“Expectations and Monetary Policy: Experimental Evidence”

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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 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 roughly a half of macroeconomic variance.

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1. Introduction

The modern economy is a complex and inherently uncertain environment. In order to make optimal decisions in such environment, households and firms in the economy must take into account possible unraveling 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 as well as 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 not only to understand 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 size 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. Since expectations are not directly observed, inference about their formation is mostly based on economic models that assume a particular expectation formation. The vast majority of modern macroeconomic models assume rational expectations, according to which households and firms take into account all information available, have complete understanding of the workings of the economy, including future consequences 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 expectation formation faces a difficult task of identifying

\(^1\)Woodford (2003), Gali (2008) and Boivin, Kiley and Mishkin (2011) emphasized the importance of the management of expectations by monetary policy. Boivin (2011) highlights the importance of studying expectation formations for monetary policy design. The importance of forward guidance by central bank during the period of historically low interest rates has been stressed by Carney (2012), Woodford (2012, 2013).

\(^2\)Boivin (2011) contains an overview of studies of non-rational behaviour.
model restrictions stemming from assumed expectation 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 of the experiment form their forecasts. Our approach consists of four main parts. First, we introduce a measure of 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 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 theoretical setting. Finally, we study individual forecasting behaviour, and how subjects utilize available information in order to form their expectations.

We begin our analysis by laying out a theoretical framework based on a standard New Keynesian business cycle model à la Woodford (2003) and augmented with a flexible specification for expectation formation. To quantify the strength of the expectations channel, we first derive the responses of inflation and output gap to the natural-rate-of-interest impulse that occur in the absence of future responses of nominal interest rates. We then document how much these counterfactual responses are reduced in equilibrium with countercyclical nominal interest rate response. Our measure of the expectations channel is therefore based on the fraction of conditional variances of inflation and output gap that are decreased by systematic monetary policy response over quarters following the quarter of the shock.

For empirically plausible parametrizations of the model, we find that under rational expectations monetary policy reduces conditional variance of inflation and 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 heavily rely on past output and inflation realizations, the reduction of macro-

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3Duffy (2008), Hommes (2011), Chakravarty et al. (2011) review the literature on experimental macroeconomics. Surveys of households or professional forecasters are another source of direct evidence on expectation formations. See Mankiw, Reis and Wofers (2004), Coibion and Gorodnichenko (2012) for recent studies of expectations using survey-of-forecasters data.
economic volatility by monetary policy is less than one-third and can be as low as zero.

We then turn to designing an experiment that implements this model in a learning-to-forecast setting, in which expectations of inflation and 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 driving shock process (for the natural-rate-of-interest disturbance), as well as complete information about the underlying model. This setup 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 histories of past outcomes and shocks, and detailed model description. This allows us to monitor how information is used, and whether it improves forecast accuracy.

In the experiment, inflation and 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 expectation 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 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 output gap) under rational expectations and virtually zero under strong forms of adaptive expectations. Therefore, despite falling somewhat short of stabilization that could be achieved if agents behaved rationally, monetary policy is quite potent, reducing roughly a half of the variance of inflation and output gap.

We show that a version of the theoretical model with a weak form of adaptive expectations, that attribute significant weight on 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, 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
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 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 model’s predictions, monetary policy in both treatments provides more stabilization than in the benchmark treatment, reducing the variance of inflation (output gap) by 0.95 (0.96) in high-persistence treatment and by 0.72 (0.56) in the aggressive-policy treatment.

This paper is most closely related to recent experimental studies of expectation formations and their impact on the effectiveness of monetary policy interventions in the context of New Keynesian models. These studies typically find some form of adaptive expectations, which heavily rely on the past history of inflation or 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 upshot from 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 identifying the size of stabilization provided by monetary policy via its effect on expectations. The central piece of 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 counterfactual decrease in the variance of inflation and output gap due to systematic response of monetary policy to an exogenous

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4Recent 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. Expectation formation is inferred from estimating the forecasting rules used by subjects.
economic disturbance. Our main finding is that, despite a non-rational component in expectation formation, monetary policy is quite potent in providing stabilization, accounting for roughly a half of business cycle stabilization.

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

2. Theoretical framework
A. 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 for determining current outcomes. 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 output gap, $x_t$, as the difference between the level of output 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 log-linear approximation around a deterministic steady state):

$$x_t = E_t^s x_{t+1} - \sigma^{-1} (i_t - E_t^s \pi_{t+1} - r_t^n), \quad (1)$$

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$^5$See Woodford (2003) for a detailed assumptions and derivations of equilibrium conditions in the model under rational expectations. Clarida et al. (2000) provide closely related analysis.
where \( \sigma \) is the coefficient of risk aversion, \( i_t \) is the risk-free one-period nominal interest rate, controlled by the central bank, \( \pi_t \) is inflation rate, and \( r^n_t \) is the deviation of the natural rate of interest.\(^6\) We will assume that \( r^n_t \) follows an AR(1) process:

\[
r^n_t = \rho_r r^n_{t-1} + \varepsilon_{rt},
\]

where \( \varepsilon_{rt} \) are i.i.d. draws from \( N(0, \sigma_r^2) \).

Terms \( E^*_t x_{t+1} \) and \( E^*_t \pi_{t+1} \) denote households’ expected values of next period’s 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 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 of time. Under standard assumptions on goods demand and firm’s 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):

\[
\pi_t = \kappa x_t + \beta E^*_t \pi_{t+1}.
\]

Equation (3) says that a higher level of real activity is associated with higher marginal cost of production leading to higher new prices and inflation rate. Since for a given firm its price 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

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\(^6\)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, \( Y^n_t \), 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.
point of view of the policy maker, equation (3) represents a trade-off between inflation and output gap. For example, permanently reducing the inflation rate by 1 percentage point is associated with permanent reduction of the output gap by \( \frac{1-\beta}{\kappa} \) percent. Coefficient \( \kappa \) that governs this trade-off is a function of 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 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):

\[
i_t = \phi_\pi E^*_{t-1} \pi_t + \phi_x E^*_{t-1} x_t ,
\]

where \( i_t \) is an exogenous term reflecting variations in the interest-rate target (stemming from nominal demand disturbances or imperfect control of the nominal interest rate by the central bank), and \( \phi_\pi \), \( \phi_x \) are the coefficients in front of the expected inflation rate and output gap respectively.\(^9\) According to this specification, monetary authority sets its period-\( t \) interest rate in response to deviations of period-\( t \) inflation and output gap, expected in period \( t-1 \).\(^10\) We assume that 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\(^11\) and will also be useful in the experimental setup.

The model is closed by specifying how expected values \( E_t^* x_{t+1} \) and \( E_t^* \pi_{t+1} \) are determined as

\(^7\)See Chapter 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 setup and finds that targeting private sector expectations can be important if central bank’s inflation forecasts differ from those by private sector.

\(^9\)It is common in the literature to include in the Taylor rule an exogenous term, \( \iota_t \), 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 \( \iota_t \) on output gap and inflation in our setup are identical to those of \( r^0 \) shock, we will abstract from it here.

\(^10\)A number of papers in the literature argued in favour of a specification of the Taylor rule in which the central bank responds to deviations in \textit{expected} - as opposed to current - inflation rate, see Clarida et al. (2000), Bernanke and Boivin (2003).

functions of state history. We define these functions by imposing the following general specification for ex-ante one-period-ahead forecast errors:

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

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 output gap with respect to shock realizations in periods \( t, t-1, \ldots \). Under rational expectations, en-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 expectation 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 estimating expectations as functions of the shock history is sufficient for quantifying 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 output gap, \( \{x_t\}_{t=0}^{\infty} \), inflation \( \{\pi_t\}_{t=0}^{\infty} \) and 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 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

\(^{12}\) 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 \( s = 1, 2, \ldots \).

\(^{13}\) 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 (Chakravorty et al. 2011, Boivin, 2011).
consumption expenditures), but also on its effect on real consumption expenditures. This effect is dictated by households’ preferences to smooth their real consumption over time: real consumption expenditure today depends on 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 real aggregate supply of goods needed to satisfy consumption demand.

Hence, when prices are sticky, the trade-off between inflation and 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.

B. 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 \( \pi_{t+1} \) conditional on state history through period \( t \). As it 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 output gap are functions of only period-\( t \) realization of the real interest rate shock: \(^{15}\)

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

(6)

where \( \Phi_\pi, \Phi_x \) 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 output gap fluctuations in Canada. We use the Bank of Canada measures of inflation and output gap deviations, see Appendix for details. Standard deviation and serial correlation of the \( r_t^n \) shock process, \( \sigma_r \) and \( \rho_r \), and the slope of the New Keynesian Phillips curve, \( \kappa \), are calibrated to match the following three moments in the Canadian data: standard

\(^{15}\)Details of model solution under various expectation formations are provided in the Appendix.
deviation and serial correlation of inflation deviations, 0.44 per cent and 0.4, and the ratio of standard deviations of 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. Discount factor, $\beta$, is $0.96^{1/4}$, intertemporal elasticity of substitution, $\sigma^{-1}$, is one; and the Taylor-rule coefficients in front of expected inflation and expected 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, $r^n_t > 0$, then agents’ forecasts tend to be more elastic with respect to rational forecasts. For this reason, we term such expectation formation as “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, $r^n_t > 0$, then agents’ forecasts tend to be less elastic than rational forecasts. We therefore term these expectations “static expectations.” For example, if $L_{0\pi} = L_{0x} = -1$, expectations do not move at all, i.e., $E_t^* x_{t+1} = E_t^* \pi_{t+1} = 0$.

So far we 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 implications of forecast errors that persist for a long time, we turn to another specification of non-rational expectations. For convenience, we substitute specification (5) with an equivalent specification, in which expected values of inflation and output gap are functions of past realizations.

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16 We show in the Appendix that under sensitive (static) expectations agents’ forecasts are identical to rational forecasts under 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 of adding one or two lags to formation of sensitive and static expectations.
of inflation and output gap. Specifically, we assume that ex-ante forecast errors are

\[
E_t \left( \begin{bmatrix} \pi_{t+1} \\ x_{t+1} \end{bmatrix} - \begin{bmatrix} \pi_{t+1} \\ x_{t+1} \end{bmatrix} \right) = -\omega \left( E_t \begin{bmatrix} \pi_{t+1} \\ x_{t+1} \end{bmatrix} - \begin{bmatrix} \pi_{t-l} \\ x_{t-l} \end{bmatrix} \right)
\]

Therefore, in period \( t \) agents use period \( t - l \) realization of inflation and output gap to form expectations of period-(\( t + 1 \)) inflation and output gap. If realized inflation or output gap in period \( t - l \) are high (low), then agents’ forecasts of inflation and output gap tend to be higher (lower) than would be implied under rational expectations. We therefore term such expectations as “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 Appendix.  

How does the model economy respond to a one-standard-deviation innovation to \( r^n_t \) 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 higher output gap. The response of the output gap, however, is 1.6 times higher than implied by the direct effect of the real interest rate increase. This endogenous component of output gap response is due to two effects. First, persistence of the shock implies positive effects on future consumptions, which, due to consumption smoothing, has a positive effect on the current consumption and output gap as well. Second, future positive 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 \( \phi_\pi \) and \( \phi_x \) are not too large, future real interest rates are also not large enough to offset the future levels of \( r^n_t \).

To illustrate the role of expectations for the effectiveness of monetary policy in stabilizing such fluctuations, Figure 1 compares impulse responses of inflation for different expectation formations. Sensitive expectations imply more volatile expected values of inflation and output gap, leading to

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18 Such specification is commonly used in the literature on adaptive expectations. See, for example, Arifovic et al. (2010) 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 \( \omega = 0.5 \).
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 stabilization of such expectations by monetary policy responses following the shock is smaller.

C. Measuring the importance of expectations

Since the goal of this paper is to understand how macroeconomic stabilization by monetary policy depends on formation of expectations, the key to our analysis is to find a statistic that quantifies such stabilization. When inflation or 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 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 output gap, as well as by endogeneity of monetary policy and expectations. Namely: a) since the fundamental shock process is persistent, innovation to that shock at any period will have effects in future periods; b) since monetary policy has an endogenous component, its response depends on the history of inflation and output gap, as well as their future expected paths; c) expectations of inflation and output gap may be correlated with shock realizations; and finally, d) 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 output gap to an innovation to \( \epsilon_r \), conditional on zero future responses of nominal interest rates. Such counterfactual responses can be constructed using the following steps. Denote by \( s = 0, 1, 2, \ldots \) the number of periods after the impulse \( \epsilon_r0 \) to the natural-rate-of-interest deviation, so that its impulse response is \( r^n_s = \rho^s \epsilon_r0 \). Let \( x_s, \pi_s \) and \( i_s \) denote equilibrium impulse responses of output gap, inflation and interest rate respectively.

To construct counterfactual responses of output gap \( x_s \) and inflation \( \pi_s \), we assume that expectations of inflation and 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 output gap and inflation for \( s = T, T-1, \ldots, 0 \) under the assumption that nominal interest rate responses are zero in all periods. Denote those paths by \( \tilde{x}_s^* \) and inflation \( \tilde{\pi}_s^* \):

\begin{align*}
\tilde{x}_T^* &= \sigma^{-1} r_T^n, \quad \tilde{\pi}_T^* = \kappa \sigma^{-1} r_T^n, \\
&\hspace{1cm} \ldots \\
\tilde{x}_s^* &= \sigma^{-1} r_s^n + E_s^* \tilde{x}_{s+1}^* + \sigma^{-1} E_s^* \tilde{\pi}_{s+1}^*, \quad s = 1, \ldots, 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}^*, \quad s = 1, \ldots, T-1, \\
&\hspace{1cm} \ldots \\
\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{align*}

Note that the differences between \( \tilde{x}_s^* \), \( \tilde{\pi}_s^* \) and equilibrium responses \( x_s, \pi_s \) are due to shutting down countercyclical response of the nominal interest rate to the shock. Since we only want to focus 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 output gap:

\begin{align*}
\tilde{x}_s &= \tilde{x}_s^* - \sigma^{-1} i_s, \quad s = 0, \ldots, T, \\
\tilde{\pi}_s &= \tilde{\pi}_s^* - \kappa \sigma^{-1} i_s, \quad s = 0, \ldots, T.
\end{align*}

In computing \( \tilde{\pi}_s \) and \( \tilde{x}_s \), we assume that agents perfectly observe fundamental shock realizations as well as are able to forecast 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 experiment 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 larger than both of equilibrium responses. The size of the stabilizing effect of anticipated
monetary policy response is given by the decrease in the total response of inflation. The more 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

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

D. Model predictions for 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 monetary policy’s ability to stabilize fluctuations in the output gap and inflation. The shares of conditional variance of inflation and output decreased due to the expectations channel, \(\Xi_\pi\) and \(\Xi_x\), are 0.73 and 0.65 respectively.

To gain further intuition for the workings of the expectations channel, we compute \(\Xi_\pi\) and \(\Xi_x\) for different parameter values in the model with rational expectations.\(^{20}\) We show that \(\Xi_\pi\) and \(\Xi_x\) are monotonically increasing in \(\rho_r\), \(\kappa\), \(\sigma^{-1}\) and \(\phi_\pi\), and can even take on negative values. Higher shock persistence, \(\rho_r\), extends the horizon over which future nominal interest rates stay high, therefore increasing stabilizing effect of the expectations channel. Table 1 shows that increasing \(\rho_r\) from 0.57 to 0.80 raises stabilization from 0.73 to 0.97 for inflation, and from 0.65 to 0.98 for output gap.

For a shock of given magnitude, \(\kappa\) and \(\sigma^{-1}\) increase the elasticities of inflation and 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 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 output gap, see Table 1.

An increase in the elasticity of the nominal interest rate to expected inflation and output gap

\(^{20}\Xi_\pi\) and \(\Xi_x\) 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 \(\Xi_x\) for a range of parameter values and for alternative expectation formations.
fluctuations increases the aggressiveness of future nominal rate increases with respect to inflation and 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 output gap.\textsuperscript{21}

We also consider alternative specifications of the policy rule (4). First, we compute $\Xi_\pi$ and $\Xi_x$ 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 $\phi_\pi E_{t-1}^\pi \pi_t + \phi_x E_{t-1}^x x_t$ in our baseline model. Without a policy lag contribution of expectations to stabilization is marginally larger, increasing from 0.73 to 0.76 for inflation.

Second, we allow for interest-rate smoothing in the Taylor rule:

$$i_t = \phi_i i_{t-1} + \phi_\pi E_{t-1}^\pi \pi_t + \phi_x E_{t-1}^x x_t.$$  

This specification implies that the nominal interest rate depends, in addition to expected inflation and output gap, on its previous value, with parameter $\phi_i$ denoting the weight attached to the past value. Adding interest-rate smoothing extends the horizon during which nominal interest rate responds after the shock, thus allowing it to stabilize the economy more than without smoothing.\textsuperscript{22}

For example, for simulation with $\phi_i = 0.8$, conditional variance is decreased by 0.87 for inflation (relative to 0.73 with no smoothing) and by 0.75 for output (0.65 with no smoothing), see Table 1 (row 6).\textsuperscript{23}

Turning to the size of stabilization under non-rational expectations, Table 2, rows 1 and 2, shows 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 expectations channel of monetary policy is lower than under rational expectations, 0.55 and 0.54 for output and inflation respectively. For static expectations, the decrease is larger, 0.89 and 0.74 respectively.

Table 2, rows 3, 4 and 5, shows moments for equilibrium dynamics for adaptive(0), adaptive(1)

\textsuperscript{21}In this exercise, we change $\phi_\pi$, $\phi_x$ proportionally, so that $\phi_\pi/\phi_x = 3$.

\textsuperscript{22}This implies a well-known result that under price-level targeting (corresponding to $\phi_i = 1$), the expectations channel is stronger than under monetary policy characterized by standard Taylor rule.

\textsuperscript{23}Pfajfar and Zakelj (2013) study the stabilizing role of various Taylor rule specifications in a forward-looking New Keynesian model. They find that economic stability is enhanced when the policy rule is conditioned on current inflation, rather than expected future inflation. In their work on expectations and uncertainty, Pfajfar and Zakelj (2012) find that inflation-targeting produces lower uncertainty and higher forecast accuracy than inflation-forecast targeting, where larger deviations of expectations from target result in larger interest rate adjustments.
and adaptive(2) expectations respectively. In all cases, contribution of future nominal interest rate responses to stabilization of inflation and 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 output gap. Intuition is similar to the case of sensitive expectations: positive realization of period-t real-interest-rate shock implies higher expected future values of output gap and inflation. Unlike sensitive expectations, for which such effects last finite number of periods, period-t shock realization has long-lasting effects on agents’ forecast errors. These results demonstrate that under non-rational expectations, stabilization benefits of monetary policy can be substantially smaller, or even none.

We show in the Appendix (Figure A.3) that the relative rankings of the contribution of future terms implied by alternative expectations are invariant across all combinations of model parameters. Namely, under static expectations, monetary policy is the most effective in reducing the variance of inflation and output gap, even more effective than under rational expectations. Sensitive expectations imply a less important role for expectations than rational expectations. Finally, adaptive expectations imply the lowest contribution of future terms to inflation variance. Differences in implications under alternative expectations are larger for smaller values of $\rho_r$, $\kappa$, $\sigma^{-1}$ and $\phi_\pi$, and those differences dissipate as those values increase.

As an additional robustness check, we also compare those rankings under re-calibrated values of $\sigma_r$, $\rho_r$ and $\kappa$ that allow each version of the model to match the same calibrated targets as in the baseline model under rational expectations. The relative rankings remain the same, with differences in the degree of stabilization even larger than without re-calibration.

The above exercises demonstrate that the relative rankings of the importance of expectations for inflation variance under alternative expectation 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 output gap stabilization by monetary policy.

3. Experimental Design

The experiment was conducted at CIRANO’s Experimental Economics Laboratory in Montreal, 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 9 subjects interacting together
in a single group. Earnings, including a $10 show up fee, ranged from $18 to $45, and averaged $36 for 2 hours.

A. 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 output gap, inflation, and interest rate would evolve given their expectations, monetary policy, and shocks. Their task was to submit forecasts for next period’s inflation and 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 absolute forecast errors:

\[ S_{i,t} = R_0 \left( e^{-\alpha|E_{i,t-1}^{\pi} - \pi_t|} + e^{-\alpha|E_{i,t-1}^{x} - x_t|} \right), \]

where \( R_0 = 0.3, \alpha = 0.01, \) and \( E_{i,t-1}^{\pi}, E_{i,t-1}^{x} \) are subject i’s forecasts submitted in period \( t - 1. \)

This scoring rule implies 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 provides an incentive to make accurate forecasts: for every additional 100 basis points error for both of inflation and output gap forecasts, the subjects’ score in that period would decrease by a half.

While the written and verbal instructions, provided prior to the experiment, included a qualitative description of the IS and Phillips curve 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 output gap would occur each period, that it would gradually dissipate with persistence parameter \( \rho, \) and that its size would be randomly drawn from a normal distribution, with mean zero and variance \( \sigma^2. \) In each period, the average forecasts, \( E_{t-1}^{\pi} \) and \( E_{t-1}^{x}, \) appearing in the IS curve, the Phillips Curve, and the Taylor rule, were computed as medians across subjects’ individual forecasts, \( E_{i,t-1}^{\pi} \) and \( E_{i,t-1}^{x}. \)

\(^{24}\) Subjects never directly observe other subjects’ forecasts or the average forecasts.

\(^{24}\) Median forecasts are not sensitive to extreme individual entries, and therefore, they make it more difficult for subjects to manipulate 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, output gap and interest rate. The historical graphs and tables available to subjects displayed 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 55 periods. Periods lasted for up to 1 minute in the first 10 periods of each sequence, and 45 seconds thereafter. This sequential design of experimental sessions allowed us to control for subjects’ learning the experimental and economic environment: results from practice rounds are not included in the analysis, and the results from the first and second repetitions across sessions will be compared.

B. Interface

The experiment was programmed in Redwood, an open-source software (Pettit, 2012). Throughout the experiment, participants had access to three interchangeable screens: the main (default) screen, the history screen, and the screen with technical instructions. In addition, the header containing subject ID, period, time remaining, and total score was seen throughout the experiment. We designed the experimental interface to separate different types of information across three screens. This allowed us to track what information 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. At the beginning of each period $t$, subjects were able to enter and submit their forecasts for next period’s 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 of zero.

The history screen was located on a second tab. To access it, subjects could click on the tab located to the left of the main screen. Subjects could freely switch between the screens, although

25 Screen designs, instructions and other details of experimental interface are included in the Appendix.
only one screen could be open at a given point in time. Within the history screen, subjects could see graphs of time series for 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 of time by pointing the mouse arrow at that point.

Technical instructions were located on the third and final tab. These supplementary instructions provided a detailed description of how inflation, output, 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 each subject’s time allocated to reviewing the information in each period. Subjects were allowed to use the Windows calculator as well as write down their calculations.

This interface implements two key novel 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 presents subjects with a choice between information about the shock and information about the history of inflation and output gap, or about model details. We can use observations on how often subjects switch across these screens to understand how they use available information to form their expectations.

C. Treatments

The experiment included three treatments that explored the robustness of outcomes in our experimental economy. In the Benchmark treatment, experiment outcomes were determined by the baseline model presented in Section 2, in which expectations \( E_t^e \pi_{t+1} \) and \( E_t^e x_{t+1} \) were given by median over forecasts for inflation and 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 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 output was doubled to \( \phi_x = 3 \) 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.
We also conducted an auxiliary treatment based on the Benchmark treatment, in which in every period subjects observed on their main screens a forecast of future interest rates for the following 9 periods - Communication treatment.\footnote{The central bank’s forecast is constructed using model solution under rational expectations. See Appendix for details.} This stylized treatment provides information about the value of central bank’s communication of its likely future actions. If subjects make their decisions under complete understanding of the model (and monetary policy), such communication regarding future expected monetary policy actions should not have significant effects on the outcomes in this treatment.

In all, we conducted five sessions for each of the Benchmark, High Persistence, and Aggressive Monetary Policy treatments, and six sessions for the Communication treatment.\footnote{Prior to conducting our experiment, we ran 7 pilot sessions. These sessions allowed us to refine our instructions and design. See Appendix for details.}

4. Experiment Results: Aggregated Outcomes

A. Summary of experiment outcomes

In all of our experimental sessions (second repetitions), inflation and 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 expectation formations. Experimental outcomes, therefore, do not seem to be driven by factors outside the data-generating process, such as sunspots or strategic behaviour.\footnote{Marimon and Sunder (1993), Marimon, Spear and Sunder (1993) study non-stable behaviour in macroeconomic and monetary experimental settings.} Furthermore, throughout our experiment the results do not differ significantly between the first and second repetitions, suggesting that subjects quickly converge to their stationary behaviour. Stability of experimental outcomes provides support for the soundness of experimental implementation of our theoretical model.

Table 3 provides a summary of basic statistics for the dynamics in the experiment for each of the three treatments: Benchmark, High Persistence and Aggressive Monetary Policy. We first calculate the statistics for each session-repetition, and then provide in the table the median, min and max values of those statistics over session-repetitions.\footnote{Results in Table 3 are not sensitive to whether means, instead of medians, are reported.} In order to control for learning by subjects,
we only provide statistics for Repetition 2, noting, however, that results including Repetition 1 are very similar.

For the Benchmark treatment, monetary policy (acting via future expected path of nominal interest rates) removes about a half of the conditional variance: 0.51 for inflation and 0.45 for output. Such degree of stabilization falls in the mid-point between values predicted by 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 a half of business cycle stabilization.

What type of expectation formation leads to the outcomes observed in the benchmark treatment? Further examination of Table 3 reveals that both inflation and 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 standard deviation of 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 experiment results with model predictions in Table 2 suggests that the closest fit to 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 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 serial correlation of inflation is 0.40 (0.56 in the experiment). The model with adaptive(1) expectations, in turn, slightly over-predicts the size and persistence of inflation fluctuations and under-predicts stabilization by monetary policy.

The bottom two panels in Table 3 compare outcomes in two alternative treatments – High Persistence and Aggressive Monetary Policy – to the Benchmark treatment. In both cases, experimental outcomes are consistent with those predicted by the theoretical model, see Table 2.\textsuperscript{30} Namely, increasing shock persistence leads to more volatile and persistent output gap and inflation

\textsuperscript{30} Mann-Whitney tests significantly reject the null hypotheses that the statistics are identical across treatments (p<0.02 in all cases).
fluctuations, smaller ratio of output gap volatility to inflation volatility, and finally, larger decrease in the fraction of conditional variance explained by expectations channel of monetary policy. In turn, more aggressive monetary policy leads to less volatile and less persistent output gap and inflation fluctuations, larger ratio of output gap volatility to inflation volatility, and larger decrease in the fraction of conditional variance explained by future nominal interest rates.\footnote{Assenza et al. (2012) find in their experiments 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 \% point reduction of the conditional variance of inflation and output.}

Such consistency of experimental results with 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 auxiliary Communication treatment. We show in the Appendix (Table A.4) that public announcements of the forecast of future interest rates lead to more volatile fluctuations, and therefore, less effective monetary policy. For example, standard deviation and persistence of inflation in the Communication treatment are 1.18 per cent and 0.75, both higher than 0.79 and 0.56 in the Benchmark treatment. The fraction of conditional variance of inflation and output decreased via expectations channel of monetary policy is 0.19 and 0.10, both lower than 0.51 and 0.45 in the Benchmark treatment. These results therefore point to potentially detrimental consequences of interest rate forecast announcements.\footnote{Gali (2011) questions the usefulness of announcing central banks nominal interest rate projections, using standard New Keynesian model as a reference framework. Baeriswyl and Cornaud (2012) use experiments to study the effectiveness of central bank communication in reducing overreaction of financial markets to public information.}

B. Comparisons of experimental and theoretical outcomes

Since, by design, the shock is observed, we can gain further insight on the implications of expectation formation for aggregate fluctuations by comparing experimental time series to those predicted by our theoretical model for the same history of shock realizations occured during the experiment. We compare the time series for inflation, 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

\[
E_t^t \pi_{t+1} = 0.080 r_{t-1}^n + 0.141 \varepsilon_t , \\
E_t^t x_{t+1} = 0.269 r_{t-1}^n + 0.472 \varepsilon_t , \\
\pi_t = -0.195 E_{t-1}^t \pi_t - 0.065 E_{t-1}^t x_t + 0.199 r_{t-1}^n + 0.349 \varepsilon_{rt} , \\
x_t = -1.5 E_{t-1}^t \pi_t - 0.5 E_{t-1}^t x_t + 0.919 r_{t-1}^n + 1.613 \varepsilon_{rt} , \\
i_t = 1.5 E_{t-1}^t \pi_t + 0.5 E_{t-1}^t x_t .
\]

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

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

Among the four alternative expectations, in consistence 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 output gap fluctuations are 0.58 and 0.74 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. Similar story concerns fluctuations in forecasts of inflation and 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 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 adaptive(1) expectations the range is 0.76 to 0.89. Sensitive expectations do not provide better correlations between counterfactual and experimental time series.

The previous two subsections provide evidence for outcomes observed in the experiment and compare those outcomes to those implied by model equilibria under alternative expectation formations. We find that sensitive and adaptive expectations imply outcomes that fit best (among the alternatives) to those observed in the experiment. In order 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.

C. Estimated forecast functions

In accordance with theoretical model in Section 2, equation (5), we estimate ex-ante forecast errors as functions of the history of innovations to $r^n_t$ shocks. For example, for inflation ex-ante forecast errors, we estimate the following specification:

$$E_t (\pi_{t+1} - E^*_t \pi_{t+1}) = G^\pi_0 \varepsilon_{rt} + G^\pi_1 \varepsilon_{rt-1} + \ldots + G^\pi_T \varepsilon_{rt-T}, \quad (8)$$

where $T$ is a finite integer that is big enough to approximate (5) well, and coefficients $G^\pi_i$ fully characterize inflation ex-ante forecast errors.

Panel A in Figure 3 plots ex-ante forecast errors for inflation in 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...

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33 For simple cases in the model, these functions can be derived analytically.
34 We estimate an OLS regression

$$\pi_{t+1} - E^*_t \pi_{t+1} = G^\pi_0 \varepsilon_{rt} + G^\pi_1 \varepsilon_{rt-1} + \ldots + G^\pi_T \varepsilon_{rt-T} + \varepsilon_{t+1}, \quad (9)$$

where $E_t^* \pi_{t+1}$ is the expected value of $\pi_{t+1}$ in period $t$ given by (5) or median forecast in the experiment, and $\varepsilon_{t+1}$ are i.i.d. zero mean draws. Note that $G^\pi_i$ also approximate the responses of ex-ante forecast errors in quarter $i$ after an impulse to $r^n_t$. 

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24
rational forecasts. For adaptive(1) expectations, ex-ante forecast errors display a distinct pattern: they are positive at the time of the shock, as the inflation forecast is expected to under-shoot relative to inflation next period, and they are negative thereafter, as inflation forecasts are expected to persist while inflation is slowly getting back to its pre-shock level.

To provide a better intuition for the implications of alternative forecast functions, we also estimate forecast decision functions by estimating specification (8) for median forecasts as dependent variable. Panel B in Figure 3 plots forecast functions for inflation in theoretical model for alternative expectations. For the baseline model with rational expectations, 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 images of 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 in Figure 3 plot the ex-ante forecast errors and forecast functions estimated from the experimental data (blue lines). There is a clear over- and under-shooting 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 Figure 3 that the adaptive(1) expectations provide the best fit to forecasts in our experiment. Not only the overall shape and size of forecast functions and ex-ante errors are similar to those from the experiment, but also the timing of over- and under-shooting (of forecast errors) and peaks (of forecasts) coincide as well. We therefore conclude that in forming their expectations, the subjects mostly rely on information drawn from very recent history (up to 4 lags or so) of shock realizations, 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 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 $\gamma^n_t$ shock, inflation and output gap expectations take one quarter to catch up with growing inflation and output gap, and then they are persistently higher when inflation and output gap start their return back to the pre-shock level.

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35 We estimate equations (8) and (??) for each of the five second repetitions in the benchmark treatment. We plot median point estimates, together with two-standard-deviation bands.

36 Adam (2007) considers a two-equation New Keynesian model that is similar to one in this paper and asks whether sluggish expectations can account for considerable persistence of output and inflation. Similar to our results, he...
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 therefore that the model with adaptive(1) expectations most accurately predicts fluctuations that we observe in experimental setting.

5. Experiment Results: Individual Behaviour

A. Individual Forecast Errors

Our theoretical model assumes no heterogeneity in how expectations are formed. In accordance with the model, our experimental design provides full information about the driving shock and complete details about the model itself, both of which should minimize differences in subjects’ information sets during the experiment. Therefore, we assume that aggregate expectations are well approximated by the average (median) forecast and argue that implications of heterogeneity in expectations are not very important in our approach.

There is, expectedly, some degree of heterogeneity in forecasting behaviour across subjects. For example, in the Benchmark treatment (Repetition 2), the standard deviation of forecast errors for inflation (output gap) is 94 (401) basis points. Such dispersion in forecasts is of the same order of magnitude as the size of fluctuations itself: for example, the standard deviation of the median inflation (output gap) forecast is 56 (176) basis points. Although the dispersion may seem large, it does not necessarily have a large effect on the aggregate outcomes that are computed using the median forecast.

To assess the importance of the forecast dispersion, we compare the accuracy of the best and the worst forecasters to each other, as well as to the accuracy of a hypothetical rational forecaster.

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37 Dispersion in forecasts may stem from differences in subjects cognitive abilities, information sets, or strategic behaviour. See Section 2. Assenza et al. (2012) fit a heterogeneous expectations switching model to the experimental data in a New Keynesian macroeconomic setup. They show that individual learning takes the form of switching from one heuristic learning rule to another.
As in the previous section, our experimental design allows us to estimate those behaviours directly. We ask: which of the forecasts the median forecast is the closest to, the best or the worst, and whether those forecasts are close to rational?

For every session, we identify the highest and second lowest ranking forecasters as the subjects who accumulate the most and second least forecasting scores in the second repetition. To estimate the behaviour of a hypothetical rational forecaster, we estimate equilibrium outcomes for $x_t$ and $\pi_t$ in our experiment as the following functions of the state history:

$$
\pi_t = D_0^\pi \epsilon_{rt} + D_1^\pi \epsilon_{rt-1} + \ldots + D_T^\pi \epsilon_{rt-T},
$$

$$
x_t = D_0^x \epsilon_{rt} + D_1^x \epsilon_{rt-1} + \ldots + D_T^x \epsilon_{rt-T},
$$

where $T$ is a large enough integer. The specifications above imply that rational one-period ahead forecasts for inflation and output are given by

$$
E_{t+1}\pi_{t+1} = D_1^\pi \epsilon_{rt} + \ldots + D_T^\pi \epsilon_{rt-T+1},
$$

$$
E_{t+1}x_{t+1} = D_1^x \epsilon_{rt} + \ldots + D_T^x \epsilon_{rt-T+1}.
$$

By construction, rational forecasts provide an upper bound on the accuracy of individual forecasts in the experiment.

We find that inflation and output forecasts, submitted by the top performers in a given session, are not significantly different from the median forecasts. For example, Mann-Whitney tests yield p-values of $p > 0.34$ in all cases. Both median and top-performer’s forecasts are significantly different from the rational forecasts, with $p < 0.01$. These results are robust to the treatment variations we considered.

Figure 4 shows plots for inflation and output forecasts for the top and bottom forecasters, and the rational forecast for Session 5 in the Benchmark treatment. Bottom performers’ forecasts are significantly less accurate than those by top performers, the median or rational forecasts. For example, for inflation forecast in the benchmark treatment, the average RMSE for the bottom

---

38 We discard the lowest ranking subjects who may be outliers.
performer is 110 basis points which is up to one and a half times larger that RMSE’s for the top performer, 83 basis points, and for the median forecast, 71 basis points. This also suggests that dispersion of forecast errors is mainly driven by bottom performers.

In sum, we document that (a) forecasts of best performers are not significantly different from the median forecasts, and (c) subjects’ forecasts are significantly less accurate than rational forecasts, and (c) dispersion of forecast errors is mainly driven by bottom performers. This leads us to conclude that, in accordance with our theoretical and experimental framework, taking into account heterogeneity in expectation formation is unlikely to affect results that are based on median forecasts.

B. Tab Times

Our software allowed us to track how much time a subject spent on the forecast, history, and technical instructions screens. We observe that subjects made virtually no use of the technical instructions, visiting the screen only 2.2 times over a 50-period repetition and spending each time on average 2.4 seconds, which amounts to only 0.3 per cent of the available decision time. In contrast, subjects used extensively the history screen, visiting it on average 2.4 times per period and spending there around 45% of their decision time, see Table 5. The fact that most subjects visit the history screen at least twice per period can be related to their need to form two forecasts per period (for inflation and for output gap). We therefore conclude that subjects value information about the history of aggregate outcomes much more than details about the underlying data-generating model.

There is little variation in screen usage among subjects. Across all four treatments and repetitions, median time spent on the history screen ranges from 40 to 46 per cent of subjects’ time. The top forecasters review historical information significantly more than the lowest ranking subjects, and there is no significant difference between the top and median forecasters. This provides further evidence that the top performing subjects do not follow significantly different strategies than most subjects.39

Finally, we investigate whether screen usage can tell us anything about subjects’ forecasting

39Note that for all treatments, except Communication, there is a non-monotonic relationship between the number of visits to the history screen and forecasting performance. Both top and bottom forecasters visited the screen less frequently than the median forecaster. This may suggest a non-monotonic relationship between the value of the history-screen information and forecasters’ ability to use that information.
behaviour. We find a statistically significant relationship between the amount of time a subject spent reviewing historical information, and the weight they assign on recent shocks when forming their forecasts. Using Repetition 2 data, we estimate individual forecast functions and compare the results with the subjects’ screen usage. Pooling data from the Benchmark, High Persistence, and Aggressive Monetary Policy treatments, we find that the average proportion of time spent reviewing the history screen is positively correlated with the weight of $\varepsilon_{t-2}$ on $E_{t,t}^s \pi_{t+1}$ and $E_{t,t}^s x_{t+1}$: Spearman correlation coefficient for inflation forecasts is $\rho = 0.17 (p = 0.04)$ and for output forecasts is $\rho = 0.19 (p = 0.02)$. Subjects’ tab usage was not significantly correlated with current shocks, $\varepsilon_t$, or one-period lagged shocks, $\varepsilon_{t-1}$. Subjects in the Communication treatment exhibit similar behaviour.

Hence, in our experiment, subjects mostly rely on the recent data and qualitative understanding of the workings in the economy to form their forecasts, rather than study the technical instructions to learn quantitative details of economic mechanisms. Our findings therefore suggest that subjects avoid costly effort associated with information overload by using simplifying heuristics.\textsuperscript{40} The upshot of our analysis therefore is that such behaviour, at the aggregate level, does not preclude monetary policy from being effective in stabilizing macroeconomic fluctuations.

C. Questionnaires

Subjects were asked to complete follow-up questionnaires after each session. More than 70 percent (95 / 135) of subjects in our Benchmark, High Persistence, and Aggressive Monetary Policy treatments do take nominal interest rates into consideration while forming their forecast. We asked subjects to describe the strategies and information they used to form their forecasts. 81 per cent of subjects (109 / 135) report that they used some form of historical information to construct their forecast (e.g., past inflation and output levels, forecasts, and forecast errors), while 23 per cent of subjects (31 / 135) discuss extrapolating trends from the data. This supports our earlier findings that subjects rely significantly on historical information when forecasting. Finally, we find very little evidence of strategic considerations in subjects’ responses. Only 5 out of 135 subjects make

\textsuperscript{40}Decision-science literature studies behaviour aimed at reducing the amount of effort exerted to make a decision or complete a task when the decision or task becomes more complex, see Payne, Bettman and Johnson (1998), Payne, Bettman and Luce (1996). Stigler (1961) and Nelson (1970, 1974) demonstrate that consumers will utilize information more extensively, if it costs less time or money to acquire.
any reference to other subjects' behaviour when forming their forecasts. None of these five subjects were among the top performers in their session.

Subjects in the Communication treatment more frequently stated that they conditioned their forecasts on the interest rate. Over 83 percent (45 / 54) of subjects considered the nominal interest rate, suggesting that the additional information had some success at emphasizing that nominal interest rates were important. Many subjects noted that they initially used the interest rate forecasts to aid in their decision making, but later ignored the information as it did not appear to be helpful for their forecasting accuracy. Otherwise, information usage was not considerably different from other treatments.

6. Conclusions

Monetary policy plays an important role in guiding public expectations of future inflation and output, and thus 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. Using a standard New Keynesian business cycle model, we show that under rational expectations monetary policy reduces conditional variance of inflation and output gap by at least two-thirds. These stabilization benefits can be substantially smaller – even none – if expectations are non-rational. 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 mostly rely on the recent data and qualitative understanding of the workings in 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 a half of 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


Table 1: Model Predictions under Rational Expectations

<table>
<thead>
<tr>
<th></th>
<th>Fraction of conditional variance decreased via expectations channel</th>
<th>std((\pi_t))</th>
<th>ser.cor.((\pi_t))</th>
<th>(\frac{\text{std}(x_t)}{\text{std}(\pi_t)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\pi_t)</td>
<td>(x_t)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0.73 0.65 0.44 0.40 4.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 High persistence</td>
<td>0.97 0.98 1.16 0.71 2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Steep NKPC</td>
<td>0.89 0.86 0.80 0.39 2.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Lower risk aversion</td>
<td>0.81 0.88 0.66 0.35 5.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Aggressive policy</td>
<td>0.82 0.75 0.31 0.35 5.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 No policy lag</td>
<td>0.76 0.73 0.34 0.57 3.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Interest-rate smoothing</td>
<td>0.87 0.75 0.27 0.19 6.3</td>
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Table 2: Model Predictions under Alternative Expectations

<table>
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<th></th>
<th>Fraction of conditional variance decreased via expectations channel</th>
<th>std((\pi_t))</th>
<th>ser.cor.((\pi_t))</th>
<th>(\frac{\text{std}(x_t)}{\text{std}(\pi_t)})</th>
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<tr>
<td>(\pi_t)</td>
<td>(x_t)</td>
<td></td>
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</tr>
<tr>
<td>Baseline</td>
<td>0.73 0.65 0.44 0.40 4.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Sensitive</td>
<td>0.55 0.54 0.70 0.40 3.7</td>
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<td></td>
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</tr>
<tr>
<td>2 Static</td>
<td>0.89 0.74 0.18 0.57 7.7</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3 Adaptive(0)</td>
<td>0.55 0.51 0.81 0.14 3.5</td>
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</tr>
<tr>
<td>4 Adaptive(1)</td>
<td>0.20 0.32 1.00 0.74 2.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Adaptive(2)</td>
<td>-0.14 0.35 0.96 0.87 2.4</td>
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</table>
Table 3: Experimental evidence, summary statistics

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fraction of conditional variance decreased via expectations channel</th>
<th>std((\pi_t))</th>
<th>ser.cor.((\pi_t))</th>
<th>std((x_t))/std((\pi_t))</th>
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<tr>
<td></td>
<td>(\pi_t)</td>
<td>(x_t)</td>
<td></td>
<td></td>
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<td><strong>Benchmark</strong></td>
<td></td>
<td></td>
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<tr>
<td>Model (Rational)</td>
<td>0.73</td>
<td>0.65</td>
<td>0.44</td>
<td>0.40</td>
</tr>
<tr>
<td>Model (Adaptive 1)</td>
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<td>1.00</td>
<td>0.74</td>
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<td>0.79</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>min</td>
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<td></td>
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<td>0.49</td>
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<td>max</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.56</td>
<td>0.56</td>
<td>0.92</td>
<td>0.69</td>
</tr>
<tr>
<td><strong>High persistence</strong></td>
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<td></td>
</tr>
<tr>
<td>Model (Rational)</td>
<td>0.97</td>
<td>0.98</td>
<td>1.16</td>
<td>0.71</td>
</tr>
<tr>
<td>Model (Adaptive 1)</td>
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<td>0.98</td>
<td>2.07</td>
<td>0.87</td>
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<tr>
<td>Experiments</td>
<td>median</td>
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<td>0.95</td>
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<td>0.81</td>
</tr>
<tr>
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</tr>
<tr>
<td></td>
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<td>0.92</td>
<td>1.80</td>
<td>0.76</td>
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<tr>
<td></td>
<td>max</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>0.97</td>
<td>0.98</td>
<td>11.18</td>
<td>0.87</td>
</tr>
<tr>
<td><strong>Aggressive policy</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model (Rational)</td>
<td>0.82</td>
<td>0.75</td>
<td>0.31</td>
<td>0.35</td>
</tr>
<tr>
<td>Model (Adaptive 1)</td>
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<td>0.46</td>
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</tr>
<tr>
<td>Experiments</td>
<td>median</td>
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<td>0.71</td>
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<tr>
<td></td>
<td>0.79</td>
<td>0.59</td>
<td>0.56</td>
<td>0.44</td>
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</table>

Notes: Statistics for each treatment in the experiments are computed for 5 sessions of repetition 2.
Table 4: Time-series comparisons, Experiment vs Model

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Rational</th>
<th>Sensitive</th>
<th>Static</th>
<th>Adaptive(1)</th>
<th>Adaptive(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{\text{std}(X_{t}^{\text{Model}})}{\text{std}(X_{t}^{\text{Experiment}})} )</td>
<td>( E_{t}(\pi_{t+1}) )</td>
<td>0.36</td>
<td>0.72</td>
<td>0.15</td>
<td>1.24</td>
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<tr>
<td></td>
<td>( E_{t}(x_{t+1}) )</td>
<td>0.38</td>
<td>0.76</td>
<td>0.23</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>( \pi_{t} )</td>
<td>0.58</td>
<td>0.93</td>
<td>0.27</td>
<td>1.24</td>
</tr>
<tr>
<td></td>
<td>( x_{t} )</td>
<td>0.74</td>
<td>1.01</td>
<td>0.53</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>( i_{t} )</td>
<td>0.43</td>
<td>0.86</td>
<td>0.23</td>
<td>1.07</td>
</tr>
<tr>
<td>( \text{corr}(X_{t}^{\text{Model}}, X_{t}^{\text{Experiment}}) )</td>
<td>( E_{t}(\pi_{t+1}) )</td>
<td>0.55</td>
<td>0.55</td>
<td>-0.46</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>( E_{t}(x_{t+1}) )</td>
<td>0.56</td>
<td>0.56</td>
<td>-0.52</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>( \pi_{t} )</td>
<td>0.71</td>
<td>0.69</td>
<td>0.83</td>
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<tr>
<td></td>
<td>( x_{t} )</td>
<td>0.68</td>
<td>0.66</td>
<td>0.83</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>( i_{t} )</td>
<td>0.61</td>
<td>0.61</td>
<td>-0.51</td>
<td>0.83</td>
</tr>
</tbody>
</table>

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 5 sessions.

Table 5: Individual usage of history screen

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Clicks per period</th>
<th>Fraction of time per period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median forecaster</td>
<td>Top forecaster</td>
</tr>
<tr>
<td>Benchmark</td>
<td>2.4</td>
<td>1.9</td>
</tr>
<tr>
<td>High persistence</td>
<td>2.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Aggressive policy</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Communication</td>
<td>1.7</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Notes: Entries are means across periods for sessions in the Benchmark treatment (Repetition 2).
Figure 1: Inflation responses to 113 bps $r^n_t$ impulse

Figure 2: Stabilization of inflation via expectations
Figure 3: Responses of inflation forecasts and errors, Model vs Experiment

A. Ex-ante forecast errors, Model

B. Forecasts, Model

C. Ex-ante forecast errors, Experiment

D. Forecasts, Experiment
Figure 4: Inflation forecasts in experiment

Benchmark treatment, Session 5, Repetition 2