# HIGH-FREQUENCY IDENTIFICATION OF MONETARY NON-NEUTRALITY: THE INFORMATION EFFECT*

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We present estimates of monetary non-neutrality based on evidence from high-frequency responses of real interest rates, expected inflation, and expected output growth. Our identifying assumption is that unexpected changes in interest rates in a 30-minute window surrounding scheduled Federal Reserve announcements arise from news about monetary policy. In response to an interest rate hike, nominal and real interest rates increase roughly one-for-one, several years out into the term structure, while the response of expected inflation is small. At the same time, forecasts about output growth also increase—the opposite of what standard models imply about a monetary tightening. To explain these facts, we build a model in which Fed announcements affect beliefs not only about monetary policy but also about other economic fundamentals. Our model implies that these information effects play an important role in the overall causal effect of monetary policy shocks on output. *JEL Codes*: E30, E40, E50.

## I. Introduction

A central question in macroeconomics is how monetary policy affects the economy. The key empirical challenge in answering this question is that most changes in interest rates happen for a reason. For example, the Fed might lower interest rates to counteract the effects of an adverse shock to the financial sector. In this case, the effect of the Fed's actions are confounded by the financial shock, making it difficult to identify the effects of monetary

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policy. The most common approach to overcoming this endogeneity problem is to try to control for confounding variables. This is the approach to identification in vector autoregression (VAR) studies such as Christiano, Eichenbaum, and Evans (1999) and Bernanke, Boivin, and Eliasz (2005), and in the work of Romer and Romer (2004). The worry with this approach is that despite efforts to control for important confounding variables, some endogeneity bias remains (see, e.g., Rudebusch 1998).

An alternative approach—the one we pursue in this article—is to focus on movements in bond prices in a narrow window around scheduled Federal Open Market Committee (FOMC) meetings. This high-frequency identification approach was pioneered by Cook and Hahn (1989), Kuttner (2001), and Cochrane and Piazzesi (2002). It exploits the fact that a disproportionate amount of monetary news is revealed at the time of the eight regularly scheduled FOMC meetings each year. The lumpy way monetary news is revealed allows for a discontinuity-based identification scheme.

We construct monetary shocks using unexpected changes in interest rates over a 30-minute window surrounding scheduled Federal Reserve announcements. All information that is public at the beginning of the 30-minute window is already incorporated into financial markets and therefore does not show up as spurious variation in the monetary shock. Such spurious variation is an important concern in VARs. For example, Cochrane and Piazzesi (2002) show that VAR methods (even using monthly data) interpret the sharp drop in interest rates in September 2001 as a monetary shock as opposed to a reaction to the terrorist attacks on 9/11/2001.

A major strength of the high-frequency identification approach we use is how cleanly it is able to address the endogeneity concern. As is often the case, this comes at the cost of reduced statistical power. The monetary shocks we estimate are quite small (they have a standard deviation of only about 5 basis points). This "power problem" precludes us from directly estimating their effect on future output. Intuitively, output several quarters in the future is influenced by myriad other shocks, rendering the signal-to-noise ratio in such regressions too small to yield reliable inference.

We can, however, measure the response of variables that respond contemporaneously, such as financial variables and survey expectations. Since the late 1990s it has been possible to observe the response of real interest rates via the Treasury Inflation

Protected Securities (TIPS) market. This is important because the link between nominal interest rates and real interest rates is the distinguishing feature of models in which monetary policy affects real outcomes. All models—neoclassical and New Keynesian—imply that real interest rates affect output. However, New Keynesian and neoclassical models differ sharply as to whether monetary policy actions can have persistent effects on real interest rates. In New Keynesian models, they do, whereas in neoclassical models real interest rates are decoupled from monetary policy. By focusing on the effects of monetary policy shocks on real interest rates, we are shedding light on the core empirical issue in monetary economics.

We use the term structure of interest rates at the time of FOMC meetings to show that the monetary shocks we identify have large and persistent effects on expected real interest rates as measured by TIPS. Nominal and real interest rates respond roughly one-for-one several years out into the term structure in response to our monetary shocks. The effect on real rates peaks at around 2 years and then falls monotonically to 0 at 10 years. In sharp contrast, the response of break-even inflation (the difference between nominal and real rates from TIPS) is essentially zero at horizons up to three years. At longer horizons, the response of break-even inflation becomes modestly but significantly negative. A tightening of monetary policy therefore eventually reduces inflation—as standard theory would predict. However, the response is small and occurs only after a long lag.

What can we conclude from these facts? Under the conventional interpretation of monetary shocks, these facts imply a great deal of monetary non-neutrality. Intuitively, a monetary policy-induced increase in real interest rates leads to a drop in output relative to potential, which in turn leads to a drop in inflation. The response of inflation relative to the change in the real interest rates is determined by the slope of the Phillips curve (as well as the intertemporal elasticity of substitution). If the inflation response is small relative to the change in the real rates, the slope of the Phillips curve must be small, implying large nominal and real rigidities and therefore large amounts of monetary non-neutrality.

There is, however, an additional empirical fact that does not fit this interpretation. We document that in response to an unexpected increase in the real interest rate (a monetary tightening), survey estimates of expected output growth rise. Under the conventional interpretation of monetary shocks, tightening policy should lead to a fall in output growth. Our empirical finding regarding output growth expectations is therefore the opposite direction from what one would expect from the conventional interpretation of monetary shocks.

A natural interpretation of this evidence is that FOMC announcements lead the private sector to update its beliefs not only about the future path of monetary policy but also about other economic fundamentals. For example, when the Fed chair announces that the economy is strong enough to withstand higher interest rates, market participants may react by reconsidering their own beliefs about the economy. Market participants may contemplate that perhaps the Fed has formed a more optimistic assessment of the economic outlook than they have and that they may want to reconsider their own assessments. Following Romer and Romer (2000), we refer to the effect of FOMC announcements on private sector views of non-monetary economic fundamentals as "Fed information effects."

The Fed information effect calls for more sophisticated modeling of the effects of monetary shocks than is standard. The main challenge is how to parsimoniously model these information effects. We present a new model in which monetary shocks affect not only the trajectory of the real interest rate, but also private sector beliefs about the trajectory of the natural rate of interest. This is a natural way of modeling the information content of Fed announcements since optimal monetary policy calls for interest rates to track the natural rate in simple models. Because the Fed is attempting to track the natural rate, it is natural to assume that Fed announcements contain information about the path of the natural rate.

This is important in interpreting the response of real interest rates and inflation to monetary shocks that we estimate. The reason is that the response of inflation is determined by the response of the real interest rate gap—the gap between the response of real interest rates and the natural real rate—which may be smaller than the response of real interest rates themselves. If there is an information effect, some of the increase of real rates is interpreted not as a tightening of policy relative to the natural rate—which would push inflation down—but as an increase in the natural rate itself—which does not.

In the extreme case where most of the changes in real interest rates at the time of FOMC announcements are due to a Fed information effect, even a large response of real interest rates to a monetary shock is consistent with the conventional channel of monetary non-neutrality being modest (since the real interest rate movement is mostly due to a change in the natural real rate). However, this does not mean that the Fed is powerless. On the contrary, if the Fed information effect is large, the Fed has a great deal of power over private sector beliefs about economic fundamentals, which may in turn have large effects on economic activity. If a Fed tightening makes the private sector more optimistic about the future, this may raise current consumption and investment. Depending on the strength of the Fed information effect, our evidence therefore suggests either that the Fed has a great deal of power over the economy through traditional channels or that the Fed has a great deal of power over the economy through nontraditional information channels (or some combination of the two).

To assess the extent of Fed information and the nature of Fed power over the economy, we estimate our Fed information model using as target moments the responses of real interest rates, expected inflation, and expected output growth discussed above. Here, we follow in the tradition of earlier quantitative work such as Rotemberg and Woodford (1997) and Christiano, Eichenbaum, and Evans (2005), with two important differences. First, our empirical targets are identified using high-frequency identification as opposed to a VAR. Second, we allow for Fed information effects in our model.

Our estimates provide strong support for both the Fed information effect and more conventional channels of monetary non-neutrality. Roughly two-thirds of the response of real interest rates to FOMC announcements are estimated to be a response of the natural rate of interest and one-third is a tightening of real rates relative to the natural rate. This large estimate of the Fed information effect allows us to simultaneously match the fact that beliefs about output growth rise following a monetary shock and inflation eventually falls. Beliefs about output growth rise because agents are more optimistic about the path for potential output. Inflation falls because a portion of the shock is interpreted as rates rising relative to the natural rate. Our estimates of the conventional effect of monetary policy – while smaller than they would be ignoring the Fed information effect – still imply that the Phillips curve is very flat.

Once we allow for Fed information effects, the causal effect of monetary policy is much more subtle to define. Our estimates imply that surprise FOMC monetary tightenings have large positive effects on expectations about output growth. Does this imply that the monetary announcements cause output to increase by large amounts? Not necessarily. Much of the news the Fed reveals about non-monetary fundamentals would have eventually been revealed through other sources. To correctly assess the causal effect of monetary policy, one must compare versus a counterfactual in which the changes in fundamentals the Fed reveals information about occur even in the absence of the announcement. The causal effect of the Fed information is then limited to the effect on output of the Fed announcing this information earlier than it otherwise would have become known.

Our model makes these channels precise. Recent discussions of monetary policy have noted the Fed's reluctance to lower interest rates for fear it might engender pessimistic expectations that would fight against its goal of stimulating the economy. Our analysis suggests that these concerns may be well founded at least at the zero lower bound.[1] Moreover, our model suggests that the implications of systematic monetary policy actions are quite different from those of monetary shocks. Monetary shocks are likely to entail particularly large information effects because they are the component of monetary policy that surprise the private sector. In contrast, systematic monetary policy actions don't entail information effects because, by definition, they are not based on private information. This implies that the systematic component of monetary policy is likely to yield a more conventionally Keynesian response of the economy than monetary shocks. The information content of a surprise policy change may also depend on how the Fed communicates its motivation for the policy change.

Our measure of monetary shocks is based not only on surprise changes in the Federal Funds rate but also on changes in the path of future interest rates in response to FOMC announcements. This is important because over the past 15 years forward guidance has become an increasingly important tool in the conduct of monetary policy (Gürkaynak, Sack, and Swanson 2005). This also implies that it is important to focus on a narrow 30-minute window as opposed to the one-day or two-day windows more commonly used in

1. Revealing information about natural rates, even bad news, is likely to be welfare improving as long as the Fed can vary interest rates to track the natural rate. At the zero lower bound, the Fed however loses its ability to track the natural rate. Withholding bad news may then be optimal.

prior work. We make use of Rigobon's (2003) heteroskedasticity-based estimator to show that OLS results based on monetary shocks constructed from longer-term interest rate changes over one-day windows around FOMC announcements are confounded by substantial "background noise" that lead to unreliable inference and in particular can massively overstate the true statistical precision of the estimates. In contrast, OLS yields reliable results when a 30-minute window is used.

An important question about our empirical estimates is whether some of the effects of our monetary shocks on longer-term real interest rates reflect changes in risk premia as opposed to changes in expected future short-term real interest rates. We use three main approaches to analyze this issue: direct survey expectations of real interest rates, an affine term structure model, and an analysis of mean reversion. None of these pieces of evidence suggest that movements in risk premia at the time of FOMC announcements play an important role in our results. In other words, our results suggest that the expectations hypothesis of the term structure is a good approximation in response to our monetary shocks, even though it is not a good approximation unconditionally. This is what we need for our analysis to be valid.

Another important (and related) question is whether there might be a predictable component of the monetary shocks we analyze and how this might affect the interpretation of our results. In our analysis of real interest rates, the dependent variables are high-frequency changes. The error terms in these regressions, therefore, only contain information revealed in that narrow window, and the identifying assumption is that our monetary shock is orthogonal to this limited amount of information. This methodology has the advantage that we need not assume that our monetary shock is orthogonal to macro shocks occurring on other days or to slow-moving confounding variables. The identifying assumptions are stronger when we analyze the effects of our monetary shocks on survey expectations from the Blue Chip data. In that analysis, the dependent variable is a monthly change and the identifying assumption is that the monetary shock is orthogonal to confounders over the whole month. Similar (stronger) assumptions are required when high-frequency monetary shocks are used as external instruments in a VAR—as in Gertler and Karadi (2015)—since the outcome variables are changes over several months. In addition, predictability is difficult to establish convincingly because of data mining and peso problem concerns.

Our article relates to several strands of the literature in monetary economics. The seminal empirical paper on Fed information is Romer and Romer (2000). Faust, Swanson, and Wright (2004) present a critique of their findings. More recently, Campbell et al. (2012) show that an unexpected tightening leads survey expectations of unemployment to fall. The theoretical literature on the signaling effects of monetary policy is large. Early contributions include Cukierman and Meltzer (1986) and Ellingsen and Söderström (2001). Recent contributions include Berkelmans (2011), Melosi (2017), Tang (2015), Frankel and Kartik (forthcoming), and Andrade et al. (2016). The prior literature typically assumes that the central bank must communicate only through its actions (e.g., changes in the Fed funds rate), whereas we allow the Fed to communicate through its words (FOMC statements).

Our estimates of the effects of monetary announcements on real interest rates using high-frequency identification are related to recent work by Hanson and Stein (2015) and Gertler and Karadi (2015). We make different identifying assumptions than Hanson and Stein, use a different definition of the monetary shock, and come to quite different conclusions about the long-run effects of monetary policy.[2] There are also important methodological differences between our work and that of Gertler and Karadi (2015). They rely on a VAR to estimate the dynamic effects of monetary policy shocks. They are subject to the usual concern that the VAR they use may not accurately describe the dynamic response of key variables to a monetary shock. Our identification approach is entirely VAR-free. Our article is also related to several recent papers that have used high-frequency identification to study the effects of unconventional monetary policy during the recent period over which short-term nominal interest rates have been at their zero lower bound (Gagnon et al. 2010; Krishnamurthy and Vissing-Jørgensen 2011; Rosa 2012; Wright 2012; Gilchrist, Lopez-Salido, and Zakrajsek 2015).

The article proceeds as follows. Section II describes the data we use in our analysis. Section III presents our empirical results regarding the response of nominal and real interest rates and

2. In earlier work, Beechey and Wright (2009) analyze the effect of unexpected movements in the Fed funds rate at the time of FOMC announcements on nominal and real 5-year and 10-year yields and the 5- to 10-year forward over the period February 2004 to June 2008. Their results are similar to ours for the 5-year and 10-year yields.

TIPS break-even inflation to monetary policy shocks. Section IV presents our empirical evidence on output growth expectations. Section V presents our Fed information model, describes our estimation methods, and presents the results of our estimation of the Fed information model. Section VI discusses how to think about the causal effect of the monetary announcement in the face of Fed information. Section VII concludes.

## II. Data

To construct our measure of monetary shocks, we use tick-by-tick data on Fed funds futures and eurodollar futures from the CME Group (owner of the Chicago Board of Trade and Chicago Mercantile Exchange). These data can be used to estimate changes in expectations about the Fed funds rate at different horizons after an FOMC announcement (see Online Appendix A). The tick-by-tick data we have for Fed funds futures and eurodollar futures is for the sample period 1995–2012. For the period since 2012 we use data on changes in the prices of the same five interest rate futures over the same 30-minute windows around FOMC announcements that Refet Gürkaynak graciously shared with us.

We obtain the dates and times of FOMC meetings up to 2004 from the appendix to Gürkaynak, Sack, and Swanson (2005). We obtain the dates of the remaining FOMC meetings from the Federal Reserve Board website at http://www.federalreserve.gov/monetarypolicy/fomccalendars.htm. For the latter period, we verified the exact times of the FOMC announcements using the first news article about the FOMC announcement on Bloomberg. We cross-referenced these dates and times with data we obtained from Refet Gürkaynak and in a few cases used the time stamp from his database.

To measure the effects of our monetary shocks on interest rates, we use several daily interest rate series. To measure movements in Treasuries at horizons of one year or more, we use daily data on zero-coupon nominal Treasury yields and instantaneous forward rates constructed by Gürkaynak, Sack, and Swanson (2007). These data are available on the Fed's website at http://www.federalreserve.gov/pubs/feds/2006/200628/200628abs.html. We also use the yields on three-month and six-month Treasury bills. We retrieve these from the Federal Reserve Board's H.15 data release.

To measure movements in real interest rates, we use zero-coupon yields and instantaneous forward rates constructed by

Gürkaynak, Sack, and Wright (2010) using data from the TIPS market. These data are available on the Fed's website at http://www.federalreserve.gov/pubs/feds/2008/200805/200805abs.html. TIPS are "inflation protected" because the coupon and principal payments are multiplied by the ratio of the reference CPI on the date of maturity to the reference CPI on the date of issue.[3] The reference CPI for a given month is a moving average of the CPI two and three months prior to that month, to allow for the fact that the Bureau of Labor Statistics publishes these data with a lag.

TIPS were first issued in 1997 and were initially sold at maturities of 5, 10, and 30 years, but only the 10-year bonds have been issued systematically throughout the sample period. Other maturities have been issued more sporadically. Although liquidity in the TIPS market was initially poor, TIPS now represent a substantial fraction of outstanding Treasury securities. We start our analysis in 2000 to avoid relying on data from the period when TIPS liquidity was limited. For two- and three-year yields and forwards we start our analysis in 2004. Gürkaynak, Sack, and Wright (2010) only report zero-coupon yields for these maturities from 2004 onward. One reason is that to accurately estimate zero-coupon yields at this maturity it is necessary to wait until longer maturity TIPS issued several years earlier have maturities in this range. To facilitate direct comparisons between nominal and real interest rates, we restrict our sample period for the corresponding two- and three-year nominal yields and forwards to the same time period.

To measure expectations, we use data on expectations of future nominal interest rates, inflation and output growth from the Blue Chip Economic Indicators. Blue Chip carries out a survey during the first few days of every month soliciting forecasts of these variables for up to the next eight quarters. We use the mean forecast for each variable. We also use data on Green Book forecasts from the Philadelphia Fed. These data are hosted and maintained on the data set at https://www.philadelphiafed.org/research-and-data/real-time-center/greenbook-data/philadelphia-data-set. We use the real GDP growth variable from this data set.

To assess the role of risk premia, we use a daily decomposition of nominal and real interest rate movements into risk-neutral

3. This holds unless cumulative inflation is negative, in which case no adjustment is made for the principal payment.

expected future rates and risk premia obtained from Abrahams et al. (2015). To assess the robustness of our results regarding the response of real interest rates we use daily data on inflation swaps from Bloomberg. Finally, we estimate the response of stock prices to monetary announcements using daily data on the level of the S&P500 stock price index obtained from Yahoo Finance.

## III. Response of Interest Rates and Expected Inflation

Our goal in this section is to identify the effect of the monetary policy news contained in scheduled FOMC announcements on nominal and real interest rates of different maturities. Specifically, we estimate

$$\Delta s_t = \alpha + \gamma \Delta i_t + \epsilon_t, \quad (1)$$

where $\Delta s_t$ is the change in an outcome variable of interest (e.g., the yield on a five-year zero-coupon Treasury bond), $\Delta i_t$ is a measure of the monetary policy news revealed in the FOMC announcement, $\epsilon_t$ is an error term, and $\alpha$ and $\gamma$ are parameters. The parameter of interest is $\gamma$, which measures the effect of the FOMC announcement on $\Delta s_t$ relative to its effect on the policy indicator $\Delta i_t$.

To identify a pure monetary policy shock, we consider the change in our policy indicator ($\Delta i_t$) in a 30-minute window around scheduled FOMC announcements.[4] The idea is that changes in the policy indicator in these 30-minute windows are dominated by the information about future monetary policy contained in the FOMC announcement. Under the assumption that this is true, we can simply estimate equation (1) by OLS. We also present results for a heteroskedasticity-based estimation approach (Rigobon 2003; Rigobon and Sack 2004) which is based on a weaker identifying assumption to verify that our baseline identifying assumption is reasonable. In our baseline analysis, we focus only on scheduled FOMC announcements, since unscheduled meetings may occur in reaction to other contemporaneous shocks.

The policy indicator we use is a composite measure of changes in interest rates at different maturities spanning the first year of the term structure. Until recently, most authors used unanticipated changes in the Fed funds rate (or closely related changes in

4. Specifically, we calculate the monetary shock using a 30-minute window from 10 minutes before the FOMC announcement to 20 minutes after it.

very short-term interest rates) as their policy indicator. The key advantage of our measure is that it captures the effects of "forward guidance." Forward guidance refers to announcements by the Fed that convey information about future changes in the Fed funds rate. Over the past 15 years, the Federal Reserve has made greater and greater use of such forward guidance. In fact, changes in the Fed funds rate have often been largely anticipated by markets once they occur. Gürkaynak, Sack, and Swanson (2005) convincingly argue that unanticipated changes in the Fed funds rate capture only a small fraction of the monetary policy news associated with FOMC announcements in recent years (see also Campbell et al. 2012).

The specific composite measure we use as our policy indicator is the first principal component of the unanticipated change over the 30-minute windows discussed above in the following five interest rates: the Fed funds rate immediately following the FOMC meeting, the expected Fed funds rate immediately following the next FOMC meeting, and expected three-month eurodollar interest rates at horizons of two, three, and four quarters. We refer to this policy indicator as the "policy news shock." We use data on Fed funds futures and eurodollar futures to measure changes in market expectations about future interest rates at the time of FOMC announcements. The scale of the policy news shock is arbitrary. For convenience, we rescale it such that its effect on the one-year nominal Treasury yield is equal to one. Online Appendix A provides details about the construction of the policy news shock.[5]

### *III.A. Baseline Estimates*

Table I presents our baseline estimates of monetary shocks on nominal and real interest rates and break-even inflation. Each estimate in the table comes from a separate OLS regression of the form discussed above—equation (1). In each case the independent variable is the policy news shock measured over a 30-minute

5. Our policy news shock variable is closely related to the "path factor" considered by Gürkaynak, Sack, and Swanson (2005). The five interest rate futures that we use to construct our policy news shock are the same five futures as Gürkaynak, Sack, and Swanson (2005) use. They motivate the choice of these particular futures by liquidity considerations. They advocate the use of two principal components to characterize the monetary policy news at the time of FOMC announcements—a "target factor" and a "path factor." We focus on a single factor for simplicity. See also Barakchian and Crowe (2013).

TABLE I
RESPONSE OF INTEREST RATES AND INFLATION TO THE POLICY NEWS SHOCK

| | Nominal | Real | Inflation |
|---|---|---|---|
| 3M Treasury yield | 0.67 | | |
| | (0.14) | | |
| 6M Treasury yield | 0.85 | | |
| | (0.11) | | |
| 1Y Treasury yield | 1.00 | | |
| | (0.14) | | |
| 2Y Treasury yield | 1.10 | 1.06 | 0.04 |
| | (0.33) | (0.24) | (0.18) |
| 3Y Treasury yield | 1.06 | 1.02 | 0.04 |
| | (0.36) | (0.25) | (0.17) |
| 5Y Treasury yield | 0.73 | 0.64 | 0.09 |
| | (0.20) | (0.15) | (0.11) |
| 10Y Treasury yield | 0.38 | 0.44 | −0.06 |
| | (0.17) | (0.13) | (0.08) |
| 2Y Treasury inst. forward rate | 1.14 | 0.99 | 0.15 |
| | (0.46) | (0.29) | (0.23) |
| 3Y Treasury inst. forward rate | 0.82 | 0.88 | −0.06 |
| | (0.43) | (0.32) | (0.15) |
| 5Y Treasury inst. forward rate | 0.26 | 0.47 | −0.21 |
| | (0.19) | (0.17) | (0.08) |
| 10Y Treasury inst. forward rate | −0.08 | 0.12 | −0.20 |
| | (0.18) | (0.12) | (0.09) |

*Notes*. Each estimate comes from a separate OLS regression. The dependent variable in each regression is the one-day change in the variable stated in the left-most column. The independent variable is a change in the policy news shock over a 30-minute window around the time of FOMC announcements. The sample period is all regularly scheduled FOMC meetings from 1/1/2000 to 3/19/2014, except that we drop July 2008 through June 2009. For two-year and three-year yields and real forwards, the sample starts in January 2004. The sample size for the two-year and three-year yields and forwards is 74. The sample size for all other regressions is 106. In all regressions, the policy news shock is computed from these same 106 observations. Robust standard errors are in parentheses.

window around an FOMC announcement, while the change in the dependent variable is measured over a one-day window.[6]

The first column of Table I presents the effects of the policy news shock on nominal Treasury yields and forwards. Recall that the policy news shock is scaled such that the effect on the one-year Treasury yield is 100 basis points. Looking across different maturities, we see that the effect of the shock is somewhat smaller for shorter maturities, peaks at 110 basis points for the 2-year yield and then declines monotonically to 38 basis points for

6. The longer window for the dependent variable adds noise to the regression without biasing the coefficient of interest.

the 10-year yield. Because longer-term yields reflect expectations about the average short-term interest rate over the life of the long bond, it is easier to interpret the time-path of the response of instantaneous forward rates. Abstracting from risk premia, these reveal market expectations about the short-term interest rate that the market expects to prevail at certain points in time in the future.[7] The impact of our policy news shock on forward rates is also monotonically declining in maturity from 114 basis points at 2 years to −8 basis points at 10 years. We show below that the negative effect on the 10-year nominal forward rate reflects a decline in break-even inflation at long horizons.[8]

The second column of Table I presents the effects of the policy news shock on real interest rates measured using TIPS. Although the policy news shock affects nominal rates by construction, this is not the case for real interest rates. In neoclassical models of the economy, the Fed controls the nominal interest rate but has no impact on real interest rates. In sharp contrast to this, we estimate the impact of our policy news shock on the two-year real yield to be 106 basis points, and the impact on the three-year real yield to be 102 basis points. Again, the time-path of effects is easier to interpret by viewing estimates for instantaneous forward rates. The effect of the shock on the 2-year real forward rate is 99 basis points. It falls monotonically at longer horizons to 88 basis points at 3 years, 47 basis points at 5 years, and 12 basis point at 10 years (which is not statistically significantly different from zero). Evidently, monetary policy shocks can affect real interest rates for substantial amounts of time (or at least markets believe they can). However, in the long run, the effect of monetary policy shocks on real interest rates is zero as theory would predict.

The third column of Table I presents the effect of the policy news shock on break-even inflation as measured by the difference between nominal Treasury rates and TIPS rates. The first several rows provide estimates based on bond yields, which indicate that the response of break-even inflation is small. The shorter horizon estimates are actually slightly positive but then become

7. For example, the effect on the two-year instantaneous forward rate is the effect on the short-term interest rate that the market expects to prevail in two years' time.

8. Our finding that long-term inflation expectations decline in response to a contractionary monetary policy shock is consistent with Beechey, Johannsen, and Levin (2011) and Gürkaynak, Levin, and Swanson (2010).

negative at longer horizons. None of these estimates are statistically significantly different from zero. Again, it is helpful to consider instantaneous forward break-even inflation rates to get estimates of break-even inflation at points in time in the future. The response of break-even inflation implied by the two-year forwards is slightly positive, though statistically insignificant. The response is negative at longer horizons: for maturities of 3, 5, and 10 years, the effect is −6, −21, and −20 basis points, respectively. Only the responses at 5 and 10 years are statistically significantly different from zero. Our evidence thus points to break-even inflation responding modestly and quite gradually to monetary shocks that have a substantial effect on real interest rates.

Table I presents results for a sample period from January 1, 2000, to March 19, 2014, except that we drop the period spanning the height of the financial crisis in the second half of 2008 and the first half of 2009.[9] We choose to drop the height of the financial crisis because numerous well-documented asset pricing anomalies arose during this crisis period, and we wish to avoid the concern that our results are driven by these anomalies. However, similar results obtain for the full sample including the crisis, as well as a more restrictive data sample ending in 2007, and for a sample that also includes unscheduled FOMC meetings (see Appendix Table A.1). The results for the sample ending in 2007 show that our results are unaffected by dropping the entire period during which the zero-lower-bound is binding and the Fed is engaged in quantitative easing. Appendix Table A.2 presents results analogous to those of Table I but using the unexpected change in the Fed funds rate as the policy indicator.

Figure I presents a binned scatter plot of the relationship between the policy news shock and the five-year real yield (the average expected response of the short-term real interest rates over the next five years). The variation in the policy news shock ranges from −11 basis points to +10 basis points. The relationship between the change in the five-year real yield and the policy news shock does not seem to be driven by a few outliers.

### *III.B. Background Noise in Interest Rates*

A concern regarding the estimation approach we describe above is that other nonmonetary news might affect our monetary policy indicator during the window we consider around FOMC

9. The sample period for two- and three-year yields and forwards is somewhat shorter (it starts in 2004) because of data limitations (see Section II for details).

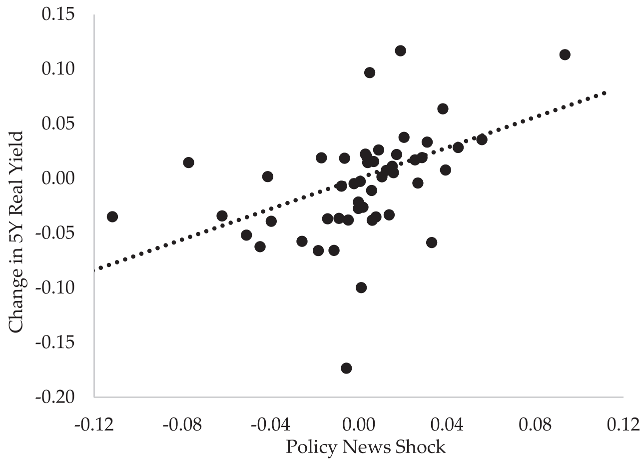


FIGURE I

Binned Scatter Plot for Five-Year Real-Yield Regression

announcements. If this is the case, it will contaminate our measure of monetary shocks. This concern looms much larger if one considers longer event windows than our baseline 30-minute window. It has been common in the literature on high-frequency identification of monetary policy to consider a one- or two-day window around FOMC announcements (e.g., Kuttner 2001; Cochrane and Piazzesi 2002; Hanson and Stein 2015). In these cases, the identifying assumption being made is that no other shocks affect the policy indicator in question during these one or two days. Especially when the policy indicator is based on interest rates several quarters or years into the term structure—as has recently become common to capture the effects of forward guidance—the assumption that no other shocks affect this indicator over one or two days is a strong assumption. Interest rates at these maturities fluctuate substantially on non-FOMC days, suggesting that other shocks than FOMC announcements affect these interest rates on FOMC days. There is no way of knowing whether these other shocks are monetary shocks or nonmonetary shocks.

To assess the severity of this problem, Table II compares estimates of equation (1) based on OLS regressions to estimates based on a heteroskedasticity-based estimation approach developed by Rigobon (2003) and Rigobon and Sack (2004). We do this both for a 30-minute window and for a 1-day window.

TABLE II

ALLOWING FOR BACKGROUND NOISE IN INTEREST RATES

| | 2-year forward | | 5-year forward | | 10-year forward | |
|---|---|---|---|---|---|---|
| | Nominal | Real | Nominal | Real | Nominal | Real |
| Policy news shock, 30-minute window | | | | | | |
| OLS | 1.14 | 0.99 | 0.26 | 0.47 | −0.08 | 0.12 |
| | [0.23, 2.04] | [0.41, 1.57] | [−0.12, 0.64] | [0.14, 0.80] | [−0.43, 0.28] | [−0.12, 0.36] |
| Rigobon | 1.10 | 0.96 | 0.22 | 0.46 | −0.12 | 0.11 |
| | [0.31, 2.36] | [0.45, 1.82] | [−0.14, 0.64] | [0.15, 0.84] | [−0.46, 0.24] | [−0.13, 0.35] |
| Policy news shock, 1-day window | | | | | | |
| OLS | 1.24 | 1.00 | 0.44 | 0.48 | 0.05 | 0.15 |
| | [0.80, 1.69] | [0.57, 1.43] | [0.18, 0.70] | [0.20, 0.76] | [−0.20, 0.29] | [−0.10, 0.39] |
| Rigobon | 0.93 | 0.82 | −0.11 | 0.33 | −0.51 | −0.04 |
| | [−0.64, 2.08] | [0.38, 3.20] | [−1.23, 0.33] | [−0.07, 1.12] | [−1.93, −0.08] | [−0.51, 0.45] |
| 2-year nominal yield, 1-day window | | | | | | |
| OLS | 1.23 | 0.94 | 0.64 | 0.54 | 0.18 | 0.20 |
| | [1.07, 1.38] | [0.69, 1.20] | [0.43, 0.84] | [0.31, 0.76] | [0.01, 0.35] | [0.02, 0.38] |
| Rigobon (90% CI) | 1.14 | 0.82 | −0.11 | 0.33 | −0.51 | −0.04 |
| | [0.82, 1.82] | [0.62, 2.98] | [−7.94, 0.60] | [−0.01, 7.48] | [−10.00, −0.21] | [−4.57, 0.38] |

*Notes*. Each estimate comes from a separate "regression." The dependent variable in each regression is the one-day change in the variable stated at the top of that column. The independent variable in the first panel of results is the 30-minute change in the policy news shock around FOMC meeting times, in the second panel it is the one-day change in the policy news shock, and in the third panel it is the one-day change in the two-year nominal yield. In each panel, we report results based on OLS and Rigobon's heteroskedasticity-based estimation approach. We report a point estimate and 95% confidence intervals except in the last row of Rigobon estimates, which reports 90% confidence intervals. The sample of "treatment" days for the Rigobon method is all regularly scheduled FOMC meeting days from 1/1/2000 to 3/19/2014; this is also the period for which the policy news shock is constructed in all "regressions." The sample of "control" days for the Rigobon analysis is all Tuesdays and Wednesdays that are not FOMC meeting days over the same period of time. In both the treatment and control samples, we drop July 2008 through June 2009 and 9/11/2001–9/21/2001. For two-year forwards, the sample starts in January 2004. Confidence intervals for the OLS results are based on robust standard errors. Confidence intervals for the Rigobon method are calculated using the weak-IV robust approach discussed in Online Appendix C with 5,000 iterations.

The heteroskedasticity-based estimator is described in detail in Online Appendix B. It allows for "background" noise in interest rates arising from other shocks during the event windows being considered. The idea is to compare movements in interest rates during event windows around FOMC announcements to other equally long and otherwise similar event windows that do not contain an FOMC announcement. The identifying assumption is that the variance of monetary shocks increases at the time of FOMC announcements, while the variance of other shocks (the background noise) is unchanged.

The top panel of Table II compares estimates based on OLS to those based on the heteroskedasticity-based estimator (Rigobon estimator) for a subset of the assets we consider in Table I when the event window is 30 minutes as in our baseline analysis. The difference between the two estimators is very small, both for the point estimates and the confidence intervals.[10] This result indicates that there is in fact very little background noise in interest rates over a 30-minute window around FOMC announcements and the OLS identifying assumption—that only monetary shocks occur within the 30-minute window—thus yields a point estimate and confidence intervals that are close to correct. Table A.3 presents a full set of results based on the Rigobon estimator and a 30-minute window. It confirms that OLS yields very similar results to the Rigobon estimator for all the assets we consider when the event window is 30 minutes.

In contrast, the problem of background noise is quite important when the event window being used to construct our policy news shocks is one day. The second panel of Table II compares estimates based on OLS to those based on the Rigobon estimator for policy news shocks constructed using a one-day window. In this case, the differences between the OLS and Rigobon estimates are substantial. The point estimates in some cases differ by dozens of basis points and have different signs in three of the six cases considered. However, the most striking difference arises for the

10. The confidence intervals for the Rigobon estimator in Table II are constructed using a procedure that is robust to inference problems that arise when the amount of background noise is large enough that there is a significant probability that the difference in the variance of the policy indicator between the sample of FOMC announcements and the "control" sample is close to zero. In this case, the conventional bootstrap approach to constructing confidence intervals will yield inaccurate results. Online Appendix C describes the method we use to construct confidence intervals in detail. We thank Sophocles Mavroeidis for suggesting this approach to us.

confidence intervals. OLS yields much narrower confidence intervals than those generated using the Rigobon method. According to OLS, the effects on the five-year nominal and real forwards are highly statistically significant, while the Rigobon estimator indicates that these effects are far from being significant.

This difference between OLS and the Rigobon estimator indicates that there is a large amount of background noise in the interest rates used to construct the policy news shock over a one-day window. The Rigobon estimator is filtering this background noise out. The fact that the confidence intervals for the Rigobon estimator are so wide in the one-day window case implies that there is very little signal left in this case. The OLS estimator, in contrast, uses all the variation in interest rates (both the true signal from the announcement and the background noise). Clearly, this approach massively overstates the true statistical precision of the effect arising from the FOMC announcement when a one-day window is used.

The difference between OLS and the Rigobon estimator is even larger when a longer-term interest rate is used as the policy indicator that proxies for the size of monetary shocks. The third panel of Table II compares results based on OLS to those based on the Rigobon estimator when the policy indicator is the change in the two-year nominal yield over a one-day window. Again, the confidence intervals are much wider using the Rigobon estimator than OLS. In fact, here we report 90% confidence intervals for the Rigobon estimator since the 95% confidence intervals are in some cases infinite (i.e., we were unable to find any value of the parameter of interest that could be rejected at that significance level).

An important substantive difference arises between the OLS and Rigobon estimates in the case of the 10-year real forward rate when the 2-year nominal yield is used as the policy indicator. Here, OLS estimation yields a statistically significant effect of the monetary shock on forward rates at even a 10-year horizon. This result is emphasized by Hanson and Stein (2015). However, the Rigobon estimator with appropriately constructed confidence intervals reveals that this result is statistically insignificant. Our baseline estimation approach using a 30-minute window and the policy news shock as the proxy for monetary shocks yields a point estimate that is small and statistically insignificant.[11]

11. Hanson and Stein (2015) also present an estimator based on instrumenting the two-day change in the two-year rate with the change in the two-year rate

### *III.C. Risk Premia or Expected Future Short-Term Rates?*

One question that arises when interpreting our results is to what extent the movements in long-term interest rates we identify reflect movements in risk premia as opposed to changes in expected future short-term interest rates. A large literature suggests that changes in risk premia do play an important role in driving movements in long-term interest rates in general. Yet for our analysis, the key question is not whether risk premia matter in general but how important they are in explaining the abrupt changes in interest rates that occur in the narrow windows around the FOMC announcements that we focus on.[12]

In Online Appendix D, we present three sets of results that indicate that risk premium effects are not driving our empirical results. First, the impact of our policy news shock on direct measures of expectations from the Blue Chip Economic Indicators indicate that our monetary shocks have large effects on expected short-term nominal and real rates. Second, the impact of our policy news shock on risk-neutral expected short rates from the state-of-the-art affine term structure model of Abrahams et al. (2015) is similar to our baseline results. Third, the impact of our policy news shock on interest rates over longer event windows does not suggest that the effects we estimate dissipate quickly (although the standard errors in this analysis are large).

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during a 60-minute window around the FOMC announcement. This yields similar results to their baseline. Since this procedure is not subject to the concerns raised above, it suggests that there are other sources of difference between our results and those of Hanson and Stein than econometric issues. One possible source of difference is that we use different monetary shock indicators. Their policy indicator (the change in the two-year yield) is further out in the term structure and may be more sensitive to risk premia. As we discuss in Section III.C, our measure of monetary shocks is uncorrelated with the risk premia implied by the affine term structure model of Abrahams et al. (2015), whereas Hanson and Stein's monetary shocks are associated with substantial movements in risk premia. The difference could also arise from the fact that Hanson and Stein focus on a two-day change in long-term real forwards, which could yield different results if the response of long-term bonds to monetary shocks is inertial.

12. Piazzesi and Swanson (2008) show that Fed funds futures have excess returns over the Fed funds rate and that these excess returns vary counter-cyclically at business cycle frequencies. However, they argue that high-frequency changes in Fed funds futures are likely to be valid measures of changes in expectations about future Fed funds rates because they difference out risk premia that vary primarily at lower frequencies.

We also consider an alternative, market-based measure of inflation expectations based on inflation swap data.[13] The sample period for this analysis is limited by the availability of swaps data to begin on January 1, 2005. Unfortunately, due to the short sample available to us, the results are extremely noisy, and are therefore not particularly informative. As in our baseline analysis there is no evidence of large negative responses in inflation to our policy news shock (as would arise in a model with flexible prices). Indeed, the estimates from this approach (which are compared to our baseline results in Appendix Table A.4) suggest a somewhat larger "price puzzle"—that is, positive inflation response—at shorter horizons, though this is statistically insignificant.

## IV. The Fed Information Effect

The results in Section III show that variation in nominal interest rates caused by monetary policy announcements have large and persistent effects on real interest rates. The conventional interpretation of these facts is that they imply that prices must respond quite sluggishly to shocks. We illustrate this in a conventional business cycle model in Online Appendix E. This conventional view of monetary shocks has the following additional prediction that we can test using survey data: a surprise increase in interest rates should cause expected output to fall. To test this prediction, we run our baseline empirical specification—equation (1)—at a monthly frequency with the monthly change in Blue Chip survey expectations about output growth as the dependent variable and the policy news shock that occurs in that month as the independent variable.[14]

Table III reports the resulting estimates. The dependent variable is the monthly change in expected output growth over the

13. An inflation swap is a financial instrument designed to help investors hedge inflation risk. As is standard for swaps, nothing is exchanged when an inflation swap is first executed. However, at the maturity date of the swap, the counterparties exchange $R_t^x - \Pi_t$, where $R_t^x$ is the $x$-year inflation swap rate and $\Pi_t$ is the reference inflation over that period. If agents were risk neutral, therefore, $R_t$ would be expected inflation over the $x$ year period. See Fleckenstein, Longstaff, and Lustig (2014) for an analysis of the differences between break-even inflation from TIPS and inflation swaps.

14. We exclude policy news shocks that occur in the first week of the month because in those cases we do not know whether they occurred before or after the survey response.

TABLE III

RESPONSE OF EXPECTED OUTPUT GROWTH OVER THE NEXT YEAR

| | 1995–2014 | 2000–2014 | 2000–2007 | 1995–2000 |
|---|---|---|---|---|
| Policy news shock | 1.01 | 1.04 | 0.95 | 0.79 |
| | (0.32) | (0.35) | (0.32) | (0.63) |
| Observations | 120 | 90 | 52 | 30 |

*Notes*. We regress changes from one month to the next in survey expectations about output growth over the next year from the Blue Chip Economic Indicators on the policy news shock that occurs in that month (except that we drop policy news shocks that occur in the first week of the month because we do not know whether these occurred before or after the survey response). Specifically, the dependent variable is the change in the average forecasted value of output growth over the next three quarters (the maximum horizon over which forecasts are available for the full sample). See Online Appendix F for details. We present results for four sample periods. The longest sample period we have data for is 1995m1–2014m4; this is also the period for which the policy news shocks are constructed. We also present results for 2000m1–2014m4 (which corresponds to the sample period used in Table I), 2000m1–2007m12 (a precrisis sample period), and 1995m1–1999m12. As in our other analysis, we drop data from July 2008 through June 2009. Robust standard errors are in parentheses.

next year (see Online Appendix F for details). In sharp contrast to the conventional theory of monetary shocks, policy news shocks that raise interest rates lead expectations about output growth to rise rather than fall.[15] We present results for four sample periods. The longest sample period for which we are able to construct our policy news shock is 1995–2014. We also present results for the sample period 2000–2014, which corresponds to the sample period we use in most of our other analysis. For robustness, we also present results for two shorter sample periods (1995–2000 and 2000–2007). The results are similar across all four sample periods, but of course less precisely estimated for the shorter sample periods.

Figure II presents a binned scatter plot of the relationship between changes in expected output growth and our policy news shock over the 1995–2014 sample period. This scatter plot shows that the results in Table III are not driven by outliers. Finally, Appendix Table A.5 presents the response of output growth expectations separately for each quarter that the Blue Chip survey asks about. These are noisier but paint the same picture as the results in Table III.

A natural interpretation of this evidence is that FOMC announcements lead the private sector to update its beliefs not only about the future path of monetary policy but also about other economic fundamentals. For example, when an FOMC announcement

15. Campbell et al. (2012) present similar evidence regarding the effect of surprise monetary shocks on Blue Chip expectations about unemployment.

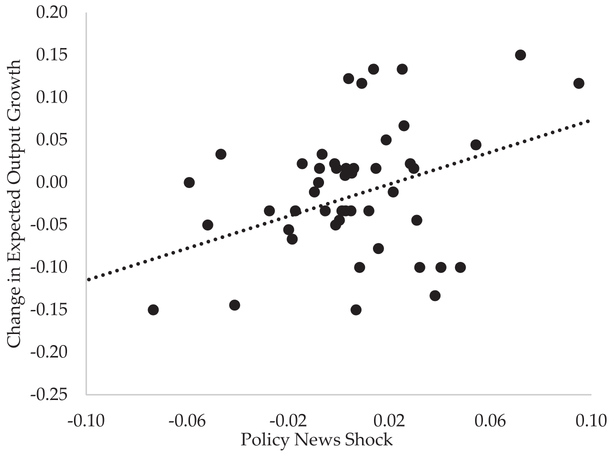


FIGURE II

Binned Scatter Plot for Expected Output Growth Regression

signals higher interest rates than markets had been expecting, market participants may view this as implying that the FOMC is more optimistic about economic fundamentals going forward than they had thought, which in turn may lead the market participants themselves to update their own beliefs about the state of the economy. We refer to effects of FOMC announcements on private sector views of non-monetary economic fundamentals as "Fed information effects."

The idea that the Fed can have such information effects relies on the notion that the FOMC has some knowledge regarding the economy that the private sector doesn't have or has formulated a viewpoint about the economy that the private sector finds valuable. Is it reasonable to suppose that this is the case? In terms of actual data, the FOMC has access to the same information as the private sector with minor exceptions.[16] However, the Fed does employ a legion of talented, well-trained economists whose primary role is to process and interpret all the information being released

16. The FOMC may have some advance knowledge of industrial production data since the Federal Reserve produces these data. It also collects anecdotal information on current economic conditions from reports submitted by bank directors and through interviews with business contacts, economists, and market experts. This information is subsequently published in reports commonly known as the Beige Book.

about the economy. This may imply that the FOMC's view about how the economy will evolve contains a perspective that affects the views of private agents. This is the view Romer and Romer (2000) argue for in their classic paper on Federal Reserve information.[17]

The idea that the Fed can influence private sector beliefs through its analysis of public data is somewhat unconventional in macroeconomics. However, the finance literature on analyst effects suggests this is not implausible. This literature finds that the most influential analyst announcements can have quite large effects on the stock market (see, e.g., Loh and Stulz 2011, p. 593). Loh and Stulz note: "Kenneth Bruce from Merrill Lynch issued a recommendation downgrade on Countrywide Financial on August 15, 2007, questioning the giant mortgage lender's ability to cope with a worsening credit crunch. The report sparked a sell-off in Countrywide's shares, which fell 13% on that day." If Kenneth Bruce can affect the market's views about Countrywide, perhaps it is not unreasonable to believe that the Fed can affect the market's views about where the economy is headed.

If Fed information is important, one might expect that contractionary monetary shocks would disproportionately occur when the Fed is more optimistic than the private sector about the state of the economy. In Online Appendix G, we test this proposition using the Fed's Green Book forecast about output growth as a measure of its optimism about the economy.[18] We find that indeed, our policy news shocks tend to be positive (i.e., indicate a surprise increase in interest rates) when the Green Book forecast about current and future real GDP growth is higher than the corresponding Blue Chip forecast (Table G.1, panel A). We furthermore find that the difference between Green Book and Blue Chip forecasts tends to narrow after our policy news shocks occur (Table G.1, panel B). This suggests that private sector forecasters may update their forecasts based on information they gleam from FOMC announcements.

17. This does not necessarily imply that the Fed should be able to forecast the future evolution of the economy better than the private sector. The private sector, of course, also processes and interprets the information released about the economy. It may therefore also be able to formulate a view about the economy that the Fed finds valuable. In other words, information can flow both ways with neither the Fed nor the private sector having a clear advantage.

18. The Green Book forecast is an internal forecast produced by the staff of the Board of Governors and presented at each FOMC meeting. Greenbook forecasts are made public with a five-year lag.

## V. Characterizing Monetary Non-Neutrality with Fed Information

The evidence we present in Section IV calls for more sophisticated modeling of the effects of monetary announcements than is standard in the literature. Rather than affecting beliefs only about current and future monetary policy, FOMC announcements must also affect private sector beliefs about other economic fundamentals.

An important consequence of this is that our evidence does not necessarily point to nominal and real rigidities being large. It may be that the responses of real interest rates that we estimate in response to FOMC announcements mostly reflect changes in private sector expectations about the natural rate of interest. If this is the case, the fact that we find that our shocks have little effect on inflationary expectations may be consistent with small nominal and real rigidities, since the tightening of policy relative to the natural rate is small.[19]

But even if this is true—that the responses of real interest rates that we estimate mostly reflect changes in private sector expectations about the natural rate of interest—this does not imply that the Fed is powerless. Quite to the contrary, in this case, the Fed has enormous power over beliefs about economic fundamentals, which may in turn have large effects on economic activity.

Our evidence on the response of real interest rates and expected inflation to a monetary announcement, therefore, implies that either (i) nominal and real rigidities are large, or (ii) the Fed can affect private sector beliefs about future nonmonetary fundamentals by large amounts. In other words, it implies that the Fed is powerful, either through the conventional channel or a nonconventional channel (or some combination).

To make these arguments precise, we now present a New Keynesian model of the economy augmented with Fed information effects. We then estimate this model to match the responses of interest rates, expected inflation, and expected output growth to FOMC announcements calculated above. Finally, we use the estimated model to assess the degree of monetary non-neutrality implied by our evidence and to assess how much of this monetary non-neutrality arises from traditional channels versus information effects.

19. This idea is explained in more detail below and in Online Appendix E.

### V.A. A New Model with Fed Information Effects

Most earlier theoretical work on the signaling effect of monetary policy has made the very restrictive assumption that the Fed can only signal through its actions. The focus of much of this literature has been on the limitations of what the Fed can signal with its actions. The recent empirical literature on monetary policy has, however, convincingly demonstrated that the Fed also signals through its statements (Gürkaynak, Sack, and Swanson 2005). This implies that the Fed's signals can be much richer; they can incorporate forward guidance, and they can distinguish between different types of shocks. With a much richer signal structure, the key question becomes: what information would the Fed like to convey?

We model FOMC announcements as affecting private sector beliefs about the path of the "natural rate of interest," the real interest rate that would prevail absent pricing frictions. This is a natural choice since tracking the natural rate is optimal in the model we consider absent information effects. If the Fed's goal is to track the natural rate of interest, it seems natural that announcements by the Fed about its current and future actions provide information about the future path of the natural rate of interest.

Apart from including a Fed information effect, the model we use differs in two ways from the textbook New Keynesian model: households have internal habits, and we allow for a backward-looking term in the Phillips curve. These two features allow the model to better fit the shapes of the impulse responses we have estimated in the data. Detailed derivations of household and firm behavior in this model are presented in Online Appendix H. There, we show that private sector behavior in this model can be described by a log-linearized consumption Euler equation and Phillips curve that take the following form:

$$\hat{\lambda}_{xt} = E_t\hat{\lambda}_{xt+1} + (\hat{\imath}_t - E_t\hat{\pi}_{t+1} - \hat{r}^n_t), \tag{2}$$

$$\Delta\hat{\pi}_t = \beta E_t\Delta\hat{\pi}_{t+1} + \kappa\omega\hat{\zeta}\hat{x}_t - \kappa\hat{\zeta}\hat{\lambda}_{xt}. \tag{3}$$

Hatted variables denote percentage deviations from steady state. $\Delta\hat{\pi}_t = \hat{\pi}_t - \hat{\pi}_{t-1}$. The variable $\hat{\lambda}_{xt} = \hat{\lambda}_t - \hat{\lambda}^n_t$ denotes the marginal utility gap (the difference between actual marginal utility of consumption $\hat{\lambda}_t$ and the "natural" level of marginal utility $\hat{\lambda}^n_t$ that would prevail if prices were flexible), $\hat{x} = \hat{y}_t - \hat{y}_t^n$ denotes the "output gap," $\hat{\pi}_t$ denotes inflation, $\hat{\imath}_t$ denotes the gross return on a one-period, risk-free, nominal bond, and $\hat{r}_t^n$ denotes the "natural rate of interest," which is a function of exogenous shocks to technology. The parameter $\beta$ denotes the subjective discount factor of households, while $\kappa$, $\omega$, and $\hat{\zeta}$ are composite parameters that determine the degree of nominal and real rigidities in the economy. With internal habits, the marginal utility gap is

$$\hat{\lambda}_{xt} = -(1 + b^2\beta)\sigma_c\hat{x}_t + b\sigma_c\hat{x}_{t-1} + b\beta\sigma_c E_t\hat{x}_{t+1}, \tag{4}$$

where $b$ governs the strength of habits and $\sigma_c = -\frac{\sigma^{-1}}{(1-b)(1-b\beta)}$, where $\sigma$ is the intertemporal elasticity of substitution.

We assume that the monetary authority sets interest rates according to the following simple rule:

$$\hat{\imath}_t - E_t\hat{\pi}_{t+1} = \bar{r}_t + \phi_\pi\hat{\pi}_t, \tag{5}$$

with $\bar{r}_t$ following an AR(2) process

$$\bar{r}_t = (\rho_1 + \rho_2)\bar{r}_{t-1} - \rho_1\rho_2\bar{r}_{t-2} + \epsilon_t, \tag{6}$$

where $\rho_1$ and $\rho_2$ are the roots of the lag polynomial for $\bar{r}_t$ and $\epsilon_t$ is the innovation to the $\bar{r}_t$ process. Here $\epsilon_t$ is the monetary shock. Notice that it can potentially have a long-lasting effect on real interest rates through the AR(2) process for $\bar{r}_t$. We choose this specification to be able to match the effects of the monetary shocks we estimate in the data. The shocks we estimate in the data have a relatively small effect on contemporaneous interest rates but a much larger effect on future interest rates (see Table I)—that is, they are mostly but not exclusively forward guidance shocks. The AR(2) specification for $\bar{r}_t$ can capture this if $\rho_1$ and $\rho_2$ are both large and positive leading to a pronounced hump shape in the impulse response of $\bar{r}_t$ (and therefore a pronounced hump shape across the term structure in the contemporaneous response of longer-term interest rates as in Table I).[20]

20. How should the monetary shocks $\epsilon_t$ be interpreted? A natural interpretation is the following: the Fed seeks to target the natural rate of interest. When the Fed makes an announcement, it seeks to communicate changes in its beliefs about the path of the natural rate to the public. The changes in beliefs sometimes surprise the public and therefore lead to a shock.

As discussed already, the way we model the Fed information effect is by assuming that FOMC announcements may affect the private sector's beliefs about the path of the natural rate of interest. The simplest way to do this is to assume that private sector beliefs about the path of the natural rate of interest shift by some fraction $\psi$ of the change in $\bar{r}_t$. Formally, in response to a monetary announcement

$$E_t \hat{r}^n_{t+j} = \psi E_t \bar{r}_{t+j}. \tag{7}$$

Moreover, we assume that the shock to expectations about the current value of the natural rate of output is proportional to the shock to expectations about the current monetary policy with the same factor of proportionality, that is, $E_t \hat{y}^n_t = \psi E_t \bar{r}_t$.[21]

Here the parameter $\psi$ governs the extent to which monetary announcements have information effects versus traditional effects. A fraction $\psi$ of the shock shows up as an information effect, while a fraction $1 - \psi$ shows up as a traditional gap between the path for real interest rates and the (private sector's beliefs about the) path for the natural rate of interest.[22]

### *V.B. Estimation Method*

We estimate four key parameters of the model using simulated method of moments. The four parameters we estimate are the two autoregressive roots of the shock process ($\rho_1$ and $\rho_2$), the information parameter ($\psi$) and the "slope of the Phillips curve" ($\kappa\hat{\zeta}$). We fix the remaining parameters at the following values: we choose a conventional value of $\beta = 0.99$ for the subjective discount factor. Our baseline value for the intertemporal elasticity of substitution is $\sigma = 0.5$, but we explore robustness to this choice. We fix the Taylor rule parameter to $\phi_\pi = 0.01$. This is roughly equivalent to a value of 1.01 for the more conventional Taylor rule

21. Here we assume that the FOMC meeting occurs at the beginning of the period, before the value of $\hat{y}^n_t$ is revealed to the agents. In reality, uncertainty persists about output in period $t$ until well after period $t$, due to heterogeneous information. We abstract from this.

22. This way of modeling the information effect has the crucial advantage that it is simple and parsimonious enough to allow us to account for the effects of FOMC announcements on the entire path of future interest rate expectations—that is, the role of forward guidance. This is a distinguishing feature versus previous work. Ellingsen and Söderström (2001) present a model in which the signaling effect derives from announcements about the current interest rate.

specification without the $E_t\hat{\pi}_{t+1}$ term on the left-hand side of equation (5). We choose this value to ensure that the model has a unique bounded equilibrium but at the same time limit the amount of endogenous feedback from the policy rule. This helps ensure that the response of the real interest rate dies out within 10 years as we estimate in the data.[23] We set the elasticity of marginal cost with respect to own output to $\omega = 2$. This value results from a Frisch labor supply elasticity of 1 and a labor share of $\frac{2}{3}$. Finally, we set the habit parameter to $b = 0.9$, a value very close to the one estimated by Schmitt-Grohé and Uribe (2012).

To ease the computational burden of the simulated method of moments estimation we use a two-stage iterative procedure. In the first stage, we estimate the two autoregressive roots of the monetary shock process ($\rho_1$ and $\rho_2$) to fit the hump-shaped response of real interest rates to our policy news shock. We do this for fixed values of the information parameter and the slope of the Phillips curve. The moments we use in this step are the responses of 2-, 3-, 5-, and 10-year real yields and forwards reported in Table I. In the second step, we estimate the information parameter ($\psi$) and the slope of the Phillips curve ($\kappa\hat{\zeta}$) for fixed values of the two autoregressive roots. The moments we use in this step are the responses of 2-, 3-, 5-, and 10-year break-even inflation (both yields and forwards) reported in Table I and the responses of output growth expectations reported in Appendix Table A.5. We iterate back and forth between these steps until convergence.

In both steps, we use a loss function that is quadratic in the difference between the moments discussed above and their theoretical counterparts in the model.[24] We use a weighting matrix with the inverse standard deviations of the moments on the diagonal, and with the off-diagonal values set to 0. We use a bootstrap procedure to estimate standard errors. Our bootstrap procedure is to resample the data with replacement, estimate the empirical moments on the resampled data, and then estimate the structural

23. Recent work has shown that standard New Keynesian models such as the one we are using are very sensitive to interest rate movements in the far future (Carlstrom, Fuerst, and Paustian 2015; Mckay, Nakamura, and Steinsson 2016).

24. The theoretical counterparts are the responses of the corresponding variable to a monetary shock in the model. Since the magnitude of the shock in our simulations is arbitrary, we make sure to rescale all responses from the model in such a way that the three-year real forward rate is perfectly matched. We use the methods and computer code described in Sims (2001) to calculate the equilibrium of our model.

TABLE IV
ESTIMATES OF STRUCTURAL PARAMETERS

| | $\psi$ | $\kappa\hat{\zeta} \times 10^{-5}$ | $\rho_1$ | $\rho_2$ |
|---|---|---|---|---|
| Baseline | 0.68 | 11.2 | 0.9 | 0.79 |
| | [0.33, 0.84] | [0.0, 60.2] | [0.83, 0.96] | [−0.69, 0.89] |
| No Fed information | 0.00 | 3.4 | 0.9 | 0.79 |
| ($\psi = 0$) | — | [0.0, 24.1] | [0.83, 0.96] | [−0.69, 0.89] |
| Full Fed information | 0.99 | 563 | 0.9 | 0.79 |
| ($\psi = 0.99$) | — | [0, 12,538] | [0.82, 0.96] | [−0.67, 0.89] |
| Lower IES | 0.67 | 13.7 | 0.9 | 0.79 |
| ($\sigma = 0.25$) | [0.25, 0.89] | [0.0, 94.6] | [0.83, 0.96] | [−0.69, 0.89] |
| Higher IES | 0.68 | 8.2 | 0.9 | 0.79 |
| ($\sigma = 1$) | [0.42, 0.81] | [0.0, 44.0] | [0.83, 0.96] | [−0.69, 0.89] |
| No habits | 1 | 1,000 | 0.9 | 0.79 |
| ($b = 0$) | [0.92, 1.00] | [0, 43,236] | [0.83, 0.96] | [−0.69, 0.89] |

*Notes*. The table reports our estimates of the structural parameters of the model that we estimate. We report 95% confidence intervals in square brackets below the point estimate for each parameter. These are based on the bootstrap procedure described in the text. In the No Fed information case and the Full Fed information case, the slope of the Phillips curve is estimated only off of inflation moments. In the other cases, the slope of the Phillips curve and the information parameter are estimated off of both inflation and GDP growth moments.

parameters as described above using a loss function based on the estimated empirical moments for the resampled data.[25] We repeat this procedure 1,000 times and report the 2.5% and 97.5% quantiles of the statistics of interest. Importantly, this procedure for constructing the confidence intervals captures the statistical uncertainty associated with our empirical estimates in Table I and Appendix Table A.5.

### *V.C. Results and Intuition*

Our primary interest is to assess the extent to which FOMC announcements contain Fed information and how this affects inference about other key aspects of the economy such as the slope of the Phillips curve. Table IV presents our parameter estimates,

25. The resampling procedure is stratified because the empirical moments are estimated from different data sets and different sample periods. The stratification makes sure that each resampled data set is consistent with the original data set along the following dimensions: the number of observations for the yields and forwards before and after 2004 is the same as in the original data set (since the sample period for the two-year and three-year yields and forwards starts in 2004). The number of Blue Chip observations that do not report four and seven quarters ahead expected GDP growth are the same as in the original data set, since Blue Chip only asks forecasters to forecast the current and next calendar year.

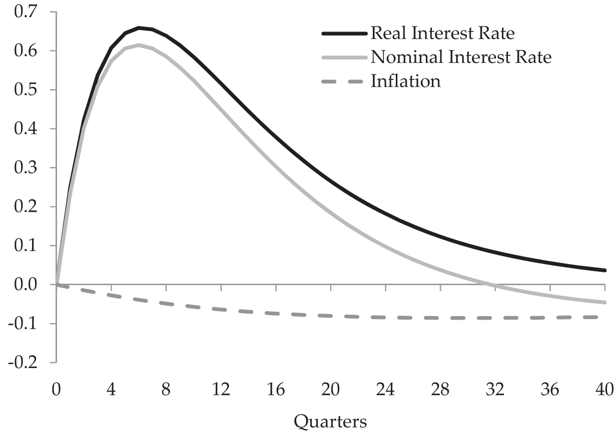


FIGURE III

Responses of Nominal and Real Rates and Inflation to a Contractionary Shock

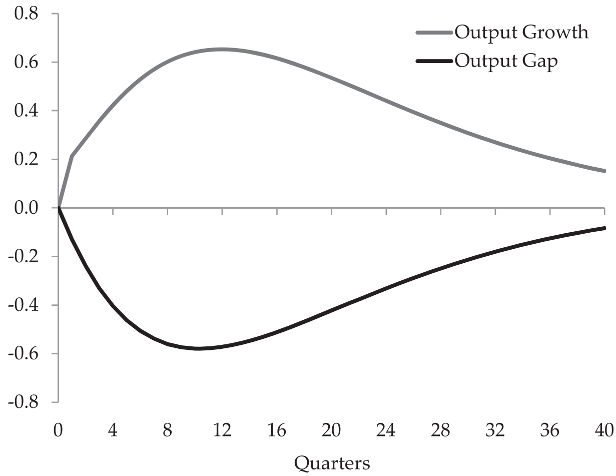


FIGURE IV

Responses of Expected Output Growth and Output Gap to a Contractionary Shock

and Figures III–V illustrate the fit of the model. As in the data, the estimated model generates a persistent, hump-shaped response of nominal and real interest rates with a small and delayed effect on expected inflation (see Figure III). To generate this type of response, we estimate that both of the autoregressive roots of the

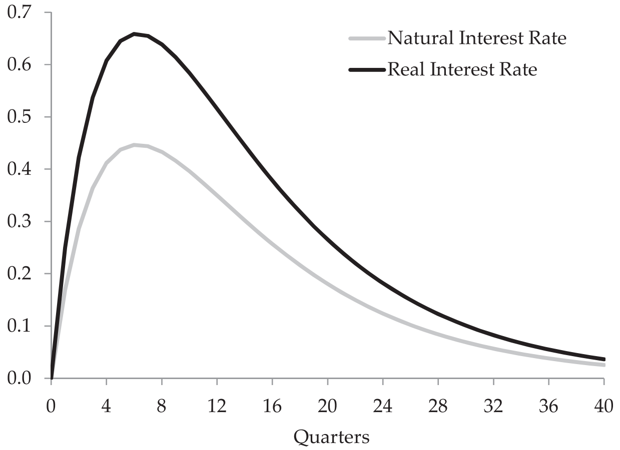


FIGURE V

Decomposition of Real Rate into Interest Rate Gap and Natural Interest Rate

monetary shock process are large and positive, and we estimate a small slope of the Phillips curve.

We also estimate that the monetary shock leads to a pronounced increase in expectations about output growth as in the data (see Figure IV). The model can match the increase in expected growth following a surprise increase in interest rates by estimating a large information effect. We estimate that roughly two-thirds of the monetary shock is a shock to beliefs about future natural rates of interest (see Figure V).

As Figure IV illustrates, our monetary shock simultaneously leads to an increase in expectations about output growth and a decrease in output relative to the natural rate of output (i.e., a decrease in the output gap). This is a consequence of the fact that the information effect is large but still substantially smaller than the overall increase in interest rates. Output growth expectations rise because the monetary shock is interpreted as good news about fundamentals. But since the Fed increases interest rates by more than the private sector believes the natural rate of interest rose, private sector expectations about the output gap fall.

Despite estimating a large information effect, we estimate a very flat Phillips curve. This is consistent with prior empirical work. Mavroeidis, Plagborg-Moller, and Stock (2014) survey the literature that has estimated Phillips curves and, using a common data set, run a huge number of a priori reasonable specifications that span different choices made in this literature. They find that the estimated values of the slope of the Phillips curve vary substantially across specifications and are symmetrically dispersed around a value of 0. One reason our estimated Phillips curve is very flat is that the shocks that we estimate are substantially more persistent than most other identified monetary policy shocks (e.g., Christiano, Eichenbaum, and Evans 2005). This means that our shocks imply forward guidance about interest rates quite far in the future. It has recently been shown that standard New Keynesian models implies that far future forward guidance has large effects on current outcomes (Carlstrom, Fuerst, and Paustian 2015; McKay, Nakamura, and Steinsson 2016).

To illustrate how allowing for the information effect affects our estimates, we reestimate the model setting the information effect to 0. In this case, we remove the expected output growth moments from the objective function of the estimation because these moments are impossible to match without an information effect. The second row in Table IV presents the estimates for this case. We see that ignoring the information effect yields a substantially flatter Phillips curve—implying a substantial overestimate of nominal and real rigidities—relative to our baseline estimation. We also report a case where the information effect is set to a value close to 1. In this case, the slope of the Phillips curve is estimated to be much steeper than in our baseline case.

Clearly, the information effect has an important effect on inference about the slope of the Phillips curve. This arises because the effect of the monetary shock on the interest rate gap—the gap between the interest rate and the natural rate of interest—is much smaller when the information effect is estimated to be large than it is when the information effect is estimated to be small. It is the response of the interest rate gap as opposed to the response of the real interest rate itself that determines the response of inflation (see equation (12) in Online Appendix E). The intuition is that, when the Fed raises rates, people perceive this as good news about economic fundamentals, and this counters the conventional channel of monetary policy whereby an interest rate hike lowers output.

Table IV also reports alternative estimates where we vary the value of the intertemporal elasticity of substitution (IES) and the habit formation parameter. Varying the IES does not affect our estimates much. This may seem surprising. A smaller value of the IES implies that larger movements in the natural rate of

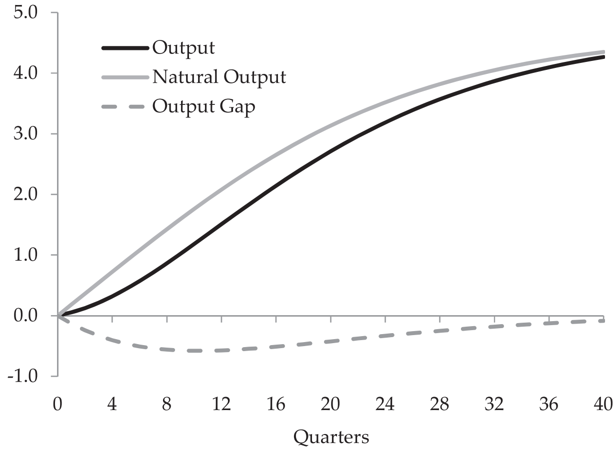


FIGURE VI

Response of Actual and Natural Expected Output

interest are needed to match the movements in expected growth rates observed in the data. This would suggest that a lower value of the IES would yield a larger value of the information effect. However, in our model with substantial habit formation the IES and the information parameters also affect the shape of the response of output growth. These effects imply that similar values of the information parameter are estimated for a wide range of values of the IES. In contrast, when we set the habit parameter to 0, we estimate that the entire change in interest rates is an information effect. As a consequence, we also estimate a much steeper Phillips curve. However, the fit of the model to the output growth moments is much worse without habit formation.

## VI. THE CAUSAL EFFECT OF MONETARY SHOCKS

The large information effect we estimate in Section V fundamentally changes how we should interpret the response of output and inflation to monetary policy announcements. Figure VI plots the response of private sector beliefs about output, the natural rate of output, and the output gap to a monetary shock that increases interest rates in our estimated model from Section V. The figure shows that this surprise monetary tightening leads to a large and permanent increase in expected output.

How can this be? Can monetary policy really have such huge effects on output 10 years in the future? Isn't monetary policy neutral in the long run? Shouldn't a monetary tightening decrease output? Here it is crucial to recognize that the information the Fed reveals about economic fundamentals is largely (perhaps mostly) information that the private sector would have learned about eventually through other channels in the absence of the Fed's announcement. This introduces an important subtlety into the assessment of the effect of monetary policy that has, to our knowledge, not been discussed in the existing literature. To correctly assess the causal effect of monetary policy on output, we need to compare versus a reasonable counterfactual that accounts for the fact that the changes in fundamentals that the Fed's announcement reveals would have occurred even in the absence of the announcement. In other words, we want a counterfactual in which the path of productivity—the exogenous fundamental we assume the Fed provides information about—follows the same path as in the actual response.

To construct this counterfactual, we must take a stand on when the private sector would have learned about the changes in fundamentals revealed by the Fed in the absence of the Fed announcement. We choose a particularly simple counterfactual. In this counterfactual, the private sector learns about changes in productivity when they occur and it believes that productivity follows a random walk. To be clear, this counterfactual represents our assumption about what would have happened regarding private sector beliefs about economic fundamentals in the absence of the Fed announcement. One could consider other counterfactuals. We don't have any data to precisely pin down the counterfactual. But we think that our chosen counterfactual is reasonable and it serves the purpose of illustrating the main issue that one needs to use a counterfactual in which the changes in economic fundamentals that the Fed provides information about would occur even in the absence of the Fed announcement.

We must also make an assumption about how monetary policy reacts to changes in the natural rate of interest in the counterfactual. In keeping with the general assumption that the Fed seeks to track the natural rate of interest, we assume that monetary policy varies the interest rate to track the natural rate of interest in the counterfactual.

Figure VII presents actual and counterfactual output growth constructed in this way. The figure reveals that most of the

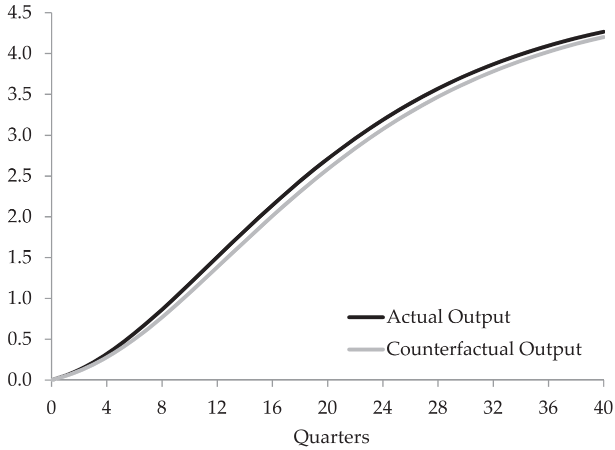


FIGURE VII

Response of Actual and Counterfactual Expected Output

increase in output would have occurred anyway in the absence of the Fed announcement. Given this new counterfactual, the “causal effect” of the Fed on output growth—the difference between what happens following the monetary shock and what would have happened as represented by the counterfactual—no longer looks so implausible. This difference is much more modest than the overall change in beliefs about the path of output (which includes the effects of the productivity shocks the Fed is informing the public about).

Figure VIII plots this measure of the causal effect of monetary shocks on output. The figure also decomposes it into two components: the effect on the output gap (which falls) and the effect on the natural rate of output (which rises). The effect on the output gap is the conventional channel of monetary policy: an interest rate increase relative to the natural rate of interest leads to a drop in output relative to the natural rate of output. The second component is a novel effect of Fed information.

A positive shock to beliefs about economic fundamentals—which leads the future path of the natural rate of interest to rise—has a positive causal effect on output even relative to the counterfactual described above. Why is this? This effect arises because of the dynamic linkages in our model. In our model habit formation by households is important and households understand this. When consumers expect consumption to be high in the

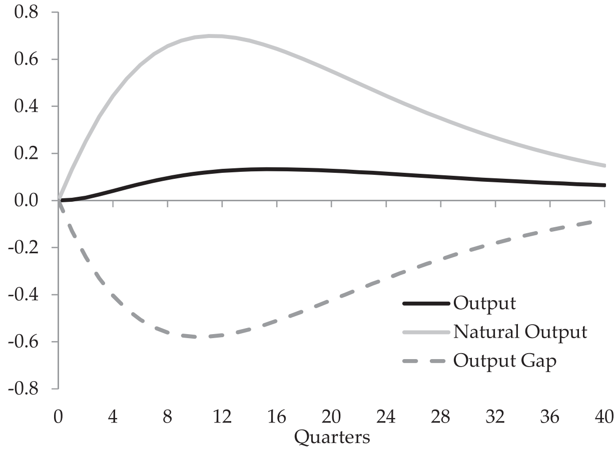


FIGURE VIII

Causal Effect of Monetary Shocks on Expected Output

future, they want to consume more today to build up their habit. This implies that positive news about the future raises consumption and output today. Other dynamic linkages would yield similar effects of Fed information. For example, in a model with capital accumulation, news about high future productivity would cause an increase in investment on announcement and thereby affect current output.

### *VI.A. Policy Implications*

The findings discussed above have important policy implications. The fact that the information effect of surprise Fed tightenings stimulates output implies that the Fed is "fighting against itself" when it surprises markets. Figure VIII shows that for our estimated parameters the overall effect of the two channels is for an interest rate increase to raise output—the opposite from the conventional view of how monetary policy works.[26] If the Fed would like to stimulate economic activity, a surprise policy easing may be counterproductive because the increase in pessimism that it causes itself pulls the economy further down.

26. Recall that this result is not simply an implication of the fact that the Fed's announcement is good news that raises output expectations. We are subtracting the counterfactual. The effect we are talking about here is the effect that learning the good news earlier has on the path of output.

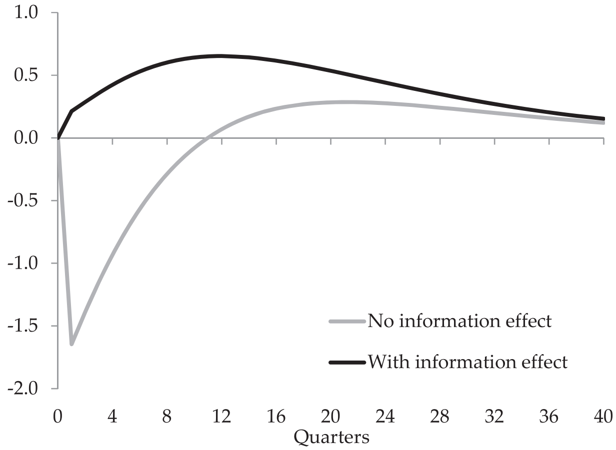


FIGURE IX

Expected Output Growth with and without the Information Effect

This raises the question: should the Fed withhold bad news about the economy to avoid the increased pessimism this information would cause? A full analysis of this question is beyond the scope of this article. But we note two reasons it may not be the case that the Fed should withhold bad news. First, an attempt by the Fed to systematically bias its signals is likely to be ineffective because the private sector will learn how to interpret what the Fed says and adjust for the bias. Second, advance knowledge about changes in fundamentals allows agents to prepare gradually for these changes, which is likely to improve welfare. A possible exception to this intuition is a circumstance when the Fed is not able to respond to the information it is revealing by tracking the updated natural rate, for example, when interest rates are at the zero lower bound. In that case, it may be optimal for the Fed to withhold information.

The information effect also implies that there is an important distinction between interest rate changes associated with the monetary policy rule and deviations from this rule. The systematic response of monetary policy to public information—by definition—does not have information effects associated with it and therefore will not lead to the "perverse" effects on output discussed above. Figure IX contrasts the consequences of an unexpected monetary shock with its associated information effect and the effects of a similarly sized change in interest rates that comes about due to the systematic component of monetary policy and therefore does not have an information effect associated with it.[27] The contrast is stark. Since our estimates imply considerable nominal and real rigidities, increases in interest rates associated with the monetary policy rule reduce output substantially.

This analysis makes clear that the information content of a monetary shock matters in determining its effects. Most of what the Fed does is anticipated by markets exactly because it depends in a systematic way on public information. The effects of this systematic component of monetary policy are likely to be more conventionally Keynesian than the effects of monetary surprises that contain significant information effects and are therefore a mix of the response to a conventional monetary shock and the response to the nonmonetary news contained in the Fed surprise.[28] The effects of monetary surprises will also vary depending on the amount and nature of the information they convey. In the case of the Volcker disinflation, for example, the narrative evidence suggests that few observers interpreted Volcker's decision to raise interest rates as reflecting an optimistic view of the economic outlook. To the extent that the Volcker tightening was broadly interpreted as reflecting a different loss function, or a greater degree of "conservatism" in dealing with inflation, then this would have a small information effect. Although we do not allow for any heterogeneity of this nature in our model, this strikes us as an interesting avenue for future research.

### *VI.B. Stock Price Effects*

We finish the article with one additional piece of evidence that sheds light on the information content of FOMC announcements. Table V presents the response of stock prices to FOMC announce-

27. It is important to understand that our empirical results can be used to think about both the effects of monetary policy shocks and changes in interest rates that come about due to the systematic component of policy. In the linear models we use, it does not matter why interest rates change (except for the information effect). In other words, the comparative static of a given change in interest rates on other variables is the same irrespective of the reason for the interest rate change (except for the information effect).

28. This distinction is analogous to the "local average treatment effect" versus "average treatment effect" distinction in applied microeconomics.

TABLE V
RESPONSE OF STOCK PRICES

| | Stock prices |
|---|---|
| Response in the data | −6.5 |
| | (3.9) |
| Response in the model | |
| Baseline | −6.8 |
| | [−11.5, −1.6] |
| No Fed Information effect | −11.1 |
| | [−19.4, −2.5] |

ments. A pure tightening of monetary policy leads stock prices to fall for two reasons: higher discount rates and lower output. However, good news about future fundamentals can raise stock prices (if higher future cash flows outweigh higher future discount rates). In the data, we estimate that the S&P500 index falls by 6.5% in response to a policy news shock that raises the two-year nominal forward by 1%.[29] This estimate is rather noisy, with a standard error of 3.3%.

Table V also presents the response of stock prices to our monetary policy shock in our estimated model.[30] In the calibration of our model where monetary policy announcements convey information about both future monetary policy and future exogenous economic fundamentals, stock prices fall by 6.8% in response to the FOMC announcement. In contrast, if monetary policy is assumed not to convey information about future exogenous fundamentals, stock prices fall by 11%. The response of stock prices in the data is thus another indicator that favors the view that monetary policy conveys information to the public about future exogenous fundamentals.

## VII. CONCLUSION

We use a high-frequency identification approach to estimate the causal effect of monetary shocks. The monetary shocks that

29. Earlier work by Bernanke and Kuttner (2005) and Rigobon and Sack (2004) finds large responses of the stock market to surprise movements in the Fed funds rate.

30. For simplicity, we model stocks as an unlevered claim to the consumption stream in the economy.

we identify have large and persistent effects on real interest rates. Real rates move essentially one-for-one with nominal rates several years into the term structure. Contractionary monetary shocks lead to no significant effect on inflation in the short run and the effect becomes significantly negative only several years into the term structure. However, in sharp contrast with the implications of standard monetary models, contractionary shocks raise expectations about output growth.

We interpret the increase in expected output growth after a monetary tightening as evidence of a Fed information effect. When the Fed raises interest rates, this leads to increased optimism about economic fundamentals. We develop a model of this Fed information effect, in which the private sector interprets part of an unexpected increase in the interest rate as information about the natural rate. We estimate the model and find strong evidence for both channels: the conventional monetary policy channel and the information effect. One implication of our analysis is that the information content of a monetary shock matters in determining its causal effects.

APPENDIX TABLE A.1

Response of Interest Rates to Monetary Shocks for Different Sample Periods

| | Baseline sample | | Precrisis (2000–2007) | | Full sample | | Baseline w/ unsched. | |
|---|---|---|---|---|---|---|---|---|
| | Nominal | Real | Nominal | Real | Nominal | Real | Nominal | Real |
| 3M Treasury yield | 0.67 | | 0.76 | | 0.73 | | 0.76 | |
| | (0.14) | | (0.13) | | (0.15) | | (0.11) | |
| 6M Treasury yield | 0.85 | | 0.85 | | 0.90 | | 0.91 | |
| | (0.11) | | (0.12) | | (0.12) | | (0.10) | |
| 1Y Treasury yield | 1.00 | | 1.00 | | 1.00 | | 1.00 | |
| | (0.14) | | (0.14) | | (0.13) | | (0.13) | |
| 2Y Treasury yield | 1.10 | 1.06 | 1.11 | 1.04 | 1.19 | 1.46 | 1.30 | 1.21 |
| | (0.33) | (0.24) | (0.36) | (0.24) | (0.29) | (0.39) | (0.37) | (0.26) |
| 3Y Treasury yield | 1.06 | 1.02 | 1.03 | 0.97 | 1.21 | 1.34 | 1.26 | 1.18 |
| | (0.36) | (0.25) | (0.39) | (0.25) | (0.31) | (0.33) | (0.40) | (0.28) |
| 5Y Treasury yield | 0.73 | 0.64 | 0.67 | 0.58 | 0.78 | 0.81 | 0.69 | 0.68 |
| | (0.20) | (0.15) | (0.20) | (0.15) | (0.18) | (0.16) | (0.16) | (0.11) |
| 10Y Treasury yield | 0.38 | 0.44 | 0.36 | 0.44 | 0.50 | 0.57 | 0.38 | 0.43 |
| | (0.17) | (0.13) | (0.18) | (0.13) | (0.17) | (0.16) | (0.13) | (0.10) |
| 2Y Tr. inst. forward rate | 1.14 | 0.99 | 1.07 | 0.90 | 1.31 | 0.97 | 1.34 | 1.15 |
| | (0.46) | (0.29) | (0.48) | (0.27) | (0.38) | (0.30) | (0.49) | (0.31) |
| 3Y Tr. inst. forward rate | 0.82 | 0.88 | 0.66 | 0.76 | 1.14 | 1.09 | 1.00 | 1.03 |
| | (0.43) | (0.32) | (0.43) | (0.29) | (0.41) | (0.35) | (0.46) | (0.34) |
| 5Y Tr. inst. forward rate | 0.26 | 0.47 | 0.20 | 0.47 | 0.44 | 0.61 | 0.27 | 0.45 |
| | (0.19) | (0.17) | (0.19) | (0.16) | (0.21) | (0.21) | (0.13) | (0.12) |
| 10Y Tr. inst. forward rate | −0.08 | 0.12 | −0.01 | 0.21 | 0.05 | 0.10 | −0.07 | 0.04 |
| | (0.18) | (0.12) | (0.19) | (0.13) | (0.17) | (0.13) | (0.12) | (0.11) |

*Notes*. Each estimate comes from a separate OLS regression. The dependent variable in each regression is the one-day change in the variable stated in the left-most column. The independent variable is a change in the policy news shock over a 30-minute window around regularly scheduled FOMC announcements, except the last two columns where we include unscheduled FOMC announcements. The baseline sample period is 1/1/2000 to 3/19/2014, except that we drop July 2008 through June 2009. The “precrisis” sample is January 2000 through December 2007. The “full sample” is 1/1/2000 to 3/19/2014. In the last two columns, we exclude a 10-day period after 9/11/2001. For two-year and three-year yields and real forwards, the sample starts in 2004. For each sample period, we construct the policy news shocks from the same sample of observations as the regressions are run on, that is, the results from the different sample periods use slightly different policy news shock series. Robust standard errors are in parentheses.

APPENDIX TABLE A.2

Response to a Fed Funds Rate Shock

| | Nominal | Real | Inflation |
|---|---|---|---|
| 3M Treasury yield | 0.50 | | |
| | (0.16) | | |
| 6M Treasury yield | 0.59 | | |
| | (0.10) | | |
| 1Y Treasury yield | 0.41 | | |
| | (0.16) | | |
| 2Y Treasury yield | 0.48 | 0.50 | −0.02 |
| | (0.32) | (0.20) | (0.15) |
| 3Y Treasury yield | 0.38 | 0.41 | −0.03 |
| | (0.34) | (0.19) | (0.18) |
| 5Y Treasury yield | 0.11 | 0.21 | −0.10 |
| | (0.16) | (0.12) | (0.09) |
| 10Y Treasury yield | −0.00 | 0.10 | −0.10 |
| | (0.12) | (0.09) | (0.07) |
| 2Y Treasury inst. forward rate | 0.29 | 0.30 | −0.01 |
| | (0.40) | (0.20) | (0.25) |
| 3Y Treasury inst. forward rate | 0.07 | 0.13 | −0.06 |
| | (0.34) | (0.19) | (0.22) |
| 5Y Treasury inst. forward rate | −0.09 | 0.07 | −0.16 |
| | (0.13) | (0.12) | (0.07) |
| 10Y Treasury inst. forward rate | −0.11 | −0.02 | −0.08 |
| | (0.16) | (0.11) | (0.09) |

*Notes*. Each estimate comes from a separate OLS regression. The dependent variable in each regression is the one-day change in the variable stated in the left-most column. The independent variable is a change in the Fed funds future over the remainder of the month over a 30-minute window around the time of FOMC announcements. The sample period is all regularly scheduled meetings from 1/1/2000 to 3/19/2014, except that we drop July 2008 through June 2009. For two-year and three-year yields and real forwards, the sample starts in January 2004. The sample size for the two-year and three-year yields and forwards is 74. The sample size for all other regressions is 106. In all regressions, the policy news shock is computed from these same 106 observations. Robust standard errors are in parentheses.

APPENDIX TABLE A.3

RESPONSES TO POLICY NEWS SHOCK USING THE RIGOBON ESTIMATOR

| | Nominal | Real | Inflation |
|---|---|---|---|
| 3M Treasury yield | 0.69 | | |
| | (0.15) | | |
| 6M Treasury yield | 0.85 | | |
| | (0.12) | | |
| 1Y Treasury yield | 0.98 | | |
| | (0.15) | | |
| 2Y Treasury yield | 1.07 | 1.03 | 0.05 |
| | (0.37) | (0.29) | (0.20) |
| 3Y Treasury yield | 1.03 | 0.99 | 0.04 |
| | (0.42) | (0.30) | (0.19) |
| 5Y Treasury yield | 0.69 | 0.62 | 0.07 |
| | (0.22) | (0.16) | (0.12) |
| 10Y Treasury yield | 0.34 | 0.42 | −0.08 |
| | (0.19) | (0.14) | (0.09) |
| 2Y Treasury inst. forward rate | 1.10 | 0.96 | 0.14 |
| | (0.51) | (0.34) | (0.25) |
| 3Y Treasury inst. forward rate | 0.78 | 0.86 | −0.08 |
| | (0.49) | (0.37) | (0.17) |
| 5Y Treasury inst. forward rate | 0.22 | 0.46 | −0.24 |
| | (0.20) | (0.18) | (0.09) |
| 10Y Treasury inst. forward rate | −0.12 | 0.11 | −0.22 |
| | (0.19) | (0.13) | (0.10) |

*Notes*. Each estimate comes from a separate "regression." The dependent variable in each regression is the one-day change in the variable stated in the left-most column. The independent variable is a change in the policy news shock over a 30-minute window around the time of FOMC announcements. All results are based on Rigobon's (2003) method of identification by heteroskedasticity. The sample of "treatment" days for the Rigobon method is all regularly scheduled FOMC meeting days from 1/1/2000 to 3/19/2014; this is also the period for which the policy news shock is constructed in all regressions. The sample of control days for the Rigobon analysis is all Tuesdays and Wednesdays that are not FOMC meeting days over the same period of time. In both the treatment and control samples, we drop July 2008 through June 2009 and 9/11/2001–9/21/2001. For two-year forwards, the sample starts in January 2004. Standard errors are calculated using a nonparametric bootstrap with 5,000 iterations.

APPENDIX TABLE A.4

BREAKEVEN INFLATION VERSUS INFLATION SWAPS

| | Breakeven | Swaps |
|---|---|---|
| Inflation over next 2 years | −0.02 | 0.37 |
| | (0.18) | (0.35) |
| Inflation over next 3 years | −0.03 | 0.41 |
| | (0.17) | (0.32) |
| Inflation over next 5 years | −0.13 | −0.02 |
| | (0.14) | (0.15) |
| Inflation over next 10 years | −0.22 | −0.17 |
| | (0.12) | (0.16) |

*Notes*. Each estimate comes from a separate OLS regression. The dependent variable in each regression is the one-day change in expected inflation measured either by break-even inflation from the difference between nominal Treasuries and TIPS (first column) or from inflation swaps (second column) for the period stated in the left-most column. The independent variable is a change in the policy news shock over a 30-minute window around the time of FOMC announcements, where the policy news shocks are constructed on the 2000–2014 sample used in Table I. The sample is all regularly scheduled FOMC meeting days from 1/1/2005 to 11/14/2012, except that we drop July 2008 through June 2009. Robust standard errors are in parentheses.

APPENDIX TABLE A.5

RESPONSE OF EXPECTED OUTPUT GROWTH

| | |
|---|---|
| Exp. output growth in current qr | 1.38 |
| | (0.72) |
| Exp. output growth 1 qr ahead | 1.56 |
| | (0.54) |
| Exp. output growth 2 qr ahead | 0.66 |
| | (0.37) |
| Exp. output growth 3 qr ahead | 0.82 |
| | (0.27) |
| Exp. output growth 4 qr ahead | 0.51 |
| | (0.25) |
| Exp. output growth 5 qr ahead | 0.54 |
| | (0.28) |
| Exp. output growth 6 qr ahead | 0.48 |
| | (0.25) |
| Exp. output growth 7 qr ahead | 0.90 |
| | (0.57) |

*Notes*. Each estimate comes from a separate OLS regression. We regress changes in survey expectations from the Blue Chip Economic Indicators on the policy news shock. Since the Blue Chip survey expectations are available at a monthly frequency, we construct a corresponding monthly measure of our policy news shock. In particular, we use any policy news shock that occurs over the month except for those that occur in the first week (because we do not know whether these occurred before or after the survey response). The dependent variable is the change in the forecasted value of output growth $N$ quarters ahead, between this month's survey and last month's survey. See Online Appendix F for details. The sample period is all regularly scheduled FOMC meetings between January 1995 to April 2014, except that we drop July 2008 through June 2009 and the aforementioned first-week meetings. The policy news shock is constructed on the same sample period. Sample sizes are 120 for the first five rows, then 75, 45, and 13. Robust standard errors are in parentheses.

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## SUPPLEMENTARY MATERIAL

An Online Appendix for this article can be found at *The Quarterly Journal of Economics* online. Data and code replicating the tables and figures in this article can be found in Nakamura and Steinsson (2018), in the Harvard Dataverse, doi:10.7910/DVN/HZOXKN.

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