The Information Effect of Monetary Policy

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Abstract

A large empirical literature documents that central bank monetary policy changes signal information about future economic fundamentals to the private sector. The canonical Gali (2008) model is modified to analyze this mechanism and understand the information effect of monetary policy. We assume the central bank observes a private signal of future economic fundamentals and uses the filtered information in its Taylor rule. As a result, the nominal interest rate serves an additional function as a noisy signal of future economic fundamentals and there is an information effect of monetary policy. We find that a contractionary monetary policy induces an expansionary information effect, but for reasonable calibrations, the net effect is contractionary.

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1. Introduction

Most people understand that the central bank raises the interest rate when it deems the economy to be "heating up" too quickly. Sometimes, this belief of the economy's expansion is commonly held between both the central bank and private sector, and an interest rate increase does not qualify as a monetary policy shock. Other times, however, the private sector is caught completely off guard by a central bank interest rate increase.

In these instances, and given the understood relationship between interest rates and the state of the economy, logic dictates that private sector agents should be able to infer that the central bank must believe that the economy is expanding at an undesirably high rate. Since the interest rate increase is unexpected, it must also be the case that the private sector did not believe that the economy is expanding at a rate to warrant such an increase. There is a difference in beliefs, which may stem from different information or different interpretations of the same information.

When there is a difference in beliefs between the central bank and the private sector, the effect of increasing interest rates is twofold. On the one hand, the traditionally held view is that an increase in the interest rate is contractionary. Intuitively, increasing the interest rate makes borrowing more expensive and saving more attractive. On the other hand, consumers and firms in the economy make their decisions taking into account the entire expected path of the economy's underlying fundamentals. Since they can infer that a surprise increase in the interest rate must be because the underlying economic fundamentals are in better shape than they initially believed, an increase in interest rates is a positive signal about economic fundamentals, which might induce an expansionary effect.

For example, suppose a household is considering leasing a car and then the central bank announces a higher interest rate. The direct cost of purchasing the car has increased, which is in the intended contractionary effect. At the same time, the household may now be more optimistic about its employment income in the future because it reasons that if the central bank thinks the economy is in good shape, then the household's employer is likely to remain open for business. This information effect is expansionary as it makes the car purchase more likely.

It is easy to imagine many scenarios where these partially offsetting effects are relevant. Naturally, it must be the case that, overall, the direct effect is dominant, or otherwise monetary policy would be not only ineffective but consistently working against its intended purpose. Rather, it is likely the case that monetary policy efficacy is dampened by the information effect, but a contractionary monetary policy shock has a net contractionary effect on the economy.

The strength of the information effect is directly related to how confident the private sector is that the central bank will not deviate from the (commonly known) policy reaction function. For example, suppose that the private sector is very confident that the central bank will respond to 3% inflation by raising the interest rate by 1%. If both the central bank and the private sector observe 3% inflation but the central bank raises the interest rate by 5%, then it must be the case that there is some other informational difference that spurred the unexpected nominal interest rate increase. If, however, the private sector is not sure how the central bank will respond to 3% inflation, then consumers and firms will prescribe some of the 5% increase to informational differences, but it may well be that the central bank simply has a strong response to inflation.

The relative strength of the information effect is also related to how confident the private sector is that it holds the same beliefs as the central bank. When the private sector is confident that its beliefs about economic fundamentals are aligned with the central bank, then a change in the interest rate will be attributed mostly to a temporary deviation from standard operating procedure (i.e. a pure monetary policy shock) versus a difference in information. Alternatively, if the private sector is unsure about economic fundamentals or is unsure about how to interpret a new piece of information (for example, a new statistical release), then a change in the interest rate will be attributed primarily to a difference in information sets, and the private sector will update its information accordingly.

This paper formalizes this intuition in a standard macroeconomic model and isolates the direct and information effects of monetary policy. The central bank observes a private signal about future economic fundamentals and incorporates the Kalman-filtered information into the nominal interest rate via a standard forward-looking Taylor rule. The nominal interest rate thus serves two purposes to the private sector. First, the interest rate retains its standard role as the cost of intertemporal substitution. Second, as described above, the nominal interest serves as a noisy signal of underlying fundamentals. The private sector also uses a Kalman filter to obtain estimates of the news and monetary policy shocks. The relative strength of the two effects is parameterized by the noise-to-signal ratios that are standard in Kalman filtering problems.

We show that, as expected, the information effect of a contractionary monetary policy is expansionary. However, for reasonable parameterizations, the net effect of a contractionary monetary policy is to contract the economy, though by less than if there were no information effect. Importantly, the model emphasizes that the central bank need not have superior information than the private sector. It is sufficient for the central bank to have different information, and for the private sector to use the nominal interest rate as a signal. The central bank may have different but inferior information if it receives a purely noisy signal, but the central bank cannot ex ante determine the accuracy of the signal. Thus any signal is fed into the nominal interest rate in the same way, and it is up to the private sector's filtering process to assign probabilities that the signal was news or noise.

An important assumption we maintain is that the central bank observes a private signal and therefore inherently has a different information set than the private sector. We interpret this as the Fed employing an army of economists whose job it is to analyze incoming information and form a forecast for the economy. Though the private sector freely has access to the same statistical releases and financial market data, it is clear that the average consumer or firm does not invest the effort required to convert these data to a signal about the future state of the economy. We will discuss this assumption at length in section 3.

Our paper builds on the very large empirical literature that studies differences in information between the central bank and private sector. Romer and Romer (2000) were among the first to provide evidence that the Federal Reserve was an ex post superior forecaster than private sector forecasters, implying an informational advantage. However, over a similar timeframe, Faust et al. (2004) provided evidence against this claim using a different set of private sector forecasters. Later, D'Agostino and Whelan (2008), N.Gamber and K.Smith (2009), and Champagne et al. (2018), among others, showed that although central banks may have been better forecasters in the mid- to late-20th century, central bank and private forecasts perform fairly equally.

Part of this can be attributed to less volatility in macroeconomic aggregates due to the adoption of inflation targeting and more stringent monetary policy frameworks. At the same time, a large part of this convergence to common forecasts can be attributed to increased central bank communication. Binder (2018) studies how much attention the media pays to the Federal Reserve and shows that the share of media stories related to monetary policy has increased over time and spikes around congressional testimony and, relevant to this paper, monetary policy announcements.

Instead of emphasizing the superiority of central bank forecasts, a more recent literature has focused on differences in information sets and whether private sector beliefs are influenced by the central bank. Postponing a detailed analysis of the evidence in the next section, the primary takeaway is that the private sector appears to at least partially treat monetary policy announcements as signals about underlying economic fundamentals. Thus when the central bank raises interest rates, not only is there the standard intended contractionary effect, but also an unintended informational effect that is robust across countries, samples, and estimation techniques.

Of course, information effects of monetary policy are only unintended in normal times. In times of unconventional monetary policy, Eggertsson and Woodford (2003) detail why these information effects are of primal importance, and a large literature documents the information effect of forward guidance (see, for example, Campbell et al. (2012) and Campbell et al. (2016)). In particular, central banks may use "Delphic" forward guidance to explicitly attempt in shaping private sector expectations about future economic fundamentals. In this paper, we are concerned with the implicit influence of central bank decisions on private sector beliefs, though the mechanism is the same.

Taking the empirical literature as given, we contribute to the theoretical literature by incorporating an informational effect of monetary policy into an otherwise standard macroeconomic model. Gilchrist and Zhao (2015) was the first paper to explicitly model agents using the nominal interest rate as a noisy signal in a standard Kalman filtering problem. The focus in that paper is on the information effect of monetary policy on asset prices, whereas we focus on the information effect on macroeconomic aggregates like output and inflation. **?** builds a dynamic general equilibrium model where only firms use the information content of interest rate announcements to learn about the future. In his model, there are informational differences between the central bank, firms, and consumers. In our model, the only informational differences are those between the central bank and private sector, and we focus on how this difference is important in general equilibrium.

Tang (2015) builds a model where agents are uncertain about the endogenous contemporaneous variables in the economy. This can arise in an "islands" economy where agents face idiosyncratic shocks and are thus unaware of contemporaneous aggregate variables. In our setup, agents share contemporaneous beliefs[1] but differ in their beliefs of the future state of the economy. Since agents and firms both face dynamic decisions, these differences are relevant and have economic significance both in future periods and in the current period's decisions.

The remainder of this paper is structured as follows. Section 2 details the empirical evidence regarding the influence of central bank actions on private sector expectations. Section 3 details the information sets of agents in the economy and how expectations are formed, and section 4 embeds those expectations into a standard New Keynesian model and studies the effects of a monetary policy shock. Section 5 concludes and discusses avenues for future research.

2. Empirical Evidence

A large empirical literature details the information content of central bank announcements. In this section, I review the key strands of the literature and highlight the empirical facts that motivate the analysis undertaken in this paper. The literature shows that when the central bank makes an an-

[1] To be clear, the central bank and private sector perfectly observe aggregate variables like output and inflation, as well as the exogenous stochastic process for TFP. The central bank, however, observes a private signal and the monetary policy shock, whereas the private sector only observes the nominal interest rate and must form beliefs of the signal and monetary policy shock.

nouncement, some information is conveyed to the private sector, and the private sector responds by updating their beliefs of variables that are driven by economic fundamentals. Broadly speaking, from this we can infer that private sector expectations are formed using monetary policy announcements as noisy signals of underlying economic fundamentals.

The primary feature of the first set of papers we review is that they use survey data to measure forecasts of macroeconomic fundamentals and use these data to study the information content of monetary policy announcements. However, the relatively low frequency of surveys poses significant identification problems which we discuss below. The second and recently more popular strand of the literature uses uses high frequency stock market data to analyze price changes immediately before and after monetary policy announcements. Reassuringly, the two different approaches appear to present a consensus set of stylized facts.

2.1 Survey Data

Broadly speaking, the approach with survey data is to measure changes in expectations of future economic variables, like inflation or GDP, before and after a central bank's announcement. Though the intuition is clear, the primary issue with this approach is that because the survey data is usually low frequency (i.e. monthly or quarterly), there are large identification challenges. Suppose, for example, that private forecasts of GDP are made on the first day of each month, and the central bank makes a monetary policy announcement on the 15th day of each month. Consider a scenario where in some month, on the 7th day, an all-knowing being credibly and publicly announces that GDP will decrease significantly. In response, the central bank will respond on the 15th, as will the private sector when it next makes a forecast. However, if we do not control for the fact that the all-knowing being made an announcement, then the subsequent change in the private forecast will be fully attributed to the action by the central bank.

In reality, there are a multitude of factors that can fill in for the all-knowing being. Between private sector forecasts, a plethora of data releases are published by relevant statistical organizations. Further, each individual forecaster may interpret these public data releases differently, and it may be the case that different forecasters use different and non-mutually exclusive data sources. The literature is well aware of this identification challenge and attempts to control for new information released between private sector forecasts, but because of the difficulty in this task, it is safest to interpret the evidence in this part of the literature as upper bounds on the information effects of monetary policy announcements.

Hubert (2015) examines central bank and private survey inflation forecasts in Sweden, the United Kingdom, Canada, Switzerland, and Japan. These countries are chosen because their central banks publish inflation forecasts in realtime, and often concurrently with monetary policy announcements. The author regresses revisions in private forecasts on revisions in central bank forecasts in each country and finds a positive correlation, indicating that private sector forecasts tend to be updated in the same direction as central bank forecasts. He also shows that there is no evidence that the private sector's forecasts influence those of the central bank.

Hubert lists three reasons for why the private sector might be influenced by central bank forecasts. First, central bank forecasts may be historically more accurate (in real-time) and thus private sectors will optimally use them to refine their own forecasts. Second, and as noted above as a crucial ingredient in our model, the information set of the central bank may be different than that of the private sector, leading private sectors to update their own information sets. Third, it may be the case that since the central bank has relatively more control of the object being forecast than the private sector, the private sector can learn something about the central bank's policy objectives and update their forecasts accordingly.[2]

Stopping short of taking a firm stance on which hypothesis may be correct, Hubert shows that except for in Sweden, there is little evidence over the entire sample that the central bank is a superior forecaster than the private sector. Although the first hypothesis may still be true if forecasters simply believe the central bank is a better forecaster, it is more likely that the other hypotheses are more important in understanding why the private sector follows the central bank's lead with respect to forecast revisions.

Nakamura and Steinsson (2018) focus on the US and analyze changes in private forecasts of inflation and GDP in response to monetary policy surprises. They construct a series of monetary policy using principal components of five short-term interest rates, allowing them to include the period after 2008 during which the Federal Funds Rate was at the effective lower bound. This approach is more general because the central bank may have unexpectedly changed the interest rate while keeping its inflation forecast the same. This monetary policy surprise may induce private agents to adjust their forecasts, but would be captured in the analysis above as the private sector spuriously adjusting their forecasts, and dilute the results.

Their primary findings are that a 25 bps monetary policy shock induces a 25 bps increase in both expected inflation and expected output growth. This approach is still subject to a difficult identification challenge since the private sector forecasts are again constructed using lower frequency survey data, and therefore this fairly large effect should again be interpreted as an upper bound.

[2]In an extreme example, suppose that all economic indicators and past central bank forecasts point to 2% inflation and then the central bank suddenly forecasts 10% inflation (and provides no other information nor explanation). The private sector may then infer a radical policy change and update its beliefs because it believes that going forward, the central bank has a 10% inflation target and will achieve it.

2.2 Stock Market Data

The benefit of using stock market data is that it is easy to isolate changes immediately around a monetary policy announcement. By using a sufficiently tight window around an announcement, one can plausibly claim that the only thing that affected stock prices in that window was the announcement itself, and therefore the effect of the monetary policy announcement is identified. The drawback with this approach is that the relationship between monetary policy announcements and stock price movements is not immediately obvious and thus the interpretation of the effect depends on how one believes the economy works.

Jarocinski and Karadi (2018) use a structural VAR approach with a sign restriction to identify information versus direct effects of monetary policy surprises in the USA and Eurozone. In particular, they argue that the direct effect of a positive monetary policy surprise depresses stock prices while the information effect raises stock prices. The direct effect is to depress stock prices because as the interest rate rises, the net present value of a stock's dividend stream decreases, and therefore so should the price. On the other hand, positive news about the future will increase beliefs of future dividends, increasing the stock price. Thus if stock prices rise after the central bank increases rates, it must be the case that the information effect dominated the direct effect.

They further show that in the months following a monetary policy shock, the economy behaves very differently depending on whether the monetary shock produced a dominant direct or information effect. The behavior of the economy after a dominant direct effect is exactly as predicted by standard models, but after a dominant information effect, the economy tends to experience increased inflation and real activity. In most cases, the central bank will have induced a positive monetary policy surprise exactly to counter increased inflation and real activity, so this outcome is highly undesirable.

Cieslak and Schrimpf (2018) extend this analysis by using additional information from the entire yield curve to further separate a monetary policy surprise into a direct effect, information effect, and risk premium effect. They build a structural state-of-the-art macrofinance model and use its predictions as identifying restrictions in a structural VAR. This paper analyzes central banks in the USA, Eurozone, England, and Japan, and broadly finds that the non-direct effects of monetary policy dominate more than half of all studied events.

2.3 Summary of Key Empirical Facts

In short, the empirical evidence from the two different strands of literature appears to agree on two broad facts:

1. Private sector forecasts of future economic variables are influenced by and converge towards central bank forecasts.
2. Positive monetary policy surprises contain both a direct contractionary effect and an indirect expansionary information effect.

3. Central Bank and Private Sector Beliefs

In this section, we focus on beliefs of the exogenous variables. First, we examine how the central bank's beliefs of future TFP are affected by the signals it receives. The dynamic model we use is irrelevant for the central bank's signal extraction problem. However, the dynamic model becomes relevant for the private sector's signal extraction problem because it is the means by which the central bank's extracted signal is converted into a nominal interest rate decision. This nominal interest rate signal is in turn used by the private sector to inform their beliefs of exogenous variables. In the penultimate section of this paper, we show how these beliefs of exogenous variables matter for the endogenous dynamics.

3.1 Central Bank Signal Extraction

The signal observed by the central bank has a news and a noise component:

$$s_t = \epsilon^a_{t+1} + \epsilon^s_t.$$

We interpret this signal as, for example, a statistical release by the government's statistical bureau. We take the Romer and Romer (2000) stance that this signal is in fact observable by everyone in the economy but the central bank is one of the few entities that devotes significant resources to converting this signal into a useable forecast. Though we forego microfounding this part of the model, consider a simple "forecast production function" whereby the signal is combined with labour to produce a useable forecast. Suppose that as labour increases, the variance of the signal decreases, and when labour is zero, the variance of the signal is infinite. It is reasonable to assume that the central bank exerts significant to labour to producing forecasts, while households and firms exert relatively little effort since, for the most part, doing so is costly with only marginal benefit. With so little effort, it is as-if households and firms observe a very noisy signal, and at the extreme, it is as-if they do not observe the signal at all.

Since both the news and noise processes are white noise, the optimal Kalman gain for each is trivial to derive and depends solely on the ratio of the variances:

$$K_a^M = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_s^2}$$
$$K_s^M = \frac{\sigma_s^2}{\sigma_a^2 + \sigma_s^2}.$$

These two values sum to unity and can be interpreted as weights. The larger is the variance of each underlying process, the more weight will be attributed to that process by the optimal Kalman gain. This is somewhat counter-intuitive because it means that the relatively "noisier" process has a larger weight. The correct interpretation hinges on the fact that upon observing a higher value of s_t, there is a larger probability that the higher value came from the process with a larger value. Therefore, more weight should be attributed to the process with the larger variance.

Given these weights, the central bank's beliefs of the TFP shock, ϵ_{t+1}^a, is given by:

$$E_t^M \epsilon_{t+1}^a = K_a^M s_t,$$

and therefore belief of tomorrow's TFP is given by:

$$E_t^M a_{t+1} = \rho_a a_t + K_a^M s_t.$$

The relevant parameter for a Kalman signal extraction problem is the ratio of the underlying processes variances, defined generally as

$$\rho_{ij} = \frac{\sigma_i}{\sigma_j}.$$

In the central bank's signal extraction, this ratio, ρ_{as}, is between the variance of the TFP process and the variance of the white noise process. For illustrative purposes, we consider three different possibilities: a high ratio, a middle ratio, and a low ratio. We keep σ_a the same and vary σ_s. We also make the sizes of the shocks equal: one unit news shock and one unit noise shock.

In Figure 1, the central bank observes a signal at time 0, triggered by either a one unit news or noise shock. The figure plots the true TFP process from time 1 onward. In the event of a news shock, the TFP process is equal to unity at time 1 and converges towards zero. In a standard macroeconomic model where the news shock is perfectly observed, the expectation at time zero of future TFP is equal to actual future TFP; in other words, the forecast error is zero for every future period. In our model, however, the central bank cannot perfectly decipher whether the observed signal is because of news or noise, and therefore only partially attributes the signal to a news shock. The three dashed lines represent the three cases for the ratio of the news to noise, ρ_{as}. Each line plots the time-zero expectation of future TFP levels, i.e. $E_t a_{t+i}$. In a standard model, $E_t a_{t+i} = a_{t+i}$ after an initial (and no other) shocks, whereas in our model, this equality does not hold in general. As the news-to-noise ratio decreases, the central bank attributes weight to the news shock, and the forecast error increases.

A one unit noise shock generates the exact same path of beliefs. The difference is that the technology process remains flat at zero. When the news-to-noise ratio is high, this induces a large forecast error, because the central bank attributes much of the signal to a news shock when in fact it is purely noise. Note that in our case, when the news to noise ratio is 10 and the standard deviation of the news shock is held constant at unity, the standard deviation of the noise shock must be 0.1. A one-unit shock is therefore a 10-standard-deviation event and is extremely unlikely, so the central bank attributes most of the weight to a news shock.

3.2 Private Sector Signal Extraction

The private sector does not directly observe the signal, s_t, but knows that the central bank incorporates the signal into its policy rule. Generalizing the Taylor rule presented above, the central bank sets the nominal interest rate according to:

$$i_t = F(i_{t-1}, \hat{y}_t, \dots) + G(s_t) + \nu_t,$$

where $F(\cdot)$ is the central bank's response to the endogenous variables in the economy, $G(s_t)$ is how the central bank incorporates the signal, and ν_t is the monetary policy shock. The private sector knows $F(\cdot)$ and observes the endogenous variables that feed into it. However, the private sector does not individually observe $G(s_t)$ nor ν_t, and therefore observes the nominal interest rate as a noisy signal:

$$i_t = F(i_{t-1}, \hat{y}_t, \dots) + H(s_t, \nu_t).$$

Since both i_t and $F(\cdot)$ are observed, the general signal can be defined as:

$$z_t = i_t - F(\cdot) = H(s_t, \nu_t). \tag{1}$$

The private sector's signal extraction problem is to use z_t to form a belief about the underlying components of $H(s_t, \nu_t)$, with the primary goal of forming a belief for the news component of s_t. When the monetary policy shock has an autoregressive component, i.e. $|\rho_\nu| > 0$, it also becomes important for the private sector to form a belief for the current monetary policy shock.

4. Model

4.1 Benchmark Model

In the benchmark model, firms and households do not use the nominal interest rate to infer the central bank's private TFP signal. The model is a standard three-equation New Keynesian DSGE model whose derivation is well documented elsewhere. The key equations are the dynamic IS curve and the Phillips curve:

$$\tilde{y}_t = E_t^{\hat{P}} \tilde{y}_{t+1} - \sigma^{-1}(i_t - E_t^{\hat{P}} \pi_{t+1} - r_t^n)$$
$$\pi_t = \beta E_t^{\hat{P}} \pi_{t+1} + \kappa \tilde{y}_t.$$

The Taylor rule is given by:

$$i_t = \bar{r} + \rho_i i_{t-1} + (1 - \rho_i)(\phi_\pi E_t^M \pi_{t+1} + \phi_y \hat{y}_t) + \nu_t,$$

where $\nu_t = \rho_\nu \nu_{t-1} + \epsilon_t^\nu$ is the monetary policy shock process. Agents can perfectly observe the history of nominal rates and contemporaneous endogenous variables and they also know the structural parameters of the economy, including those in the Taylor rule. This expression implicitly assumes that agents in the economy can individually stratify the monetary policy shock from changes in the other components in the Taylor rule.

The expectation operators are defined with respect to the information sets available to the private sector and to the central bank, namely,

$$E_t^{\hat{P}} \pi_{t+1} = E_t[\pi_{t+1} | \mathcal{I}_t^{\hat{P}}],$$
$$E_t^M \pi_{t+1} = E_t[\pi_{t+1} | \mathcal{I}_t^M].$$

The central bank's information set, $\mathcal{I}_t^M$, contains the entire history of all stochastic processes and, by extension, all endogenous processes. The private sector's information set is the same except that it excludes the central bank's private signal: $\mathcal{I}_t^{\hat{P}} = \mathcal{I}_t^M \setminus \{s_t\}$.

We highlight that the expectation for inflation in the Taylor rule is different than in the dynamic IS and Phillips curves. In the Taylor rule, the central bank forms its belief of inflation using the additional information from the private signal it observes. As we will show in the model with learning, the household and firm should be able to infer from the nominal interest rate something about the signal since they know how the expectation is formed, but in the benchmark model no such effect is present.

4.2 Learning Model

We now allow for agents to learn from the central bank's nominal interest rate announcement. Specifically, agents now use the nominal interest rate in two ways. First, and as before, the nominal interest rate feeds directly into the dynamic IS curve and serves as an important determinant in intertemporal substitution. Second, and new to the learning model, agents use the nominal interest rate as a noisy signal of future TFP. They can do so because they know that the central bank received a signal of future TFP, and that the central bank incorporates its TFP signal into the nominal interest rate. We assume that the agents know the exact structure of the Taylor rule, the signal, and the central bank's learning parameters (ie. K^M).

The dynamic IS curve and Phillips curve are now given by:

$$\tilde{y}_t = E_t^P \tilde{y}_{t+1} - \sigma^{-1}(i_t - E_t^P \pi_{t+1} - r_t^n)$$
$$\pi_t = \beta E_t^P \pi_{t+1} + \kappa \tilde{y}_t,$$

where $E_t^P \pi_{t+1} = E_t[\pi_{t+1} | \mathcal{I}_t^P]$ are the expectations used by consumers and firms.[3] The Taylor rule is still given by:

$$i_t = \bar{r} + \rho_i i_{t-1} + (1 - \rho_i)(\phi_\pi E_t^M \pi_{t+1} + \phi_y \hat{y}_t) + \nu_t,$$

where ν_t is the same monetary policy shock process defined above. Defining z_t as the nominal interest rate signal, the key difference between the model with learning and the benchmark model is that $z_t \in \mathcal{I}_t^P$ only in the model with learning. Further, $\nu_t \notin \mathcal{I}_t^P$ because the private sector observes only the nominal interest rate, i_t, and the endogenous output gap and inflation, and thus cannot separate the signal from the monetary policy shock.

Crucially, the central bank continues not to internalize that its announcements have an information effect. This is an important assumption because, as noted in the empirical review, it appears that only recently (relative to the entire history of monetary policy operation) has the central bank noted that the information it reveals is of first order importance. If we were to allow the central bank to internalize the information effect of its announcements, then we would by construction eliminate the offsetting contractionary direct and expansionary information effects. In essence, the central bank would be able to manipulate private sector beliefs to achieve its intended policy. While an interesting approach and one that is potentially more relevant today than in the past, the focus on this paper is to focus on the unintended effects of the information effect.

4.2.1 Beliefs in the Learning Model

As detailed in the appendix, the central bank's expectation of future inflation can be reduced to a function of the economy's exogenous disturbances, and

[3]The superscript P denotes beliefs used by the private sector, in contrast to the beliefs used by the central bank or monetary authority, denoted by superscript M.

the Taylor rule can be expressed as:

$$i_t = \bar{r} + (1-\rho_i)\phi_y \hat{y}_t + G_{ii} i_{t-1} + G_{ia} a_t + G_{i\nu} \nu_t + G_{is} s_t.$$

It is important to note that in this expression, the signal s_t comes from the central bank's belief of inflation, but is not observed individually by the agent. As above, agents observe the history of nominal returns, the contemporaneous endogenous variables, and the structural parameters of the economy. However, since the agent does not individually observe s_t, the agent cannot fully disentangle the monetary policy shock, ν_t, either. Recalling the general form of the signal in (1), the signal in this model is defined as:

$$z_t = i_t - \underbrace{(\bar{r} + (1-\rho_i)\phi_y \hat{y}_t + G_{ii} i_{t-1} + G_{ia} a_t)}_{F} = \underbrace{G_{i\nu} \nu_t + G_{is} s_t}_{G}.$$

Agents only observe z_t, and must infer which portion is the monetary policy shock and which is the central bank's signal, s_t. They must then infer which part of the signal was noise and which part is news, namely the TFP component, ϵ^a_{t+1}. In this sense, agents in the economy face a "double signal extraction" problem. Even if the central bank does not observe a signal and is subject only to a monetary policy shock, the private sector will always associate some positive probability to the signal. Similarly, if there is no monetary policy shock and only a news or noise shock, the private sector will associate some positive probability to a monetary policy shock.

This is the primary objective of the mechanism and speaks to the core of this paper: consumers in the economy observe the central bank's actions and must determine whether the central bank has different information or if they are simply making an unexpected deviation from standard operating procedure. In the model, different information manifests itself as the signal, whereas an unexpected deviation from standard operating procedure is the monetary policy shock.

In reality, an unexpected deviation from standard operating procedure can arise for many reasons. For example, it may be the case that the central bank becomes temporarily more sensitive to news on inflation, which in the model implies a higher value for ϕ_π than the agents believe. In this example, this unexpected deviation from ϕ_π manifests as a monetary policy shock, and it is therefore not very restrictive to assume that agents know what the policy parameters are.

The expressions for the private sector's Kalman filter are more difficult to derive and closed form expressions exist only when the monetary policy shock is a noise process. In any case, the private sector forms expectations using the weights K_a^P, K_ν^P, and K_s^P, where, in a slight deviation of notation, K_a^P refers to the news component of the signal and K_s^P refers only to the noise component of the signal. Using these weights, the private sector's beliefs of the future TFP process are thus given by:

$$E_t^P a_{t+1} = \rho_a a_t + K_a^P z_t.$$

As a result of the double signal extraction, the private sector's Kalman weights K^P will be functions of the central bank's weights K^M, and the private sector is affected by changes in the structure of the central bank's signal, even though they never directly observe it.

To understand the effects of a news/noise shock or a monetary policy shock, we need to understand both parts of the "double" signal extraction problem: first, how the central bank's signal feeds into the nominal interest rate, and second, how nominal interest rate signal is filtered into a monetary policy, news, or noise shock.

Recall that the central bank's belief of future inflation is constructed from the benchmark model with no learning by the private sector. The central bank simply looks forward one period and calculates what will happen to inflation given its beliefs about the shocks in that period. Given any positive signal in the current period, the central bank's belief of a positive news shock (i.e., a positive TFP shock in the next period) is strictly positive. It is well known that in the standard Gali (2008) model we use, a positive TFP shock lowers inflation. Thus, anticipating that in one period TFP will be higher, the central bank calculates that future inflation will be lower. As a result, $E_t^M \pi_{t+1}$ is decreasing in the signal, and so is the nominal interest rate.

Altogether, a positive signal observed by the central bank induces a larger belief of future inflation, which in turn leads to a smaller nominal interest rate. In the second part of the signal extraction problem, the private sector knows that this smaller nominal rate can be the result of a positive news shock, a positive noise shock, or a negative monetary policy shock. The private sector uses the Kalman fitler and therefore assigns a positive probability to all three shocks, again weighted by the relative variances.

Figure 2 illustrates the effect of a positive one unit news/noise shock when $\rho_{as} = 100$ and $\rho_{a\nu} = 1$. The effect on future expectations is the same for news or noise since both imply a one unit positive signal shock, which in turn generates a negative nominal interest rate signal. With a noise shock, actual TFP remains flat, whereas a news shock implies a positive future TFP shock. The upper panel shows that the effect of a news shock is significantly dampened, implying a small, positive, and persistent difference between realized and forecast TFP. With a noise shock, this forecast error is small, negative, and persistent. In both cases, we see in the lower panel that the overwhelming majority of the change in the nominal interest rate is perceived as a negative monetary policy shock.

Figure 3 shows the effect of a positive one unit monetary policy shock which generates a positive nominal interest rate signal. In the lower panel, we see that the private sector correctly attributes only a fraction of the interest rate signal to a monetary policy shock. The rest is divided between the news and noise, and, as described above, a positive interest rate signal generates a negative belief of the news/noise. In fact, in the upper panel, we see that the monetary policy shock induces a larger change in TFP beliefs than did a news/noise shock. This is because of the "double" filtering of the news/noise shock, whereas the monetary policy shock has a more direct effect on the nominal interest rate.

5. Macroeconomic Effects of Learning

In this section we analyze the dynamic properties of the endogenous variables in the model. We have shown above that any single exogenous shock, whether it be monetary policy, noise, news, will be filtered through the private sector's signal extraction problem and perceived as a combination of all three shocks. Once the signal is filtered into the three shocks, the analysis of the full dynamic model is exactly as if the model were full-information and subject to those three shocks. Thus with the heavy lifting of belief formation out of the way, analyzing the effects of learning in general equilibrium is straightforward.

As in a standard NK DSGE model, a positive news shock is contractionary. Though this is counter to one of the main motivations of our analysis, and a clear shortcoming of this modeling technique, the mechanism we are interested in studying is still relevant. In particular, a positive interest rate signal is perceived by the household as the combination of two shocks: a contractionary (positive) monetary policy shock and an expansionary (negative) news/noise shock. In the benchmark model, only the "direct" monetary policy shock channel is active. In the learning model, both the direct and "information" effects are active and work against each other. The net effect will depend on the strength of the information signal, which we have demonstrated depends on the ratio of the underlying processes' variances.

Figure 4 illustrates the effects of a unit contractionary (positive) monetary policy shock that raises the nominal interest rate. Table 1 outlines the calibration of model parameters, and we generally follow the benchmark calibration in chapter 3 of Gali (2008). In the benchmark model, this contractionary shock lowers inflation and widens the output gap, as in any standard New Keynesian DSGE model. For our benchmark calibration of the learning model, the overall effect of the contractionary monetary policy shock is also to lower inflation and widen the output gap, but both inflation and the output gap are larger than they are in the benchmark model. The expansionary information effect works against the contractionary direct effect, but not to an extent such that the overall effect of a contractionary shock is net expansionary.

5.1 Discussion of Results

For reasonable calibrations of the model's parameters, we find that the overall effect of a contractionary monetary policy is always contractionary, but less so under learning than in the benchmark model. This is likely consistent with the relative importance of the direct and informational effects of monetary policy in the real world. In particular, it is generally accepted that contractionary monetary policy, i.e. raising the interest rate, is indeed contractionary. However, on certain occasions, and as outlined in the empirical review in section 2, it may be the case that the central bank inadvertently works against itself if the information effect of the interest rate change is large.

We note that for the information effect to be economically relevant, it is important that the monetary policy shock process be at least partially autoregressive. Recall that the private sector knows the structure of the economy, including the autoregressive parameters of all the exogenous processes. If the monetary policy shock process is white noise, then the "true" nature of the signal will be immediately revealed in the next period, and the effect of learning is essentially nil. The more autoregressive is the monetary policy shock process, the stronger is the learning effect, since the private sector will increasingly (and mistakenly) attribute the nominal interest rate signal to the direct and informational effects.

6. Conclusion

Motivated by the empirical evidence, we construct a model in which a contractionary monetary policy shock has both a direct contractionary effect and an indirect expansionary information effect. For reasonable calibrations of the model, and consistent with the observed history of monetary policy efficacy, we find that the net effect of a contractionary monetary policy shock is indeed contractionary, though less so because of the accompanying information effect.

The crucial assumption made in this paper is that the central bank does not internalize its information effect, and therefore there exists an unintended expansionary information effect when the nominal interest rate is unexpectedly increased. We argue that this is consistent with the entire history of monetary policy, but that more recently central banks worldwide have realized that the information they convey is relevant. Most notably, during the Great Recession and subsequent recovery propelled by unconventional monetary policy, central banks employed "Delphic" forward guidance to explicitly change future beliefs of underlying economic fundamentals.

In regular times, central banks may also begin to directly incorporate the information effect of monetary policy announcements into their rationale.

The analysis in this paper shows that if they do not, they face an uphill task in that every contractionary monetary policy shock is paired with an expansionary information shock, and in this sense the central bank is working against itself.

As noted in the introduction, it is likely that the information effect is changing over time, which through the lens of the model implies that the variances of the underlying processes must be changing over time. It has been documented in other strands of literature that indeed TFP and monetary policy shock variances are time-varying, and a natural next step is to estimate this model over time. Though the author has attempted to estimate the model in this paper, the shocks were not identified in the data and the estimation failed. The next step is to further develop the model to make it more amenable for meaningful quantitative exercises.

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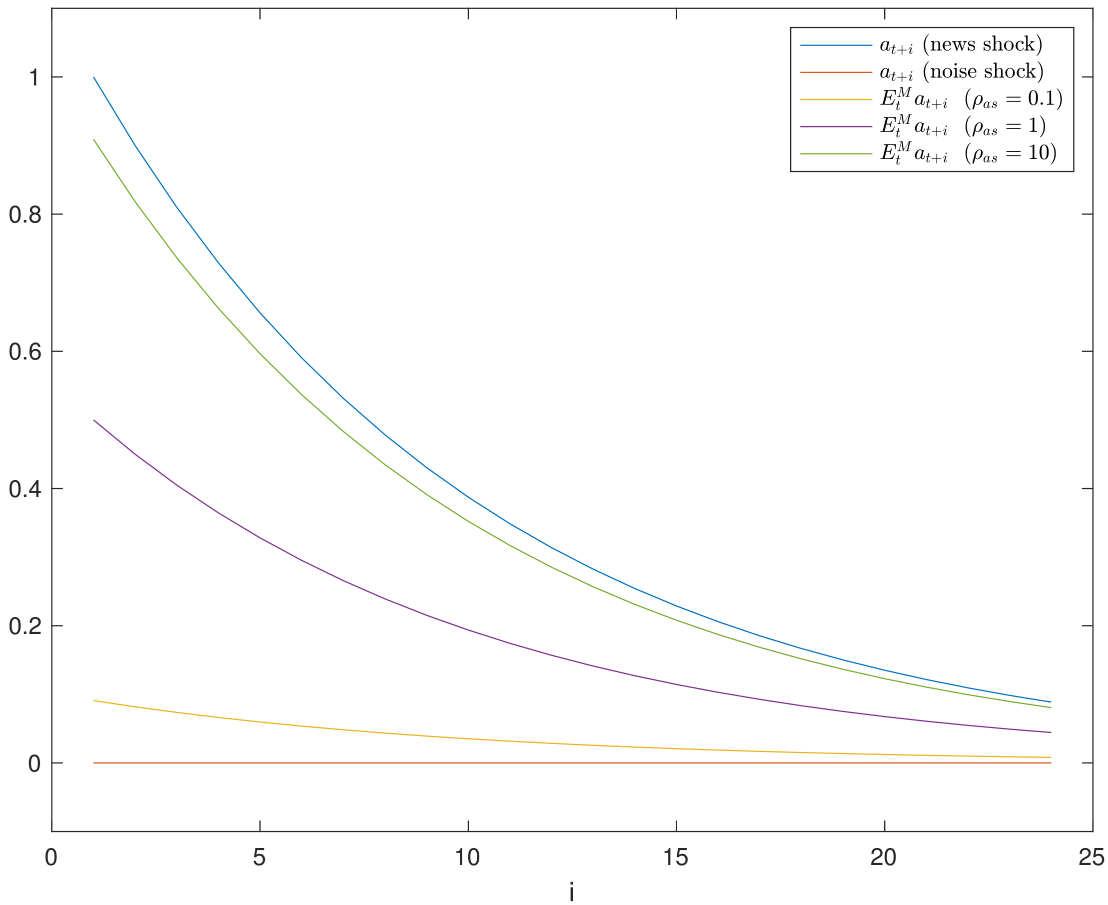
Tables and Figures

Figure 1: Central Bank Beliefs of Exogenous Processes



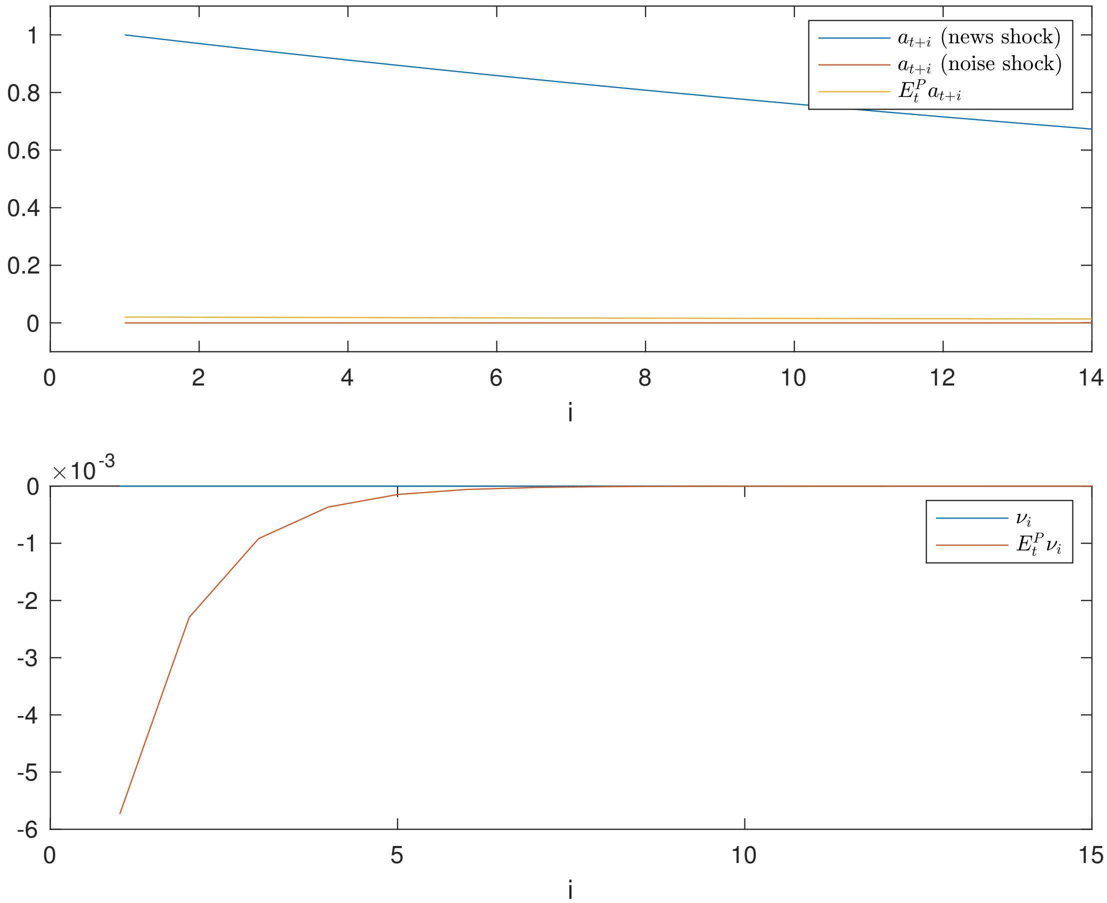
Notes: This figure illustrates central bank beliefs after a one unit positive signal observed at time t generated by either a one unit positive news or noise shock. $E_t^M a_{t+i}$ is the expectation held by the central bank of TFP. The blue line, a_{t+1}, is the actual TFP process after a one unit positive news shock, while the red line is the actual TFP process after a noise shock.

Table 1: Calibrated Parameters

Description	Parameter	Value
Primitives		
Coefficient of Risk Aversion	σ	1.5
Calvo Parameter (Price Stickiness)	θ	$2/3$
Discount Factor	β	0.99
Labour Share in Production	$1-\alpha$	2/3
Elasticity of Substitution B/W Goods	ϵ	6
Taylor Rule		
Interest Rate Smoothing	ρ_i	0.7
Steady State Interest Rate	$\bar{r}$	0
Inflation Response	ϕ_π	1.5
Output Gap Response	ϕ_y	0.125
Exogenous Processes		
TFP Persistence	ρ_a	0.97
Monetary Policy Persistence	ρ_ν	0.4
Ratio of News to Noise Signals	ρ_{as}	10
Ratio of News to MP Signals	$\rho_{a\nu}$	1

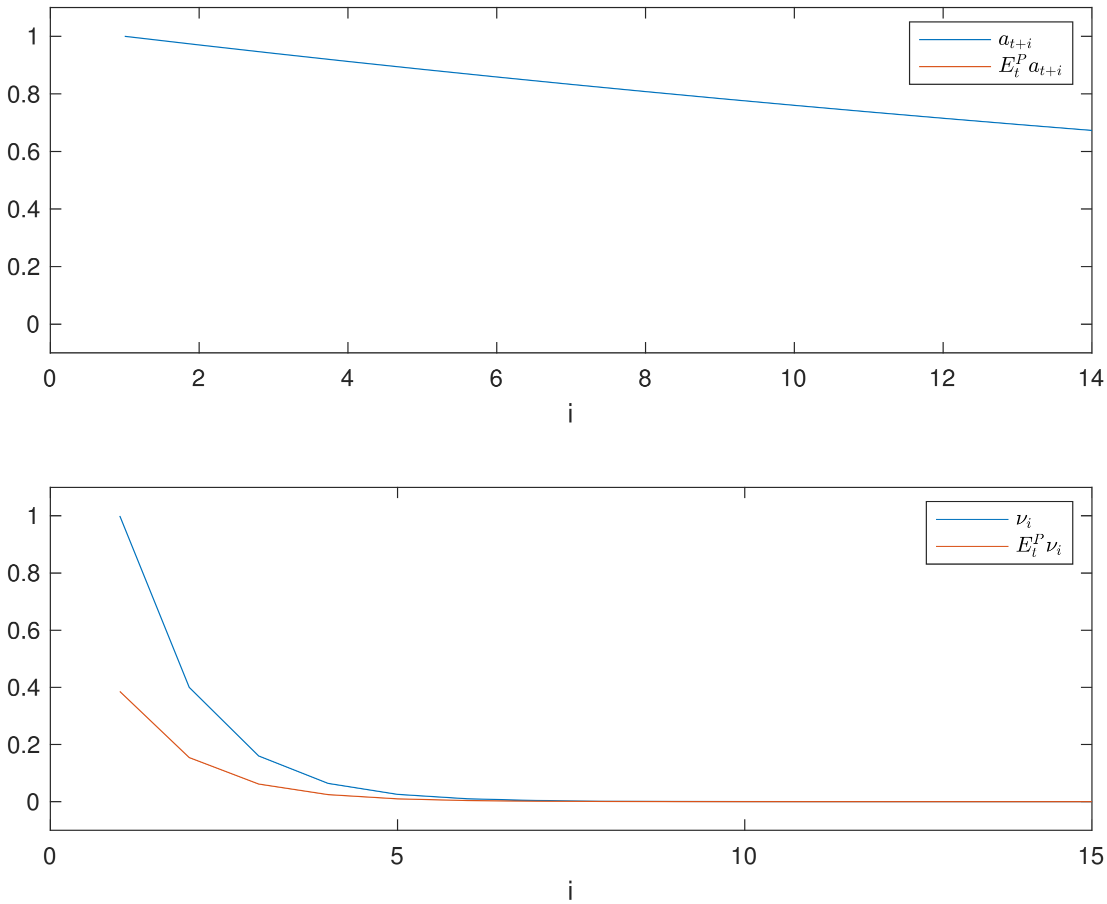
Notes: Most of these parameter values are the same as in Gali (2008). The interest rate smoothing and monetary policy persistence parameters are chosen such that

Figure 2: Private Sector Beliefs of Exogenous Processes After News/Noise Shock



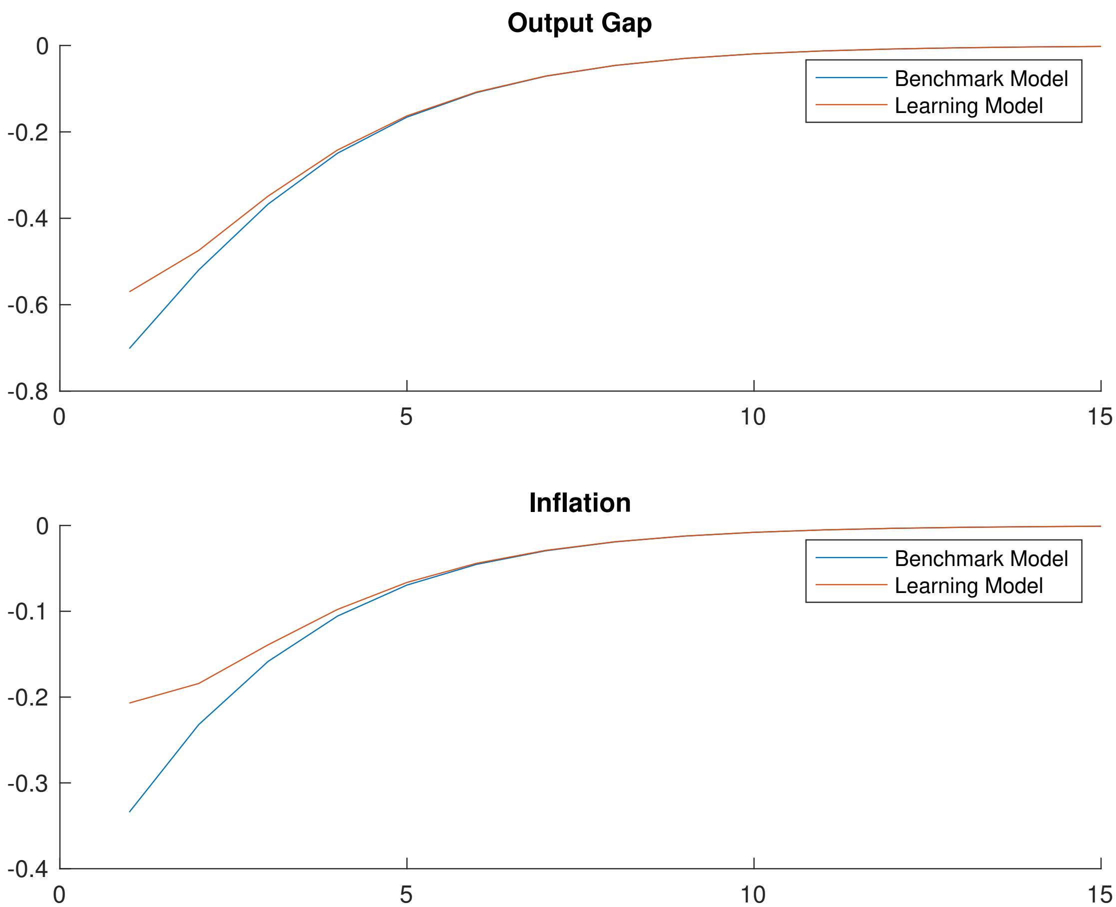
Notes: This figure illustrates the effects on private sector expectations after a one unit positive nominal interest rate signal observed at time t generated by either a one unit positive news or noise shock. In the upper panel, $E_t^P a_{t+i}$ is the expectation held by the private sector of TFP. The blue line, a_{t+1}, is the actual TFP process after a one unit positive news shock, while the red line is the actual TFP process after a noise shock. In the lower panel, $E_t^P \nu_t$ is the belief of the monetary policy process, including the contemporaneous value on impact of the shock, while ν_t is the actual monetary policy process.

Figure 3: Private Sector Beliefs of Exogenous Processes After Monetary Policy Shock



Notes: This figure illustrates the effects on private sector expectations after a one unit positive nominal interest rate signal observed at time t generated by a one unit positive monetary policy shock. In the upper panel, $E_t^P a_{t+i}$ is the expectation held by the private sector of TFP. The blue line, a_{t+1}, is the actual TFP process, and remains flat. In the lower panel, $E_t^P \nu_t$ is the belief of the monetary policy process, including the contemporaneous value on impact of the shock, while ν_t is the actual monetary policy process.

Figure 4: IRFs of Endogenous Variables After Monetary Policy Shock



Notes: This figure shows the response of the economy's primary endogenous variables after a one unit positive monetary policy shock. The model is calibrated primarily following Gali (2008). In the Benchmark Model, the central bank observes a private signal about the future economic fundamental and incorporates this signal into its Taylor Rule. The private sector does not internalize that they can learn about the future economic fundamental from the announced nominal interest rate. In the Learning Model, the private sector "inverts" the nominal interest rate using a Kalman filter and learns about the future economic fundamental.