Noisy Monetary Policy Announcements*

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Abstract

We address two main questions. First, are monetary policy announcements noisy? Second, if yes, what are the effects of policy noise on the economy? The answer to the first question is ''yes." The answer to the second is ''small," except on federal funds rate expectations. The results are obtained by estimating with US data a VAR model where monetary policy noise is identified using dynamic rotations. Finally, we show that announcements about future tightening are mainly interpreted as Delphic over our sample.

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1 Introduction

The press pays close attention to the words of every member of the Federal Open Market Committee (FOMC) and, above all, to the words of the Federal Reserve's Chairman. Over the past decades, communicating its future intentions via post-meeting statements or speeches has become a key monetary policy tool of the Federal Reserve. Such communications are known as "forward guidance."

By using forward guidance in their policy announcements, the Federal Reserve communicates its future policy intentions. Agents, then, look at these announcements which reveal new information ("news") about the future path of interest rates and adjust their policy rate expectations accordingly. However, monetary policy announcements may be noisy as the central bank faces two main communication challenges: First, communication about future monetary policy by the central bank could be unclear; e.g., there could be ambiguity in words, sentences, or paragraphs. Second, agents may interpret the announcement from the central bank incorrectly due to their preconceived notions about the central bank's biases based on its track record, i.e., central bank credibility. As time passes, agents learn how noisy an announcement about future policy was by looking at the realized policy rate.

In this paper we introduce an empirical model allowing for imperfect central bank communication. We shed light on the following questions: How do we identify noise in monetary policy? How noisy are announcements about future monetary policy decisions? What are the economic and financial effects of noise shocks? In particular, we expand the noisy information setting as in Forni et al. (2017a) to monetary policy. We provide a unified empirical framework that can identify the noise component of announcements and study the effects of noisy communication. To reveal the announcement, we use measures of federal (fed) funds rate expectations.[1]

The theoretical and empirical literature assessing the effects of forward guidance has largely abstracted from noise. By doing so, one assumes that the expectations about future policy actions always materialize and, thus, one potentially ignores the communication challenges inherent to monetary policy. One notable exception is the recent paper by Campbell et al. (2019) which introduces a theoretical model of imperfect central bank communication and shows that poor communications have been a source of macroeconomic volatility. Our paper differs by introducing an empirical model which identifies noise shocks in monetary policy. This allows us to study the role of imperfect central bank communications for

[1] In our setting, QE announcements could potentially be part of the news shock at the zero lower bound, as long as they affect policy rate expectations.

macroeconomic outcomes as well as financial markets. We also associate the noise shock with communications in FOMC announcements over our sample.

Identifying the noise component in FOMC policy announcements, also helps us to contribute to the ongoing discussions on the economic effects of forward guidance. On the one hand, in standard models with nominal price rigidities (e.g., Eggertsson and Woodford, 2003, Laséen and Svensson, 2011, Bundick and Smith, 2020) communication aimed at lowering the expected path of policy rates can effectively stimulate economic activity and increase inflation.[2] On the other hand, empirical work by, e.g., Campbell et al. (2012), Nakamura and Steinsson (2018), and Lakdawala (2019) shows that communicating lower expected rates may be interpreted as negative signals about the state of the economy. Through this "information effect", these papers suggest that lowering expected policy rates may cause a contraction in expected economic activity.[3]

We shed further light on these discussions by assessing the nature of policy announcements in the presence of imperfect communication. To do so, we first estimate the noise shock and remove the noise component from the announcements. Then, similar to Jarociński and Karadi (2020) and Andrade and Ferroni (2021), we identify two announcement shocks: a Delphic shock reflecting news about the future economic state and an Odyssean shock reflecting news about future policy actions.[4]

Modeling noise in monetary policy imposes a challenge for empirical analysis because standard VAR methods fail. Because agents cannot observe the current structural noise shocks but need to look into the future to do so, current and past values of economic time series are not sufficient to recover such shocks (Blanchard, L'Huillier and Lorenzoni, 2013). This implies that structural shocks are non-fundamental with respect to the agents' information set (see Hansen and Sargent, 1991 and Lippi and Reichlin, 1993, 1994).[5]

[2]However, Negro et al. (2015), McKay et al. (2016), among others argue that these models overestimate the expansionary effects of forward guidance.

[3]Moreover, recent papers have further investigated the empirical importance of the information effect. For example, Bauer and Swanson (2020) revisit the analysis in Nakamura and Steinsson (2018) and conclude that there is little role for an information effect. Hoesch et al. (2020) show that although the information channel appears to be important historically, there is no empirical evidence of its presence in the recent years once instabilities are accounted for.

[4]We follow the terminology of Delphic and Odyssean shocks introduced by Andrade and Ferroni (2021) since it refers to the interpretation of forward guidance and monetary policy news. The literature also has used the term "information shock", see e.g., Jarociński and Karadi (2020), related to conventional monetary policy actions.

[5]The non-fundamentalness issue is due to the signal extraction problem related to imperfect communication. Anticipation in monetary policy (foresight about future movements in policy variables) can also lead to a non-fundamental moving average representation in structural VARs (see Ramey, 2016). However, in the case of imperfect communication incorporating policy rate expectations into the SVAR does not solve the issue of non-fundamentalness. The reason is simple; if agents face a signal extraction problem, and are unable to separate out the noise, then the econometrician, faced with either the same data as the agents or

Against this backdrop, we follow the approach originally proposed by Forni et al. (2017a) and introduce a non-standard structural VAR framework for monetary policy that allows for estimation of the structural shocks when the signals are noisy. In particular, we use dynamic rotations of the VAR residuals to recover the structural shocks (Lippi and Reichlin, 1994). Since agents need to look at the actual realizations of the policy rate in the future to understand how noisy a past announcement was, combinations of future values of the VAR residuals identify the current noise shock. That is, as time passes, realized monetary policy actions reveal the noise component contained in the past policy announcements. This approach has been successfully introduced to study stock market bubbles (Forni et al., 2017a) and business cycle issues (Forni et al., 2017b).

We use US data from January 1994 to October 2016 and rely on high-frequency measures of fed funds rate expectations (changes in interest rate futures around FOMC announcements) to reveal the announcement about future monetary policy actions. We find that monetary policy announcements are quite noisy with noise explaining a major part of future policy rate expectations. However, noise does not play a major role for economic outcomes. In particular, a noise shock associated with a future tightening has no effect on output and prices. Also, noise only explains a trivial part of fluctuations in those variables. The same holds for financial market variables. That is, the explained variations of stock prices, stock market volatility, and bond spreads are small.

Finally, we shed light on the nature of announcements after removing the noise component. Identifying a Delphic shock and an Odyssean shock based on the noise-free data, we find that both shocks are important for policy rate expectations. This implies that FOMC announcements reveal both news about the future monetary policy action and news about future economic fundamentals. Our findings corroborate the results of Jarociński and Karadi (2020) for the U.S. and Andrade and Ferroni (2021) for the Euro Area which both abstracted from noise. Further, we show that Delphic shocks play a more important role than Odyssean shocks for economic variables and that announcements are mainly interpreted as Delphic over our sample.

The paper proceeds as follows. Section 2 presents our econometric approach. Section 3 discusses the data and our empirical results and Section 4 concludes.

a subset of these data, cannot do it either.

2 Econometric approach

In this section we present our econometric approach to identify monetary policy noise shocks. The approach is based on Forni et al. (2017a) and Forni et al. (2017b) and adapted to the context of monetary policy announcements. We start discussing a very stylized framework of noisy monetary policy to motivate the econometric approach and then we present our econometric strategy.

2.1 Noisy Monetary Policy

We start by discussing a two-equation theoretical framework of imperfect information to show, on the one hand, the potential role played by noise associated to monetary policy announcements, and, on the other hand, to give the intuition of our empirical approach.

To begin with, let us consider the simplest case and assume that the interest rate is set by the bank according to

$$i_t = \varepsilon_{t-1} \tag{1}$$

where ε_t is the monetary policy news shock, a shock occurring in t but affecting the policy rate with one period of delay. This rule is extremely simplified since it does not include a conventional non-anticipated policy shock or other non-policy shocks. However, this is on purpose since it makes it easier to illustrate our point. We will generalize the rule below.

The policy action, ε_t, is announced in t, but the announcement can be noisy in the sense that it does not fully and perfectly reveal the future actual path of the interest rate. This could be due to the lack of clear communication or lack of credibility by the central bank. We model the policy announcement as

$$s_t = \varepsilon_t + \nu_t, \tag{2}$$

where ν_t is the noise shock that is uncorrelated with the shock ε_t at all leads and lags so that the variance of the signal is simply the sum of the variance of the shock and the noise $\sigma_s^2 = \sigma_\varepsilon^2 + \sigma_\nu^2$. The announcement can be interpreted as the signal agents receive at every point in time about the true shock.

Agents in period t observe current and past vales of the interest rate and the announcement. Their information set is therefore $\mathcal{I}_t = \{i_{t-j}, s_{t-j}\}$ for $j \geq 0$. Conditional on their information, agents form expectations rationally about the future path of the interest rate

$$E(i_{t+1}|\mathcal{I}_t) = \gamma(\varepsilon_t + \nu_t)$$

where $\gamma = \sigma_\varepsilon^2/\sigma_s^2$ is the coefficient of the linear projection of ε_t onto s_t. Expectations depend both on the monetary policy news shock and the noise. If, as it is reasonable to believe, consumption and other macroeconomic variables depend on the expected path of the interest rate, it turns out that the noise component can, in principle, affect macroeconomic dynamics. We do not attempt here to model consumption or other macroeconomic aggregates since our purpose is just to give the intuition of why noise can affect macroeconomic variables.

From an empirical perspective, imperfect information implies that the shocks cannot be estimated using standard SVAR techniques. The reason is the following. Suppose the econometrician observes the interest rate and the announcement, i.e., he has all the information available to the agents. The structural model for the two variables is

$$\begin{pmatrix} i_t \\ s_t \end{pmatrix} = \begin{pmatrix} L & 0 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} \epsilon_t \\ \nu_t \end{pmatrix}. \tag{3}$$

This representation is non-invertible since the determinant of the polynomial matrix is zero in zero. By running a VAR for i_t and s_t one would be able to estimate the Wold representation

$$\begin{pmatrix} i_t \\ s_t \end{pmatrix} = \begin{pmatrix} 1 & \gamma L \\ 0 & 1 \end{pmatrix} \begin{pmatrix} u_t \\ s_t \end{pmatrix}. \tag{4}$$

However, there is no matrix of constants which would deliver the true structural impulse response functions since any linear combination of the Wold impulse response functions would deliver an invertibe representation, while the structural one is not. Nonetheless, and this is the key of our procedure, there is a dynamic combination, i.e., a function of L, which would deliver the structural impulse response functions. This combination is given by the matrix

$$\begin{pmatrix} (1-\gamma)L & -\gamma L \\ 1 & 1 \end{pmatrix}. \tag{5}$$

Indeed post-multiplying the Wold response functions, we can obtain the structural impulse response functions

$$\begin{pmatrix} 1 & \gamma L \\ 0 & 1 \end{pmatrix} \begin{pmatrix} (1-\gamma)L & -\gamma L \\ 1 & 1 \end{pmatrix} = \begin{pmatrix} L & 0 \\ 1 & 1 \end{pmatrix} \tag{6}$$

and the corresponding structural shocks

$$\begin{pmatrix} \varepsilon_t \\ \nu_t \end{pmatrix} = \begin{pmatrix} L^{-1} & \gamma \\ -L^{-1} & (1-\gamma) \end{pmatrix} \begin{pmatrix} u_t \\ s_t \end{pmatrix}. \tag{7}$$

The above is just a simple example to give the intuition of our approach. We develop a general model below.

2.2 The Model

We assume that the stationary n-dimensional vector y_t has the following Wold representation

$$y_t = D(L)\xi_t, \tag{8}$$

where $D(L) = I + D_1L + D_2L^2 + ...$ is a matrix of impulse response functions (L is the lag operator) and $\xi_t \sim WN(0, \Sigma)$ is the vector of Wold shocks. The Cholesky representation is

$$y_t = A(L)\eta_t, \tag{9}$$

where $A(L) = A_0 + A_1L + A_2L^2 + ...$ is a matrix of impulse response functions, A_0 is the Cholesky factor of Σ and $\eta_t \sim WN(0, I)$ is the vector of Cholesky shocks.

The structural representation is given by

$$y_t = C(L)\omega_t \tag{10}$$

where $C(L) = C_0 + C_1L + C_2L^2 + ...$ is a matrix of structural impulse response functions and $\omega_t \sim WN(0, I)$ is a vector of structural shocks. Unlike in standard SVAR models, here we assume that the relationship between the Cholesky and structural impulse response functions is a dynamic one: $C(L) = A(L)B(L)$, where the Blaschke matrix is such that $B(L)B(L^{-1})' = I$, see Lippi and Reichlin (1993, 1994). So is the relationship between the Cholesky and structural shocks: $\eta_t = B(L)\omega_t$.

To identify the structural shocks, first the Cholesky representation of the model can be estimated using a VAR model. Second, a dynamic combination of the Cholesky shocks is taken using the Blaschke matrix $B(L)$. The only difference with respect to the standard structural VAR setting is that structural shocks, or at least some of them, are dynamic combinations, and not static, of the reduced form residuals. Below we discuss how to estimate representation (10) both in a bivariate setting and a multivariate setting.

2.3 Identification

Let ε_t be the monetary policy news shock, a shock which affects the interest rate with some periods of delay. More specifically, we assume:

(A1) the structural interest rate rule is

$$i_t = c(L)\varepsilon_t + q(L)'w_t \tag{11}$$

where $c(L)$ is a polynomial in the lag operator L with $c(0) = 0$; $q(L)$ is a $n-2$-dimensional column vector of lag polynomials and $w_t = [w_t^s \; w_t^f]$ is $n-2$-dimensional vector of economic shocks possibly including the standard non-anticipated monetary policy shock. For tractability, we assume that w_t is perfectly observable in t.

We make the following assumption about the central bank communication strategy:

(A2) The central bank, at every point in time, makes an announcement, s_t, communicating its future interest rate policy ε_t. The announcement is observed by the agents with noise:

$$s_t = \varepsilon_t + \nu_t, \tag{12}$$

where ν_t is the noise shock that is uncorrelated with ε_t at all leads and lags (the variance of the signal is $\sigma_s^2 = \sigma_\varepsilon^2 + \sigma_\nu^2$).

We further assume that

(A3) The econometrician does not directly observe the agents' signal s_t but observes a variable, z_t, which conveys the same information.

Now let $y_t = [y_t^s \;\; i_t \;\; z_t \;\; y_t^f]'$, where y_t^s is a n_s-dimensional vector including slow-moving variables (variables which react slowly to the policy shock), i_t is the federal funds rate, z_t is the announcement-revealing variable, and the vector y_t^f is a n_f-dimensional vector including fast-moving variables (variables which react immediately to the policy shock). Under these assumptions, $n_s + n_f = n - 2$. In our main specification, y_t^s includes three variables (see the next section for the exact definition of the variables employed): output, prices, and the change around FOMC announcements (surprise) in current-month interest rate expectations. In other specifications, we add a fast-moving variables, such as the surprise in the S&P 500 index around FOMC announcements, other financial variables or a measure of output expectations. We assume that

(A4) all the information available about ε_t (and ν_t) is contained in $\{i_{t-k}, s_{t-k}\}$ with $k \geq 0$ and, by A3, in $\{i_{t-k}, z_{t-k}\}$.

Assumption A4 implies that the dynamics of all of the remaining variables depend on the dynamics of i_t and s_t. This implies that the structural model

$$y_t = C(L)\omega_t$$

is noninvertible, see Appendix A, since the rank of $C(0)$ is less or equal to $n-1$. Finally we assume that

(A5) the noise shock and the news shock do not affect y_t^s on impact,

and

(A6) the interest rate does not respond contemporaneously to y_t^f.

Identification is implemented as follows, see Appendix B for details. Let us consider the Cholesky representation

$$\begin{pmatrix} y_t^s \\ i_t \\ z_t \\ y_t^f \end{pmatrix} = A(L) \begin{pmatrix} w_t^s \\ u_t/\sigma_u \\ s_t/\sigma_s \\ w_t^f \end{pmatrix}, \tag{13}$$

This is the invertible representation satisfying assumption (A5) and (A6).

Let $C_1(L)$ be the $n \times 2$ submatrix of $C(L)$ containing the structural impulse response functions to $\varepsilon_t/\sigma_\varepsilon$ and ν_t/σ_ν. This matrix can be obtained as

$$C_1(L) = A(L)B_1(L)$$

where

$$B_1(L) = \begin{pmatrix} \mathbf{0}_{n_s} & \mathbf{0}_{n_s} \\ b(L)\frac{\sigma_\nu}{\sigma_s} & -b(L)\frac{\sigma_\varepsilon}{\sigma_s} \\ \frac{\sigma_\varepsilon}{\sigma_s} & \frac{\sigma_\nu}{\sigma_s} \\ \mathbf{0}_{n_f} & \mathbf{0}_{n_f} \end{pmatrix}$$

where $\mathbf{0}_j$ is a j-dimensional column vector of zeros. and

$$b(L) = \prod_{j=1}^{n} \frac{L - r_j}{1 - \bar{r}_j L} \tag{14}$$

is the Blaschke factor, with r_j, $j = 1, ..., n$, are the roots of $c(L)$ that are smaller than 1 in modulus and $\bar{r}_j$ being the complex conjugate of r_j. This step imposes restriction (A1). (A2) and (A4) allow us to find the non-zero parameters of $B_1(L)$, see Appendix B.

2.4 Estimation

The model is estimated through the following steps:

1. Estimate, with OLS, a reduced-form VAR for y_t and estimate the Cholesky representation.
2. Estimate $b(L)$ by calculating the roots of $\hat{A}_{n_s+1,n_s+2}(L)$, choosing those which are smaller than 1 in modulus in equation (14).
3. Estimate $\sigma_\epsilon/\sigma_\nu$ as the ratio $\frac{\widehat{A}_{n_s+1,n_s+2}(1)}{\widehat{A}_{n_s+1,n_s+1}(1)}$. Using $\sigma_\nu^2/\sigma_s^2 + \sigma_\epsilon^2/\sigma_s^2 = 1$, obtain $\widehat{\sigma_\epsilon/\sigma_s}$ and $\widehat{\sigma_\nu/\sigma_s}$ as $\sin(\arctan(\widehat{\sigma_\epsilon/\sigma_\nu}))$ and $\cos(\arctan(\widehat{\sigma_\epsilon/\sigma_\nu}))$, respectively.

Step 1 provides an estimate of $A(L)$ and steps 2-3 provide an estimate of $B(L)$.

2.5 Discussion

Here we provide an extended discussion of our identifying assumptions. Assumption (A1) implies that the noise shock does not affect the interest rate at all horizons, and that the monetary policy news shock does not affect the interest rate on impact. The second implication is just the definition of a news shock in our context: an announcement revealing information on the future path of interest rates at time t which materializes later when the actual change in the policy rate occurs. The first implication we believe is reasonable for the following two reasons: First, while there is evidence of incidences in which the Fed clarified their policy intentions following the miscommunication or misinterpretation of their initial statement, it's unlikely that the Fed responds with an actual rate change. Second, central banks change the policy rate following their mandate. To motivate their policy rate decision, central banks generally mention the underlying drivers of the economy (e.g., supply, demand, and financial conditions). We are not aware of any statement in which the central bank states that economic conditions are driven by their miscommunication or incorrect interpretation of their statements.

Assumptions (A2)-(A4) are related to the agent's and econometrician's information set and are useful to pin down the elements of $B_1(L)$. (A2) is pretty standard in the limited information literature. (A3) is very reasonable since the econometrician typically does not have direct access to the signal received by the agents but has access to variables that reveal the signal.[6] In this paper we use changes in policy rate expectations around announcements to reveal the signal. Assumption (A4) simply implies that the interest rate and the announcement contain all the information available about the announced future path of the interest rate.

Assumption (A5) and (A6) are those employed to identify the standard monetary policy shock using a Cholesky identification scheme, as in Christiano et al. (1999). The difference with the standard identification is that the news shock, by (A1), has no effect contemporaneously on the federal funds rate either. Assumption (A5) implies that the shock does not affect output and prices contemporaneously, which we believe being quite reasonable at monthly frequencies. Also the assumption implies that the effect on current-month interest rate expectations is zero. This helps the identification of the news shock since the shock should not have any effects on current-month policy rate expectations.

Notice that, by including the current-month policy rate expectations in the VAR, we allow for the presence of the standard monetary policy shock, which is left unidentified. As long as the current expectation is driven by the standard monetary policy shock, as it is reasonable to believe, our procedure makes the news shock orthogonal to the non-anticipated one since our measure is orthogonal to current values of the current-month expectations.

Assumption (A6) is not relevant for our main specification. It applies to other specifications in which we include fast-moving variables such as financial variables and implies that those variables respond immediately to the news shock. It also implies that the federal funds rate does not react contemporaneously to fast moving variables like financial variables which we deem quite plausible at monthly frequencies and given central banks' mandates.

3 Empirical Evidence

In this section we present our main empirical findings.

3.1 Data

We estimate our model at monthly frequency over the sample 1994:01–2016:10.[7] We start our sample in 1994 since the FOMC introduced policy statements in February 1994 for the first time. Before that the Federal Reserve did not announce its monetary policy decision to

[6]Note that in our case the announcement is observable as text, however, the econometrician does not directly observe how the signal is interpreted by the agents.

[7]Our results are robust if we exclude the zero lower bound period, i.e., use data until December 2008.

the public. Markets were left to infer the FOMC's decisions by watching the open market desk selling or buying securities.

To measure output and prices, we use the U.S. Industrial Production (IP) Index and the Consumer Price Index (CPI); the same variables used by Gertler and Karadi (2015) in their study of monetary policy shocks. Both series are obtained from Haver Analytics. In an unreported exercise we repeat our analysis if we measure economic activity using monthly measures of GDP provided by Stock and Watson (2014) and prices using the PCE Deflator and results are similar.

Next, we choose a set of variables defining monetary policy in the VAR. First, to identify the structural shocks, news and noise, we have to choose a series that reflects the policy rate and is unaffected by noise—i.e., i_t—and one that reveals the announcement, z_t. We use the monthly average of the effective fed funds rate for i_t and choose a market-based measure of expectations based on future rates to reveal the announcement.

The measure of fed fund rate expectations relies on interest rate futures since they have long been regarded as an effective means of tracking market expectations of monetary action by the FOMC. One disadvantage of working with market-based expectations measures such as futures is that they contain a risk premium. We follow Kuttner (2001), and use the difference between futures before and after FOMC announcement dates (surprise) to purge for risk premia. Using the surprise also addresses the potential concern that other news shocks, different from the monetary policy announcement, such as news about TFP, could influence fed funds rate expectations.

In particular, we use the path factor by Gürkaynak et al. (2005) to reveal the monetary policy announcement. Gürkaynak et al. (2005) look at changes in futures around a tight window which begins ten minutes prior to the monetary policy announcement and ends twenty minutes after the policy announcement, so-called surprises.[8] The path factor is obtained by extracting the first two unobserved factors from a set of federal funds and Eurodollar futures surprises with one year or less to expiration and by rotating the second factor such that it moves only expected future rates without changing the current federal funds rate. We use two versions of the path factor; one that excludes the observations of September 17, 2001 and March 18, 2009 as discussed in Campbell et al. (2012) and one that includes all FOMC meetings. We also use the surprise in three-month and six-month federal funds futures. These last two measures are based on the daily change (rather than the 30-min window) in these future rates around regularly scheduled FOMC meetings.

To control for conventional (non-anticipated) monetary policy, we again use fed funds

[8] Gürkaynak et al. (2005) consider both regularly scheduled and unscheduled FOMC meetings

futures data. In particular, we use the daily surprise in current-month fed funds futures around FOMC announcements. Following Kuttner (2001) the surprise in current-month futures is scaled to account for the timing of the announcement within the month.[9]

For all four measures of fed funds expectations and the current-month surprise, because FOMC meetings are not held on a monthly basis, to obtain a monthly surprise series, we assume that the surprise in the futures is zero in months with no meeting (see Romer and Romer, 2004, among others).

Finally, in the second specification, we use the surprise in the S&P 500 index around FOMC announcements (in a tight window) from Gürkaynak et al. (2005). In the third specification, to measure output expectations, we use the consensus forecasts of GDP from the Blue Chip survey. We use forecasts at the six-months-ahead horizon.[10]

To assess the relevance of noise for financial markets, we also separately estimate Specification 1 adding one of the following financial market variables: monthly averages of the S&P 500 stock price index, the VIX, the excess bond premium (EBP) from Gilchrist and Zakrajsek (2012), the corporate bond spread (difference between the Moody's seasoned BAA and AAA corporate bond yields), and the term spread (difference between 10-year government bond yields and 3-month T-bill rates).

3.2 Noise

We now assess the effects of noise in monetary policy announcements. Table 1 reports the results of the variance decomposition obtained in the three specifications discussed in Section 3.1. Results are shown for our various alternative measures of policy rate expectations: 1) path factor excluding some announcements dates as in Campbell et al. (2012), 2) path factor as in Gürkaynak et al. (2005), 3) daily surprise in six-month fed funds futures, and 4) daily surprise in three-month fed funds futures. Moreover, Figure 1 showcases the impulse responses using Specification 1 and the first path factor as a proxy for federal funds rate expectations. In all specifications, the number of lags included is determined by the BIC.

The noise shock accounts for most of the variance of policy rate expectations on impact and after two years across all specifications and all measures of policy rate expectations. For example, in Specification 1, noise can explain between 46% and 98% of expectations on impact and between 41% and 93% after two years. On the contrary, noise is irrelevant

[9] In principle one could also use the target factor of Gürkaynak et al. (2005) which is based on a 30-minute window around announcements. Results are unaffected when using the target factor instead.

[10] Note that both the Blue Chip forecasts are fixed-event forecasts implying that the forecast horizon changes for each month of a quarter. To work with consistent forecast horizons across months, we follow Chun (2011) and Dovern et al. (2012) and transform the forecasts to fixed horizon.

for fluctuations in the federal funds rate since the variance explained is close to zero across all specifications and expectation measures. This is consistent with model assumptions. Looking at the representative impulse responses in Figure 1, we see that interest rate expectations (as measured by the path factor) sharply increase on impact, then the effect vanishes quickly over time. The shock has no significant effect on the federal funds rate. Taken together, this suggests that FOMC announcements are very noisy and that noise appears to be a major driver of federal funds rate expectations.

	Specification 1									
	Measure		FFR		Current		Price		Output	
Measure	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24
1	96.5	89.3	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
2	97.7	93.2	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
3	62.0	57.8	0.0	0.0	0.0	1.2	0.0	3.5	0.0	0.5
4	45.8	41.4	0.0	0.0	0.0	0.4	0.0	1.9	0.0	1.3

	Specification 2											
	Measure		FFR		Current Sur.		Price		Output		S&P500 Sur.	
Measure	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24
1	97.0	89.5	0.0	0.0	0.0	0.5	0.0	0.1	0.0	0.0	13.9	13.7
2	97.8	93.2	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	16.1	15.7
3	65.3	56.9	0.0	0.0	0.0	1.0	0.0	3.5	0.0	0.5	9.1	8.9
4	47.9	41.0	0.0	0.0	0.0	0.3	0.0	1.9	0.0	1.3	5.8	5.8

	Specification 3											
	Measure		FFR		Current Sur.		Price		Output		Output Exp.	
Measure	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24
1	95.6	88.2	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.3	0.2	0.8
2	97.7	93.2	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.2	0.2
3	62.2	57.8	0.0	0.0	0.0	1.2	0.0	3.7	0.0	0.2	0.0	0.3
4	45.7	41.1	0.0	0.0	0.0	0.4	0.0	2.1	0.0	0.4	0.0	0.3

	Additional Variables (added in Specification 1)									
	S&P 500		EBP		VIX		Baa-Aaa		Term Spread	
Measure	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24	k=0	k=24
1	0.0	0.1	0.1	0.3	0.0	0.1	0.5	0.9	0.1	0.3
2	1.0	0.8	0.8	0.7	1.2	1.1	0.5	1.3	0.2	0.3
3	0.5	0.3	0.9	0.9	1.6	2.7	0.0	0.4	0.4	0.2
4	0.4	0.2	0.9	0.8	1.5	2.9	0.0	0.6	0.5	0.1

Table 1: Variance decomposition of noise shocks. The entries are the percentage of variance explained at the specified horizons k. Measures are as follows: 1) path factor excluding some announcements dates as in Campbell et al. (2012); 2) path factor as in Gürkaynak et al. (2005); 3) daily surprise in six-month fed funds futures; 4) daily surprise in three-month fed funds futures.

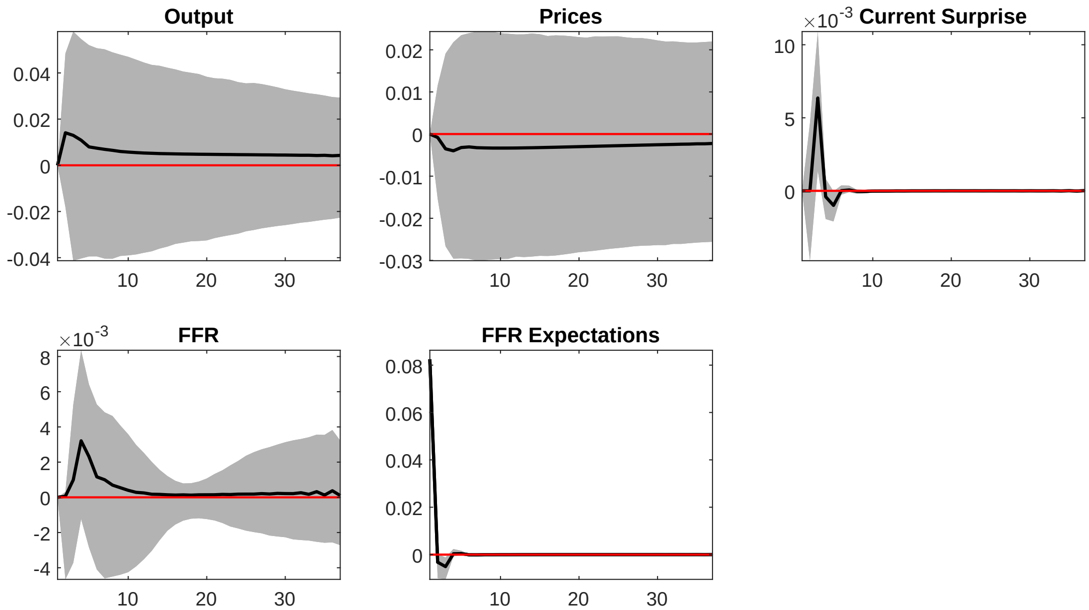

Figure 1: The effects of noise shocks. Impulse responses to a one standard deviation noise shock. Federal funds rate expectations are proxied by the path factor excluding some announcements dates as in Campbell et al. (2012) (measure 1). The solid black lines denote the point estimate and the shaded areas represent the confidence bands at the 68% levels.

So the question is: to what extent does monetary policy noise affect economic fluctuations? Table 1 shows that noise plays a negligible role for macroeconomic outcomes. Specifically, the variation in output explained by noise is very small varying from 0.0% to 1.3% at the two year horizons across the three specifications and policy rate expectations measures. A similar picture arises for prices. Generally, noise can only account for a small part of price fluctuations since for all expectation measures across the three specifications the explained variance is small. Figure 1 shows that the responses of output and prices are small and not even significant at the 68% confidence level. Further, noise seems also to be irrelevant for fluctuations in output expectations (see Specification 3).

Looking at Specification 2, we can also observe that noise can explain a non-trivial part of the surprise in the S&P 500 around FOMC announcements. Up to 14% of variation in stock prices in the 10 minutes before and 20 minutes after the FOMC announcement is explained by the noise shock. However, when looking at the monthly aggregate of the S&P 500 noise becomes irrelevant since the variance explained is very small (between 0.0% and 1.0% on impact). Similar patterns arise for other monthly aggregates of other financial variables. Noise explains a negligible part of variations in the EBP, the VIX, the corporate bond spread (Baa - Aaa), and the term spread (10-year government bond yield - 3-month T-bill rate).

3.3 Noise Shocks and FOMC Announcements

Like for Figure 1, here we use Specification 1 and the path factor excluding some announcements dates as in Campbell et al. (2012) (measure 1) to proxy federal funds rate expectations. With the estimates at hand, we first inspect the noise shock series to gain insights on the relevance of noise surrounding FOMC announcements. This preliminary analysis can provide information about the historical periods where monetary policy announcements were particularly noisy, i.e., when Fed announcements shift the expected path of future interest rates which fail to materialize in future periods. As described earlier, this could be due to the lack of clear communication or lack of credibility by the central bank.

Figure 2 plots the identified noise shock over our sample alongside the fed funds rate. No systematic patterns evolve associated to easing or tightening cycles. Not surprisingly, noise shocks are small during the ZLB and then again become more pronounced surrounding the lift off of policy rates in early 2016.[11] The size of the noise shocks surrounding the lift off is relatively small if compared to pre-ZLB episodes.

To shed light of what constitutes noise in our empirical setting we look at a few narrative episodes. We pick a few observations of the noise shock and associate them with FOMC announcements and the language and guidance provided in them.

Let us start by considering the negative noise shock in May 1994. The statement released after the FOMC meeting in May 1994 announced: "These actions [interest rate hikes]... substantially remove the degree of monetary accommodation which prevailed throughout 1993." And a Wall Street Journal writer interpreted this statement as follows: "Yesterday's declaration means that the Fed now believes it is very close to neutral and does not expect any further rate increases soon." Agents perceived this announcement as a signal indicating a pause in the tightening cycle. However, after May 1994 the Federal Reserve increased the policy rate three more times with the last hike in February 1995. Hence, agents expectations of future monetary policy easings did not materialize.

One of the largest observations of the noise shock is associated with the FOMC meeting in July 1995. It brought the first easing after a long (seventeen-month) tightening cycle and the statement notes that inflationary pressures have receded. This largely raised ex-

[11] This reflects the fact that the path factor is based on futures surprises with one year or less to expiration. While futures at this horizon move continuously before the ZLB, at the ZLB they remained relatively flat.

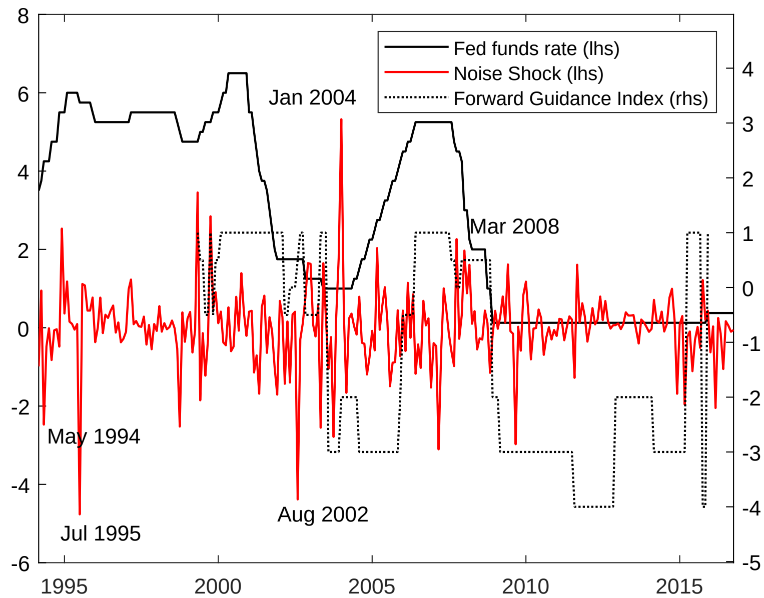

Figure 2: Noise shocks over time in Specification 1. Federal funds rate expectations are proxied by the path factor excluding some announcements dates as in Campbell et al. (2012) (measure 1). The red line depicts the time series of the noise shock and the black line denotes the fed funds target rate. The dotted black line shows the judgmentally computed index of the relative strength of net time-based or data-based content of FOMC forward guidance from Feroli et al. (2017). Negative and positive numbers indicate more time-based or data-based communication, respectively. Numbers closer to zero denote weaker guidance.

pectations of further easings in the future. However, this was only followed by two easings each of 25 basis points. Agents likely expected larger and more rate decreases than actually occurred which yields the relatively large noise shock.

Another example is the FOMC announcement of August 2002. To understand the negative observation of the noise shock, one needs to consider the actions and guidance by the Federal Reserve throughout the period of consecutive interest rate cuts from January until December 2001. During that period the FOMC accompanied each cut with a statement describing that the economic outlook risks are weighted toward "weakness." The risks were described as "balanced" at the March, May, and June 2002 meetings. However, at the August 2002 meeting, the FOMC switched back to describing the risks as weighted toward "weakness." A language that accompanied rate cuts of up to 1.0 percentage points throughout 2001. Following the August 2002 FOMC meeting the Federal Reserve only cut rates in November 2002 (-0.5 percentage points) and (-0.25 percentage points) in June

2003. Thus, the negative noise shock suggests that agents were anticipating potentially more, larger, and sooner rate cuts.

The policy announcement of January 2004 is also associated with a spike in the noise shock series. In January 2004, with policy rates still at one percent, the FOMC statement drops the commitment to keep policy unchanged for a "considerable period." The front page of The Wall Street Journal reported the following morning that "Investors interpreted the omission of "considerable period" as a signal that the Federal Reserve is closer to raising interest rates than many thought." Three meetings later in June 2004 the Federal Reserve hiked rates by 25 basis points for the first time. With the positive noise shock in June 2004 our model suggests that agents were expecting rate hikes to happen sooner (and to be potentially larger).

As a final example, let us consider an observation from the easing cycle associated with the great financial crisis. The FOMC announcement of March 2008 is associated with another positive noise shock. The FOMC statement added more emphasis to concerns around elevated inflation and inflation expectations and announced that "uncertainty about the inflation outlook has increased" and that "it will be necessary to continue to monitor inflation developments carefully." Agents perceived this as an indication of less policy accommodation in the future. The Federal Reserve decreased interest rates two more times in 2008. Thus, our model interprets this announcement as a noisy one.

Finally, we check the relationship between noise shocks and different types of guidance announced in FOMC statements. Communication can be more time based (focusing on when interest rates are likely to change) or data based (focusing on under what economic circumstances interest rates are likely to change). Feroli et al. (2017) provide a narrative (judgement-based) index (varying from -5 to 5) of relative strength of FOMC's forward guidance from May 1999 to December 2015. This index captures the intensity of net time-based (negative values) or data-based (positive values) content of FOMC communication at any point in time. The dotted black line of Figure 2 depicts the index alongside the identified noise shock. No apparent patterns emerge: One type of communication cannot be associated more with large noise shocks than the other. Also, shifts in guidance (changes from negative to positive values of the index or vice versa) are not necessarily related with larger noise shocks. For example, the shift in from time-based towards data-based in guidance from 2005-2007 is associated with relatively small noise shocks.

3.4 Monetary Policy News Shock

We have documented that announcements are quite noisy but that noise does not matter much for macroeconomic outcomes. Let us now look at the structural monetary policy news shock of the model; the shock that is associated with future policy actions. Figure 3 and Table 2 show the impulse responses and variance decomposition associated with our benchmark specification (Specification 1 using the path factor as in Campbell et al. (2012)).

	k=0	k=6	k=12	k=24
Output	0.0	5.1	9.1	8.3
Prices	0.0	1.2	2.9	3.4
Current Sur.	0.0	0.7	1.0	1.6
FFR	0.0	74.9	80.4	82.9
FFR Exp.	1.9	5.5	5.7	5.7

Table 2: Variance decomposition of news shocks in Specification 1. Federal funds rate expectations are proxied by the path factor excluding some announcements dates as in Campbell et al. (2012) (measure 1). The entries are the percentage of variance explained at the specified horizons k.

The monetary policy news shock increases federal funds rate expectations on impact and the federal funds rate with a delay. The federal funds rate reaches its peak effect after about 10 months. The news shock also increase output and prices although the effect on prices is not significant at 90% confidence levels. Contrary to the noise shock, news seem to matter for output explaining between 5% and 9% of its variations.

The positive response of output and prices raises some questions since it is not in line with the predictions of standard models with nominal price rigidities. In principle, a communicated commitment to future monetary policy tightenings is associated with a decrease in output and prices. However, the literature has shown that central bank announcements communicating future policy actions can be understood in different ways by agents. One the hand, an announcements about future monetary policy tightenings can reveal good news about future macroeconomic conditions and, at the same time, bad news of a tighter monetary policy. We shed more light on the nature of the announcements over our sample period in the following section.

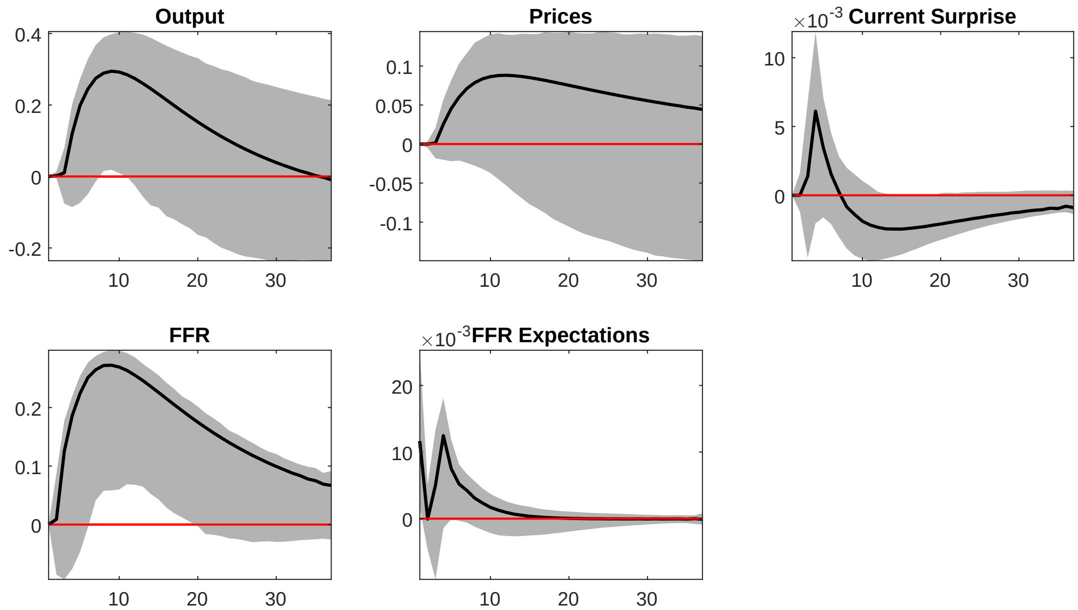

Figure 3: The effects of monetary policy news shocks. Impulse responses to a one standard deviation news shock. Federal funds rate expectations are proxied by the path factor excluding some announcements dates as in Campbell et al. (2012) (measure 1). The solid black lines denote the point estimate and the shaded areas represent the confidence bands at the 90% levels.

3.5 Odyssean vs. Delphic Policy Announcements

One advantage of our empirical approach is that we can separate noise from monetary policy announcements. In this section we investigate the nature of policy announcements once we take into account the presence of noise. In the case of that the Federal Reserve has superior information about the economy, an announcement about future monetary policy tightening (easing) can reveal two things: the anticipated monetary policy action ("Odyssean shock") or stronger (weaker) future economic conditions ("Delphic shock"). In what follows, we identify these two shocks after controlling for noisy communications. To do so, first, we remove the noise component from the series in our VAR and compute $y_t^* = y_t - C_\nu(L)\nu_t$, where $C_\nu(L)$ is the column of $C(L)$ corresponding to the noise shock. Second, we estimate a VAR with the noise-free series, y_t^*, and identify the Delphic shock and Odyssean shock with a combination of zero and sign restrictions.[12]

[12]This SVAR is singular so in principle one could make a rank reduction when identifying the shocks. We do not pursue this route.

In particular, we estimate the noise-free counterpart of Specification 2 and identify the Delphic shock as a shock with a zero impact effect on output, prices, the federal funds rate and the current surprise and which increases the fed funds rate expectations (path factor) and the stock price surprise contemporaneously. We identify the Odyssean shock as a shock with a zero impact effect on output, prices, the federal funds rate and the current surprise and which increases the fed funds rate expectations and reduces the stock price surprise contemporaneously.[13] Notice that once we remove the noise component from the data, standard techniques can be used since we remove the source of non-invertibility of the model. Now all the shocks are observable, including the Delphic and Odyssean shocks.

Identification 1								
Variable	Delphic shock				Odyssean shock			
	k=0	k=6	k=12	k=24	k=0	k=6	k=12	k=24
Output	0.0	4.9	5.6	4.7	0.0	0.2	0.4	1.7
Prices	0.0	3.2	4.8	5.5	0.0	0.8	0.7	0.6
Current Sur.	0.0	7.1	7.9	8.3	0.0	4.4	4.7	4.9
FFR	0.0	54.4	53.7	52.1	0.0	24.9	27.9	27.9
FFR Exp.	11.7	33.1	33.3	33.8	28.4	16.3	16.6	16.9
S&P 500 Sur.	61.8	57.0	56.9	56.9	33.0	30.1	30.1	30.2
Identification 2								
Variable	Delphic shock				Odyssean shock			
	k=0	k=6	k=12	k=24	k=0	k=6	k=12	k=24
Output	0.0	11.4	12.9	11.4	0.0	2.8	3.2	6.7
Prices	0.0	3.0	5.7	6.6	0.0	2.1	2.5	2.7
Current Sur.	0.0	1.6	2.1	2.2	0.0	0.8	1.2	1.6
FFR	0.0	31.7	26.1	24.3	0.0	36.7	45.4	45.9
FFR Exp.	30.3	21.7	21.4	21.7	19.8	23.4	24.0	24.2
Output Exp.	37.1	45.8	38.7	34.4	56.6	28.7	35.8	42.2

Table 3: Variance decomposition of Delphic and Odyssean shocks.

Figure 4 plots the impulse response functions of the two announcement shocks: the Delphic shock (left column) and the Odyssean shock (right column). Table 3 reports the variance decomposition. The Delphic shock is expansionary while the Odyssean shock contractionary. However, for the latter the responses are not significant at the 90% confidence level. In terms of magnitudes, the Delphic shock seems to have relatively larger effects on output of up to 0.2 percentage points compared to about 0.1 percentage points in the case of the Odyssean shock. This is also consistent with the variance decomposition: the Delphic

[13]This identification is similar to Jarociński and Karadi (2020) who use the high-frequency co-movement in the three-month fed funds future and the S&P 500 surprises to disentangle conventional monetary policy shocks from information shocks. Here we use the path factor obtained from interest rate future surprises since we focus on announcements about future monetary policy.

shock plays a larger role for output (and to a lesser extent for prices) than the Odyssean shock. Further, both shocks seem to be of importance for the stock market surprise and the fed funds rate expectations measured by the path factor.

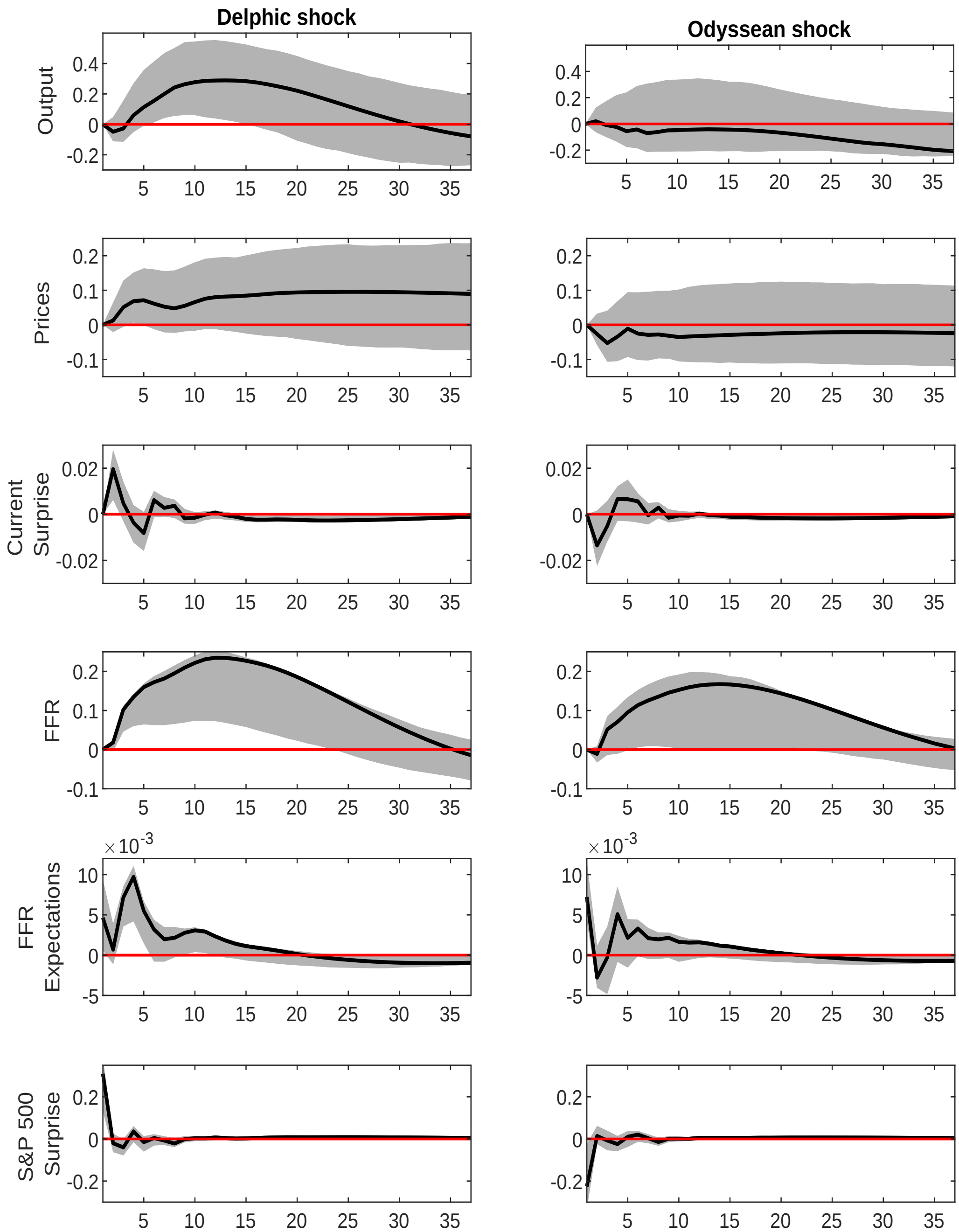

Figure 4: Impulse responses functions: Identification 1. The solid black lines denote the point estimate and the shaded areas represent the confidence bands at the 90% levels.

We also try another identification based on Specification 3. The Delphic shock has a zero impact effect on output, prices, the federal funds rate and the current surprise, and increases fed funds rate expectations and output expectations contemporaneously. If the announcements reveals news about stronger or weaker future economic conditions, this should be reflected in expectations measures of output. Thus, they should be helpful and informative in disentangling the Delphic and Odyssean shock. The Odyssean shock has a zero impact effect on output, prices, the federal funds rate and the current surprise, and increases fed funds rate expectations and decreases output expectations contemporaneously.[14] The impulse responses are reported in Figure 5 and results are corroborated. The Delphic shock is expansionary while the Odyssean shock is contractionary (although as before not significantly). Again, the Delphic shock seems to be relatively more important for macroeconomic outcomes than the Odyssean shock.

These findings suggest that the monetary policy news shock reflects announcements that are on average more Delphic in nature than Odyssean. Further, central bank communication about future policy intentions contains two components (next to noise) with distinct macroeconomic implications. On the other hand, an announcements of a future tightening reveals that future economic activity is going to be stronger than expected and results in an increase of output and prices. One the hand it, the same announcement of a future tightening reveals the actual future policy action which has little effect on macroeconomic outcomes.

[14]This identification is somewhat related to the approach in D'Amico and King (2015). They consider a quarterly VAR with macro variables and survey data on expectations of interest rates, inflation, and output. They identify anticipated monetary policy shocks by imposing sign restrictions on the pattern of expected short-term interest rates and expected GDP (and inflation).

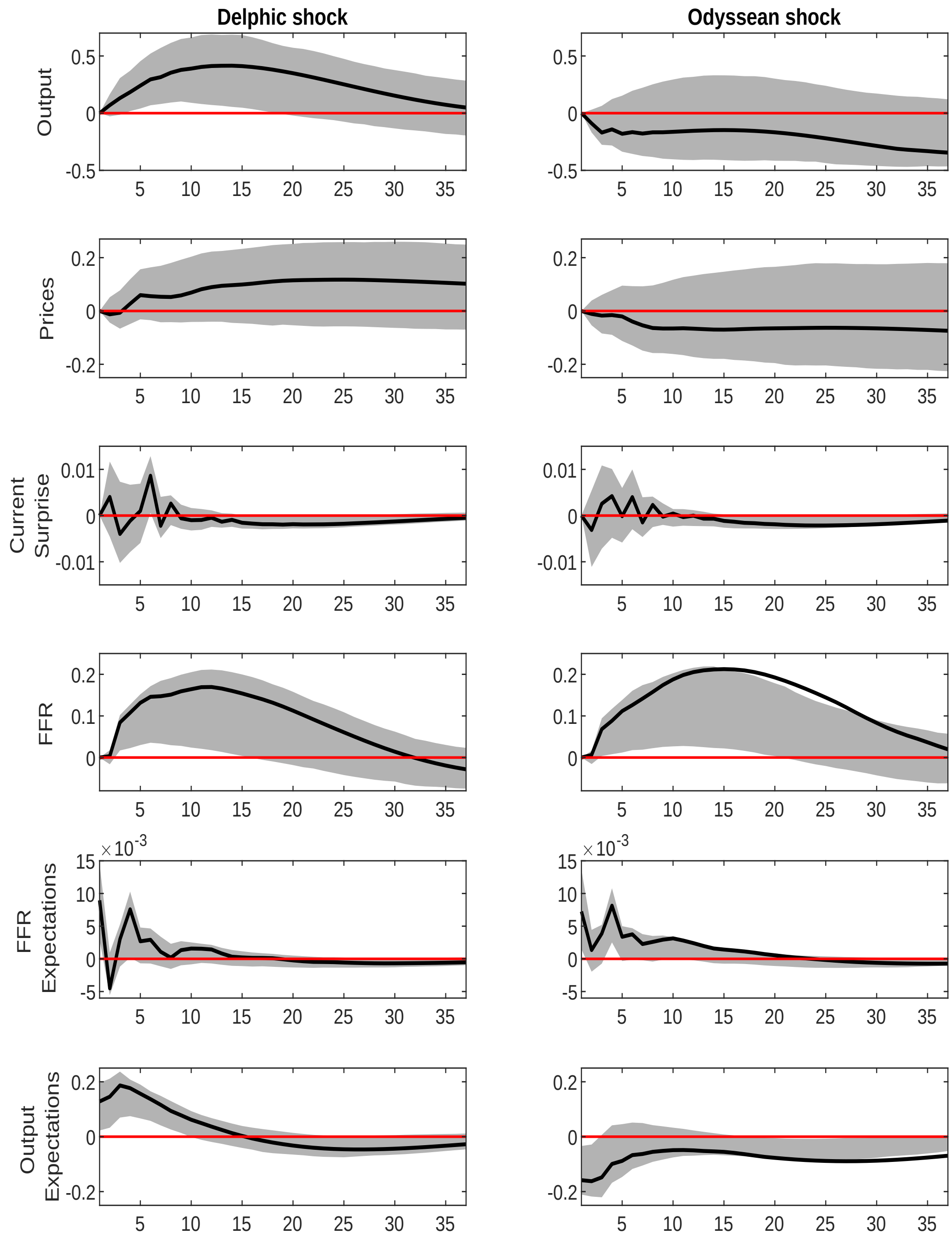

Figure 5: Impulse responses functions: Identification 2. The solid black lines denote the point estimate and the shaded areas represent the confidence bands at the 90% levels.

4 Conclusion

We provide new insights into how to characterize monetary policy announcements since the mid-1990s by assessing the role of noise in monetary policy. While monetary policy announcements are quite noisy, noise does not play a major role for economic outcomes or financial markets. After removing the noise component of the announcements, we show that central bank communications reveal both news about the future monetary policy action and news about future economic fundamentals. Over our sample, announcements seem to be more Delphic in nature.

Appendix

A

Here we show that, under assumption A4, the structural model is noninvertible. Consider the structural model

$$y_t = C(L)\omega_t$$

$$y_t = C_1(L)\omega_{1t} + C_2(L)\omega_{2t}$$

where $\omega_{1t} = [\varepsilon_t/\sigma_\varepsilon \;\; \nu_t/\sigma_\nu]'$ and ω_{2t} includes all of the remaining structural shocks. Let $\bar{C}_1(L)$ be the two rows of $C_1(L)$ associated to i_t and s_t.

By assumption A4, the dynamics of the remaining variables are combinations of the dynamics of i_t and s_t. Thus the model can be written as

$$C_1(L) = \tilde{C}_1(L)\bar{C}_1(L).$$

Under assumption A1 and A2,

$$\bar{C}_1(L) = \begin{pmatrix} c(L)\sigma_\varepsilon & 0 \\ \sigma_\varepsilon & \sigma_\nu \end{pmatrix}.$$

Therefore, $rank(C_1(0)) = 1$ since the $rank(\bar{C}_1(0)) = 1$. Thus, $rank(C(0)) \leq n-1$, $z = 0$ is a root of $C(z)$ and therefore the structural model is noninvertible.

B

The structural representation of i_t and s_t associated to the anticipated shock and the noise is

$$\begin{pmatrix} \tilde{i}_t \\ \tilde{s}_t \end{pmatrix} = \bar{C}_1(L)\omega_{1t} = \begin{pmatrix} c(L)\sigma_\varepsilon & 0 \\ \sigma_\varepsilon & \sigma_\nu \end{pmatrix} \begin{pmatrix} \varepsilon_t/\sigma_\varepsilon \\ \nu_t/\sigma_\nu \end{pmatrix}. \tag{15}$$

This representation, as seen above, is non-invertible since the determinant of $\bar{C}_1(z)$, i.e. $c(z)$, is zero at $z = 0$ by A1. An invertible representation can be found by projecting the variables onto its past:

$$\begin{pmatrix} \tilde{i}_t \\ \tilde{s}_t \end{pmatrix} = \bar{A}_1(L)\eta_t = \begin{pmatrix} \frac{c(L)\sigma_u}{b(L)} & \frac{c(L)\sigma_\epsilon^2}{\sigma_s} \\ 0 & \sigma_s \end{pmatrix} \begin{pmatrix} u_t/\sigma_u \\ s_t/\sigma_s \end{pmatrix} \tag{16}$$

where

$$b(L)=\prod_{j=1}^{n}\frac{L-r_j}{1-\bar{r}_jL} \tag{17}$$

is the Blaschke factor and r_j, $j=1,...,n$, are the roots of $c(L)$ that are smaller than 1 in modulus and $\bar{r}_j$ being the complex conjugate of r_j. One can see that the Wold representation above is also the Cholesky representation of the two variables by noticing that the representation is invertible, the shocks are orthogonal to each other (see formula below), and the element $(1,2)$ of the VMA matrix is zero since $c(0)=0$.

The Cholesky shocks are related to the structural shocks through the following equation

$$\begin{pmatrix} u_t/\sigma_u \\ s_t/\sigma_s \end{pmatrix}=\bar{B}(L)\begin{pmatrix} \varepsilon_t/\sigma_\epsilon \\ \nu_t/\sigma_\nu \end{pmatrix}=\begin{pmatrix} b(L)\frac{\sigma_\nu}{\sigma_s} & -b(L)\frac{\sigma_\varepsilon}{\sigma_s} \\ \frac{\sigma_\varepsilon}{\sigma_s} & \frac{\sigma_\nu}{\sigma_s} \end{pmatrix}\begin{pmatrix} \varepsilon_t/\sigma_\varepsilon \\ \nu_t/\sigma_\nu \end{pmatrix}. \tag{18}$$

Now let us consider the Cholesky representation of the whole model

$$\begin{pmatrix} y_t^s \\ i_t \\ z_t \\ y_t^f \end{pmatrix}=A(L)\begin{pmatrix} w_t^s \\ u_t/\sigma_u \\ s_t/\sigma_s \\ w_t^f \end{pmatrix}, \tag{19}$$

Using (19) to replace the structural shock in the equation above, we have

$$\begin{pmatrix} y_t^s \\ i_t \\ z_t \\ y_t^f \end{pmatrix}=A(L)\begin{pmatrix} I_{n_s} & \mathbf{0}_{n_s} & \mathbf{0}_{n_s} & \mathbf{0}_{n_s,n_f} \\ \mathbf{0}_{n_s}' & b(L)\frac{\sigma_\nu}{\sigma_s} & -b(L)\frac{\sigma_\epsilon}{\sigma_s} & \mathbf{0}_{n_f}' \\ \mathbf{0}_{n_s}' & \frac{\sigma_\epsilon}{\sigma_s} & \frac{\sigma_\nu}{\sigma_s} & \mathbf{0}_{n_f}' \\ \mathbf{0}_{n_f,n_s} & \mathbf{0}_{n_f} & \mathbf{0}_{n_f} & I_{n_f} \end{pmatrix},\begin{pmatrix} w_t^s \\ \varepsilon_t/\sigma_\varepsilon \\ \nu_t/\sigma_\nu \\ w_t^f \end{pmatrix}, \tag{20}$$

where $\mathbf{0}_j$ is a j-dimensional column vector of zeros, $\mathbf{0}_{i,n_s}$ is a $i\times j$ matrix of zeros, I_j is a j-dimensional identity matrix. The structural impulse response functions to $\varepsilon_t/\sigma_\varepsilon$ and ν_t/σ_ν are

$$C_1(L)=A(L)B_1(L)$$

where

$$B_1(L) = \begin{pmatrix} \mathbf{0}_{n_s} & \mathbf{0}_{n_s} \\ b(L)\frac{\sigma_\nu}{\sigma_s} & -b(L)\frac{\sigma_\varepsilon}{\sigma_s} \\ \frac{\sigma_\varepsilon}{\sigma_s} & \frac{\sigma_\nu}{\sigma_s} \\ \mathbf{0}_{n_f} & \mathbf{0}_{n_f} \end{pmatrix}.$$

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