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Noisy Monetary Policy

by Tatjana Dahlhaus and Luca Gambetti

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Abstract

We introduce limited information in monetary policy. Agents receive signals from the central bank revealing new information ("news") about the future evolution of the policy rate before changes in the rate actually take place. However, the signal is disturbed by noise. We employ a non-standard vector autoregression procedure to disentangle the economic and financial effects of news and noise in US monetary policy since the mid-1990s. Using survey- and market-based data on federal funds rate expectations, we find that the noisy signal plays a relatively important role for macroeconomic dynamics. A signal reporting news about a future policy tightening shifts policy rate expectations upwards and decreases output and prices. A sizable part of the signal is noise surrounding future monetary policy actions. The noise decreases output and prices and can explain up to 16% and 13% of their variations, respectively. Furthermore, it significantly increases the excess bond premium, the corporate spread and financial market volatility, and decreases stock prices.

Bank topics: Transmission of monetary policy; Monetary policy implementation; Econometric and statistical methods; Business fluctuations and cycles; Financial markets
JEL codes: C18; C32; E02; E43; E52

Résumé

Nous introduisons des informations limitées sur la politique monétaire. Les agents reçoivent des signaux de la banque centrale qui révèlent de nouvelles informations (des « nouvelles ») sur l'évolution future du taux directeur avant qu'il ne soit réellement modifié. Cependant, ces signaux sont brouillés par du « bruit ». Nous employons un modèle vectoriel autorégressif non standard pour démêler les répercussions économiques et financières qu'ont eues les nouvelles et le bruit sur la politique monétaire des États-Unis depuis le milieu des années 1990. Les données d'enquête et les données de marché sur les attentes relatives au taux des fonds fédéraux permettent de constater que les signaux entachés de bruit jouent un rôle relativement important dans la dynamique macroéconomique. Un signal associé à un resserrement futur de la politique monétaire amène à s'attendre davantage à une hausse du taux directeur et entraîne une baisse de la production et des prix. Une grande partie du signal est du bruit autour des mesures à venir des autorités monétaires. Ce bruit cause une diminution de la production et des prix, et permet d'expliquer les variations de ces deux variables, respectivement jusqu'à 16 % et 13 % de la variance. De plus, il fait augmenter sensiblement la prime excédentaire sur les obligations d'entreprise, l'écart de taux des obligations de sociétés et la volatilité des marchés financiers, et fait baisser les cours des actions.

Sujets : Transmission de la politique monétaire; Mise en œuvre de la politique monétaire; Méthodes économétriques et statistiques; Cycles et fluctuations économiques; Marchés financiers
Codes JEL : C18; C32; E02; E43; E52

Non-Technical Summary

Over the past few decades, the nature of monetary policy-making has changed. In addition to the traditional approach of using interest rates to stabilize the economy, central banks across the globe have increasingly relied on various communication strategies in their conduct of monetary policy.

For example, the Federal Reserve Bank's communication has become richer and more forward looking. Before 1994, the change in the Federal funds rate per se was the only policy action made at a Federal Open Market Committee (FOMC) meeting, but in 1994 the Federal Reserve started to issue post-meeting statements. In mid-1999, for the first time, the Federal Reserve's statement included forward-looking language. When the federal (fed) funds rate hit the zero lower bound in December 2008, communication became even more explicit, since it was one of the only ways for the Federal Reserve to provide monetary stimulus.

The FOMC's emergent use of guidance concerning future policy decisions since the 1990s suggests that monetary policy actions are anticipated to some extent. Agents receive signals from the central bank revealing new information ("news") about the future path of the policy rate well before changes in the rate occur, and adjust their expectations accordingly. Signals can be transmitted to the public via statements, press releases or speeches, for example. However, the signal may be disturbed by noise in the sense that agents do not receive a clear signal and, thus, do not understand or interpret the news correctly. Therefore, agents observe only a noisy signal, which can be decomposed into a news shock (future or anticipated monetary policy shock) and a noise shock. The source of noise in monetary policy can be twofold. 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 signal 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 about past news shocks by looking at the realized policy rate and can disentangle the real news from noise.

Modelling news and noise in monetary policy imposes a challenge for empirical analysis because standard vector autoregression (VAR) methods fail. Against this backdrop, we apply a non-standard structural VAR framework for monetary policy, which allows us to quantify the impacts of news and noise in monetary policy communication. Our analysis uses US data over the period from 1994 to 2016.

We find the following: First, on average, US monetary policy signals contain more noise than news. Second, noise can be economically costly since it decreases output and prices. Third, noise affects financial markets by decreasing stock prices and by increasing financial market volatility and excess bond premia.

Summing up, noise seems to be an empirically and economically relevant component of monetary policy. Further, our results suggest caution in the use of forward-looking language in the conduct of monetary policy in the sense that providing information about the future path of the policy rate can be valuable if clearly communicated and credible.

"The fundamental reason that communication is so important is that monetary policy is more appropriately viewed as the path of the policy rate, not simply the current rate. This is evident today as the markets seem highly attentive to signals regarding the future path of the funds rate not simply its current setting." Charles I. Plosser, 2014.

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, communication has become a monetary policy tool of the Federal Reserve in addition to the traditional tool of interest rates. Especially with the federal (fed) funds rate stuck at the zero lower bound (ZLB) after the global financial crisis, so-called "forward guidance" has been the only way for the Federal Reserve to affect market expectations of future monetary policy.[1]

At the same time, Federal Reserve communication has become richer and more forward looking. Before 1994 the change in the fed funds rate per se was the only policy action made at a FOMC meeting, but in 1994 the Federal Reserve started to issue post-meeting statements. In mid-1999, for the first time, the Federal Reserve's statement included forward-looking language. When the fed funds rate hit the ZLB in December 2008, communication became even more explicit since it was one of the only ways for the Federal Reserve to provide monetary stimulus. Specifically, in December 2008, the FOMC announced that the Federal funds rate will remain exceptionally low "for some time," which in March 2009 was replaced by "for an extended period of time." In August 2011, forward guidance became date-specific with the FOMC announcing low rates "at least through mid-2013."

The FOMC's emergent use of guidance concerning future policy decisions since the '90s suggests that monetary policy actions are anticipated to some extent. Agents receive signals from the central bank revealing new information ("news") about the future path of the policy rate well before changes in the rate actually occur and adjust their expectations accordingly. Signals can be transmitted to the public via statements, press releases or speeches, for example. However, the signal may be disturbed by noise in the sense that agents do not receive a clear signal and, thus, do not understand or interpret the news correctly. Therefore, agents observe only a noisy signal, which can be decomposed into a news shock (future or anticipated monetary policy shock) and a noise shock. The source of noise in monetary policy can be twofold. First, communication about future monetary policy by the central bank could be unclear; e.g., there could be ambiguity in words, sentences, or

[1] In addition, quantitative easing (QE) may also affect expectations about future policy rate decisions.

paragraphs. Second, agents may interpret the signal 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 about past news shocks by looking at the realized policy rate and can disentangle the real news from noise.

This raises a few interesting questions: How do we identify news and noise in monetary policy? How noisy are signals about future monetary policy decisions? What are the economic and financial effects of anticipated (news) and noise shocks? Does noise in monetary policy matter? In this paper we address these questions by expanding the noise-news setting as in Forni et al. (2017a) to monetary policy. We provide a unified empirical framework that can disentangle the economic effects of news and noise in monetary policy when the signal about future monetary policy actions is noisy.[2] To reveal the signal, we use survey-based and market-based measures of fed funds rate expectations.

The bulk of the empirical literature assessing the effects of monetary policy has focused mainly on the economic effects of unanticipated changes in the fed funds rate: the so-called "surprise." (See for example, Sims, 1992, Christiano et al., 1999, Bernanke et al., 2005, and Forni and Gambetti, 2010, among many others.) There seems to be considerable agreement about the qualitative effects on the macroeconomy. After an unanticipated monetary expansion, i.e., an unexpected decrease in the policy rate, short-term interest rates decrease and economic aggregates such as investment, output and prices generally increase.

A communicated commitment of future policy easing made by the central bank should have similar stimulative effects on the economy. Indeed, there are some theoretical models providing support for this belief (see, e.g., Eggertsson and Woodford (2003) and Laséen and Svensson (2011)). Moreover, Milani and Treadwell (2012) show that anticipated monetary policy shocks have a larger, delayed and more persistent effect than unanticipated shocks. Further, there is empirical evidence showing that central banks affect market expectations of future interest rates and, therefore, asset prices (see, e.g., Gürkaynak et al., 2005, Gürkaynak, 2005, Campbell et al., 2012). In addition, Swanson (2017) separately identifies the effects on asset prices of Federal Reserve forward guidance and large-scale asset purchases during the ZLB period.

Empirical studies assessing the macroeconomic effect of such news shocks in monetary policy are still scarce. There exist some early contributions regarding the role of monetary policy anticipation, for example, Mishkin (1982) and Cochrane (1998). More recently, Gertler and Karadi (2015) and Lakdawala (2016) take into account the anticipated com-

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

ponent of monetary policy in vector autoregressions (VARs) using external instruments from futures market data. Further, D'Amico and King (2015) use a VAR including survey expectations directly to assess the effects of anticipated monetary policy.

However, so far, the literature has abstracted from noise. Although it is plausible to assume that positive news about future monetary policy actions has stimulative economic effects if it materializes as expected, it is less clear what the consequences of deviations from these announced actions are. Such policy reversals could potentially be costly for the economy. In that vein, Goodfriend and King (2005) show that imperfect credibility of the Federal Reserve during Volcker's disinflation period intensified output losses.

Modelling news and noise in monetary policy imposes a challenge for empirical analysis because standard VAR methods fail. Because agents cannot observe the current structural news shocks, 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).

Against this backdrop, we follow the approach originally proposed by Forni et al. (2017) 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 cannot distinguish between the current news shock and the noise shock, combinations of current and past values of the VAR residuals do not identify the structural shocks. However, combinations of future values of such residuals identify the current news and noise shock because, as time passes, realized monetary policy actions reveal the noise component contained in the news shock. This approach has been successfully introduced to study stock market bubbles (Forni et al., 2017a) and business cycle issues (Forni et al., 2017b).

We find the following: first, monetary policy seems to be partly anticipated (at least since the '90s). Second, the noisy signal, containing news about future monetary policy tightening, shifts policy rate expectations upwards, and decreases output and prices. Third, a sizable part of the signal is noise surrounding future monetary policy decisions. The noise shock decreases output and prices and can explain up to 16% and 13% of their variations, respectively. Finally, financial markets react significantly to the noise surrounding future monetary policy. In particular, stock prices fall, and financial market volatility and the excess bond premium increase following a monetary policy noise shock. Our results are robust to controlling for non-anticipated monetary policy shocks as well as other news shocks. Therefore, noise seems to be an empirically relevant component of monetary policy as it can be economically costly and can disrupt financial markets.

The paper proceeds as follows. Section 2 documents monetary policy anticipation and presents a simple model of monetary policy with imperfect information. Section 3 discusses the econometric implications and introduces the VAR identification strategy for the bivariate and multivariate case. Section 4 presents our empirical results for news and noise in monetary policy based on our benchmark specification. Section 5 discusses additional results and robustness. Section 6 concludes.

2 Anticipated Monetary Policy and Imperfect Information

2.1 Is Monetary Policy Anticipated?

Twenty-five years ago, the Federal Reserve did not announce its monetary policy decisions to the public. Markets were left to infer the FOMC's decision by watching the open market desk buying or selling securities in financial markets. However, since then, FOMC communication has changed radically. In February 1994, for the first time, the Federal Reserve started issuing a statement immediately after the FOMC, noting its decision to tighten. The Federal Reserve mentioned that the statement was issued "to avoid any misunderstanding of the committee's purposes, given the fact that this is the first firming of reserve market conditions by the committee since early 1989." Since then, the Federal Reserve has become more and more transparent in its policy deliberations. Today, when the FOMC makes monetary policy decisions, it releases a detailed statement outlining the rationale for its current decisions and providing guidance for future ones. The FOMC also releases minutes and quarterly projections and holds press conferences. Further, the Chairman and the FOMC members give numerous speeches and press interviews throughout the year to explain their thinking. These tools help the FOMC to communicate its beliefs about the likely stance of monetary policy over the coming months and quarters.

Given the history of Federal Reserve communication, it is hard to argue that monetary policy decisions were always anticipated. This is especially before 1994, when the only signal agents received about future policy decisions were changes in the fed funds rate per se. However, with the first release of a FOMC statement in 1994, the idea that monetary policy is partly anticipated has gained ground and is largely accepted nowadays. For example, Gürkaynak et al. (2005) and Campbell et al. (2012) have demonstrated that monetary policy news (from FOMC statements) affects expectations about future monetary policy decisions. At the same time, Poole (2005) shows that since February 1994, policy decisions taken at regularly scheduled FOMC meetings, whether or not they have involved a federal funds target change, have generated relatively little surprise in the federal funds futures market. Such current decisions have been well anticipated by market participants. Moreover, Coibion and Gorodnichenko (2012) find an increase in the ability of financial markets and professional forecasters to predict subsequent interest rate changes after 1994. Similarly, Swanson (2006) documents improved predictability of US monetary policy by both professional forecasters and fed funds futures after communications reforms (including the introduction of FOMC statements in 1994).

Figure 1 plots the fed funds target rate with its expectations, i.e., six-months-ahead fed funds rate forecasts (both survey and market based). Expectations follow the dynamics of the fed funds rate well, indicating that future target rate decisions are anticipated to some extent. However, anticipation is not perfect as there is generally a gap between expectations and the policy rate. Policy cycle turning points seem hard to predict. Further, predictability of the fed funds rate seems to improve after 1994 as the gap between expectations and the fed fund rate gets smaller, especially during the 2001 and 2005 tightening cycles. In addition, the standard deviation of fed funds forecast has been declining over time, indicating increasing predictability of the policy rate.

2.2 A Simple Model of Noisy Monetary Policy

We present a simple theoretical framework to illustrate the effects of anticipated monetary policy shocks in an environment of imperfect information. The framework is a version of the one proposed in Forni et al. (2017) for news shock to total factor productivity (TFP), but adapted for the case of monetary policy.

Let us start from the assumption that there are two type of agents: the central bank, which has full information about the shocks hitting the economy, and the agents, who only have partial information in a sense that will be discussed and clarified below.[3] As a first step, let us consider the simplest case and assume that the interest rate is set by the bank according to

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

The shock ε_t affects the policy rate with a delay and defines the news or anticipated monetary policy shock.

We assume that agents form expectations rationally but information is limited. Agents receive news about the future path of interest rate, i.e., ε_t, in every period. We can think of the central bank announcing the future path of the interest rate. However, the announcement can be noisy in the sense that it does not fully reveal the future actual path of the interest rate.

[3]Note that in our setting, agents can observe other economic shocks fully.

This could be due to the lack of clear communication or lack of credibility by the central bank. As a result, in many cases market expectations might remain unfulfilled. We model this situation by assuming that the agents receive a signal, i.e., the communicated path of the interest rate,

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

where ν_t is the noise shock that is uncorrelated with ϵ_t at all leads and lags and 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 agents' information set, $\mathcal{I}_t$, consists of $\{i_{t-j}, s_{t-j}\}$ for $j \geq 0$. Now assume that agents make consumption decisions on the basis of the expected path of the interest rate, very simplistically $c_t = aE(i_{t+1}|\mathcal{I}_t)$. The expectation will coincide with the linear projection of ε_t onto s_t, $c_t = \gamma(\varepsilon_t + \nu_t)$, where $\gamma = \sigma_\varepsilon^2/\sigma_s^2$ is the linear projection coefficient. This means that the noise component can generate fluctuations in consumption. In general, under rational expectations and limited information, any variable that is the outcome of an agent's decisions and depends on the expected future interest rate will be affected by the noise component.

Now let us generalize the framework. First, we assume that there are other $n-2$ shocks ($n > 2$) driving the economy. All these additional shocks are observed both by the central bank and by the agents (and uncorrelated with news and noise shocks). Second, by definition of the news shock, we have a general impulse response function of the interest rate to the news/anticipated shock with a zero impact effect. Third, we assume that the central bank does not respond to the noise shock. This means that the bank will not react to fluctuations in the economy generated by the noise component. Notice that this last assumption implies a policy framework that is not consistent with a standard Taylor rule, where the interest rate responds to inflation and output. It is consistent with a rule where monetary policy reacts only to the non-noise component of inflation and output, the component driven by genuine economic shocks. So, the equation for the interest rate becomes

$$i_t = c(L)\varepsilon_t + q(L)'w_t, \tag{3}$$

where $q(L)$ is a $n-2$-dimensional column vector of lag polynomials and w_t is $n-2$-dimensional vector of economic shocks. The vector might include the standard non-anticipated policy shock as well as other real or nominal shocks. As before, agents do not observe the news shock but receive only a noisy signal. The information set of the agents is now the set spanned by $\{i_{t-j}, s_{t-j}, w_{t-j}\}$, $j \geq 0$. As long as agents react to the expected path of current and future interest rates, the economy will be affected by the noise shock. We do not model the non-policy part of the economy as the empirical strategy does not require any additional assumptions other than those discussed above.

3 The Econometric Model

As is well known, in the model described above, standard VAR methods using i_t and s_t fail in correctly identifying the anticipated shock since agents themselves cannot distinguish between news and noise shocks. In other words, the information set of agents differs from the information set spanned by the structural shocks, implying that the VAR is non-fundamental. To identify the news and noise shock in monetary policy, we follow Forni et al. (2017a) and Forni et al. (2017b). These papers propose a new identifying approach to recover the structural shocks in a noisy information setting based on dynamic rotations of future VAR residuals (see, e.g., Lippi and Reichlin, 1994). Here we discuss the main features of the econometric approach and we refer the reader to the papers for details. For ease of explanation, we start by describing a bivariate specification and then move to a more general specification that includes output and prices.

3.1 Bivariate Specification

Suppose that the policy rate is driven only by the news shock affecting the policy rate with a delay, i.e.,

$$i_t = c(L)\epsilon_t, \tag{4}$$

where $c(L)$ is a rational function in the lag operator with $c(0) = 0$ and the monetary policy news shock, ϵ_t, is a white noise process. As before, at time t agents receive some information about ϵ_t, i.e., the announcement. More specifically, they observe the signal that is given by equation 2. Agents also observe the policy rate at time t so that the agent's information set is $I_t = \text{span}(i_{t-k}, s_{t-k}, k \geq 0)$. Then, the structural representation becomes

$$\begin{pmatrix} i_t \\ s_t \end{pmatrix} = \begin{pmatrix} c(L) & 0 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} \epsilon_t \\ \nu_t \end{pmatrix}. \tag{5}$$

This representation is non-fundamental since the determinant of the MA matrix (i.e., $c(L)$) is zero at $L = 0$ by definition of the news shock. This implies that a VAR representation for i_t and s_t in the structural shocks does not exist, as present and past values of the observed series contain strictly less information than the present and past values of the structural shocks. However, we can find a fundamental representation with orthogonal innovations, i.e.,

$$\begin{pmatrix} i_t \\ s_t \end{pmatrix} = \begin{pmatrix} \frac{c(L)}{b(L)} & \frac{c(L)\sigma_\epsilon^2}{\sigma_s^2} \\ 0 & 1 \end{pmatrix} \begin{pmatrix} u_t \\ s_t \end{pmatrix}, \tag{6}$$

where

$$b(L) = \prod_{j=1}^{n} \frac{L - r_j}{1 - \bar{r}_j L} \tag{7}$$

with r_j, $j = 1, ..., n$, being the roots of $c(L)$ that are smaller than 1 in modulus and $\bar{r}_j$ being the complex conjugate of r_j. Moreover, u_t and s_t are orthogonal innovations for I_t, i.e., I_t =span$(u_{t-k}, s_{t-k}, k \geq 0)$ given by

$$\begin{pmatrix} u_t \\ s_t \end{pmatrix} = \begin{pmatrix} b(L)\frac{\sigma_\nu^2}{\sigma_s^2} & -b(L)\frac{\sigma_\epsilon^2}{\sigma_s^2} \\ 1 & 1 \end{pmatrix} \begin{pmatrix} \epsilon_t \\ \nu_t \end{pmatrix}. \tag{8}$$

The innovation u_t is the deviation of the realized policy rate from agents' expectations, that is, agents' new information due to the observation of i_t. Future realizations of the policy rate convey information about how noisy past signals were. This means that representation (8), although not invertible in the past, can be inverted in the future:

$$\begin{pmatrix} \epsilon_t \\ \nu_t \end{pmatrix} = \begin{pmatrix} b(F) & \frac{\sigma_\epsilon^2}{\sigma_s^2} \\ -b(F) & \frac{\sigma_\nu^2}{\sigma_s^2} \end{pmatrix} \begin{pmatrix} u_t \\ s_t \end{pmatrix}, \tag{9}$$

where F is the forward operator and $1/b(L) = b(F)$. The above equation shows that the news shock and noise shock are linear combinations of future and present values of u_t and s_t.

We further assume that the signal, s_t, is not observed by the econometrician but rather there is a variable z_t that reveals to the econometrician the information contained in the signal received by the agents. The signal-revealing series may depend on both u_t and s_t. Then, the representation in terms of the econometrician's information set (and with unit variance shocks) is given by

$$\begin{pmatrix} i_t \\ z_t \end{pmatrix} = \begin{pmatrix} a_{11}(L) & a_{12}(L) \\ a_{21}(L) & a_{22}(L) \end{pmatrix} \begin{pmatrix} u_t/\sigma_u \\ s_t/\sigma_s \end{pmatrix} = \begin{pmatrix} \frac{c(L)}{b(L)}\sigma_u & \frac{c(L)\sigma_\epsilon^2}{\sigma_s} \\ d(L)\sigma_u & f(L)\sigma_s \end{pmatrix} \begin{pmatrix} u_t/\sigma_u \\ s_t/\sigma_s \end{pmatrix}. \tag{10}$$

The mapping between the normalized innovations and the normalized structural shocks is

$$\begin{pmatrix} u_t/\sigma_u \\ s_t/\sigma_s \end{pmatrix} = \begin{pmatrix} b(L)\frac{\sigma_\nu}{\sigma_s} & -b(L)\frac{\sigma_\epsilon}{\sigma_s} \\ \frac{\sigma_\epsilon}{\sigma_s} & \frac{\sigma_\nu}{\sigma_s} \end{pmatrix} \begin{pmatrix} \epsilon_t/\sigma_\epsilon \\ \nu_t/\sigma_\nu \end{pmatrix}. \tag{11}$$

The structural representation is obtained by combining equations (10) and (11):

$$\begin{pmatrix} i_t \\ z_t \end{pmatrix} = \begin{pmatrix} c(L)\sigma_\epsilon & 0 \\ f(L)\sigma_\epsilon + b(L)d(L)\frac{\sigma_\nu^2\sigma_\epsilon}{\sigma_s^2} & f(L)\sigma_\nu - b(L)d(L)\frac{\sigma_\nu\sigma_\epsilon^2}{\sigma_s^2} \end{pmatrix} \begin{pmatrix} \epsilon_t/\sigma_\epsilon \\ \nu_t/\sigma_\nu \end{pmatrix}. \tag{12}$$

Estimation of representation (12) consists of two parts: first, we estimate and identify the fundamental representation (10); second, we identify (11). More specifically,

1. Estimate a reduced-form VAR for i_t and z_t and identify by imposing $\hat{a}_{12}(0) = 0$ (i.e., the signal does not affect the policy rate on impact). In the bivariate case, this is sufficient to identify u_t and s_t and to obtain an estimate of the impulse response function of equation (10).

2. Estimate $b(L)$ by calculating the roots of $\hat{a}_{12}(L)$, choosing those which are smaller than 1 in modulus in equation (7).

3. Estimate $\sigma_\epsilon/\sigma_\nu$ as the ratio $\frac{\hat{a}_{12}(1)}{\hat{a}_{11}(1)}$. 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.

This provides estimates of all the elements of representations (10) and (11) and, thus, (12).

3.2 Four-variable Specification

We now extend the above framework to a VAR specification that will be also used in the empirical application, which includes two additional variables: a measure of output and prices. In this four-variable VAR, the innovation representation in (10) becomes

$$\begin{pmatrix} y_t \\ p_t \\ i_t \\ z_t \end{pmatrix} = \begin{pmatrix} m_{11}(L) & m_{12}(L) & m_{13}(L) & m_{14}(L) \\ m_{21}(L) & m_{22}(L) & m_{23}(L) & m_{24}(L) \\ q_1(L) & q_2(L) & \frac{c(L)}{b(L)}\sigma_u & \frac{c(L)\sigma_\epsilon^2}{\sigma_s} \\ m_{41}(L) & m_{42}(L) & d(L)\sigma_u & f(L)\sigma_s \end{pmatrix} \begin{pmatrix} w_{1t} \\ w_{2t} \\ u_t/\sigma_u \\ s_t/\sigma_s \end{pmatrix}, \tag{13}$$

where y_t and p_t are time series for output and prices, $q(L) = [q_1(L)\ q_2(L)]$ and w_{1t} and w_{2t} are two structural orthonormal white noise shocks. Within this specification, the condition that s_t does not affect i_t on impact is no longer sufficient to identify the two innovations. Therefore, in order to identify the innovation, u_t, and the signal, s_t, we impose a Cholesky triangularization with output and prices ordered before the policy rate and the signal-revealing variable. That is, $m_{12}(0) = m_{13}(0) = m_{14}(0) = m_{23}(0) = m_{24}(0) = 0$ in addition to the maintained assumption that $c(0) = 0$. The u_t and the s_t will be the third and fourth innovations of this Cholesky representation, respectively. The advantage of this approach is that, by ordering interest rate after prices and output, we make the signal orthogonal to current and past prices and output. This is important to ensure that our identified noise is not contaminated by other factors like demand shocks or other policy shocks. The drawback is that, in the presence of a standard non-anticipated monetary policy shock satisfying the standard zero restrictions of no contemporaneous effect on prices and output, the fed funds rate innovation could mix u_t and the non-anticipated shock. We confront this problem by also identifying the standard policy shock. It turns out that the results obtained by including the non-anticipated shock are almost identical, suggesting that this potential drawback is not empirically relevant.

The structural representation is obtained by post-multiplying the matrix above with the multivariate extension of the matrix that maps innovations to structural shocks, equation (11), that is,

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & b(L)\frac{\sigma_\nu}{\sigma_s} & -b(L)\frac{\sigma_\epsilon}{\sigma_s} \\ 0 & 0 & \frac{\sigma_\epsilon}{\sigma_s} & \frac{\sigma_\nu}{\sigma_s} \end{pmatrix}. \tag{14}$$

The multivariate model can be estimated by following the same steps as in the bivariate case. Note that the model can be easily extended to include additional variables as long as we impose additional restrictions on the innovation representation. For example, one could include financial time series by ordering them last, assuming that the signal affects financial variables immediately.

4 Empirical Evidence

4.1 Data

We estimate our model at monthly frequency over the sample 1994:01–2016:10. As described earlier, starting the sample in 1994 is motivated by the introduction of policy statements by the FOMC. For output and prices, we use the U.S. Industrial Production (IP) Index and the Consumer Price Index (CPI). Both series are obtained from Haver Analytics. In addition, 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 signal, z_t. We use the monthly average of the effective fed funds rate for i_t and choose measures of expectations of the fed funds rate to reveal the signal. In particular, in the baseline specification, we use the Blue Chip Financial Forecast (BCFF) survey to obtain a measure of fed funds rate expectations. In the robustness section, we also use a market-based measure of expectations obtained from fed funds futures.

4.1.1 Survey-based Expectation Measures

First, we employ survey-based expectations of the fed funds rate. The BCFF is the only one that provides forecasts of the Federal Reserve's policy rate per se. Since 1982, the BCFF survey has been conducted monthly, covering approximately 50 analysts ranging from broker-dealers to economic consulting firms. The BCFF is published on the first day of each month and presents forecasts from a survey conducted during two consecutive business days one to two weeks earlier. The precise dates of the survey vary and are not generally noted in the publication. Since April 1983, each month the BCFF has provided the forecasts of the average interest rate over a particular quarter, beginning with the current quarter and up to four or five quarters into the future.[4] For example, in January, the forecast of the current quarter is given by the average expected realization over January, February and March, and the one-quarter-ahead forecast is given by the average expected realization over April, May, and June.

Therefore, the monthly BCFF forecasts are fixed-event forecasts of interest rates over the quarter, implying that their forecast horizon changes with each month in the quarter. We construct fixed-horizon forecasts by weighting the two given fixed-event forecasts following Chun (2011) (or see Dovern et al. (2012) for an application to the survey data of GDP and prices). We focus on the one-quarter- to four-quarters-ahead forecasts and define the six-months-ahead (fixed-horizon) forecast as follows. In the first month of the quarter, the six-months-ahead forecast is simply the forecast of the one-quarter-ahead forecast. In the second month of the quarter, the six-months-ahead forecast is obtained by taking the average of the one-quarter- and two-quarters-ahead forecasts with weights equal to 2/3 and 1/3, respectively. The six-months-ahead forecast for the final month of the quarter is the weighted average of the one-quarter- and two-quarters-ahead forecast with weights equal to 1/3 and 2/3. The nine-months-ahead forecasts are calculated as the weighted average of the two-quarters- and three-quarters-ahead forecasts given by the survey with weights similar to the ones discussed above. The 12-months-ahead forecasts are defined accordingly. Finally, we use the consensus forecast (mean across the 50 analysts).

4.1.2 Market-based Expectation Measures

Second, we use market-based expectations of the fed funds rate. The fed funds futures contract price represents the market opinion of the average daily fed funds effective rate as calculated and reported by the Federal Reserve Bank of New York for a given calendar month. It is designed to capture the market's need for an instrument that reflects Federal

[4] Before 1983, forecasts only exist for the current and then every other quarter.

Reserve monetary policy. Fed funds futures and options have long been regarded as an effective means of tracking market expectations of monetary action by the FOMC. Futures for the fed funds rate started trading in the late '80s (December '88) but only up to a six-months-ahead horizon. Meaningful trading volumes of up to 24 months ahead begin only in 2004 (up to 36 months ahead in 2011). We use six-months-ahead fed funds futures as an alternative measure for expectations of future monetary policy. One disadvantage of working with market-based expectations measures such as futures is that they contain a risk premium (that is increasing with horizon). (See, e.g., Kuttner, 2001 and Coibion et al., 2017 for a more general discussion.) We follow Kuttner (2001), and use the difference between the future price before and after FOMC announcement dates to purge for risk premia. Because FOMC meetings are not held on a monthly basis, to transform a monthly series we assume that the daily change in the fed funds rate is zero in months with no meeting (see Romer and Romer, 2004 among others). Finally, the data on fed funds futures are obtained from Bloomberg, and the FOMC announcements dates are obtained from the Federal Reserve's website.[5]

4.2 Bivariate VAR

We start by estimating a VAR containing the policy rate and its expectations, i.e., the noise-free and signal-revealing series, respectively. Specifically, the VAR includes the fed funds rate and the BCFF expectations of the fed funds rate at the six-month horizon. We include nine lags in line with the Akaike Information Criterion (AIC) and identify the innovation, u_t, the signal, news and noise shocks as described in Section 3.1; i.e., the signal does not affect the policy rate on impact. Figure 2 shows the impulse response functions of the fed funds rate and its survey-based expectations for the signal and the news and noise shocks, respectively. Light- and dark-shaded areas represent the confidence bands at the 90% and 68% levels, respectively, and are obtained by Kilian (1998)'s method.

The signal shock increases fed funds rate expectations on impact but does not affect the policy rate (by assumption). Afterwards the signal shock increases the policy rate significantly. Decomposing the signal between news and noise, fed funds rate expectations increase on impact following both the news and noise shock. However, the noise shock has a bigger impact effect. The effect of noise turns insignificant after about five months. In line with theory, the effect of the noise shock on the policy rate is small and insignificant across all horizons.

[5] See `https://www.federalreserve.gov/monetarypolicy/fomc_historical_year.htm`.

4.3 Four-variable VAR

Our benchmark specification includes the log of IP, the log of CPI, the effective fed funds rate and six-months-ahead BCFF expectations of the fed funds rate. We include nine lags, as suggested by the AIC. As explained in Section 3, identification is achieved by assuming that IP and prices do not react on impact to the policy rate innovation and the signal. Moreover, the signal does not affect the fed funds rate on impact.

Figure 3 shows the impulse response function of the four variables in the VAR to the signal, news and noise shocks. As before, light- and dark-shaded areas represent confidence bands at the 90% and 68% level, respectively. As expected, the signal shock increases fed funds expectations (by about 10 basis points) and significantly anticipates the future policy rate. Moreover, the signal decreases IP significantly at all horizons with a peak effect of circa -0.4 percentage points after about three years. Prices also decrease significantly following the signal shock.

Let us now consider effects of news and noise shocks. First, note that the estimates of σ_ϵ/σ_s and σ_ν/σ_s are 0.51 and 0.86, respectively, implying that the signal is quite noisy. The noise, as predicted by the model, has no significant effect on the fed funds rate at all horizons. However, the news shock increases the fed funds rate significantly with a delay, reaching its peak response after about a year. The response turns insignificant after around two years. Further, the news shock increases fed funds expectations significantly for about two years, while the noise shock does so for about a quarter.

Turning to macroeconomic variables, the news shock decreases IP in the medium to long run as the response turns negative after about two years (significantly negative after three years). In contrast, the noise shock decreases IP significantly in the short run, reaching its minimum response of -0.4 percentage points after about a year. The noise shock response of IP reverts after about two years and becomes insignificant. The effects of the noise shock seem to vanish once agents learn that the signal was just noise. At the same time, the actual news starts to show its effect on IP. As for prices, a news shock seems to negatively affect prices in the long run, while the noise shock decreases prices significantly across all horizons.

Moreover, Table 4 presents the estimated decomposition of the forecast error variance at different horizons. The signal explains between 13% and 19% of variations in the fed funds rate, providing further evidence that interest rate decisions are partly anticipated. It explains 60% of the variance in fed funds expectations on impact and afterwards between 20% and 27%. Concerning the macroeconomic variables, the signal innovation explains a relatively large fraction of IP (4%–22%) and the signal can explain up to 16% of the forecast error variance of prices in the long run.

Turning to the analysis of news and noise shocks, on impact, monetary policy expectations are largely driven by noise but less so at longer horizons as news takes on a bigger role. In line with our assumption, the fed funds rate is barely explained by noise and its largest driver is the monetary policy news shock, explaining between 80% and 86% of its variation. Fluctuations in IP and CPI seem to be driven more by noise than news surrounding future monetary policy decisions in the short and medium run. At the longer horizon, the noise shock accounts for up to 16% and 13% of the variance of IP and prices, respectively. News accounts for up to 19% and 6% of the long-run variation of IP and prices, respectively.

5 Additional Analysis

In what follows, we assess the robustness of our results when employing alternative measures of fed funds expectations, i.e., first, survey expectations at the nine-month and 12-month horizon, and second, the daily change in fed funds futures at the six-month horizon. Next, we provide evidence on the nature of monetary policy before 1994. Further, we perform additional analysis, studying the effects of monetary policy news and noise in financial markets. Finally, we assess the role of unanticipated (conventional) monetary policy shocks in our setting.

5.1 Alternative Measure of Expectations

First, we use the BCFF survey-based expectations at the nine-months- and 12-months-ahead horizons. Figure 4 shows the impulse responses for the four-variate VAR including the nine-months-ahead fed funds expectations. Responses are very similar. The signal decreases output and prices significantly across all horizons. (The responses of prices to the signal are not always significant in the short run.) The effects of the signal on the fed funds rate and its expectations at the nine-month horizon are nearly identical with our benchmark specification. Moreover, the responses of IP and prices to news and noise shocks remain similar. The corresponding figure including the 12-months-ahead survey expectations are again very similar and are not presented here, for the sake of brevity.

In addition, let us consider the estimates of σ_ϵ/σ_s and σ_ν/σ_s. Recall that in the case of six-month survey expectations, these ratios are 0.51 and 0.86, respectively, implying that the signal is quite noisy. Table 2 summarizes these ratios for alternative expectations horizons. The signal becomes noisier as the horizon increases. This is quite intuitive and suggests that the Federal Reserve provides relatively clearer signals for the near future.

Given that the survey-based expectations are published at the monthly frequency, one could argue that other news shocks, different from the monetary policy news, such as news about TFP, could influence fed funds rate expectations. This would imply that our identified monetary policy news shock could potentially mix different shocks. We address this concern by using the market-based measure of interest rate expectations described in Section 4.1.2. In particular, we replace the fourth variable in our four-variate specification with the monthly and cumulated representation of the daily change in six-months-ahead fed funds futures around FOMC announcement dates.[6] This measure of expectations reflects the monetary policy news contained in the announcement and is unlikely to be influenced by other macroeconomic news. Figure 5 reports the responses for signal, and news and noise shocks, respectively. Responses show the same patterns as before, although less significant.

5.2 Monetary Policy before 1994

In the sections above, we argued that there is little support for monetary policy anticipation before 1994. So, one could ask what results are obtained by the new-noise econometric framework using an estimation sample that stops in 1993. The impulse responses for the four-variate VAR estimated over 1983:04-1993:12 are provided in Figure 6. Over this sample period, neither the signal shock, the news shock nor the noise shock have any significant effects. Moreover, the signal shock has no significant effect on the fed funds rate, consistent with the view that before 1994, there was little anticipation of future monetary policy decisions.[7]

5.3 News, Noise, and Financial Markets

We now assess the effects of news and noise for financial markets. To do so, we separately estimate five-variate VARs, each including one of the following financial market variables: the excess bond premium (EBP), the corporate bond spread, the S&P 500 stock price index, and the VIX. In particular, the EBP is obtained from Gilchrist and Zakrajsek (2012) and is a popular indicator of tightness in credit markets. The EBP estimates the extra compensation demanded by bond investors for bearing exposure to U.S. non-financial corporate credit risk beyond the compensation for expected losses. For the corporate bond spread, we use the difference between the Moody's seasoned BAA and AAA corporate bond yields.

Figure 7 shows the responses of the financial market variables to signal, news and noise shocks. For the sake of brevity, we do not present the responses of the macroeconomic

[6]Like Romer and Romer (2004) and Barakchian and Crowe (2013), we cumulate the market-based measure. The rationale for using the cumulated series, which is I(1) by construction, is that the output and price series are generally considered I(1); hence, if the I(0) series were included, the VAR would be statistically unbalanced.

[7]The same results are obtained when estimating the bivariate VAR over 1983:04 - 1993:12.

variables since they are very similar to the responses obtained in our benchmark specification. The signal increases the EBP, the corporate spread and volatility in financial markets as measured by the VIX for about a year, while it decreases stock prices. When we decompose the signal into news and noise, the monetary policy news shock has a significant effect on the EBP and stock prices in the short run. Moreover, noise surrounding future monetary policy decisions affects all financial market indicators significantly on impact and up to about a year. Looking at the variance decompositions, the noise shock can explain between 2% and 12% of the variation in stock prices while news explains between 1% and 7%. Further monetary policy news seems to be a more important driver of the EBP than noise. Finally, the noise shock explains between 3% and 6% of the variation in the VIX.

5.4 The Role of Non-anticipated Monetary Policy

A potential drawback of our approach is that the innovation in the fed funds rate estimated with the Cholesky representation could potentially mix the innovation u_t and the non-anticipated policy shock, if present. Here we explicitly identify the non-anticipated shock, in addition to the anticipated one, in order to check whether the results are unchanged and confirm the validity of our procedure.

In order to identify the non-anticipated monetary policy shock, we rely on the high-frequency identification approach based on fed funds futures data. In particular, we add the daily change in current-month fed funds futures around FOMC announcements, i.e., the current surprise, to our benchmark VAR. We order the current surprise after IP and prices. Similar in spirit to Gürkaynak et al. (2005), the current surprise is included in the VAR before our measure of fed funds expectations.[8] The third shock in the innovation representation can then be interpreted as the non-anticipated monetary policy or surprise shock (surprise changes in the current fed funds rate target), which is orthogonal to the signal.

Figure 8 shows the responses to the non-anticipated monetary policy shock. IP and prices decrease following a surprise change in the current fed funds target rate. (However, we can observe a light version of the price puzzle in the very short run.) The responses of IP and CPI to the signal innovation remain unchanged. Similarly, the results remain unchanged for news and noise shocks. Moreover, the current surprise does not react to

[8]Gürkaynak et al. (2005) extract the first two principal components of the daily changes in fed funds futures across several horizons. By performing a suitable rotation of these unobserved factors, they show that they can be given a structural interpretation as a "current federal funds rate target" factor, corresponding to surprise changes in the current fed funds rate target, and a "future path of policy" factor, corresponding to changes in futures rates out to horizons of one year that are independent of changes in the current funds rate target.

noise, as remains the case for the fed funds rate. Interestingly, the news shock increases the current surprises and the fed funds rate with a delay (as before). This makes sense as future changes in the fed funds rate are only partly anticipated. Hence, news is also associated with future surprises.

Turning to the variance decompositions, we find that the signal plays a relatively more important role for variations in IP than the non-anticipated shock. The surprise shock explains between 1% and 10% of IP variations, while the signal explains between 4% and 18%. However, the surprise seems to explain a larger fraction of the long-run variation in prices than the signal does. Further, we find that the role of news and noise for variations in IP and prices is relatively unchanged. Noise explains between 6% and 17% of the variance in output and between 2% and 15% of the variance in prices.

6 Conclusion

In this paper, we introduce imperfect information to the conduct of monetary policy. Agents receive news concerning future monetary policy decisions but observe only a noisy signal that can be decomposed into the news shock and the noise shock. As time passes, agents observe the actual interest rate decisions and can distinguish the news from noise. In this setting, empirical analysis becomes challenging as standard VAR methods fail. Against this backdrop, we rely on non-standard VAR methods involving rotations of future VAR residuals.

We provide new insight into how to characterize monetary policy shocks since the mid-1990s by assessing the role of news and noise in monetary policy. We find that interest rate decisions are partly anticipated. Output and prices decrease following a signal shock, revealing potential contractionary monetary policy actions in the future. Interestingly, the signal is quite noisy, implying that output and prices react sizably to noise in monetary policy. Moreover, noise surrounding future monetary policy decisions disturbs financial markets significantly as it increases the EBP, the corporate spread, and financial market volatility and decreases stock prices.

Our results suggest the following for the conduct of monetary policy. First, noise surrounding monetary policy is economically costly and can disrupt financial markets. Second, forward guidance (in the sense of guiding the future path of interest rates) can be valuable if clearly communicated and if a central bank can commit to its future decisions.

References

Barakchian, S. M. and Crowe, C. (2013). Monetary Policy Matters: Evidence from New Shocks Data, *Journal of Monetary Economics* **60**(8): 950–966.

Bernanke, B., Boivin, J. and Eliasz, P. S. (2005). Measuring the Effects of Monetary Policy: A Factor-augmented Vector Autoregressive (FAVAR) Approach, *The Quarterly Journal of Economics* **120**(1): 387–422.

Blanchard, O. J., L'Huillier, J.-P. and Lorenzoni, G. (2013). News, Noise, and Fluctuations: An Empirical Exploration, *American Economic Review* **103**(7): 3045–70.

Campbell, J. R., Evans, C. L., Fisher, J. D. M. and Justiniano, A. (2012). Macroeconomic Effects of Federal Reserve Forward Guidance, *Working Paper Series WP-2012-03*, Federal Reserve Bank of Chicago.

Christiano, L. J., Eichenbaum, M. and Evans, C. L. (1999). Monetary Policy Shocks: What Have We Learned and to What End?, *in* J. B. Taylor and M. Woodford (eds), *Handbook of Macroeconomics*, Vol. 1 of *Handbook of Macroeconomics*, Elsevier, chapter 2, pp. 65–148.

Chun, A. L. (2011). Expectations, Bond Yields, and Monetary Policy, *Review of Financial Studies* **24**(1): 208–247.

Cochrane, J. H. (1998). What do the VARs Mean? Measuring the Output Effects of Monetary Policy, *Journal of Monetary Economics* **41**(2): 277–300.

Coibion, O. and Gorodnichenko, Y. (2012). Why Are Target Interest Rate Changes So Persistent?, *American Economic Journal: Macroeconomics* **4**(4): 126–162.

Coibion, O., Gorodnichenko, Y. and Kamdar, R. (2017). The Formation of Expectations, Inflation and the Phillips Curve, *NBER Working Papers 23304*, National Bureau of Economic Research, Inc.
URL: *https://ideas.repec.org/p/nbr/nberwo/23304.html*

D'Amico, S. and King, T. B. (2015). What Does Anticipated Monetary Policy Do?, *Working Paper Series WP-2015-10*, Federal Reserve Bank of Chicago.

Dovern, J., Fritsche, U. and Slacalek, J. (2012). Disagreement Among Forecasters in G7 Countries, *The Review of Economics and Statistics* **94**(4): 1081–1096.

Eggertsson, G. B. and Woodford, M. (2003). The Zero Bound on Interest Rates and Optimal Monetary Policy, *Brookings Papers on Economic Activity* **34**(1): 139–235.

Forni, M. and Gambetti, L. (2010). The Dynamic Effects of Monetary Policy: A Structural Factor Model Approach, *Journal of Monetary Economics* **57**(2): 203–216.

Forni, M., Gambetti, L., Lippi, M. and Sala, L. (2017a). Noise Bubbles, *Economic Journal* **127**(604): 1940–1976.

Forni, M., Gambetti, L., Lippi, M. and Sala, L. (2017b). Noisy News in Business Cycles, *American Economic Journal: Macroeconomics* **9**(4): 122–152.

Gertler, M. and Karadi, P. (2015). Monetary Policy Surprises, Credit Costs, and Economic Activity, *American Economic Journal: Macroeconomics* **7**(1): 44–76.

Gilchrist, S. and Zakrajsek, E. (2012). Credit Spreads and Business Cycle Fluctuations, *American Economic Review* **102**(4): 1692–1720.

Goodfriend, M. and King, R. G. (2005). The Incredible Volcker Disinflation, *Journal of Monetary Economics* **52**(5): 981–1015.

Gürkaynak, R. (2005). Using Federal Funds Futures Contracts for Monetary Policy Analysis, *Federal Reserve Board Finance and Economics Discussion Series* **2005**(29).

Gürkaynak, R. S., Sack, B. and Swanson, E. (2005). Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements, *International Journal of Central Banking* **1**(1).

Hansen, L. and Sargent, T. (1991). Two Difficulties in Interpreting Vector Autorgressions, *in* L. Hansen and T. Sargent (eds), *Rational Expectations Econometrics*, Westview Press, chapter 4, pp. 77–119.

Kilian, L. (1998). Small-Sample Confidence Intervals For Impulse Response Functions, *The Review of Economics and Statistics* **80**(2): 218–230.

Kuttner, K. N. (2001). Monetary Policy Surprises and Interest Rates: Evidence from the Fed Funds Futures Market, *Journal of Monetary Economics* **47**(3): 523–544.

Lakdawala, A. (2016). Decomposing the Effects of Monetary Policy Using an External Instruments SVAR, *MPRA Paper 78254*, University Library of Munich, Germany. **URL:** *https://ideas.repec.org/p/pra/mprapa/78254.html*

Laséen, S. and Svensson, L. E. O. (2011). Anticipated Alternative Instrument-Rate Paths in Policy Simulations, *International Journal of Central Banking* **7**(2): 1–35.

Lippi, M. and Reichlin, L. (1993). The Dynamic Effects of Aggregate Demand and Supply Disturbances: Comment, *American Economic Review* **83**(3): 644–52.

Lippi, M. and Reichlin, L. (1994). VAR Analysis, Nonfundamental Representations, Blaschke Matrices, *Journal of Econometrics* **63**(1): 307–325.

Milani, F. and Treadwell, J. (2012). The Effects of Monetary Policy "News" and "Surprises", *Journal of Money, Credit and Banking* **44**(8): 1667–1692.

Mishkin, F. S. (1982). Does Anticipated Monetary Policy Matter? An Econometric Investigation, *Journal of Political Economy* **90**(1): 22–51.

Poole, W. (2005). How Predictable is Fed Policy?, *Federal Reserve Bank of St. Louis Review* (Nov): 659–668.

Romer, C. D. and Romer, D. H. (2004). A New Measure of Monetary Shocks: Derivation and Implications, *American Economic Review* **94**(4): 1055–1084.

Sims, C. A. (1992). Interpreting the Macroeconomic Time Series Facts: The Effects of Monetary Policy, *European Economic Review* **36**(5): 975–1000.

Swanson, E. T. (2006). Have Increases in Federal Reserve Transparency Improved Private Sector Interest Rate Forecasts?, *Journal of Money, Credit and Banking* **38**(3): 791–819.

Swanson, E. T. (2017). Measuring the Effects of Federal Reserve Forward Guidance and Asset Purchases on Financial Markets, *NBER Working Papers 23311*, National Bureau of Economic Research, Inc.

Tables and Figures

Table 1: ***Four-Variate VAR: Variance Decomposition***

Variable	Horizon (months)					
	Impact	6	12	24	48	84
	Signal					
IP	0.0	3.8	6.4	8.4	18.1	21.8
CPI	0.0	2.6	4.1	3.6	8.4	15.6
FFR	0.0	13.4	17.9	19.0	18.4	18.2
E(FFR)	58.5	26.7	24.5	21.8	20.9	20.7
	News					
IP	0.0	0.0	0.6	1.4	11.8	18.5
CPI	0.0	0.9	2.1	3.2	3.2	6.0
FFR	0.0	86.4	86.2	83.8	81.1	80.3
E(FFR)	24.4	85.5	85.2	82.0	79.4	78.6
	Noise					
IP	0.0	4.8	11.1	16.0	16.8	16.2
CPI	0.0	2.1	3.5	6.6	11.0	13.3
FFR	0.0	0.8	0.3	0.2	0.3	0.5
E(FFR)	68.1	2.9	1.2	0.8	0.9	1.0

Notes: Variance decomposition in the four-variate VAR. The entries are the percentage of variance explained by the shocks at the specified horizons.

Table 2: ***Noise-to-Signal and News-to-Noise Ratio***

	Expectation Horizon		
	6-month	9-month	12-month
σ_ϵ/σ_s	0.51	0.45	0.18
σ_ν/σ_s	0.86	0.89	0.98
$\sigma_\epsilon/\sigma_\nu$	0.60	0.51	0.18

Table 3: ***Five-Variate VARs with Financial Indicators: Variance Decomposition***

Variable	Horizon (months)					
	Impact	6	12	24	48	84
	Signal					
EBP	7.2	10.2	9.8	9.3	8.0	8.4
BAA-AAA	4.3	7.9	9.0	8.8	8.8	9.1
S&P 500	3.2	10.8	11.8	8.3	10.6	11.2
VIX	3.7	7.9	7.9	7.7	8.8	8.9
	News					
EBP	3.6	8.1	8.7	8.5	15.5	17.4
BAA-AAA	0.8	0.5	4.5	12.3	25.1	25.9
S&P 500	1.0	2.9	2.2	2.0	5.4	6.9
VIX	0.7	1.9	7.4	9.1	22.2	22.8
	Noise					
EBP	3.6	3.3	4.0	4.9	7.1	7.0
BAA-AAA	3.6	8.3	10.9	9.6	7.9	8.1
S&P 500	2.2	8.1	12.3	12.0	11.2	10.7
VIX	3.0	6.3	6.0	5.6	4.6	4.6

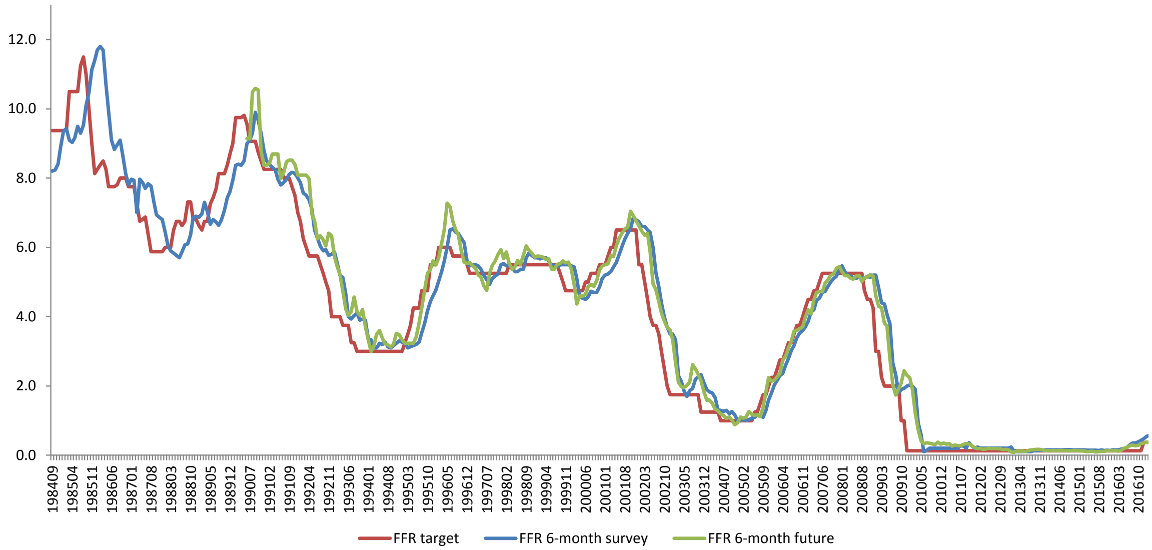
Notes: Variance decomposition in the five-variate VARs including one of the following financial indicators: the EBP, the BAA-AAA spread, the S&P 500 index, the VIX. The entries are the percentage of variance explained by the shocks at the specified horizons.

Table 4: ***Five-Variate VAR with Conventional Monetary Policy Shock: Variance Decomposition***

Variable	Horizon (months)					
	Impact	6	12	24	48	84
	Surprise					
IP	0.0	1.2	2.8	4.0	6.6	9.5
CPI	0.0	0.9	1.4	2.5	5.7	11.8
Current Surprise	99.7	91.4	83.2	75.3	57.8	49.4
FFR	8.2	10.1	7.1	9.8	11.2	10.2
E(FFR)	1.8	7.9	6.8	9.8	10.4	9.7
	Signal					
IP	0.0	3.8	6.3	8.0	16.4	17.8
CPI	0.0	3.5	3.9	2.1	3.0	5.9
Current Surprise	0.0	4.0	9.9	15.1	11.0	14.1
FFR	0.0	10.6	16.1	18.9	18.5	18.3
E(FFR)	62.2	24.0	22.5	21.8	21.1	20.7
	News					
IP	0.0	0.6	0.3	0.3	8.4	10.2
CPI	0.0	1.6	1.7	4.0	3.0	2.2
Current Surprise	0.0	4.8	11.8	13.9	9.1	9.5
FFR	0.0	55.4	62.5	59.7	58.0	54.2
E(FFR)	60.5	66.8	66.2	60.1	58.8	55.1
	Noise					
IP	0.0	5.5	14.2	19.5	17.1	16.7
CPI	0.0	2.2	5.1	9.6	11.8	14.7
Current Surprise	0.0	0.4	0.5	3.7	13.5	14.6
FFR	0.0	16.6	15.0	11.6	11.0	11.5
E(FFR)	30.1	9.3	11.2	9.5	9.2	9.8

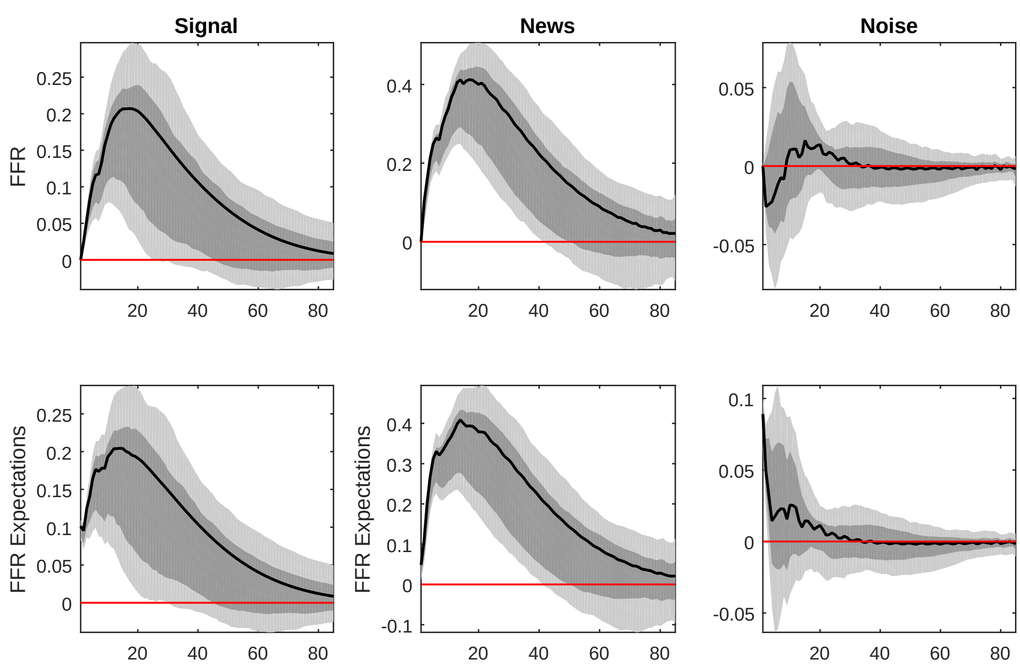
Notes: Variance decomposition in the five-variate VAR identifying the conventional monetary policy shock (surprise shock). The entries are the percentage of variance explained by the shocks at the specified horizons.

Figure 1: ***Fed Funds Rate and its Expectations***



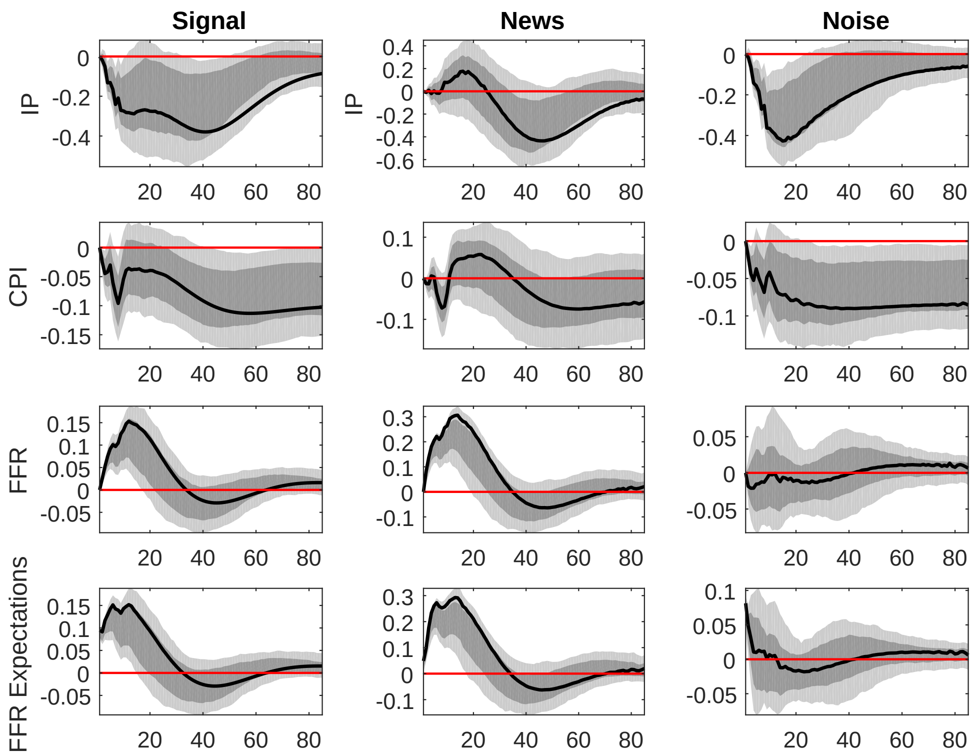
Notes: Fed funds rate at time t, i_t, along with six-months-ahead survey and market expectations at $t-6$, $E_{t-6}(i_t)$.

Figure 2: ***Bivariate VAR: Signal, News, and Noise***



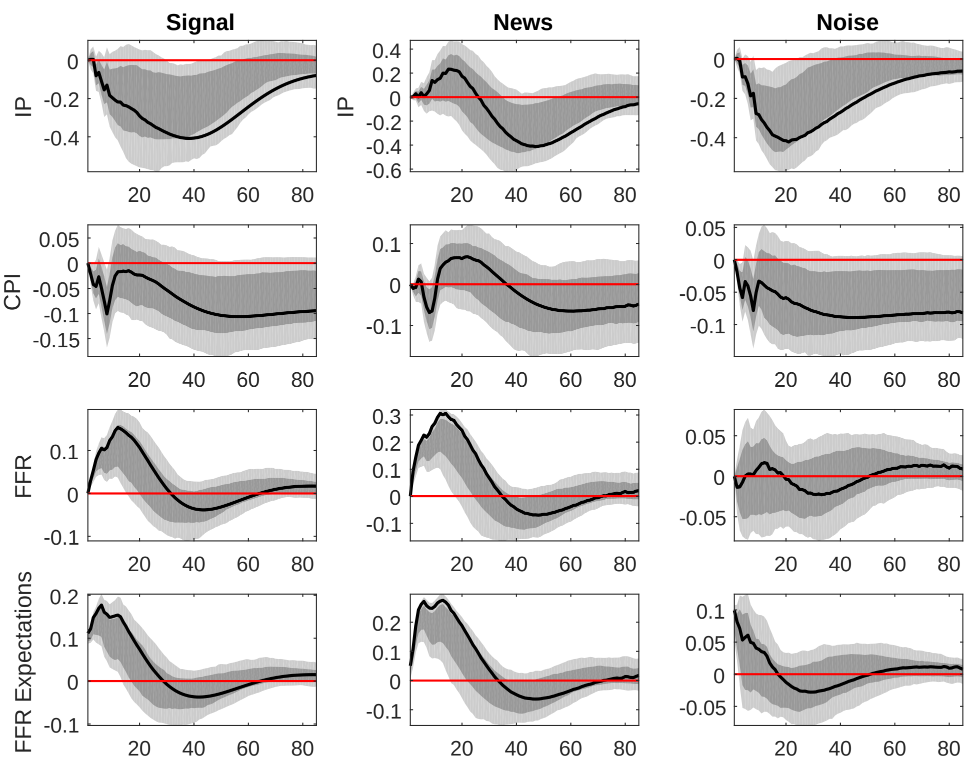
Notes: Bivariate VAR containing the fed funds rate and six-months-ahead survey-based fed funds expectations. Estimation sample: 1994 January – 2016 October.

Figure 3: ***Four-variate VAR: Signal, News, and Noise***



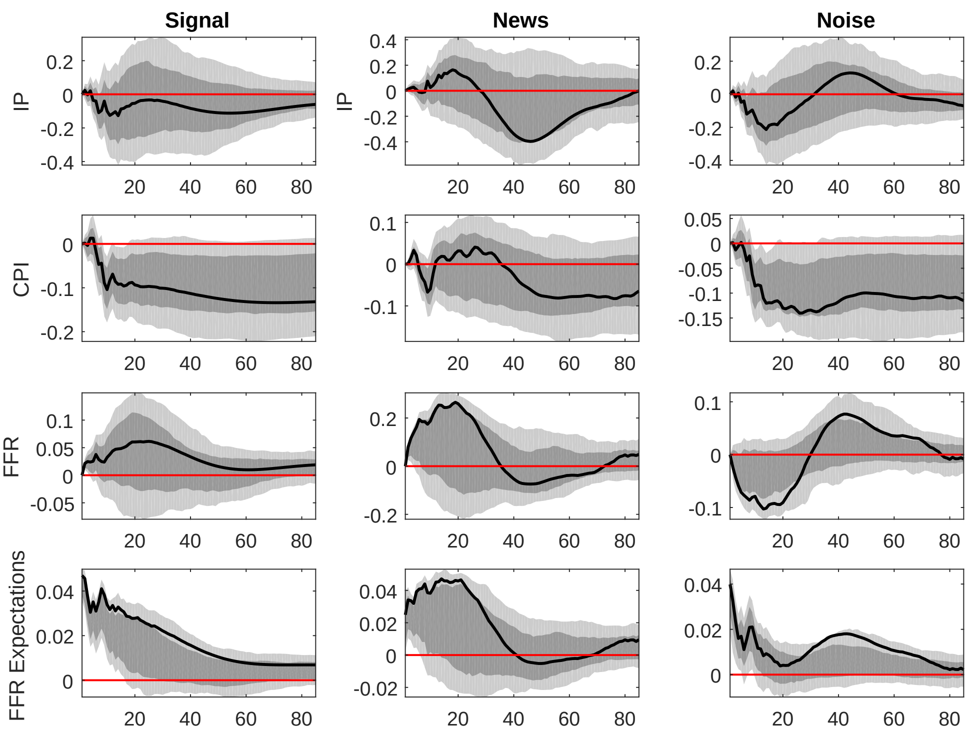
Notes: VAR containing logarithm of IP, the logarithm of CPI, the fed funds rate and six-months-ahead survey-based fed funds expectations. Estimation sample: 1994 January – 2016 October.

Figure 4: ***Four-variate VAR (Incl. Nine-month Expectations): Signal, News, and Noise***



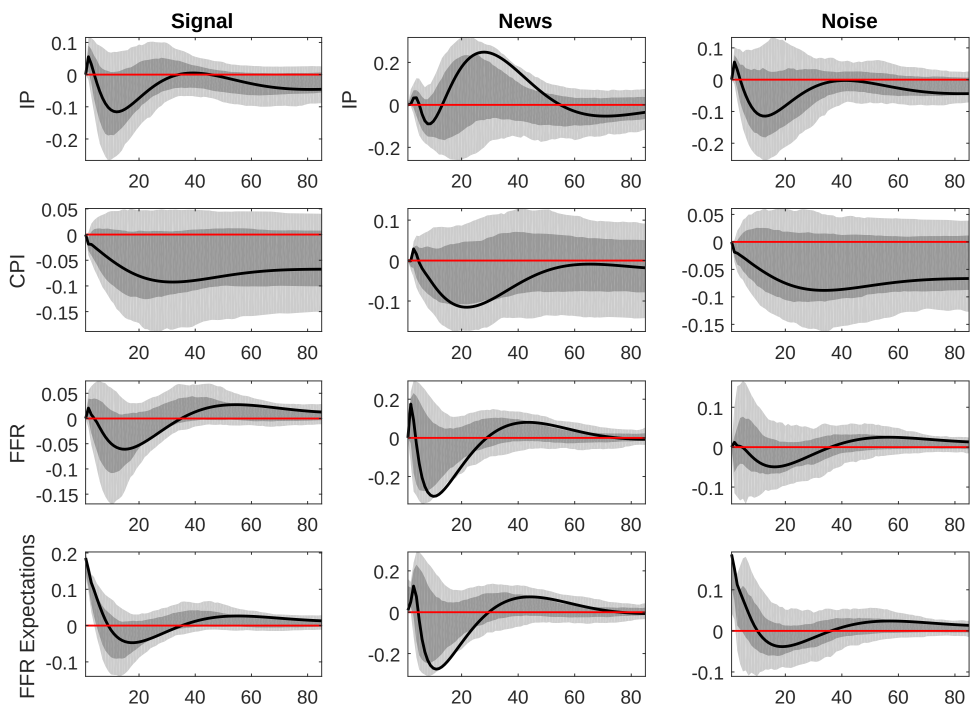
Notes: VAR containing logarithm of IP, the logarithm of CPI, the fed funds rate and nine-months-ahead survey-based fed funds expectations. Estimation sample: 1994 January - 2016 October.

Figure 5: ***Four-variate VAR (Incl. Market-based Expectations): Signal, News, and Noise***



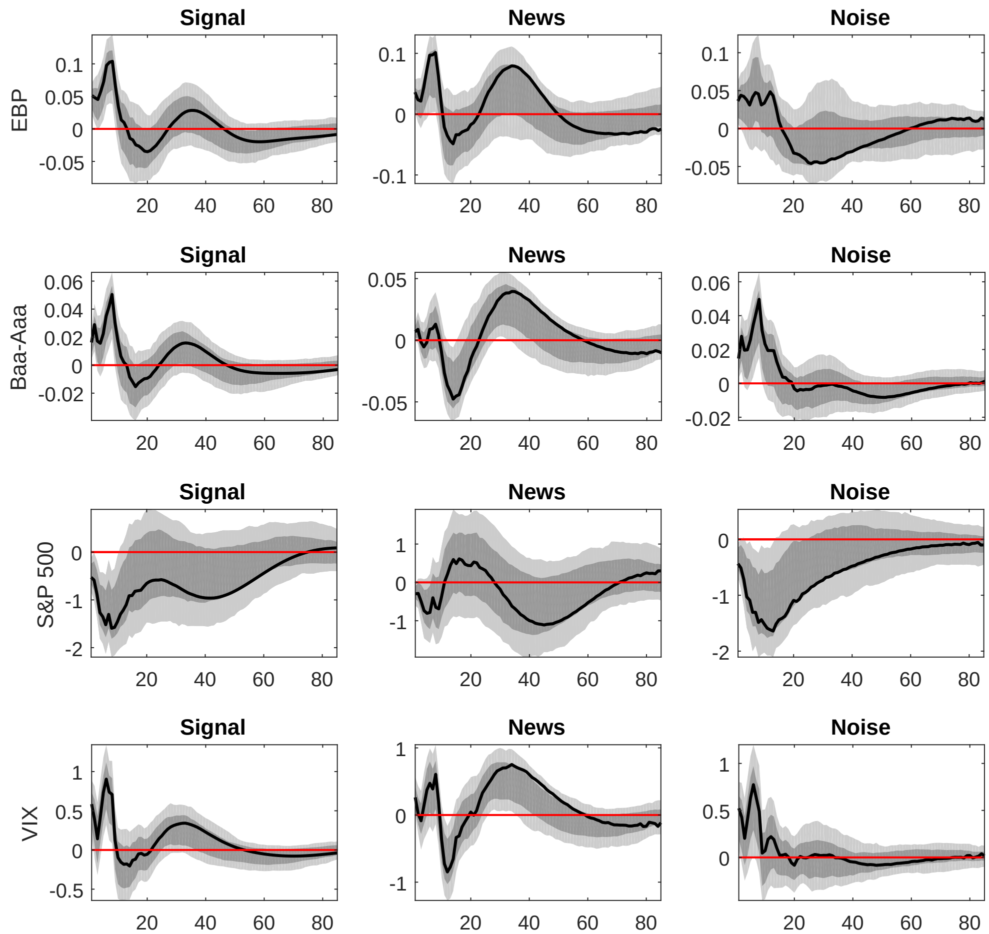
Notes: VAR containing logarithm of IP, the logarithm of CPI, the Fed funds rate and six-months-ahead market-based fed funds expectations. Estimation sample: 1994 January - 2016 October.

Figure 6: ***Four-variate VAR before 1994: Signal, News, and Noise***



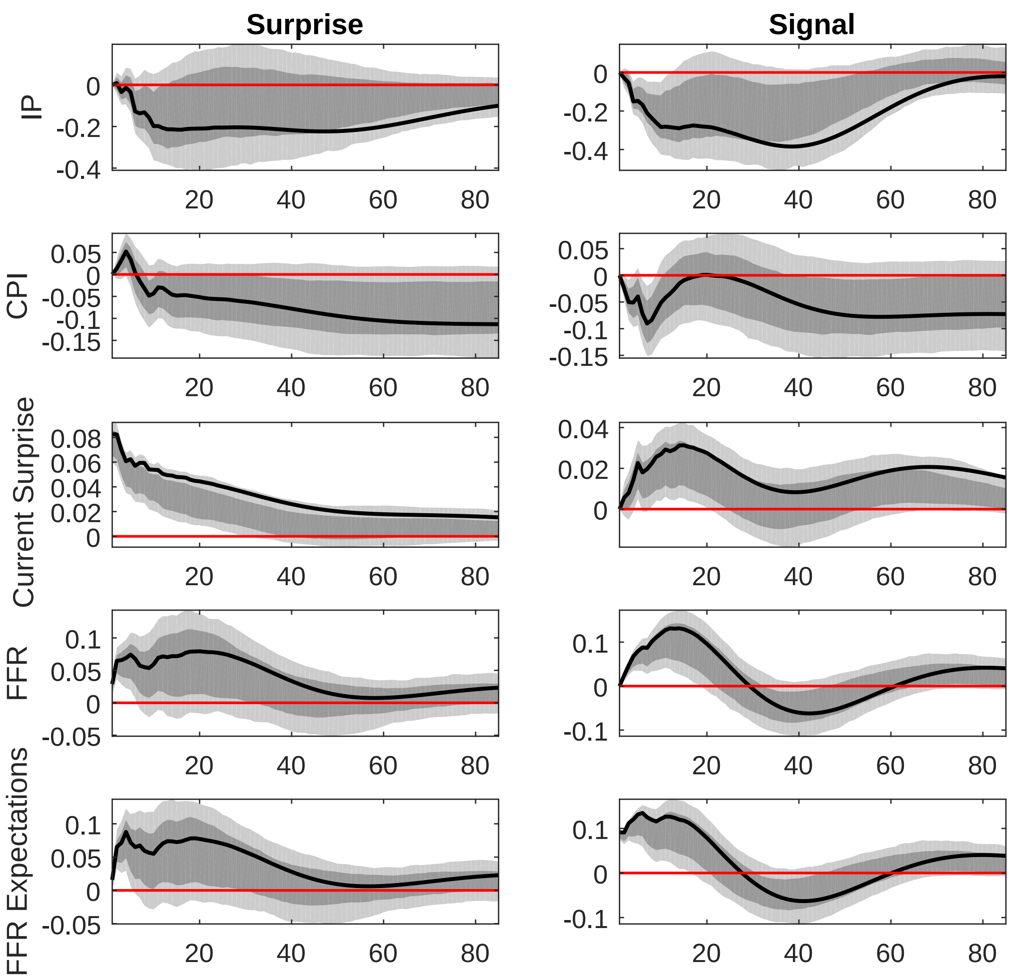
Notes: VAR containing logarithm of IP, the logarithm of CPI, the fed funds rate and six-months-ahead survey-based fed funds expectations. Estimation sample: 1983 April – 1993 December.

Figure 7: ***Five-variate VARs with Financial Indicators: Signal, News, and Noise***



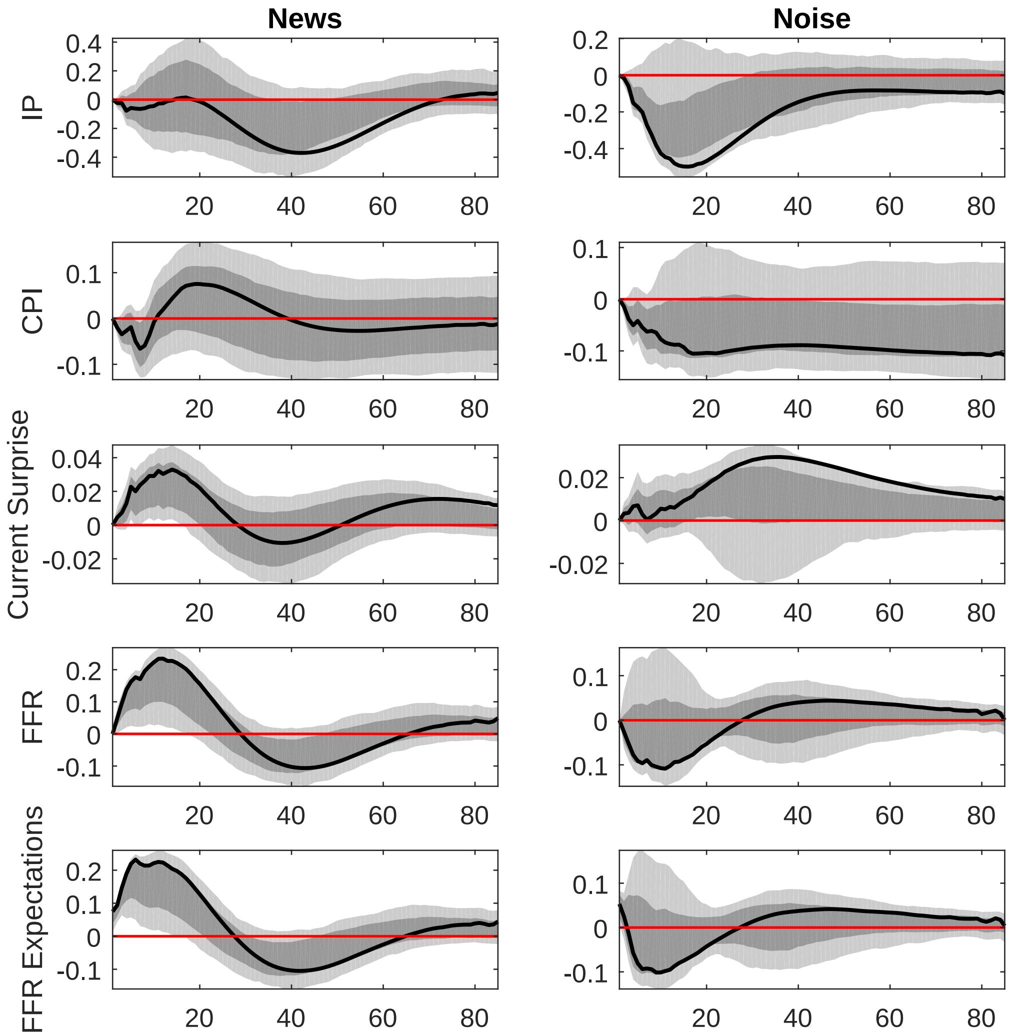
Notes: Five-variate VARs each containing the logarithm of IP, the logarithm of CPI, the fed funds rate, survey-based fed funds expectations (six months ahead), and the EBP or the BAA-AAA spread or the logarithm of the S&P 500 or the VIX, respectively. Estimation sample: 1994 January – 2016 October. (In the case of the EBP, the sample stops in August 2016 due to data availability.)

Figure 8: ***Five-variate VAR with Conventional Monetary Policy Shock: Surprise and Signal***



Notes: Five-variate VAR containing logarithm of IP, the logarithm of CPI, the current-month surprises, the fed funds rate and six-months-ahead survey-based fed funds expectations. Estimation sample: 1994 January - 2016 October.

Figure 9: ***Five-variate VAR with Conventional Monetary Policy Shock: News and Noise***



Notes: Five-variate VAR containing logarithm of IP, the logarithm of CPI, the current-month surprises, the fed funds rate and six-months-ahead survey-based fed funds expectations. Estimation sample: 1994 January - 2016 October.