 periods of each sequence, and for 60 seconds thereafter.[25]

This sequential design of the experimental sessions allowed us to control for subjects learning the experimental and economic environment: results of practice rounds are not included in the analysis, and the results of the first and second repetitions across sessions will be compared.

3.2 Interface

The experiment was programmed in Redwood, an open-source software (Pettit et al., 2013). Throughout the experiment, participants had access to three interchangeable screens: the main (default) screen, the history screen and the screen with technical instructions.[26] In addition, the header, containing subject identification, period, time remaining and total score, was seen throughout the experiment. We designed the experimental interface to separate different types of information across the three screens. This allowed us to track the information that subjects focused on when forming their forecasts, and how much time they spent on each screen.

The main screen, as a default, appeared in front of the other screens. All subjects observed the current period's interest rate and shock realization, as well as the expected value of the next period's shock. If all subjects behaved rationally, this information would be sufficient for making rational forecasts.[27]At the beginning of each period t, subjects were able to enter and submit their forecasts for the next period's the output gap and inflation. If a subject did not submit the forecasts within the time limit, those forecasts were not included in the median calculation, and the subject received a score

[25]This was a soft constraint as subjects could have taken more time if they desired. However, we made announcements prior to the end of each period to encourage subjects to submit on time. More than 95% of the decisions in each treatment were submitted before time ran out.

[26]Screen designs, instructions and other details of the experimental interface are included in the appendix.

[27]This design decision allowed us to satisfy the assumptions underlying our calculation of the expectations channel that subjects perfectly observe fundamental shock realizations and are able to forecast the next-period shock rationally.

of zero.

The history screen was located on a second tab. To access it, subjects could click on the tab located at the left of the main screen. Subjects could freely switch between the screens, although only one screen could be open at a time. Within the history screen, subjects could see graphs of time series for the realized output gap and inflation, their forecasts, the nominal interest rate and shock values. Our interactive software allowed subjects to see exact values for each series at any point on a graph by placing their cursor at that point.

Technical instructions were located on the third and final screen. These supplementary instructions provided a detailed description of how inflation, output, the interest rate, and shock evolved and included calibrated parameter values. The technical instructions were meant to imitate open-access technical material that is available on the central bank's website. Our software enabled us to monitor the time that each subject allocated to reviewing the information in each period. Subjects were allowed to use the Windows calculator as well as to write down their calculations.

This interface implements two key features of our experimental design. First, shock realizations are directly observed by the subjects. This allows us to directly estimate forecasts as functions of the shock history. Second, making the auxiliary information available at a small time cost gives subjects a choice between information about the shock and information about the history of inflation and the output gap, or about model details. We can use observations on how long subjects access each screen and switch across screens to understand how they use available information to form their expectations.

3.3 Treatments

The experiment included four treatments that explored the robustness of outcomes in our experimental economy. In the Benchmark treatment, experimental outcomes were determined by the baseline model described in section 2, in which expectations $E_t^*\pi_{t+1}$ and $E_t^*x_{t+1}$ were given by the median forecasts for inflation and the output gap provided by subjects in each period.

In the High-Persistence treatment, the persistence of the shock was increased from $\rho_r = 0.57$ to $\rho_r = 0.8$. The model predicts that although inflation and the output-gap volatilities increase, the degree of stabilization provided by monetary policy should also increase.

In the Aggressive Monetary Policy treatment, the elasticity of interest rates to inflation and the output gap was doubled to $\phi_\pi = 3$ and $\phi_x = 1$, respectively. The model predicts that a more aggressive monetary policy will provide more stabilization via its effect on expectations, leading to more-stable output-gap and inflation fluctuations.

In the Benchmark treatment, we have assumed no role for the communication of monetary policy. This assumption is consistent with our theoretical framework, in which it is assumed that agents have complete information about the model and, in particular, the way in which monetary policy is set. Specifically, conditional on the realized history of the shock, agents' expectations of inflation and the output gap are consistent with future policy actions implied by the Taylor rule specification in the model.

In the Communication treatment, we test this assumption by adding to our experiment an explicit announcement of the expected path of future nominal interest rates. In period t, subjects see on the main screen, in addition to the same information as before, conditional expected values of nominal interest rates in the following $T = 9$ periods: $E_{t-1}i_{t+1}$, $E_{t-1}i_{t+2}$, ..., $E_{t-1}i_{t+T}$. We assume that, to compute the expected path of nominal interest rates after period t, the central bank uses the solution of the model with rational expectations, conditional on history through $t-1$.

In that solution, the interest rate in period t is the following function of the shock:

$$\begin{aligned} i_t &= 1.5\left(0.141r^n_{t-1}\right) + 0.5\left(0.472r^n_{t-1}\right) \\ &= 0.448r^n_{t-1} \end{aligned}$$

This implies that

$$E_{t-1}i_{t+s} = 0.57^s i_t, \quad s = 1, ..., T$$

with one-standard-deviation bands given by adding/subtracting from those point values $\sqrt{s}\sigma_r, \quad s = 1, ..., T.$

Assuming that subjects make their decisions with a complete understanding of the model (and monetary policy), the communication of future expected monetary policy actions in this treatment *should not* have significant effects on the outcomes, particularly on how effective monetary policy is in stabilizing inflation and output-gap fluctuations.

In all, we conducted five sessions of the Benchmark and Aggressive Monetary Policy treatments and six sessions of the High Persistence and Communication treatments.[28]

4 Experimental Results

4.1 Summary of aggregate experimental outcomes

In all of our experimental sessions (second repetitions), inflation and the output gap exhibit stable cyclical behaviour, with the peak-to-trough time ranging between 3.9 and 7.5 quarters in the Benchmark treatment, which is within the range of 3 to 20 quarters predicted by our baseline model under various expectations formations. The experimental outcomes, therefore, do not seem to be driven by factors outside the data-generating process, such as sunspots or strategic behaviour.[29] Furthermore, throughout our ex-

[28]Prior to conducting our experiment, we ran seven pilot sessions, which allowed us to refine our instructions and design. See the appendix (section 2.A) for details.

[29]Marimon and Sunder (1993) and Marimon, Spear and Sunder (1993) study non-stable behaviour in macroeconomic and monetary experimental settings.

periment the results do not differ significantly between the first and second repetitions, suggesting that subjects quickly converge to their stationary behaviour. The stability of the experimental outcomes provides support for the sound experimental implementation of our theoretical model.

Table 3 provides summary statistics for the dynamics in the experiments for each of the four treatments. We first calculate the statistics for each repetition, and then provide in the table the median, min and max values of those statistics over repetitions.[30] To control for learning by subjects, we provide statistics only for repetition 2, noting, however, that results including repetition 1 are very similar.

For the Benchmark treatment, monetary policy (acting via the future expected path of nominal interest rates) removes about half of the conditional variance: 0.51 for inflation and 0.45 for output. Such a degree of stabilization falls in the midpoint between values predicted by the theoretical model under rational expectations, 0.73 and 0.65, and under adaptive(1) expectations, 0.20 and 0.32. So although the degree of stabilization is somewhat smaller than predicted by the baseline model with rational expectations, monetary policy is quite potent in providing stabilization, accounting for roughly half of the business-cycle stabilization.

What type of expectations formation leads to the outcomes observed in the Benchmark treatment? Further examination of Table 3 reveals that both inflation and the output gap are more volatile in the experiment (0.79 per cent and 3.0 per cent, respectively), relative to those in the baseline model with rational expectations (0.44 per cent and 1.9 per cent), although the ratio of the standard deviation of the output gap and inflation is not as high as in the baseline, 3.8 vs. 4.4. Fluctuations in the experiment also are more persistent than in the baseline model, with serial correlations of 0.56 and 0.40, respectively.

A comparison of the experimental results with the model predictions in Table 2

[30] Results in Table 3 are not sensitive to whether means, instead of medians, are reported.

suggests that the closest fit to the experimental results is given by models with sensitive and adaptive(1) expectations. For example, in the model with sensitive expectations, the reduction of the conditional variance for inflation and the output gap is 0.55 and 0.54 (0.51 and 0.45 in the experiment), the unconditional standard deviations are 0.70 and 2.6 per cent (0.79 and 3.0 per cent in the experiment), and the serial correlation of inflation is 0.40 (0.56 in the experiment). The model with adaptive(1) expectations, in turn, slightly overpredicts the size and persistence of inflation fluctuations and underpredicts stabilization by monetary policy.

The bottom three panels in Table 3 compare outcomes in the alternative treatments – High-Persistence, Aggressive Monetary Policy, and Communication – to the Benchmark treatment. In the High-Persistence and Aggressive Monetary Policy treatments, experimental outcomes are consistent with those predicted by the theoretical model (see Table 2).[31] Namely, increasing shock persistence leads to more-volatile and more-persistent output-gap and inflation fluctuations, a smaller ratio of output-gap volatility to inflation volatility, and finally, a larger decrease in the fraction of conditional variance explained by the expectations channel of monetary policy. In turn, more-aggressive monetary policy leads to less-volatile and less-persistent output-gap and inflation fluctuations, a larger ratio of output-gap volatility to inflation volatility, and a larger decrease in the fraction of conditional variance explained by future nominal interest rates.[32]

Such consistency between the experimental results and the predictions of theoretical model supports our assumption that subjects understand the workings of the data-generating model. This understanding, however, is not complete. This can be seen from the results of the Communication treatment. Public announcements of the forecast

[31] Mann-Whitney tests significantly reject the null hypotheses that the statistics are identical across treatments ($p < 0.02$ in all cases).

[32] Assenza et al. (2012) find that monetary policy must be significantly aggressive to changes in inflation from target levels to maintain macroeconomic stability. Our analysis allows us to map the aggressiveness of monetary policy to the reduction in the size of macroeconomic fluctuations. For example, in our experiments, the doubling of the countercyclical interest rate response implies an additional 21 and 11 percentage-point reduction of the conditional variance of inflation and output.

of future interest rates lead to more-volatile fluctuations, and, therefore, less-effective monetary policy. For example, the standard deviation and the persistence of inflation in the communication treatment are 1.18 per cent and 0.75, respectively, both higher than 0.79 and 0.56 in the Benchmark treatment. The fractions of conditional variance of inflation and output decreased via the expectations channel of monetary policy are 0.19 and 0.10, respectively, both lower than 0.51 and 0.45 in the Benchmark treatment. These results point to the potentially detrimental consequences of interest rate forecast announcements.[33]

4.2 Comparisons of experimental and theoretical outcomes

Since, by design, the shock is observed, we can gain further insight into the implications of expectations formation for aggregate fluctuations by comparing experimental time series to those predicted by our theoretical model for the *same* history of shock realizations that occurred during the experiment. We compare the time series for inflation, the output gap, their average forecasts and the interest rate observed in our experiment to their theoretical counterparts constructed using decision functions for model equilibria under alternative forecast functions characterized by (5). For example, under rational expectations, the decision functions are

$$\begin{aligned}
E_t^*\pi_{t+1} &= 0.080r_{t-1}^n + 0.141\varepsilon_{rt} \ , \\
E_t^*x_{t+1} &= 0.269r_{t-1}^n + 0.472\varepsilon_{rt} \ , \\
\pi_t &= -0.195E_{t-1}^*\pi_t - 0.065E_{t-1}^*x_t + 0.199r_{t-1}^n + 0.349\varepsilon_{rt} \ , \\
x_t &= -1.5E_{t-1}^*\pi_t - 0.5E_{t-1}^*x_t + 0.919r_{t-1}^n + 1.613\varepsilon_{rt} \ , \\
i_t &= 1.5E_{t-1}^*\pi_t + 0.5E_{t-1}^*x_t \ .
\end{aligned}$$

[33] Galí (2011) questions the usefulness of central banks announcing nominal interest rate projections, using a standard New Keynesian model as a reference framework. Baeriswyl and Cornand (2012) study the effectiveness of central bank communication in reducing the overreaction of financial markets to public information.

For each history of shock realizations observed over repetitions, we construct counterfactual sequences of model outcomes corresponding to equilibria under a given formation of expectations (in the above case, rational).[34]

Table 4 compares counterfactual time series for four alternative expectations formations to those obtained in the experiment. The time series for the experiment correspond to the Benchmark treatment (repetition 2). The time series for the model correspond to equilibrium outcomes given the same shock history. We compare moments for five time series: $E_t^* \left(\pi_{t+1}\right),\ E_t^* \left(x_{t+1}\right),\ \pi_t,\ x_t$ and i_t. The top panel provides the ratio of standard deviations for the counterfactual and empirical time series, and the bottom panel provides the correlation of the counterfactual and empirical time series. The entries in the table are medians across five sessions.

Among the four alternative expectations, in keeping with our findings in Table 3, sensitive and adaptive(1) expectations are the most consistent with the magnitude of fluctuations observed in the experiment. For example, under rational expectations, standard deviations of inflation and the output gap fluctuations are 0.58 and 0.74, respectively, relative to those in the experiment. Under sensitive and adaptive(1) expectations, they are closer in magnitude to those in the experiment, at 0.93 and 1.01, respectively, under sensitive expectations, and 1.24 and 0.91, respectively, under adaptive(1) expectations. A similar story concerns fluctuations in the forecasts of inflation and the output gap. For instance, their standard deviations are 0.36 and 0.38 under rational expectations, while under sensitive (adaptive 1) expectations they are 0.72 and 0.76 (1.24 and 0.70), respectively.

In terms of the timing of fluctuations between the counterfactual and empirical time series, adaptive(1) expectations provide the best fit. For example, while, under rational expectations, correlations between the time series range from 0.55 to 0.71, under

[34] The endogenous state variables $E_t\pi_{t+1}$ and $E_t x_{t+1}$ are themselves functions of the natural rate, so in the end x_t and π_t can be written as function of the past history of the natural rate – which we explore in our experimental work.

adaptive(1) expectations the range is 0.76 to 0.89. Sensitive expectations do not provide better correlations between the counterfactual and experimental time series.

So far we have examined evidence for outcomes observed in the experiment and compared those outcomes to those implied by model equilibria under alternative expectations formations. We find that sensitive and adaptive expectations imply outcomes that fit best (among the alternatives) those observed in the experiment. To better understand these results, we next link them to inflation and output-gap forecasts characterized as functions of the observed shock history. We first estimate these functions for model simulations and then compare them to those estimated for the experiment.

4.3 Estimated forecast functions

Panel A in Figures 3a and 4a plots Benchmark ex ante forecast errors for inflation and output, respectively, in a theoretical model for alternative expectations. For the baseline model with rational expectations, ex ante forecast errors are uncorrelated with shock innovations at any lags. For static expectations, forecast errors correlate positively with shocks, since forecasts are not sensitive to shocks. In contrast, for sensitive expectations, forecast errors are negatively correlated with shock innovations, since forecasts overshoot rational forecasts. For adaptive(1) expectations, ex ante forecast errors display a distinct pattern: they are positive at the time of the shock, since the inflation forecast is expected to undershoot relative to inflation next period, and they are negative thereafter, since inflation forecasts are expected to persist while inflation slowly returns back to its pre-shock level.

In accordance with the theoretical model in section 2.1, equation (5), we estimate ex ante forecast errors as functions of the history of innovations to r_t^n shocks.[35] For example, for inflation ex ante forecast errors, we estimate the following specification:

$$E_t\left(\pi_{t+1} - E_t^*\pi_{t+1}\right) = G_0^\pi \varepsilon_{rt} + G_1^\pi \varepsilon_{rt-1} + ... + G_T^\pi \varepsilon_{rt-T} \ , \tag{8}$$

[35] For simple cases in the model, these functions can be derived analytically.

where T is a finite integer that is big enough to approximate (5) well, and coefficients G_i^π fully characterize inflation ex ante forecast errors.[36]

To provide better intuition for the implications of alternative forecast functions, we estimate forecast decision functions by estimating specification (8) for median forecasts as a dependent variable. Panel B in Figure 3a and Figure 4a plots forecast functions for inflation and output in the theoretical model for alternative expectations. For the baseline model with rational expectations, the inflation forecast is positive and highest at the time of the impulse (which equals 113 basis points), 14 basis points. For (our parameterization of) static expectations, forecasts are identically zero. For sensitive expectations, forecasts are twice as volatile as those for rational expectations. For adaptive(1) expectations, forecasts are not only more volatile, but they peak one period after the original impulse. In other words, adaptive(1) expectations take time to respond to shock innovations, in this case, one period.

Panels C and D plot the ex ante forecast errors and forecast functions estimated from the Benchmark experimental data, respectively (blue lines).[37] There are clear over- and undershooting patterns for the ex ante forecast errors, inherent to those for the adaptive(1) expectations, as discussed in the previous paragraph. It is evident from Figures 3a and Figures 4a that the adaptive(1) expectations provide the best fit to forecasts in our Benchmark treatment. Not only the overall shape and size of forecast functions and ex ante errors are similar to those from the experiment, but the timing of over- and undershooting (of forecast errors) and peaks (of forecasts) coincide as well. We therefore conclude that, in forming their expectations, the subjects rely mostly on information drawn from very recent history (up to four lags or so) of shock realizations,

[36] We estimate an OLS regression, $\pi_{t+1} - E_t^* \pi_{t+1} = G_0^\pi \varepsilon_{rt} + G_1^\pi \varepsilon_{rt-1} + ... + G_T^\pi \varepsilon_{rt-T} + \epsilon_{t+1}$, where $E_t^* \pi_{t+1}$ is the expected value of π_{t+1} in period t given by (5) or the median forecast in the experiment, and ϵ_{t+1} are i.i.d. zero mean draws. Note that G_i^π also approximates the responses of ex ante forecast errors in quarter i after an impulse to r_t^n.

[37] We estimate equations (8) for each of the five second repetitions in the Benchmark treatment. We plot median-point estimates, together with two-standard-deviation bands.

and that this behaviour can be well-captured by a forecast rule that puts around half of the weight on lagged model outcomes (i.e., inflation and the output gap). An important implication of this behaviour is that, in response to a shock, expectations take time to align with changes in the economy: e.g., in response to a positive r_t^n shock, inflation and output-gap expectations take one quarter to catch up with the growing inflation and the output gap, and then they are persistently higher when inflation and the output gap start to return to the pre-shock level.[38]

Adaptive(1) is a relatively weak form of adaptive expectations, since half of the weight falls on very recent outcomes (as opposed to outcomes farther in the past) and since the rest of the weight is on rational expectations. We show in the appendix (Figure A.4) that stronger forms of sensitive and adaptive expectations are worse at matching the data, missing on both the timing and magnitude of responses of forecasts and forecast errors. We conclude that the model with adaptive(1) expectations most accurately predicts the fluctuations that we observe in the experimental setting.

We next consider how the set of models fit aggregate forecasting behavior in the other three treatments. To quantify the treatment effects, we estimate specification (8) using a fixed effects panel specification and interacting each of the (lagged) innovations with treatment dummies.[39] We first estimate the models using median forecasts to understand how aggregate expectations are formed. We then confirm the robustness of our aggregate findings using our subject-level data. The results are presented in Table

[38] Adam (2007) considers a two-equation New Keynesian model that is similar to the one in this paper, and asks whether sluggish expectations can account for the considerable persistence of output and inflation. Similar to our results, he finds that subjects exhibit adaptive behaviour: inflation expectations rely strongly on past inflation, although not on past output. Such behaviour leads to considerable persistence of output and inflation in response to nominal shocks. Business cycles in Adam's (2007) experiment are twice as persistent than in our experiment, possibly due to the fact that subjects neither knew the underlying model nor directly observed the fundamental shock driving the fluctuations.

[39] Specifically we estimate inflation ex ante forecast errors as functions of the history of innovations to r_t^n shocks using the following specification for inflation: $\pi_{t+1} - E^*_{i,t}\pi_{t+1} = \alpha_i + \beta_1^\pi \varepsilon_{rt} + \beta_1^\pi \varepsilon_{rt} \times HP + \beta_2^\pi \varepsilon_{rt} \times MP + \beta_3^\pi \varepsilon_{rt} \times Comm. + ... + \beta_K^\pi \varepsilon_{rt-T} \times Comm. + \mu_{it}$, and a similar specification for output forecast errors. HP, MP, and $Comm.$ refer to dummies that take the value of one for forecasts formed in the High Persistence, Aggressive Monetary Policy, and Communication treatments, respectively.

5.

Panels C and D of Figures 3b and 4b present the ex ante forecast errors and forecast functions from the High Persistence treatment. Increased persistence of shocks results in significantly greater inertia in forecast errors. Inflation and output forecast errors formed in the High Persistence treatment are significantly more positively correlated with ε_{t-1} than in the Benchmark treatment, and more negatively correlated with later lags. Consequently, inflation forecasts continue to trend upward for 6 quarters after a shock and output forecasts only return to zero after 5 quarters. While we qualify that increasing the persistence of shocks appears to lead to considerably greater heterogeneity across sessions, these findings suggest that higher persistence induces greater inertia in aggregate expectations, and that a more inertial model of expectations, such as adaptive(3) expectations, would better capture the timing of forecasts and forecast errors.

Figures 3c and 4c present the impulse responses for the Aggressive Monetary Policy treatment. The adaptive(1) model does surprisingly well at capturing the shape, size, and timing of the ex-ante errors and forecast functions in the Aggressive Monetary Policy treatment. Compared to the Benchmark treatment, median forecast errors in this treatment follow a similar pattern but are more reactive to current shocks and less reactive to lagged innovations. Aggregate forecasts errors are not statistically significant due to the variability in the Benchmark treatment. However, when we consider individual-level forecasts errors, we observe significantly muted responses to lagged innovations in the Aggressive Monetary Policy treatment.

Introducing communication of a future path of interest rates leads to increased inertia and volatility in inflation and output forecasts relative to those formed in the Benchmark treatment. In Figures 3d and 4d, we observe that inflation forecasts reach a higher peak two quarters after a shock while output gap forecasts peak one period after. Both take an extra 1-2 periods longer than Benchmark forecasts to return to zero. Our estimation of specification (8) indicates that, compared to the Benchmark, the average Communication forecast errors are more negatively correlated with past lags. Aggregate output forecast errors are significantly more negatively correlated with ε_{t-3}. Our findings are even stronger at the subject level. Individual forecast errors are significantly more reactive to most lagged innovations under communication. Thus, forward guidance alters how subjects forecast, unexpectedly away from rational expectations toward more inertial heuristics.

5 Heterogeneity of Experimental Expectations

5.1 Heterogeneity in Response to Monetary Policy

Our investigation of forecasting behavior indicates that expectations consistently depart from the rational expectations and seem to rely significantly on past realizations of inflation and output gap. This result may suggest that participants resort to simple heuristic forecasting rules to form their expectations. We therefore turn our focus to our rich individual-level expectations data in order to explore the heterogeneity in heuristics used and whether features of the economy influence the heterogeneity in expectations.

First, we consider how much subjects internalize the expectations channel of monetary policy. Do all subjects equally understand the role monetary policy plays in stabilizing inflation and output gap, or is there disagreement on how monetary policy influences the economy? To answer these questions, we generate, for each subject i, a measure of the expectations channel by treating each subject as a representative forecaster whose expectations are used to determine sequences of implied inflation and output gap, x_s^i and π_s^i, where $s = 0, ...T$: $\Xi_\pi^i = \frac{\sum_{s=0}^T |\tilde{\pi}_s| - \sum_{s=0}^T |\pi_s^i|}{\sum_{s=0}^T |\tilde{\pi}_s|}$ and $\Xi_x^i = \frac{\sum_{s=0}^T |\tilde{x}_s| - \sum_{s=0}^T |x_s^i|}{\sum_{s=0}^T |\tilde{x}_s|}$. We use the same $\tilde{\pi}_s$ and $\tilde{x}_s$ as in our aggregate analysis. To compute each period's implied inflation and output gap for each subject, we employ their forecasts for inflation and output together with the current period's shock and realized nominal interest rates.

The realized nominal interest rates i_t were computed during the experiments from the previous period's *median* expectations regarding period t inflation and output gap, and do not necessarily depend on subject i's forecasts. That is, we assume each subject takes as given the nominal interest rate when forming their forecasts. These subject-specific measures provide a useful way of comparing how effective monetary policy is at stabilizing expectations across subjects and treatments.

The distributions of Ξ_π^i and Ξ_x^i are presented by treatment and repetition in Figure 5. Consistent with our theoretical predictions and session-level results, the expectations channel at the individual level is significantly more pronounced in the High Persistence and Aggressive Monetary Policy treatments. By the second repetition, two-sample Kolmogorov Smirnov tests reject the null hypotheses that any two treatments exhibit identical distributions (p-value< 0.01 in all cases). An important conclusion is that the degree to which expectations respond to nominal interest rate differs widely across subjects. The strength of the expectations channel becomes more homogeneous as it is predicted to increase; heterogeneity is greatest in the Benchmark and Communication treatment and lowest in the High Persistence treatment.

The Benchmark and Communication treatments have the same predicted strength of the expectations channel. However, by presenting a forecasted path of nominal interest rates in the Communication treatment, it is reasonable to expect that participants are better able to internalize the stabilizing properties of monetary policy. Indeed, the majority of inexperienced participants in the first repetition of the Communication treatment form significantly more stable output gap expectations than their Benchmark counterparts. Monetary policy acting via the future expected path of nominal interest rates removes nearly 40 percent of the conditional variance in the economy generated by the median Communication participant's output gap forecasts. By contrast, only 17 percent of the conditional variance is eliminated in the median Benchmark participant's forecasts. In terms of inflation forecasts, inexperienced participants behave comparably across most of the distribution, with the median reductions in the conditional variance of inflation being 25 percent and 29 percent in the Communication and Benchmark treatments, respectively. Forward guidance in the Communication treatment does, however, lead to a weaker expectations channel for the bottom twenty percent of participants, suggesting the potential for confusion to lead to greater volatility. The fact that forward guidance is more effective at stabilizing output gap variability but not inflation suggests that while participants can easily infer the impact of monetary policy on the output gap, the indirect effect of monetary policy on output is less understood. An important takeaway is that, for inexperienced individuals, forward guidance works well to coordinate expectations and strengthen the expectations channel. However, with experience, subjects develop more adaptive heuristics to formulate their forecasts. Forward guidance loses its effectiveness as a coordination device and leads to a significantly weaker expectations channel for the majority of subjects. We attribute this to increased confusion about the role of monetary policy in stabilizing the economy.

5.2 Heterogeneity in Estimated Forecast Functions

How robust are forecasting heuristics across subjects as the data-generating process or information sets change? A priori, we may expect that disagreement in forecasts increases as the economy becomes more volatile and difficult to predict. To guage the degree of heterogeneity in behavior both within and across treatments, we estimate specification (8) for each subject and plot the cumulative density functions associated with their forecast errors' estimated responses to current and up to six lags of innovations. Figure 6 presents the responses of inflation and output forecast errors to current and one-lag innovations.[40] Panel A shows the densities associated with estimated responses to ε_t. The densities highlight the considerable heterogeneity across subjects in their responsiveness to innovations. The majority of the Benchmark subjects' forecast errors

[40]The cumulative density functions associated with later lags are presented in Figure A.5 in the appendix.

respond positively to the current shock and the weight placed on ε_t mostly ranges between 0 and 1, with a standard deviation of 0.16 and 0.56 for estimated inflation and output forecast error responses, respectively. Increasing the aggressiveness of monetary policy significantly shifts downward the distribution of the weight placed on ε_t. Our prior on heterogeneity is largely confirmed by the data. We observe a smaller standard deviation of output forecast error responses of 0.48, but a greater standard deviation in inflation forecast error responses of 0.22. That is, more aggressive monetary policy coordinates output foreasts more effectively at the expense of increased disagreement in inflation forecasts. Communicating a path of future interest rates increases the heterogeneity and degree to which subjects' forecast errors are positively correlated with ε_t, with standard deviations of 0.30 and 0.85 for inflation and output, respectively. In the High Persistence treatment, we observe extensive heterogeneity in how subjects respond to ε_t. While the estimated response of the median subject's inflation forecast errors to ε_t is 0.70, 24% of High Persistence subjects' forecast errors respond negatively on impact of a shock, that is, they are overly-sensitive to the shock. The standard deviations are 0.95 and 2.56 for inflation and output forecast error responses to ε_t.

Panel B presents the densities of inflation forecast error responses to ε_{t-1}. The negative response of forecast errors to ε_{t-1}, indicative of an adaptive(1) forecasting heuristic, is observed in more than 58% of Benchmark and 91% of Aggressive Monetary Policy subjects. High persistence of shocks induces higher persistence in forecast errors. 83% of High Persistence participants respond positively to ε_{t-1}, suggesting an adaptive(2) or more persistent model would better describe their forecasting behaviour. Central bank communication has a similar effect, resulting in three-quarters of participants forming increasingly more inertial expectations. While the reactions to current and one-period lagged innovations are relatively homogeneous in the Benchmark treatment and, especially, homogeneous in the Aggressive Monetary Policy treatments, we observe extensive variability across High Persistence and Communication subjects' responses.[41] This increased heterogeneity in forecasting heuristics is reasonable given that both of these treatments are arguably more cognitively complex than the Benchmark. Higher persistence of shocks implies that output and inflation will take longer to return to the steady state under both rational and adaptive expectations, increasing the challenge in making accurate forecasts. Central bank communication gives subjects more information to process and creates more uncertainty about what information other subjects will use when forming their forecasts. Conversely, in the Benchmark and especially in the Aggressive Monetary Policy treatments, the environments are generally more stable with output and inflation closer to the steady state. With less variability, subjects have little to disagree on.

5.3 Information Acquisition and Forecasting Performance

Our software was designed to track how much time a subject spent on the forecast, history and technical instructions screens. For each subject, we calculate the mean percentage of time spent on each screen over the two-repetition horizon and present the empirical cumulative density functions by treatment and screen in Figure 5. While there was extensive heterogeneity in how subjects used the forecast and history screen, there was little variability in the usage of technical instructions. The average subject made limited use of the technical instructions, visiting the screen only 2.2 times over a 50-period repetition, each time spending, on average, 2.4 seconds. By contrast, subjects used the history screen extensively, visiting it, on average, 2.4 times per period and spending around 45 per cent of their decision time there. The fact that most subjects visited the history screen at least twice per period can be related to their need to form two

[41] The standard deviations in estimated responses of inflation (output) forecast errors to ε_{t-1} are 0.25 (1.00) in the Benchmark treatment, 0.71 (1.55) under High Persistence, 0.16 (0.63) under Aggressive Monetary Policy, and 0.42 (0.89) under Communication. Note that Communication subjects exhibit less heterogeneity in their output forecasts' response to ε_{t-1} than their Benchmark counterparts. That is, forward guidance improves the coordination of inertial output forecasting heuristics.

forecasts per period (for inflation and for the output gap). We therefore conclude that subjects valued information about the history of aggregate outcomes much more than details about the underlying data-generating model. That is, subjects avoided costly effort associated with information overload by using simplifying heuristics.[42] Given the heterogeneity in information acquired, we can identify whether the information subjects chose to access influenced their forecast accuracy or the extent to which they understood monetary policy.

We first conduct a series of fixed effects panel regressions by treatment to observe the effects of reallocating time spent on information acquisition on subjects' absolute forecast errors. For each participant, we calculate the percentage of time spent on each screen in a given round and regress that on absolute forecast errors. We pool subjects' forecasts from both repetitions. The results are presented in Table 6. Each column refers to a different baseline: columns (1), (2), and (3) for each treatment and forecasted variable consider the effect of time allocation away from the instruction tab, history tab, and forecast tab, respectively, on forecast errors.

The importance of time allocation in forecasting differs considerably across treatments and within treatment. First, we find that reallocating time spent acquiring information in the Aggressive Monetary Policy treatment does not have quantitatively large or significant effects on forecast errors. These economies exhibit less volatility and remain closer to their steady states, making it easier for participants to formulate forecasts. As a result, there is less heterogeneity in how subjects acquire information and less variability in payoffs. By contrast, in the Benchmark and Communication treatments, time allocation matters for output forecast errors but not for inflation forecast errors, while in the High Persistence treatment, both output and inflation forecast errors are similarly and significantly affected by time allocation.

[42]The decision-science literature studies behaviour aimed at reducing the amount of effort exerted to make a decision or complete a task (see Payne, Bettman and Luce 1996; Payne, Bettman and Johnson 1998).

Despite its limited usage, subjects' output forecast errors generally increase as they reallocate their time away from the instructions tab. Reallocating a percentage point of time from the instructions screen to the history screen significantly increases forecast errors in the Benchmark treatment by 1.85 basis points, 16.67 basis points in the High Persistence treatment, and 4.62 basis points in the Communication treatment. If the participants were instead to allocate that extra time to the forecast screen, it would also significantly increase output forecast errors by 11.45 points in the High Persistent treatment and 3.79 points in the Communication treatment. This finding suggests that those who invested proportionally more time to understand the data-generating process were able to form more accurate forecasts.

Reallocating time away from the history screen to either the forecast screen or instructions screen significantly reduces forecast errors. In the Benchmark treatment, we observe that spending an additional percentage point on either of the forecast screen or instructions screen has similarly sized effects of reducing output forecast errors. By contrast, in the High Persistence and Communication treatments, participants' forecast errors decrease three and five times more if they were to reallocate extra time toward the instruction screen than to the forecast tab. That is, subjects benefit more from a better understanding of the data-generating process than extra time observing a forecast of future shocks or nominal interest rates.

Can screen usage tell us anything about subjects' ability to internalize the expectations channel of the monetary policy? Using repetition 2 data, we correlate the mean percentage of time a subject spent reviewing each screen with their individually estimated expectations channel statistic. In the Benchmark treatment, the Spearman correlation coefficient between individual mean percentage of time on the forecast screen and Ξ^i_π is 0.23 ($p = 0.13$) and for Ξ^i_x it is 0.40 ($p < 0.01$). That is, subjects that spend more time observing current and expected future fundamentals also tend to form more stable forecasts. A similar relationship is observed in the Communication treatment:

forecast screen usage is positively correlated with Ξ_x^i ($\rho = 0.22$, $p = 0.11$). Otherwise, subjects' usage of forecast and history screens in the High Persistence and Aggressive Monetary Policy treatments, as well as instruction screen usage in all treatments, is uncorrelated with their own understanding of the expectations channel. We emphasize that the heterogeneity in information acquisition and forecasting heuristics does not preclude monetary policy from being effective in stabilizing macroeconomic fluctuations.

6 Conclusions

Monetary policy plays an important role in guiding public expectations of future inflation and output, and thus in influencing economic activity. Indeed, if a central bank is successful in anchoring public expectations, monetary policy is more likely to have its intended effects. In this paper we utilize experimental laboratory evidence to quantify the expectations channel of monetary policy. We design a laboratory experiment that allows us to identify the contribution of expectations to macroeconomic stabilization achieved by systematic monetary policy.

We find that individuals rely mostly on recent data and a qualitative understanding of the working of the economy to form their expectations, importantly paying attention to the behaviour of the nominal interest rate. Despite some non-rational component in individual expectations, we find that monetary policy is quite potent in providing stabilization, accounting for roughly half of the business-cycle stabilization. This finding underlines the important role of communication as a tool that central banks use to manage agents' expectations in both normal periods and more extreme circumstances. Our communication treatment suggests, however, that public announcements of the future course of monetary policy may be detrimental to macroeconomic stability. The caveat, therefore, is that the implications of central bank communication should be studied more extensively, and that experimental approaches can be useful.

References

[1] Adam, K. 2007. "Experimental Evidence on the Persistence of Output and Inflation," *Economic Journal*, 117, 603-636.

[2] Arifovic, J., Bullard, J., and Kostyshyna, O. 2013. "Social Learning and Monetary Policy Rules," *Economic Journal*, 123(567), 38–76.

[3] Assenza, T., Heemeijer, P., Hommes, C.H., and Massaro, D., 2012. "Individual expectations and aggregate macro behavior," CeNDEF Working Paper, University of Amsterdam, July.

[4] Baeriswyl, R. and Cornand, C. 2012. "Reducing overreaction to central banks' disclosures: theory and experiment," Working Paper No. 2012-08, Swiss National Bank.

[5] Bernanke, B. S., and Boivin, J. 2003. "Monetary policy in a data-rich environment," *Journal of Monetary Economics*, 50(3), 525-546.

[6] Boivin, J. 2011. "How People Think and How It Matters," Remarks presented to Canadian Association for Business Economics, 23 August, Kingston, Ontario.

[7] Boivin, J., Kiley, M. and Mishkin, F. 2010. "How Has the Monetary Transmission Mechanism Evolved Over Time?" in *Handbook of Monetary Economics*, Benjamin M. Friedman and Michael Woodford (ed.), edition 1, volume 3, chapter 8, 369-422.

[8] Carney, M. 2012. "Guidance," Remarks presented to CFA Society Toronto, 11 December.

[9] Chakravarty, S., Friedman, D., Gupta, G., Hatekar, N., Mitra, S. and Sunder, S. 2011. "Experimental Economics: A Survey," *Economic and Political Weekly*, xlvi(35), 39-78.

[10] Christiano, L.J., Eichenbaum, M. and Evans, C.L. 1999. "Monetary Policy Shocks: What Have We Learned and to What End?", in *Handbook of Macroeconomics*, J. B. Taylor and M. Woodford (ed.), 1, 65–148.

[11] Clarida, R., Galí, J., and Gertler, M. 2000. "Monetary policy rules and macroeconomic stability: evidence and some theory," *Quarterly Journal of Economics*, 115(1), 147-180.

[12] Coibion, O. and Y. Gorodnichenko. 2012. "What Can Survey Forecasts Tell Us about Information Rigidities?" *Journal of Political Economy*, 120(1), 116-159.

[13] Duffy, J. 2008. "Macroeconomics: A Survey of Laboratory Research," Working Papers 334, University of Pittsburgh.

[14] Galí, J. 2008. *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework.* Princeton University Press.

[15] Galí, J. 2011. "Are Central Banks' Projections Meaningful?" *Journal of Monetary Economics*, 58 (6-8), 537-550.

[16] Hommes, C. 2011. "The heterogeneous expectations hypothesis: Some evidence from the lab," *Journal of Economic Dynamics and Control*, 35(11), 1-24.

[17] Hommes, C. and Lux, T. 2013. "Individual Expectations and Aggregate Behaviour in Learning-To-Forecast Experiments," *Macroeconomic Dynamics*, 17(02), 374-401.

[18] Mankiw, G. N., and R. Reis. 2010. "Imperfect Information and Aggregate Supply," in *Handbook of Monetary Economic*s, Benjamin M. Friedman & Michael Woodford (ed.), edition 1, 3(5), 183-229.

[19] Mankiw, N. G., Reis, R., and Wolfers, J. 2004. "Disagreement about inflation expectations," *NBER Macroeconomics Annual 2003*, 18, 209-270.

[20] Marimon, R., Spear, S. E., Sunder S. 1993. "Expectationally Driven Market Volatility: An Experimental Study," *Journal of Economic Theory*, 61(1), 74-103.

[21] Marimon, R. and Sunder, S. 1993. "Indeterminacy of Equilibria in a Hyperinflationary World: Experimental Evidence," *Econometrica*, 61(5), 1073-107.

[22] Nishiyama, S. I. 2009. "Monetary policy lag, zero lower bound, and inflation targeting," Bank of Canada Working Paper No. 2009-2.

[23] Pettit, J., Hewitt, J. and Oprea, R. 2013. "Redwood : Software for Graphical, Browser-Based Experiments in Discrete and Continuous Time," mimeo.

[24] Payne, J., Bettman, R., and Johnson, E. 1998. "Adaptive Strategy Selection in Decision Making," *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 14(3), 534-552.

[25] Payne, J., Bettman, R., and Luce, M. 1996. "When Time is Money: Decision Behaviour under Opportunity-Cost Time Pressure," *Organizational Behaviour and Human Decision Processes*, 66(2), 131-152.

[26] Pfajfar, D. and Zakelj, B. 2012. "Uncertainty and Disagreement in Forecasting Inflation: Evidence from the Laboratory," Working Paper, Tilburg University.

[27] Pfajfar, D. and Zakelj, B. 2013. "Inflation Expectations and Monetary Policy Design: Evidence from the Laboratory," Working Paper, Tilburg University.

[28] Preston, B. 2006. "Adaptive learning, forecast-based instrument rules and monetary policy," *Journal of Monetary Economics*, 53(3), 507-535.

[29] Veldkamp, L. 2011. *Information Choice in Macroeconomics and Finance.* Princeton University Press.

[30] Walsh, C. E. 2009. "Using monetary policy to stabilize economic activity," Prepared for the Jackson Hole Symposium on Financial Stability and Macroeconomic Policy, August.

[31] Woodford, M. 2001. "Imperfect Common Knowledge and the Effects of Monetary Policy," October 2001. [Published in P. Aghion, R. Frydman, J. Stiglitz, and M. Woodford, eds., *Knowledge, Information, and Expectations in Modern Macroeconomics: In Honor of Edmund S. Phelps*, Princeton Univ. Press, 2003.]

[32] Woodford, M. 2003. *Interest and prices: Foundations of a theory of monetary policy.* Princeton University Press.

[33] Woodford, M. 2012. "Methods of Policy Accommodation at the Interest-Rate Lower Bound," presented at the Jackson Hole symposium, August 2012.

[34] Woodford, M. 2013. "Forward Guidance by Inflation-Targeting Central Banks," prepared for the conference 'Two Decades of Inflation Targeting,' Sveriges Riksbank, 3 June 2013.

Table 1: Model Predictions under Rational Expectations

		Fraction of conditional variance decreased via expectations channel		$\text{std}(\pi_t)$	$\text{ser.cor.}(\pi_t)$	$\frac{\text{std}(x_t)}{\text{std}(\pi_t)}$
		π_t	x_t			
	Baseline	**0.73**	**0.65**	**0.44**	**0.40**	**4.4**
1	High-persistence	0.97	0.98	1.16	0.71	2.4
2	Steep NKPC	0.89	0.86	0.80	0.39	2.4
3	Lower risk aversion	0.81	0.88	0.66	0.35	5.1

Table 2: Model Predictions under Alternative Expectations

		Fraction of conditional variance decreased via expectations channel		$\text{std}(\pi_t)$	$\text{ser.cor.}(\pi_t)$	$\frac{\text{std}(x_t)}{\text{std}(\pi_t)}$
		π_t	x_t			
	Baseline	**0.73**	**0.65**	**0.44**	**0.40**	**4.4**
1	Sensitive	0.55	0.54	0.70	0.40	3.7
2	Static	0.89	0.74	0.18	0.57	7.7
3	Adaptive(0)	0.55	0.51	0.81	0.14	3.5
4	Adaptive(1)	0.20	0.32	1.00	0.74	2.6
5	Adaptive(2)	-0.14	0.35	0.96	0.87	2.4

Table 3: Experimental evidence, summary statistics

Treatment	Fraction of conditional variance decreased via expectations channel π_t	Fraction of conditional variance decreased via expectations channel x_t	std(π_t)	ser.cor.(π_t)	std(x_t)/std(π_t)
Benchmark					
Model (Rational)	**0.73**	**0.65**	**0.44**	**0.40**	**4.4**
Model (Adaptive 1)	**0.20**	**0.32**	**1.00**	**0.74**	**2.6**
Experiments					
median	0.51	0.45	0.79	0.56	3.8
min	0.25	0.03	0.54	0.49	3.0
max	0.56	0.56	0.92	0.69	4.1
High-persistence					
Model (Rational)	**0.97**	**0.98**	**1.16**	**0.71**	**2.4**
Model (Adaptive 1)	**0.95**	**0.98**	**2.07**	**0.87**	**1.6**
Experiments					
median	0.95	0.96	4.27	0.81	2.5
min	0.86	0.92	1.80	0.76	2.1
max	0.97	0.98	11.18	0.86	2.9
Aggressive policy					
Model (Rational)	**0.82**	**0.75**	**0.31**	**0.35**	**5.1**
Model (Adaptive 1)	**0.68**	**0.51**	**0.46**	**0.56**	**4.1**
Experiments					
median	0.72	0.56	0.48	0.28	5.5
min	0.71	0.48	0.40	0.11	4.7
max	0.79	0.59	0.56	0.44	6.0
Communication					
Model (Rational)	**0.73**	**0.65**	**0.44**	**0.40**	**4.4**
Model (Adaptive 1)	**0.20**	**0.32**	**1.00**	**0.74**	**2.6**
Experiments					
median	0.14	0.10	1.17	0.75	2.9
min	-0.94	-3.47	0.74	0.66	2.5
max	0.59	0.57	2.24	0.84	4.1

Note: Statistics for each treatment in the experiments are computed for five sessions of repetition 2.

Table 4: Time-series comparisons, Experiment vs. Model

Statistic	Rational	Sensitive	Static	Adaptive(1)	Adaptive(2)
$\text{std}(X_t^{\text{Model}})/\text{std}(X_t^{\text{Experiment}})$					
$E_t^*(\pi_{t+1})$	0.36	0.72	0.15	1.24	1.03
$E_t^*(x_{t+1})$	0.38	0.76	0.23	0.70	0.72
π_t	0.58	0.93	0.27	1.24	0.87
x_t	0.74	1.01	0.53	0.91	0.81
i_t	0.43	0.86	0.23	1.07	0.88
$\text{corr}(X_t^{\text{Model}}, X_t^{\text{Experiment}})$					
$E_t^*(\pi_{t+1})$	0.55	0.55	-0.46	0.76	0.48
$E_t^*(x_{t+1})$	0.56	0.56	-0.52	0.78	0.52
π_t	0.71	0.69	0.83	0.86	0.63
x_t	0.68	0.66	0.83	0.89	0.75
i_t	0.61	0.61	-0.51	0.83	0.59

Notes: Time series for the experiment correspond to benchmark treatment (repetition 2). Time series for the model correspond to equilibrium outcomes given the same shock history. The entries are medians across five sessions.

Table 5: Forecast Errors and Innovations of r_t^n Shocks

	Median Forecast Errors		Individual Forecast Errors	
	Inflation	Output Gap	Inflation	Output Gap
ε_t	0.319*	0.530	0.294***	0.593***
	(0.18)	(0.57)	(0.03)	(0.11)
$\varepsilon_t \times HighPers.$	0.309	0.814	0.320***	1.015***
	(0.23)	(0.73)	(0.10)	(0.31)
$\varepsilon_t \times Agg.MP$	-0.198	-0.462	-0.203***	-0.533***
	(0.24)	(0.76)	(0.04)	(0.13)
$\varepsilon_t \times Comm.$	0.137	0.830	0.128***	0.823***
	(0.24)	(0.76)	(0.05)	(0.15)
ε_{t-1}	-0.064	-1.306**	-0.075**	-1.300***
	(0.18)	(0.57)	(0.04)	(0.16)
$\varepsilon_{t-1} \times HighPers.$	0.732***	1.432*	0.737***	1.450***
	(0.23)	(0.73)	(0.10)	(0.25)
$\varepsilon_{t-1} \times Agg.MP$	-0.071	0.142	-0.088**	0.036
	(0.24)	(0.76)	(0.04)	(0.18)
$\varepsilon_{t-1} \times Comm.$	0.319	0.803	0.349***	0.907***
	(0.24)	(0.75)	(0.07)	(0.20)
ε_{t-2}	-0.203	-0.992*	-0.192***	-0.971***
	(0.18)	(0.57)	(0.03)	(0.11)
$\varepsilon_{t-2} \times HighPers.$	0.663***	-0.161	0.669***	-0.148
	(0.23)	(0.73)	(0.12)	(0.22)
$\varepsilon_{t-2} \times Agg.MP$	0.070	0.670	0.031	0.646***
	(0.24)	(0.76)	(0.04)	(0.13)
$\varepsilon_{t-2} \times Comm.$	0.165	-0.227	0.159***	-0.191
	(0.24)	(0.76)	(0.06)	(0.17)
ε_{t-3}	-0.127	0.127	-0.088***	0.100
	(0.18)	(0.56)	(0.02)	(0.10)
$\varepsilon_{t-3} \times HighPers.$	0.290	-2.648***	0.282***	-2.406***
	(0.23)	(0.72)	(0.11)	(0.34)
$\varepsilon_{t-3} \times Agg.MP$	0.204	0.479	0.157***	0.572***
	(0.24)	(0.76)	(0.03)	(0.14)
$\varepsilon_{t-3} \times Comm.$	-0.091	-1.421*	-0.110**	-1.296***
	(0.24)	(0.75)	(0.05)	(0.18)
ε_{t-4}	-0.009	0.337	0.001	0.330***
	(0.18)	(0.56)	(0.02)	(0.09)
$\varepsilon_{t-4} \times HighPers.$	-0.322	-3.236***	-0.346***	-3.022***
	(0.23)	(0.72)	(0.11)	(0.45)
$\varepsilon_{t-4} \times Agg.MP$	0.086	-0.115	0.086***	-0.127
	(0.24)	(0.75)	(0.02)	(0.11)
$\varepsilon_{t-4} \times Comm.$	-0.346	-1.062	-0.316***	-1.027***
	(0.24)	(0.74)	(0.05)	(0.15)
ε_{t-5}	0.014	0.084	0.005	0.023
	(0.18)	(0.55)	(0.02)	(0.05)
$\varepsilon_{t-5} \times HighPers.$	-0.860***	-2.437***	-0.802***	-2.399***
	(0.23)	(0.72)	(0.11)	(0.42)
$\varepsilon_{t-5} \times Agg.MP$	-0.092	-0.604	-0.078***	-0.567***
	(0.24)	(0.75)	(0.02)	(0.08)
$\varepsilon_{t-5} \times Comm.$	-0.354	-0.485	-0.302***	-0.393***
	(0.24)	(0.75)	(0.06)	(0.10)
ε_{t-6}	0.049	-0.053	0.033*	0.005
	(0.18)	(0.55)	(0.02)	(0.10)
$\varepsilon_{t-6} \times HighPers.$	-1.067***	-0.536	-0.922***	-0.621**
	(0.23)	(0.72)	(0.14)	(0.30)
$\varepsilon_{t-6} \times Agg.MP$	-0.109	-0.121	-0.096***	-0.177
	(0.24)	(0.75)	(0.02)	(0.12)
$\varepsilon_{t-6} \times Comm.$	-0.091	0.704	-0.101**	0.567***
	(0.24)	(0.74)	(0.04)	(0.14)
α	1.932	-7.517	-2.169	-22.455***
	(9.82)	(30.81)	(1.54)	(5.03)
N	933	933	8339	8339
F	7.994	6.828	26.12	38.43

Note: Fixed effects panel regressions using repetition 2 data. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Robust standard errors in parentheses.

Table 6: Information Usage and Absolute Forecast Errors

Benchmark Treatment	Absolute Output Forecast Error			Absolute Inflation Forecast Error		
	(1)	(2)	(3)	(4)	(5)	(6)
% time spent on forecast screen	-0.154	-2.001***		0.266	-0.030	
	(1.16)	(0.73)		(0.55)	(0.24)	
% time spent on history screen	1.847*		2.001***	0.296		0.030
	(1.08)		(0.73)	(0.49)		(0.24)
% time spent on instruction screen		-1.847*	0.154		-0.296	-0.266
		(1.08)	(1.16)		(0.49)	(0.55)
α	255.176**	439.876***	239.822***	58.568	88.169***	85.209***
	(105.90)	(40.87)	(32.60)	(51.08)	(13.37)	(10.71)
N	4332	4332	4332	4332	4332	4332
F	4.319	4.319	4.319	0.196	0.196	0.196

High Persistence Treatment	Absolute Output Forecast Error			Absolute Inflation Forecast Error		
	(1)	(2)	(3)	(4)	(5)	(6)
% time spent on forecast screen	11.454*	-5.218**		3.582	-1.518**	
	(6.42)	(2.35)		(2.38)	(0.69)	
% time spent on history screen	16.672**		5.218**	5.100**		1.518**
	(6.39)		(2.35)	(2.28)		(0.69)
% time spent on instruction screen		-16.672**	-11.454*		-5.100**	-3.582
		(6.39)	(6.42)		(2.28)	(2.38)
α	-663.576	1003.668***	481.856***	-180.626	329.376***	177.604***
	(628.32)	(126.00)	(109.50)	(230.49)	(36.88)	(32.19)
N	5173	5173	5173	5173	5173	5173
F	5.008	5.008	5.008	4.961	4.961	4.961

Aggressive Monetary Policy Treatment	Absolute Output Forecast Error			Absolute Inflation Forecast Error		
	(1)	(2)	(3)	(4)	(5)	(6)
% time spent on forecast screen	1.242	0.245		-0.033	0.173	
	(1.37)	(0.32)		(0.27)	(0.14)	
% time spent on history screen	0.998		-0.245	-0.207		-0.173
	(1.26)		(0.32)	(0.27)		(0.14)
% time spent on instruction screen		-0.998	-1.242		0.207	0.033
		(1.26)	(1.37)		(0.27)	(0.27)
α	175.899	275.685***	300.137***	71.016***	50.353***	67.694***
	(130.87)	(18.22)	(13.97)	(25.66)	(7.95)	(5.94)
N	4346	4346	4346	4346	4346	4346
F	0.498	0.498	0.498	0.901	0.901	0.901

Communication Treatment	Absolute Output Forecast Error			Absolute Inflation Forecast Error		
	(1)	(2)	(3)	(4)	(5)	(6)
% time spent on forecast screen	3.795**	-0.830*		0.247	0.109	
	(1.53)	(0.47)		(0.60)	(0.19)	
% time spent on history screen	4.625***		0.830*	0.138		-0.109
	(1.64)		(0.47)	(0.62)		(0.19)
% time spent on instruction screen		-4.625***	-3.795**		-0.138	-0.247
		(1.64)	(1.53)		(0.62)	(0.60)
α	-95.172	367.356***	284.336***	91.564	105.378***	116.313***
	(155.92)	(27.71)	(18.93)	(59.91)	(11.03)	(7.56)
N	5020	5020	5020	5020	5020	5020
F	4.268	4.268	4.268	0.249	0.249	0.249

Note: Fixed effects panel regression using repetition 1 and 2 data. Significance levels: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Robust standard errors presented in parentheses.

Figure 1: Inflation responses to 113 bps r_t^n impulse

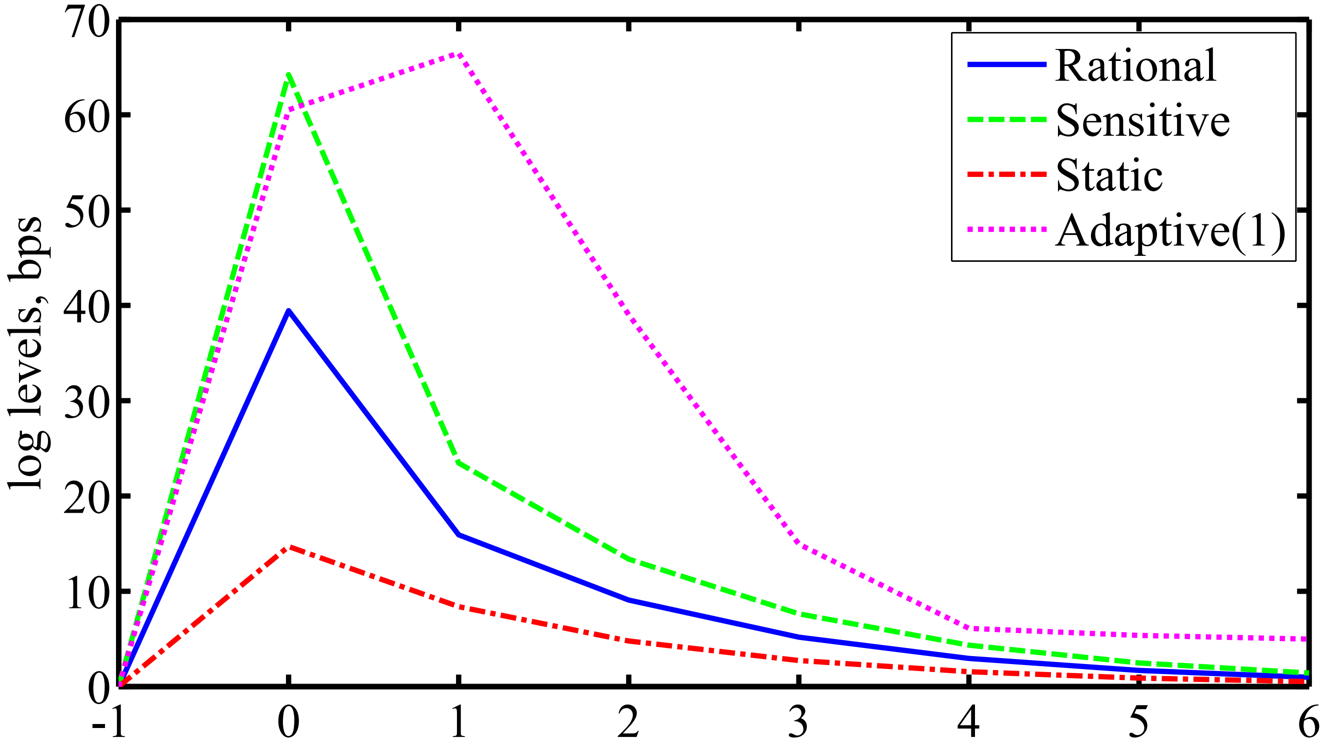


Figure 2: Stabilization of inflation via expectations

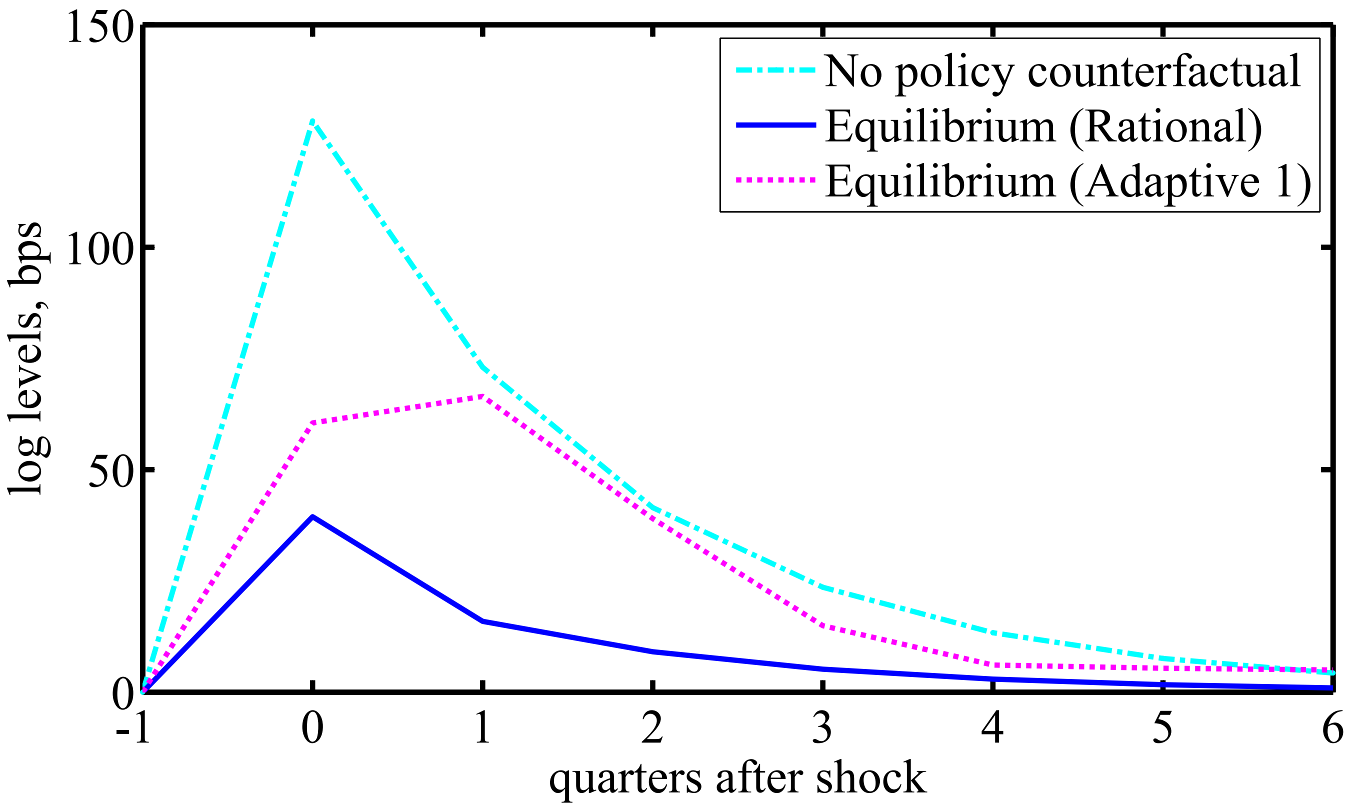


Figure 3a: Responses of inflation forecasts and forecast errors

Benchmark treatment

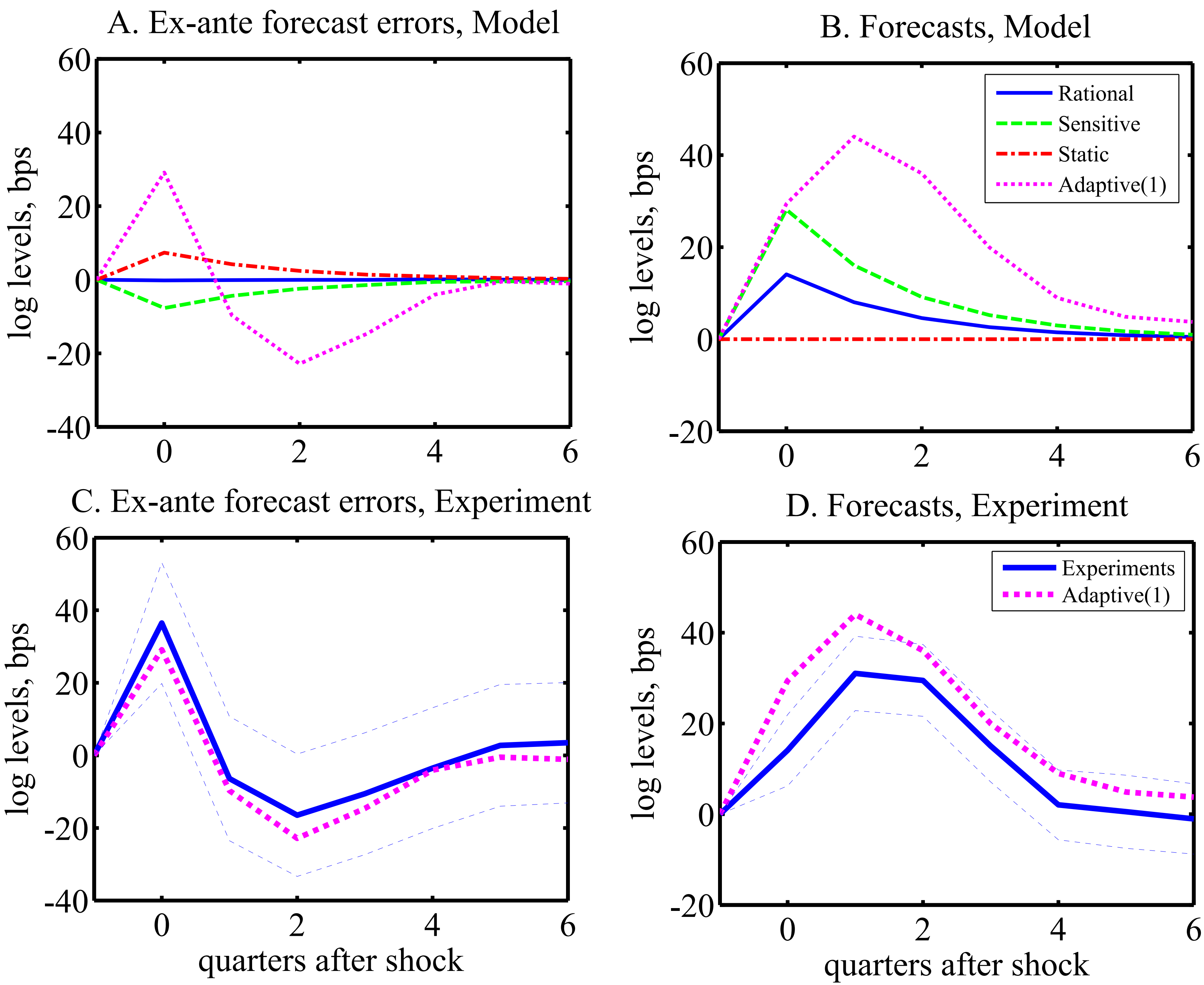


Figure 3b: Responses of inflation forecasts and forecast errors

Persistence treatment

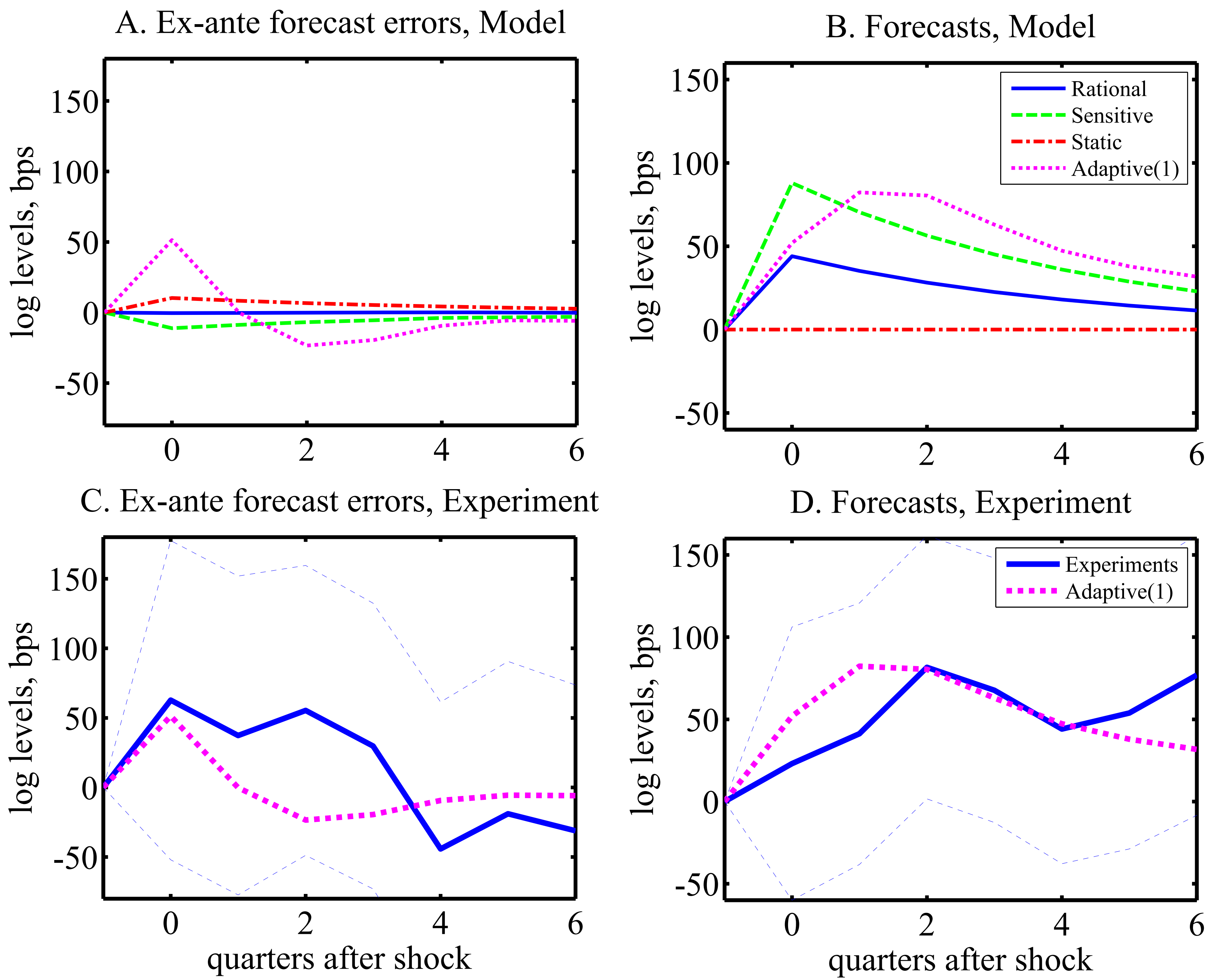


Figure 3c: Responses of inflation forecasts and forecast errors

Aggressive policy treatment

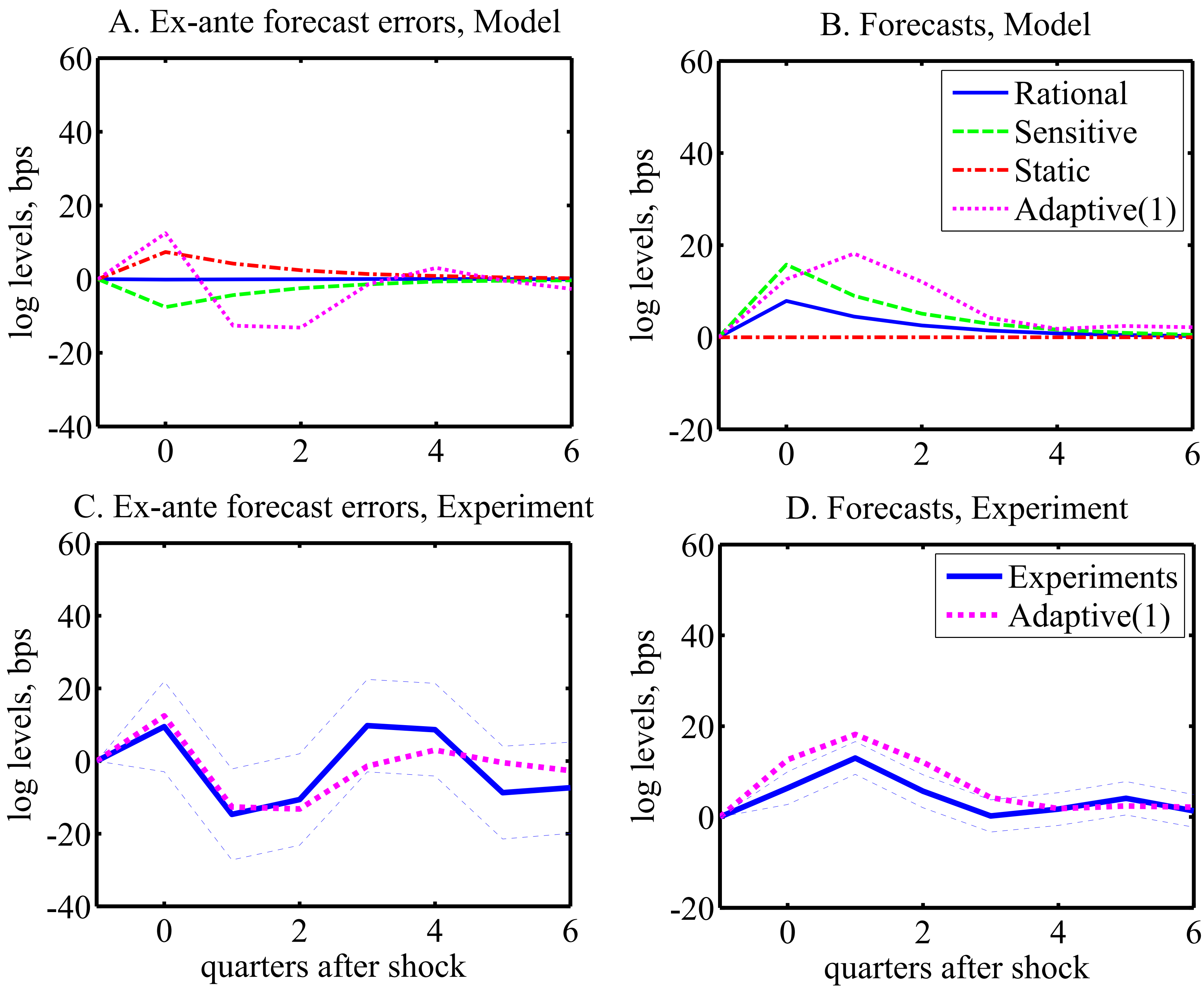


Figure 3d: Responses of inflation forecasts and forecast errors

Communications treatment

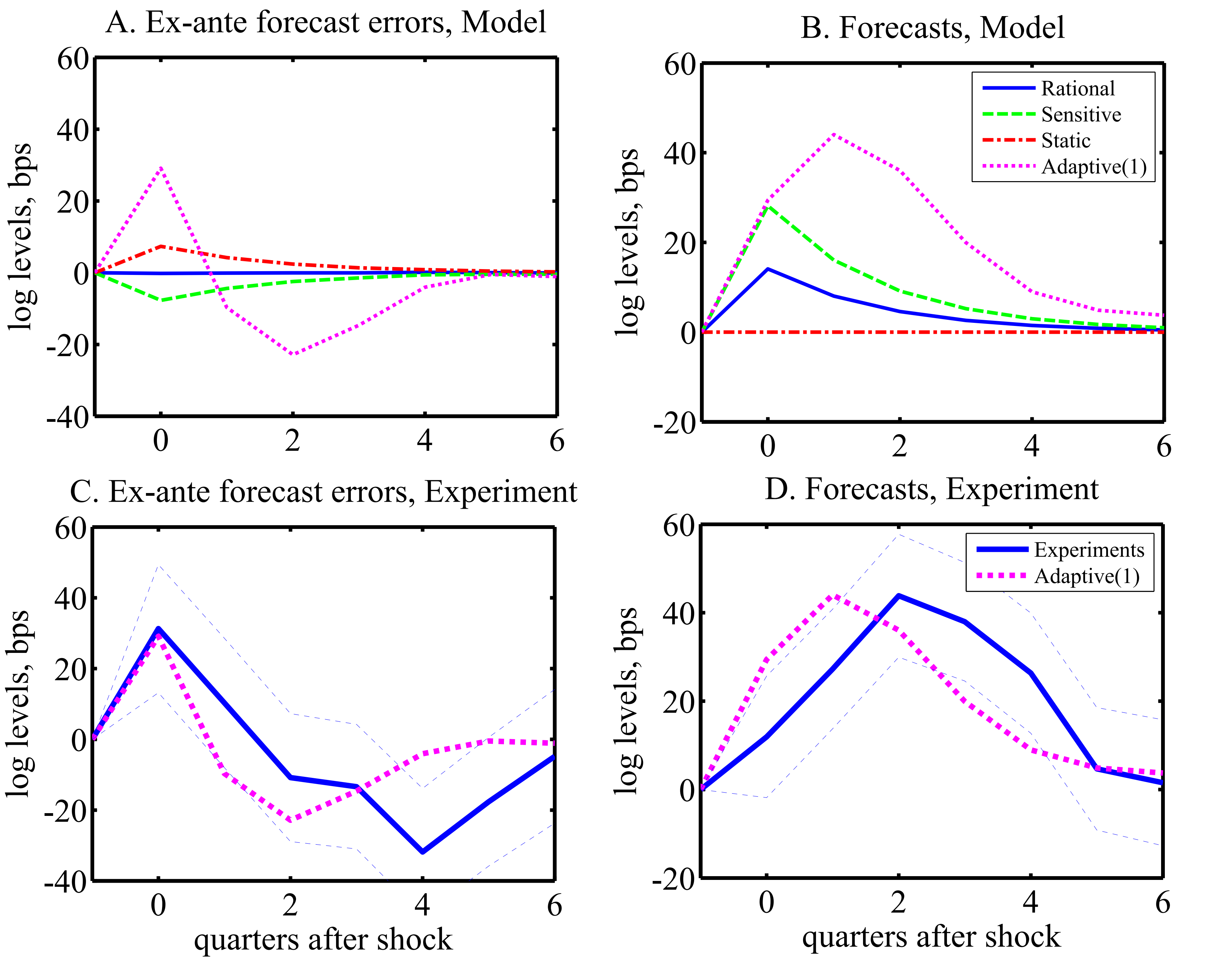


Figure 4a: Responses of output forecasts and forecast errors

Benchmark treatment

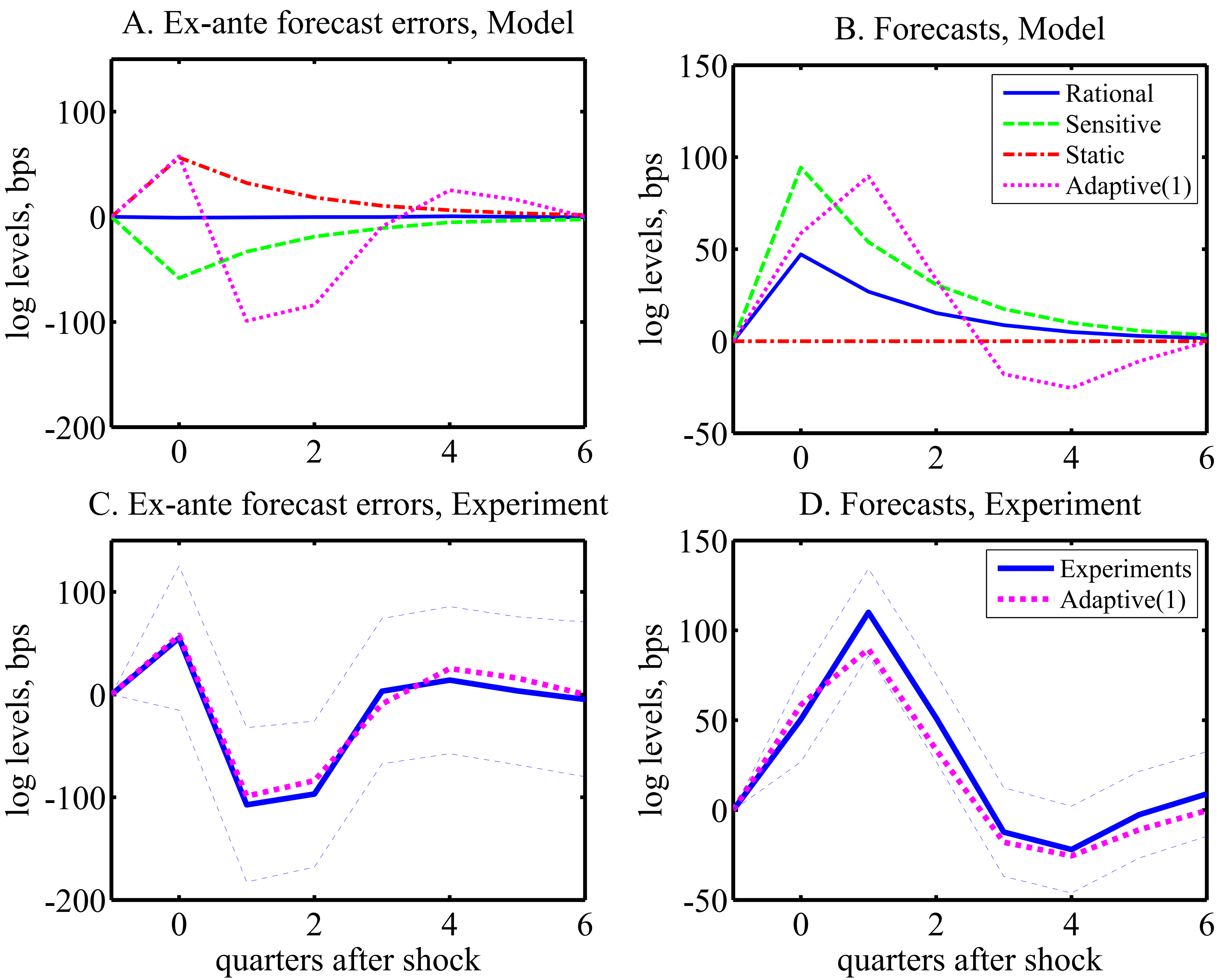


Figure 4b: Responses of output forecasts and forecast errors

Persistence treatment

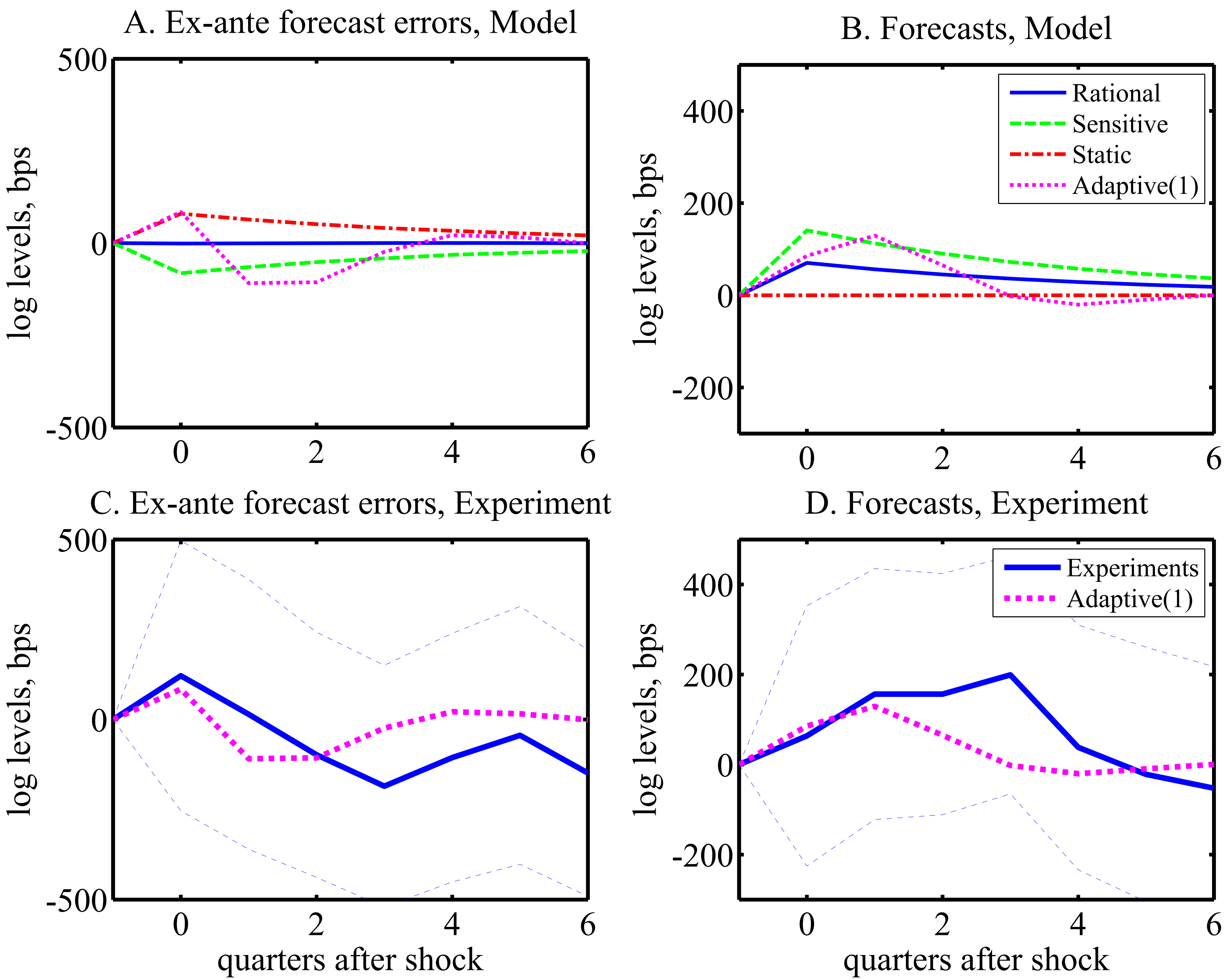


Figure 4c: Responses of output forecasts and forecast errors
Aggressive policy treatment

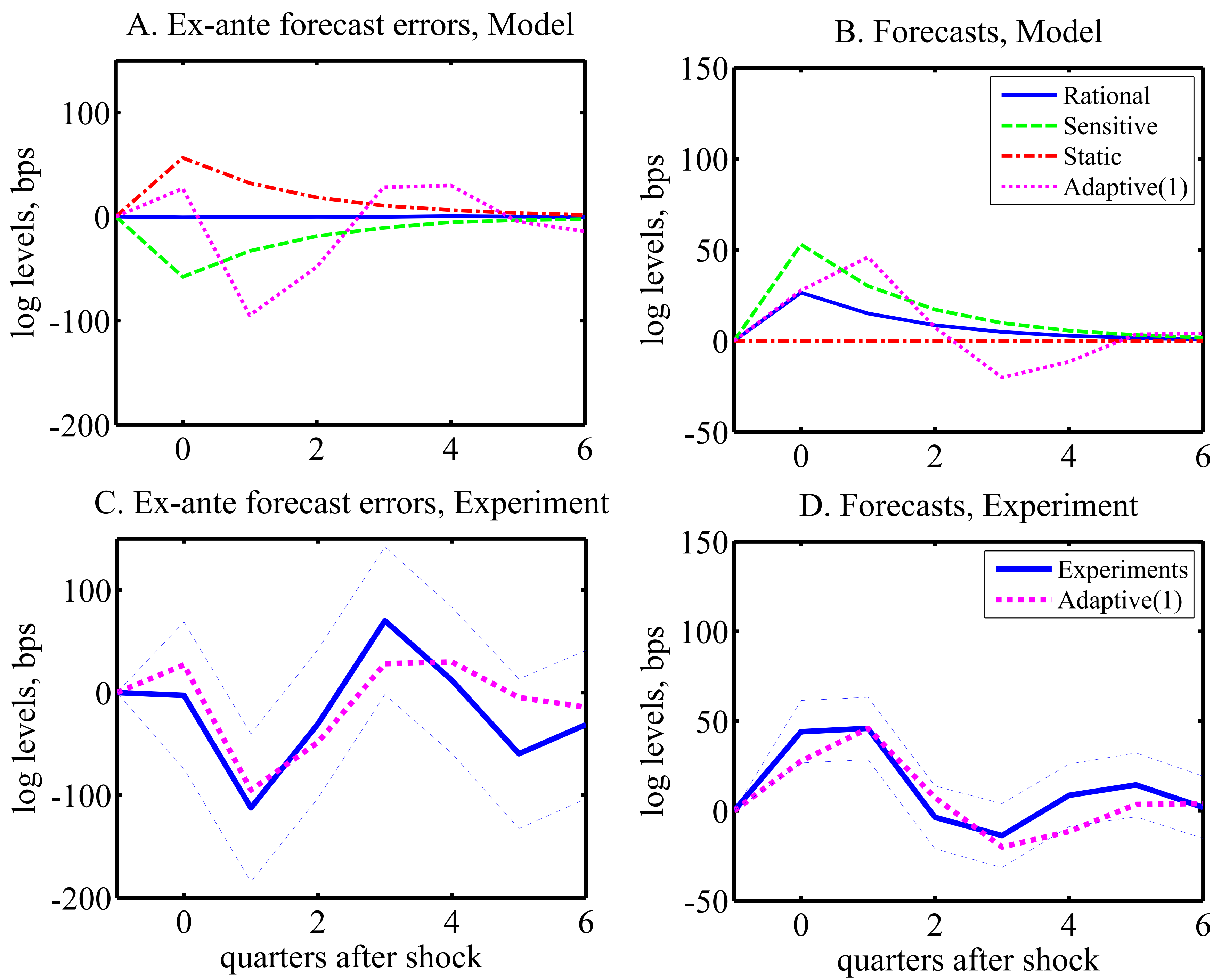


Figure 4d: Responses of output forecasts and forecast errors

Communications treatment

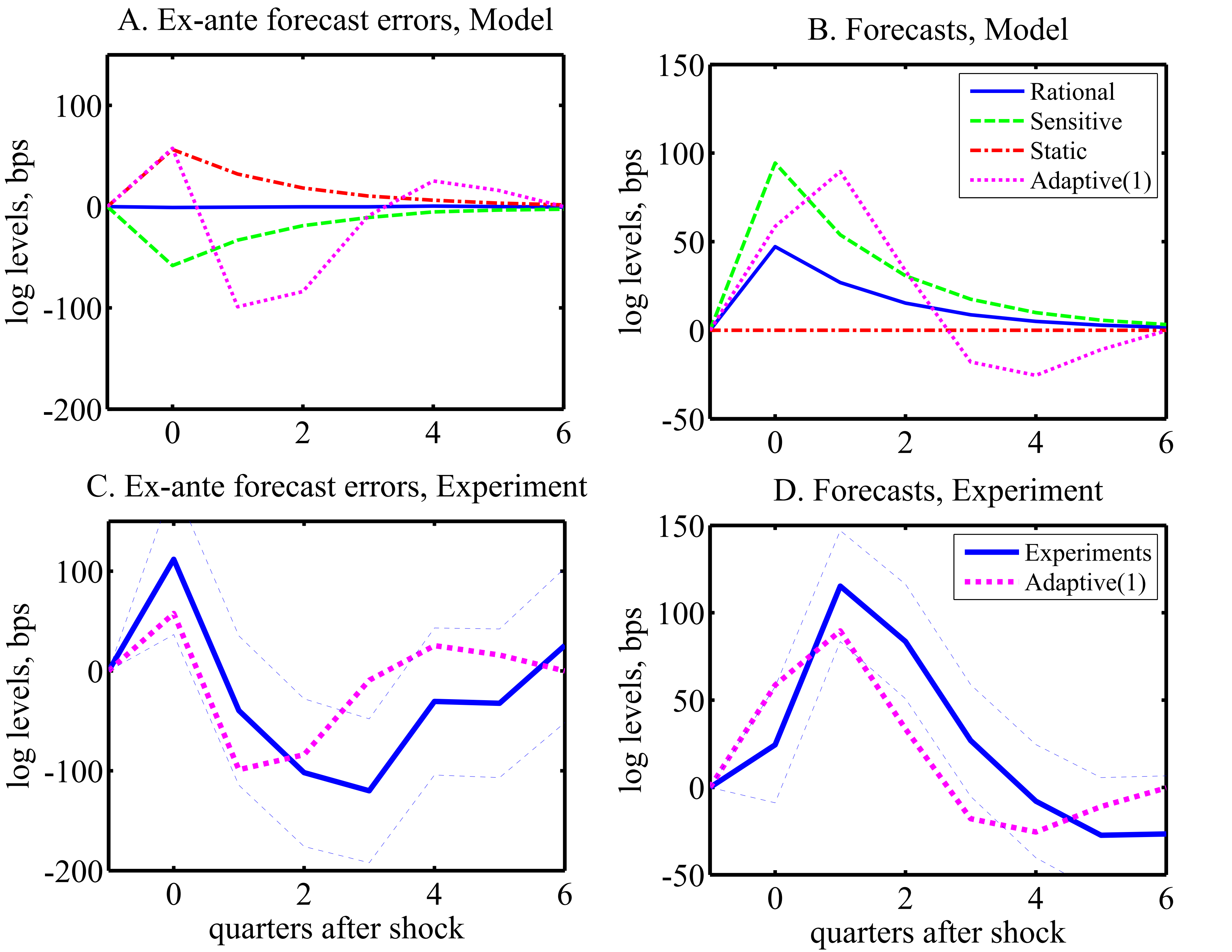
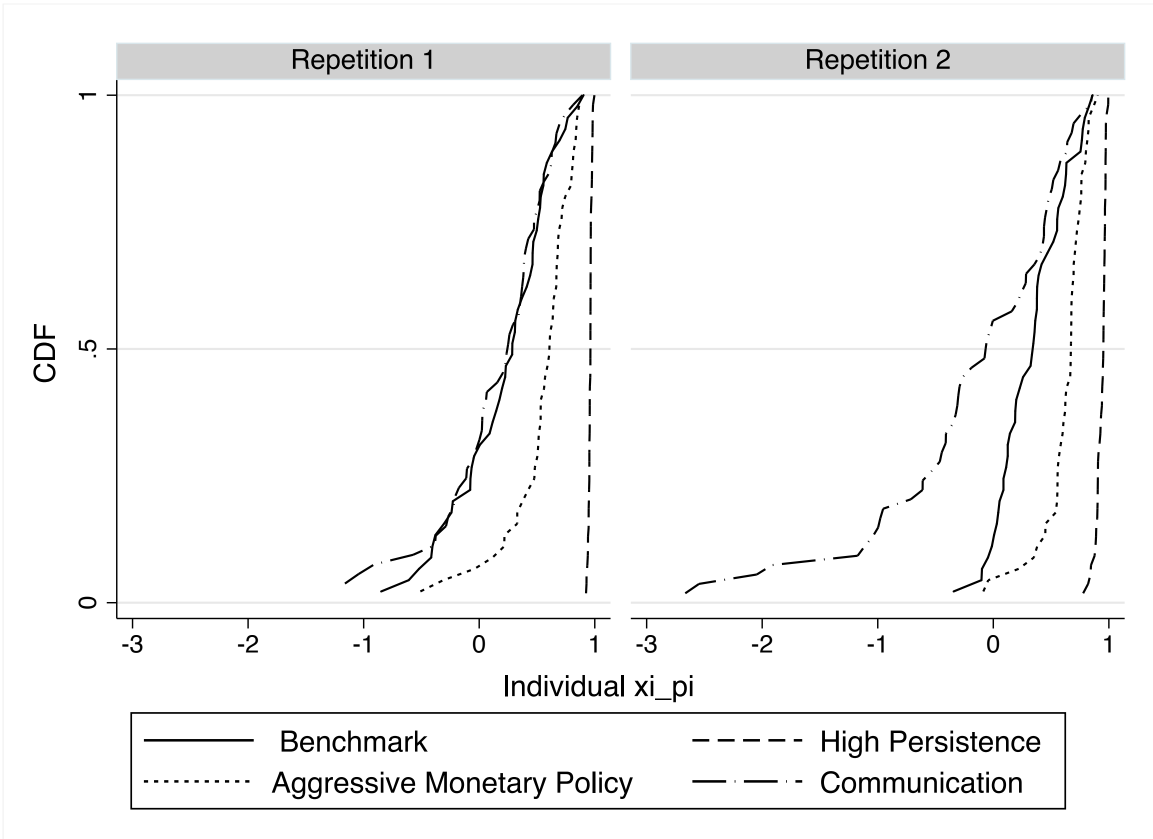


Figure 5. Distributions of Individual-Level Forecast Responses to Monetary Policy, By Treatment and Repetition

A. Inflation Forecasts



B. Output Forecasts

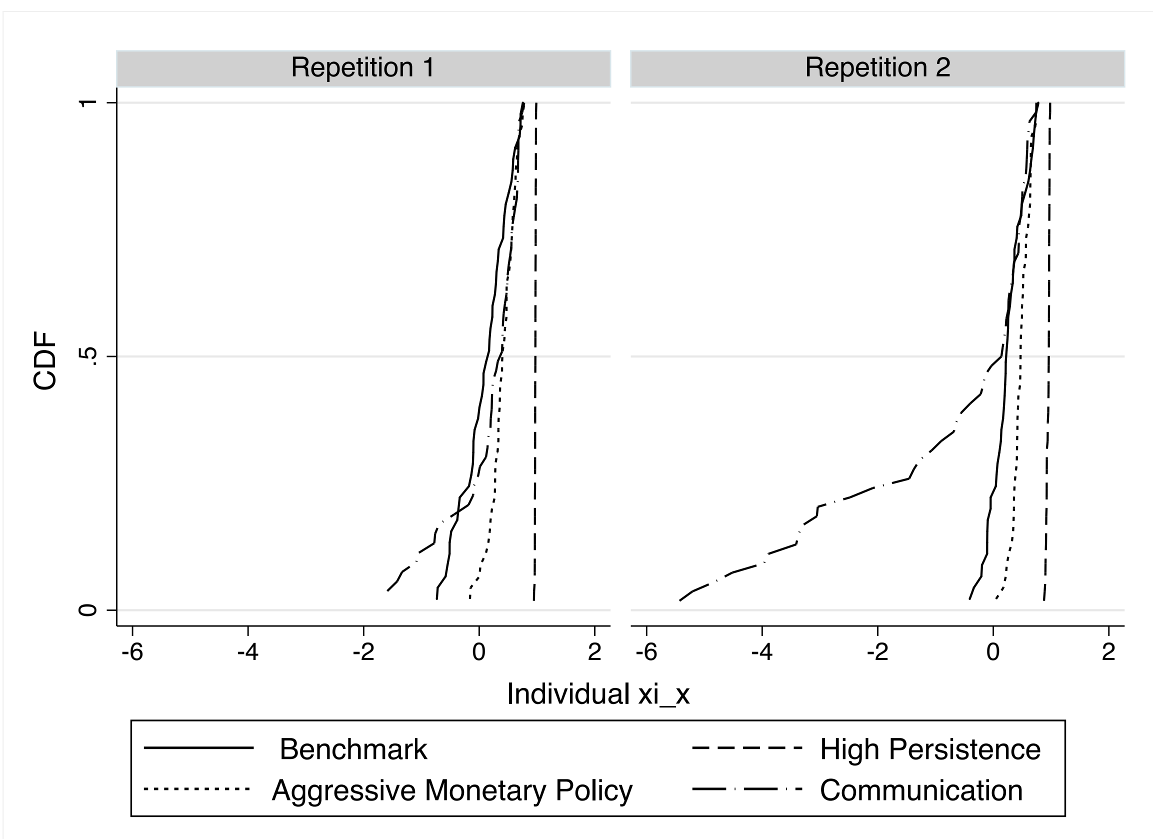
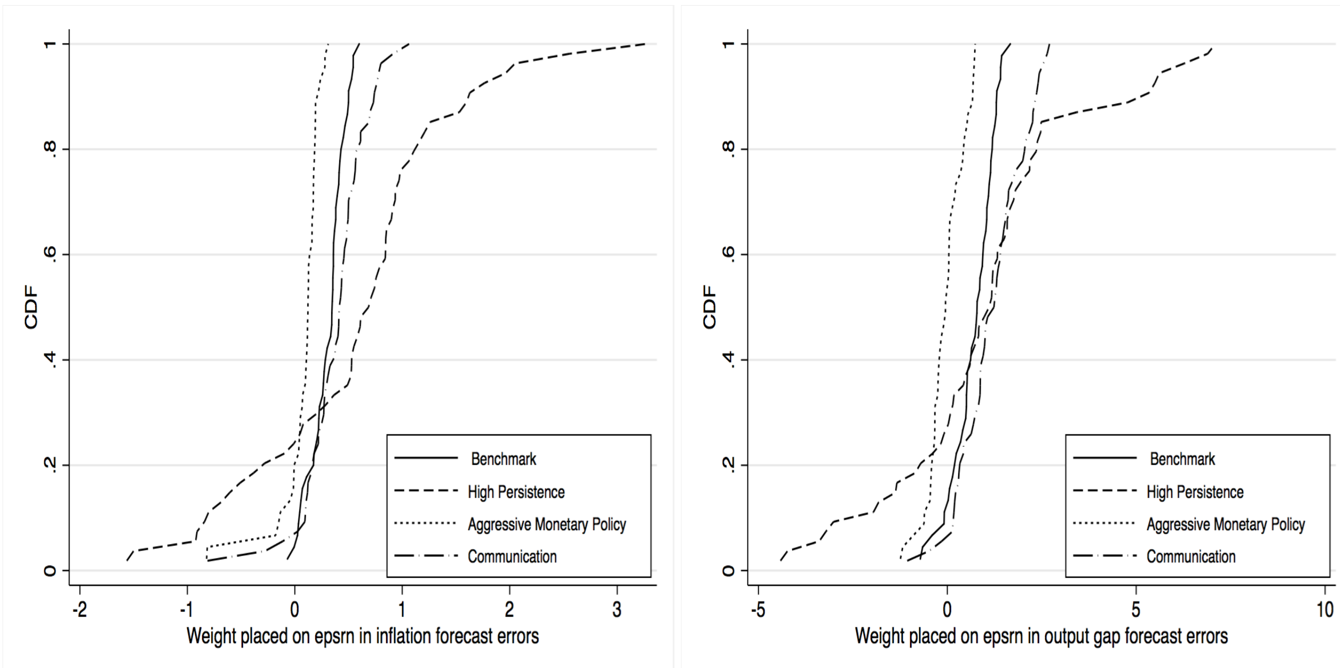


Figure 6: Distributions of Subject Forecast Error Responses to Current and Lagged Innovations, Repetition 2, By Treatment

Panel A: Response of forecast errors to ε_t



Panel B: Response of forecast errors to ε_{t-1}

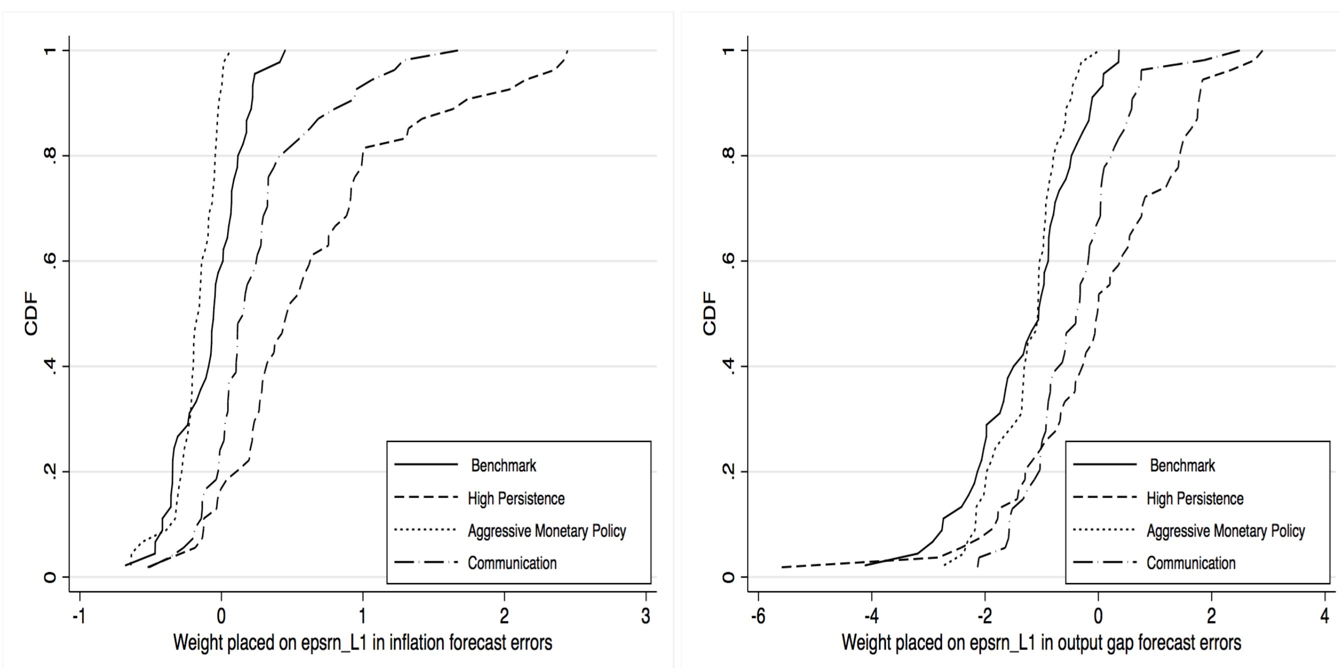


Figure 7: Distributions of Subject Mean Allocation of Time Across Information Screens, Repetition 2, By Treatment