Rising Fed Information Effects

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Abstract

We document expansionary effects on output, unemployment, prices, and investment following *contractionary* monetary policy in recent samples starting in the 1980s. These puzzling results are mainly driven by the later period beginning in the mid-1990s while results in the earlier sample match classic monetary policy effects. The rising importance of the information channel of monetary policy accounts for this shift in monetary transmission. In recent times, policy rate hikes signal improvements to the economy's outlook and stimulate activity, outweighing their conventional contractionary effects. We use a model with information frictions to formalize and study each of these effects. In our model, firms interpret changes in the federal funds rate as endogenous signals about the state of the economy, where the strength of the information effect depends on how precisely monetary policy responds to the state of the economy. We also use our model to study the role of alternative communication strategies and conclude that effective communication on the part of the Fed mitigates the information effects.

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1 Introduction

A vast empirical literature has established a consensus view on the effects of monetary policy based on data covering most of the post-WWII period.[1] In this view, contractionary monetary policy depresses economic activity as witnessed by a drop in output, investment, and prices, as well as surging unemployment. We document the opposite effects prevail in samples that concentrate on recent times. In the period 1983:M01–2007:M12, we estimate that contractionary monetary surprises raise output, investment, prices and leads to a drop in the unemployment rate.[2] Crucially, these puzzling results are to a large extent driven by the later sub-sample period 1996:M07–2007:M12. In the earlier period, 1983:M01–1996:M06, we obtain results that match the classic effects of monetary policy shocks.

We hypothesize these findings reflect the presence and rising importance of Fed information effects (Romer and Romer, 2000; Nakamura and Steinsson, 2018). A Fed policy rate hike signals improvements to the economy's outlook, stimulating economic activity. In recent times, this signal is relatively more important than the contractionary effect of higher rates and as a result the economy moves into expansion.

To investigate changes in monetary transmission over time, a contribution of this paper is a new measure of monetary surprises that (i) provides a role for Fed information effects and (ii) extends back relatively far in time. Existing shock series like that by Romer and Romer (2004) control for the information set of the central bank and thus preclude a role for Fed information effects; or are not available before the early-1990s, like the shocks by Nakamura and Steinsson (2018) based on high-frequency identification.

Specifically, we use narrative evidence by Romer and Romer (2004) on intended funds rate changes and control for expected policy actions using private sector expectations data on output, price, and unemployment from the Blue Chip Economic Indicators. Our new measure of private sector monetary surprises and shocks from the established high-frequency identification approach display very similar effects on macroeconomic variable in the later sub-sample in which they overlap. A key advantage of our measure is its relatively longer sample coverage, starting in the early-1980s and enabling the study of changes in monetary transmission over time.

If the central bank has superior information about the current and future state of the economy, private sector monetary surprises reflect both pure and exogenous monetary policy shocks as well as a component reflecting learning about the Fed's information set. Therefore, to better understand the role of each component, one needs to control for the new information that surprises private sector agents.

[1]See Ramey (2016) for a survey of this literature.
[2]Barakchian and Crowe (2013) obtain similar results for sample periods from 1988 to approximately 2007.

Following Miranda-Agrippino and Ricco (2018), we identify the Fed information effect as the fitted values in a regression of private sector monetary surprises on Greenbook forecasts. The residual of the same regression reflects the conventional interest rate channel of monetary policy. In the later sub-sample, we find that monetary transmission appears to operate mainly through affecting private sector expectations about the current and future state of the economy. The responses to the Fed information effect closely resemble those of raw private sector monetary surprises. Pure monetary policy shocks are mostly insignificant or continue to produce results that contradict classic monetary policy effects.

We also provide a model to formally interpret these results. We model information effects by assuming that firms observe all macroeconomic variables but are unable to *identify* the underlying shocks. In our model, a surprise increase in the federal funds rate is interpreted by firms in a probabilistic way based on the rule of monetary policy: they form beliefs about the likelihood of the surprise being a pure shock versus an endogenous response of the monetary authority to aggregate TFP shocks unobserved by firms. Accordingly, an expansionary shock is partially interpreted by firms as a decline in TFP, based on which they acts *as if* there was a contractionary TFP shock.

We aim to use our empirical estimates to discipline the model. The resultant effect of monetary policy shocks in our model depends on the strength of the information effect relative to the conventional effect, which is determined by the the rule of monetary policy: in policy regimes where the monetary authority is committed more to responding to the state of the economy, any change in the Federal funds rate is more likely to be perceived as an endogenous response of the monetary authority to the state of the economy, and the information effect is stronger.

Our model also allows us to formalize the role of communication strategies of the monetary authority as a policy tool. We utilize our model to discuss such counterfactuals strategies. While changes in rates are interpreted by the private sector as a signal about the state of the economy and confound the traditional effects of policy, additional communication strategies can mitigate the signaling content of rate changes and disentangle the two forces. In the extreme case where the monetary authority is completely successful in communicating its beliefs about the state of economy through its communication strategies, the two are completely separated, and surprise rate changes no longer carry an information effect.

Related Literature. Our work relates to a recent literature that emphasizes the role of monetary policy in shifting the expectations of economic agents (Melosi, 2016; Nakamura and Steinsson, 2018; Enders et al., 2019; Lewis et al., 2019). We contribute to this literature by quantifying the information effect of monetary policy shocks on several macroeconomic outcomes.

On a broader scale, our work fits in a larger set of papers that aim to understand the real effects of monetary policy shocks and its transmission channels through actions of households and firms.[3] In particular, we are motivated by the evidence that policy rate changes do not affect household consumption much (Kaplan et al., 2018). This shifts the focus on investment as potentially the main channel of monetary transmission, a point also emphasized by Auclert et al. (2019).

Our empirical strategy in purging the information effects from high-frequency identified monetary policy surprises is based on Miranda-Agrippino and Ricco (2018), who rely on Greenbook forecasts to control for Fed information effects.

Our model also speaks to the literature that documents a shift in the effects of monetary policy over time.[4] Boivin et al. (2010); Barakchian and Crowe (2013) document that the effects of monetary policy in the U.S. have become more forward-looking and smaller in the decades since the onset of the Great Moderation. This pattern is consistent with the predictions in our model that the relative strength of the information effects of monetary policy depends largely on how dedicated the monetary authority is in stabilizing the economy.

2 Empirical Findings

2.1 Data

Monetary Policy Shocks We construct a new measure of private sector monetary surprises to investigate changes in the transmission of monetary policy over time. The main advantage of this series is a relatively longer sample period, starting in the early 1980s. This feature is key to study changes in monetary propagation over time. By contrast, private sector monetary surprises from high-frequency identification are only available since the early 1990s.[5] The reason is that this approach builds on tick-by-tick data from Fed funds future markets. These markets did not exist in the 1980s.

The starting point for our new series are intended funds rate changes around meetings of the Federal Open Market Committee (FOMC) identified by Romer and Romer (2004).[6] Next, we purge any expected changes in the target rate using expectations about the current and future state of the economy. The main idea is that these expectations are sufficient statistics

[3] See, for example, Christiano et al. (2005).

[4] See, for example, Primiceri (2005).

[5] High-frequency identification recovers private sector monetary surprises as the price difference in Fed funds futures in narrow event windows around FOMC announcements. The identifying assumption is that any price movements in these windows are due to monetary surprises revealed by the announcement. Future contracts are assumed to have priced in any expected policy change.

[6] We use the series by Wieland and Yang (2020) extended through 2007.

and span the space of expected policy changes. Different from Romer and Romer (2004), however, we use private sector macroeconomic forecasts. The reason is that, by definition, only private sector surprises provide a role for the information channel of monetary policy.

Private sector expectations come from the Blue Chip Economics Indicators. The Blue Chip survey offers several advantages. First, the survey participants come predominantly from financial institutions.[7] This feature allows for a meaningful comparison to the high-frequency approach in the period in which both series overlap. High-frequency identification also relies on expectations of financial market participants which are implicitly priced in the Fed funds futures market. Second, the Blue Chip survey is available at the monthly frequency. Since there is at most one scheduled FOMC meeting per month in the time period we study, we can match every meeting with a corresponding Blue Chip forecasts.[8] Third, the Blue Chip survey has the longest history of monthly private sector expectations available since the mid-1970s. Other private sector forecasts like the Survey of Professional Forecasters (SPF) are only available at the quarterly frequency, or begin in the late 1980s, like Consensus forecasts.

Let Δff_m denote the intended funds rate change around FOMC meeting m. Following Romer and Romer (2004), we run the following regression to purge any expected funds rate changes:

$$\Delta ff_m = \alpha + \beta ffb_m + \sum_{i=-1}^{2} \gamma_i \Delta y_{mi}^{BC} + \sum_{i=-1}^{2} \lambda_i \left(\Delta y_{mi}^{BC} - \Delta y_{m-1,i}^{BC} \right) + \sum_{i=-1}^{2} \phi_i \pi_{mi}^{BC} + \sum_{i=-1}^{2} \theta_i \left(\pi_{mi}^{BC} - \pi_{m-1,i}^{BC} \right) + \rho u_{m0}^{BC} + \varepsilon_m^{raw} \tag{1}$$

Here, ffb_m is the level of the intended target rate right before meeting m. Δy_{im}, π_{im}, and u_{im} refer to forecasts for real output growth, inflation, and the unemployment rate, respectively, at horizon i.[9,10] The superscript BC indicates that these forecasts come from the Blue Chip survey. The horizons included in Equation (1) are for the previous quarter, the current quarter, and the one and two quarters-ahead forecasts.[11] In addition, for each of these horizons the regression includes forecast revisions since the last FOMC meeting. The residual

[7] Giacomini et al. (2020, Table 1) report that about two-thirds of the survey participants come from financial institutions. Another quarter represents economic consulting firms, and the remainder includes universities, research institutes, and government agencies.

[8] The Blue Chip survey is carried out in the first week of each month. We do not consider any FOMC meetings that take place in that week to ensure that expectations are elicited before the meetings takes place.

[9] We use the gross domestic product (GDP) deflator as measure of inflation.

[10] For every variable and each horizon, we use the average forecasts across all survey participants.

[11] Backcasts for the previous quarter are only available in the first month of each quarter. We carry this data over to the second and third month in any given quarter.

of this regression, ε_m^{raw}, constitutes the new measure of private sector monetary surprises we propose in this paper. We call ε_m^{raw} the "raw monetary surprise".

In a seminal paper, Romer and Romer (2000) argue that the Fed has better information about the state of the economy, and that policy actions signal this information to the public. The effect of FOMC announcements on private agents beliefs about the state of the economy is known as the "Fed information effect". The presence of this effect poses a challenge in estimating the effects of monetary policy on the economy. The reason is that private sector monetary surprises mix both policy shocks as such and new information about the economy's outlook released during the FOMC announcement.

Following Romer and Romer (2004); Miranda-Agrippino and Ricco (2018), we control for any new information about the state of the economy that was previously private to the Fed using its macroeconomic projections for real output growth, inflation, and unemployment contained in the Greenbook.[12] Abusing notation, we run the regression:

$$\varepsilon_m^{raw} = \alpha + \sum_{i=-1}^{2} \gamma_i \Delta y_{mi}^{GB} + \sum_{i=-1}^{2} \lambda_i \left(\Delta y_{mi}^{GB} - \Delta y_{m-1,i}^{GB} \right) + \sum_{i=-1}^{2} \phi_i \pi_{mi}^{GB} + \sum_{i=-1}^{2} \theta_i \left(\pi_{mi}^{GB} - \pi_{m-1,i}^{GB} \right) + \rho u_{m0}^{GB} + \varepsilon_m^{pure} \quad (2)$$

As before, Δy_{im}, π_{im}, and u_{im} refer to forecasts for real output growth, inflation, and the unemployment rate, respectively, at horizon i. The superscript GB now indicates that these forecasts come from the Greenbook. We call the residual of Equation (2), ε_m^{pure}, the "pure monetary policy shock", since the regression controls for the role of the Fed's private information in private sector monetary surprises. That is, it controls for Fed information effects. Accordingly, we call the fitted values of Equation (2) the "Fed information shock".

The sample we study excludes the period of non-borrowed reserve targeting by the Fed and starts in 1983:M01. Coibion (2012) shows that the findings in Romer and Romer (2004) are very sensitive to the inclusion of observations in that period. We end in 2007:M12, before the Great Financial Crisis. There is at most one FOMC meeting in any given month in our sample period. In months without an FOMC meeting, we set each shock series equal to zero. To merge shocks with quarterly data, we sum up all shocks in a given quarter.

Time variation in the monetary transmission channel potentially alters both the way in which expectations about the current and future state of the economy enter expected changes in policy as well as the information channel of monetary policy. That is, it affects the coefficients in Equations (1) and (2). For this reason, we estimate each equation on subsamples we will describe shortly.

[12] Again, we use the extended dataset by Wieland and Yang (2020).

Macroeconomic Data We estimate monetary transmission to several macroeconomic variables. At the monthly frequency, we study industrial production, the unemployment rate, and the consumer price index. We use data on the federal funds rate, the unemployment rate, and the commodity price index of the Commodity Research Bureau as control variables.[13] At the quarterly frequency, we study the transmission of monetary policy to real non-residential, private fixed investment from the National Income and Product Accounts (Table 5.3.3.). We use quarterly averages to time-aggregate monthly control variables.

2.2 Empirical Setup

We employ local projections following Jordà (2005) to estimate the effects of monetary policy on the economy through the conventional interest rate channel and through the information channel. Specifically, we run OLS regressions of the form

$$y_{t+h} = \mu_h + \beta_h \varepsilon_t^i + \Gamma_h X_t + u_{t+h} \tag{3}$$

for each outcome of interest y_{t+h} and each of the identified shocks ε_t^i, $i \in \{raw, pure, info\}$, one at a time. X_t denotes a vector of control variables. In the case of monthly outcomes we use the exact specification as in Ramey (2016, p.105) and include two lags of the shock ε_t, the federal funds rate, the log of industrial production, the unemployment rate, the log of the consumer price index, and the log commodity price index y_{t+h}; contemporaneous values of all these variables (except for the shock, of course); and restrict the impact response to zero. At the quarterly frequency, we include only one lag, do not add contemporaneous values, and leave all responses unrestricted because the recursiveness assumption is even less plausible in that case.[14] The coefficient estimates β_h from separate regressions for each horizon h capture the dynamic effects of a given shock on an outcome of interest. For statistical inference, we compute Newey and West (1987) standard errors with the maximum lag order of autocorrelation at each horizon h equal to $h+1$.[15]

We estimate Equations (1)–(3) separately on two different sub-samples to investigate changes in the monetary transmission channel over time. The first subsample covers the pe-

[13] We obtain all bar the last series from FRED, Federal Reserve Bank of St. Louis. The corresponding mnemonics are `CPIAUCSL`, `INDPRO`, `FEDFUNDS`, and `UNRATE`, respectively. The commodity price index of the Commodity Research Bureau comes from Thomson Reuters' Datastream and has the mnemonic `CRBSPOT`.

[14] Following Jordà (2005, p.166), we also include recursively the forecast errors from horizon $h-1$ in the local projection at horizon h to improve estimation efficiency.

[15] Since we do not consider FOMC meetings that take place in the first week of the month (see Footnote 8), shocks are missing in some instances. We follow Rho and Vogelsang (2019) and plug in zeros in this case. This imputations allows to compute Newey and West (1987) standard errors.

riod 1983:M01–1996:M06, and the second subsample covers the period 1996:M07–2007:12. At the quarterly frequency, the sub-samples cover the corresponding quarters. This sample split has at least three advantages. First, it divides the full sample into two sub-samples of roughly same length. This feature is appealing because it precludes the case in which differences in drawn inference are due to vastly different sample sizes. Second, this cutoff date also emerges from a formal criterion which maximizes the difference in estimated impulse responses of industrial production between both sub-samples. Specifically, this criterion computes the distance between sub-sample estimates at each horizon and cumulates their absolute values over 36 months. Third, by announcing its decisions at press events the Fed markedly changed its communication policy in 1994. Our sample split roughly coincides with this shift in the conduct of monetary policy.

2.3 Results

Figure 1 displays impulse responses to a one standard deviation contractionary private sector monetary surprise estimated on the full sample 1983:M01–2007:M12. For every outcome, each panel shows several estimates. In solid blue is the impulse response point estimate to private sector monetary surprises from Equation (3). Light and dark gray-shaded areas are the corresponding one standard error and two standard error confidence bands, respectively. The green dash-dot line shows the same impulse response estimated using the smooth local projections methodology by Barnichon and Brownlees (2019). Finally, the red dashed line plots the impulse response to the narrative monetary policy shock by Romer and Romer (2004), reestimated only on observations from the same sample period using the updated and extended dataset by Wieland and Yang (2020).

A puzzling feature of Figure 1 is that contractionary monetary policy leads to economic expansion. Output rises for a about a year, while the unemployment rate falls. The price level increases, although the evidence is more moderate here, and aggregate investment spending expands peaking after about two years. Overall, the Romer and Romer (2004)-shock generate very similar dynamics across all variables and, if anything, display stronger persistence. The result that impulse responses estimated on recent data display patterns that deviate from the consensus view on the empirical effects of monetary policy is also documented by Barakchian and Crowe (2013) and Ramey (2016) for output, unemployment, and prices.

We next study the role of changes in monetary transmission over time in explaining these puzzling findings. To this end, we estimate the same impulse responses on the sub-samples 1983:M01–1996:M06 and 1996:M07–2007:M12. We start with the earlier period. Figure 2 shows results. While there is moderate evidence for a short-lived economic expansion over the first two years after the shock, output eventually starts to contract after about two years with overwhelming evidence.[16] The dynamics of aggregate investment look very similar. The unemployment rate does not show any signs for initially expansionary effects while the evidence for a downturn in economic activity after about two years remains very strong. A price puzzle also emerges in this sub-sample. In sum, the consensus view that contractionary monetary policy leads to a prolonged economic recession holds in this earlier period. This finding already suggests that the puzzling effects of monetary policy estimated over the full sample are due to changes in monetary transmission in recent times.

The top-left panel in Figures 3-6 confirm that contractionary private sector monetary surprises are unambiguously expansionary in this recent period. Output rises for about two years, while unemployment falls, with overwhelming evidence each. Prices hardly respond. If anything, there is still a price puzzle but the evidence is moderate. By contrast, aggregate investment spending rises and the evidence is overwhelming.

Why does the consensus view on the effects of monetary policy not hold in this recent period? A comparison between the effects of private sector monetary surprises and the Romer and Romer (2004)-shocks, shown in the top-right panels of Figures 3-6, is instructive. While in Figure 2 their estimated consequences are extremely similar, there are now some marked differences across these shocks. In particular, the Romer and Romer (2004)-shocks do have less pronounced effects on output and investment.

Recall the difference between these shocks. We use private sector expectations from the Blue Chip survey to control for any expected changes in the current and future state of the economy and, hence, monetary policy. Romer and Romer (2004) use the Greenbook forecasts which corresponds to the Fed's information set. If the Fed has better information about the current and future state of the economy and policy actions provide a signal of said information, as Romer and Romer (2000) argue, monetary surprises perceived by the private sector possibly reflect this information channel and account for the differences between estimated impulse responses.

The bottom panels in Figures 3-6 provide a decomposition of the impulse response to private sector monetary surprises shown in the top-left panel. The bottom-left panel displays the conventional interest rate channel, after controlling for the Greenbook forecasts using Equation (2). The bottom-right panel plots the information channel of monetary policy, identified by the part of private sector monetary surprises explained by better information on the side of the Fed, i.e., the fitted values of Equation (2).

Policy rate hikes contain a strong signalling component of better-than-expected economic conditions. All variables display expansionary effects to the information channel,

[16] Following Romer (forthcoming), we refer to estimates within the 1-standard error and 2-standard error confidence bands as moderate and overwhelming evidence, respectively.

and the evidence is overwhelmingly strong, as the bottom-right panel in Figures 3-6 shows. Output increases throughout the first year after the shock, unemployment falls with some delay relative to output, prices increase, and aggregate investment rises for a prolonged period. Similar dynamics in the top-left and bottom-right panel suggests that information effects explain the bulk of the effects of private sector monetary surprises. By contrast, the conventional interest rate changes shown in the bottom-left panel continues to produce puzzling results although the evidence now becomes imprecise. The impulse responses of unemployment, price, and investment are mostly insignificant, while the evidence for expansionary effects on output remains moderate.

Overall, the results presented in this section suggest a significant change in the transmission channel of monetary policy to the economy in the mid-1990s. In the earlier period, a cut in the interest rate displays adjustment patterns that are consistent with the conventional interest rate channel. In recent times, the information channel of monetary policy becomes the dominant channel by which the Fed affects the economy.

Robustness: High-Frequency Identification We next compare our new approach to measure private sector monetary surprises to existing high-frequency identification of private sector monetary surprises in the sample in which they overlap, i.e., 1996:M07–2007:M12. An important feature of our approach is that it is available since the early 1980s while series from high-frequency identification only start in the early 1990s. This longer sample period is critical to study changes in monetary transmission over time.

The solid blue lines in Figure 7 are the same impulse responses as in the the top-left panel of Figures 3-6. The dashed red lines and gray-shaded areas are impulse responses and confidence bands to private sector monetary surprises estimated from high-frequency identification. We obtain these responses by estimating Equation (3) using the series of raw high-frequency shocks provided by Jarociński and Karadi (forthcoming). The green dash-dot line in each panel corresponds to the same response estimated using smooth local projections. As is common in high-frequency identification, we do not impose the recursiveness assumption and exclude any contemporaneous variables in the vector of controls.

By and large, Figure 7 shows that impulse responses to either measure of private sector monetary surprises are very similar. The point estimate for the impulse response to our narrative shock series falls within the confidence bands of the impulse response to the high-frequency shock series most of the time. We take this result as evidence that our new measurement approach and established high-frequency identification capture private sector monetary surprises equally well in the sample in which both overlap. This finding provides reassurance that we can use our narrative approach to study monetary transmission in the earlier period in which high-frequency shocks are unavailable.

3 Model

Our empirical findings in the previous section suggest that the information effects of monetary policy to investment seem to be non-negligible. In this section, we investigate two questions through the lens of a simple model: how does the conventional and the information effects of monetary policy interact in propagation of monetary policy shocks to investment? and what are the implications of counterfactual Central bank communication policies for the interaction of these two effects?

3.1 Environment

Time is discrete and indexed by $t \in \{0, 1, 2, \dots\}$. The economy consists of a representative household and a central bank. Using capital, the household produces a good that can be either consumed, invested in a one period risk-free bonds, or invested in future capital. Formally, the household's problem is

$$\max_{\{C_t, B_{t+1}, K_{t+1}\}_{t=0}^{\infty}} \mathbb{E}_0^h \sum_{t=0}^{\infty} \beta^t u(C_t) \qquad \text{(HH's problem)}$$

$$s.t. \quad C_t + B_{t+1} + I\left(\frac{K_{t+1}}{K_t}\right) K_t \leq e^{z_t} K_t + (1 + r_t) B_t \qquad \text{(budget constraint)}$$

$$B_0, K_0 \text{ given.} \tag{4}$$

where $\mathbb{E}_t^h[.] \equiv \mathbb{E}[.|\mathbb{I}_t]$ is the expectation operator conditional on household's information set ($\mathbb{I}_t$), C_t is her consumption, B_t is the her bond holdings at t, K_t is capital stock at t, $I(.)K_t$ is investment in capital at time t with $I(1) = \delta$, $I'(1) = 1$ and $I''(.) = \psi > 0$. Here ψ captures the degree of convex investment adjustment costs for capital. Furthermore, r_t is the net return on bonds which is taken as given by the household. Finally, z_t is a TFP shock that evolves according to

$$z_t = z_{t-1} + v_{z,t}, \quad v_{z,t} \sim N(0, \tau_z^{-1}) \tag{5}$$

Throughout our analysis we will focus on two different definitions of equilibria in this economy, which arise from different assumptions on closing the model.

Definition 1. The **natural equilibrium** of this economy is an allocation $(C_t, B_t, K_{t+1})_t \geq 0$ and a sequence of natural interest rates $(r_t^n)_{t\geq 0}$ such that:

1. given the natural interest rates, the allocation solves the household's problem with *full information* ($\mathbb{I}_t^{full} = \{z_{t-j}\}_{j\geq 0}$).

2. the market for bonds clear at zero net supply.

It is evident that in this natural equilibrium, monetary policy would be redundant as the classical dichotomy holds. To investigate the effects of monetary policy, one needs to either augment this model with a nominal side that exhibits nominal rigidities, or to relax the assumption on market clearing. These two are not unrelated. In fact, the fact that nominal rigidities allow monetary policy to affect the real side of an economy hinges on the assumption that real rates do not fully adjust after a monetary shock due to nominal frictions. Since we are interested in the effect of monetary policy on investment, which solely works through intertemporal substitution and real rates, it is appropriate to directly specify how we think monetary policy affects the real rate in what we would later call a *monetary equilibrium*.

In particular, we assume that in such equilibria, the central bank can control the return of the risk-free bond in the short-run, meaning that the they have the ability to clear the market with non-zero supply of real bonds. However, it is important to realize that the central bank has to comply by some notion of feasibility. We model this by assuming that any deviation of the real rate from its *natural rate* should be temporary, meaning that bonds are at zero net supply on average, rather than period by period.[17] the following definition formalizes this notion.

Definition 2. A **monetary equilibrium** with exogenous information for this economy is an allocation $(C_t, B_t, K_{t+1})_{t\geq 0}$ and a sequence of information sets $(\mathbb{I}_t)_{t\geq 0}$ for the households, along with a monetary policy in terms of the real rates $(r_t)_{t\geq 0}$ such that

1. given the interest rates implied by policy and the information sets, the allocation solves the household's problem.

2. any deviation of the policy rates from the natural rate are temporary:

$$\lim_{T\to\infty} \mathbb{E}_t^h[r_{t+T} - r_{t+T}^n] = 0 \tag{6}$$

The condition that the deviation of policy rates from the natural rate are transitory can also be related to the long-run non-neutrality of money. Henceforth, for any given monetary policy $(r_t)_{t\geq 0}$, we define the deviations as

$$u_t \equiv r_t - r_t^n \tag{7}$$

[17]The assumption that the central bank can control the real rate in the short-run is not without empirical support. For instance, Nakamura and Steinsson (2018) find that immediately after an unexpected change in Fed Funds rate, real rates move almost one to one with the shock, whereas inflation expectations remain unchanged.

and refer to u_t as the *purified monetary shock* at time t.

Characterization

The Natural Rate. Given an expectation operator for the household, their Euler equations are:

$$C_t^{-1} I'(\frac{K_{t+1}}{K_t}) = \beta \mathbb{E}_t^h \left[C_{t+1}^{-1} \left(e^{z_{t+1}} + \frac{K_{t+2}}{K_{t+1}} I' \left(\frac{K_{t+2}}{K_{t+1}} \right) \right) - I \left(\frac{K_{t+2}}{K_{t+1}} \right) \right] \qquad \text{(w.r.t. capital)}$$

$$C_t^{-1} = \beta(1 + r_t) \mathbb{E}_t^h \left[C_{t+1}^{-1} \right] \qquad \text{(w.r.t. bonds)}$$

In order to simplify the expressions, we focus on a log-linear approximation of these first order conditions. We start by characterizing the natural rate of interest in the economy.

Lemma 1. *Given a log-linear approximation to the household's Euler equations, the natural rate of this economy is proportional to the log-TFP and is given by*

$$r_t^n = \phi z_t, \quad \phi \equiv \frac{1 - \beta(1 - \delta)}{1 + (1 - \beta)\psi} \qquad \text{(natural rate)}$$

It follows that the natural rate also follows a random walk in this economy, where the innovations to its process are proportional to the innovations to the log-TFP:

$$r_t^n = r_{t-1}^n + v_{r,t}, \quad v_{r,t} = \phi v_{z,t} \sim N(0, \tau_r^{-1}), \quad \tau_r^{-1} \equiv \phi^2 \tau_z^{-1} \qquad \text{(natural rate process)}$$

Demand for Capital. We start by characterizing the household's demand for investment.

Proposition 1. *Consider a monetary equilibrium with $r_t = r_t^n + u_t$ where u_t is i.i.d. over time. Then, the household's demand for capital is characterized by*

$$\psi \Delta k_{t+1} = - \underbrace{r_t}_{\text{cost of funds}} + \underbrace{(1 + \psi) \mathbb{E}_t^h [r_t^n]}_{\text{expected return}} \qquad \text{(demand for capital)}$$

where Δk_{t+1} is the log-change in capital stock at time t.

The expression for investment in the proposition boils down to a simple comparison of costs and benefits. The agent weighs the cost of borrowing at the current period with expected return of the capital in the future, and the difference determines the amount of investment.

3.2 Investment Response to Pure Monetary Policy Shocks.

The expression of demand for capital also reveals the roles that the monetary could potentially play in affecting the capital stock. One object of interest here is to characterize the impulse response function of investment to a pure monetary policy shock, which, in relation to our empirical section, compares to the local projections of investment on our *purified MP shocks*.

In particular, one could expose the impulse response function of investment to a pure monetary policy shock in the following way:

$$\psi \frac{\partial \Delta k_{t+1}}{\partial u_0} = \underbrace{-\frac{\partial r_t}{\partial u_0}}_{\text{conventional effect}} + \underbrace{(1+\psi)\frac{\partial \mathbb{E}_t^h[r_t^n]}{\partial u_0}}_{\text{information effect}} \tag{8}$$

This decomposition manifests the separate role of conventional and information effects on investment: the conventional channel works through cost of funds, where a contractionary shocks increase cost of funds and lead to a *decline* in investment. In contrast, information effects work through shifting the agents' expectations about the return of investment, where a contractionary shock could potentially *increase* investment if the agent's revise their expectations about the natural rate upwards after observing an increase in the real rate.

It is also important to observe that the specific information set that the household possesses at any given time plays a tremendous role in the strength of the information effect. For the remainder of this section, we focus on two cases: one where the agents have full information about the history of shocks in the economy, and another where they observe the real rates but have to infer the underlying shocks from these rates.

Lemma 2. ***(Full information IRFs)*** *Consider a monetary equilibrium with* $r_t = r_t^n + u_t$*, where* $u_t \sim N(0, \tau_u^{-1})$ *is i.i.d. over time. Suppose the household has full information about the history of both shocks at any given time. Then, the information effect is non-existent and the effect of pure monetary policy shocks are solely driven by the conventional effect:*

$$\psi \frac{\partial \Delta k_{t+1}}{\partial u_0} = -\frac{\partial r_t}{\partial u_0} = \begin{cases} -1 & t = 0 \\ 0 & t > 0 \end{cases} \tag{9}$$

This lemma, albeit its trivial conclusion that when agents know the history of shocks, the information effects are non-existent, sets a benchmark for what is to follow: in absence of information effect, an unexpected increase in the real rate decreases investment by increasing the price of investment.

This sets the ground for our next result. We now assume that the agents do not have full information about the history of the shocks. Instead, they observe the realizations of the real rate at any given point in time, along with a potentially additional signal about the natural rate. This assumption stems from the idea that agents in reality do not observe why the Central bank changes the rates. Any unexpected change in the policy rates can either be due to a pure monetary policy shock or due to change in the real rate that was not expected by the agent due to the asymmetries in the information sets of the agents and the Central bank.

In fact, the strength of the asymmetries between the information sets of the households and the Central bank is crucial for the information effects. If agents already know the natural rate at the time of the announcement, any surprised change in the policy rate *must* be due to a pure monetary shock, whereas if the policy rate is the only signal that the agents observe, then they would assign a positive probability to both cases.

To formalize these notions, we assume that the agents' informations sets are given by

$$\mathbb{I}_t = \{r_{t-j}, s_{t-j}\}_{t\geq 0}, \quad s_{t-j} = r_t^n + v_{s,t}, \quad v_{s,t} \sim N(0, \tau_s^{-1}) \tag{10}$$

where the precision of $v_{s,t}$ determines how much the agents know about the real rate in absence of the information revealed by the Central bank. In the case where the precision of this signal is finite, the agents will use the real rate to infer about the natural rate. The following proposition derives the evolution of the agents' beliefs about the natural rate given such an information set.

Proposition 2. *Consider a monetary equilibrium with $r_t = r_t^n + u_t$, where $u_t \sim N(0, \tau_u^{-1})$ is i.i.d. over time. Suppose the household's information set is given by the specification in Equation (10). Then, in the stationary solution of the Kalman filtering system implied by these information sets, the agent's belief about the natural rate evolves according to*

$$\mathbb{E}[r_t^n|\mathbb{I}_t] = (1-\lambda)\mathbb{E}[r_{t-1}^n|\mathbb{I}_{t-1}] + \lambda r_t^n + \lambda\frac{\tau_u}{\tau_u+\tau_s}u_t + \lambda\frac{\tau_s}{\tau_u+\tau_s}v_{s,t} \tag{11}$$

where $\lambda \in [0,1]$ is the total Kalman gain of the agent in filtering information about the natural rate and is given by the positive root of

$$\frac{\lambda^2}{1-\lambda} = \frac{\tau_u+\tau_s}{\tau_r} \tag{12}$$

The main observation that needs to be drawn from this Proposition is that the agents' belief about the natural rate is shifted around with u_t. Accordingly, even in case of pure monetary policy shocks, households' beliefs about the natural rate, and hence the return of investment, are affected by the shock. The strength of this effect, however, depends on how much information households would have inferred by just observing s_t. This is clear from the coefficient on u_t in Equation (11).

Corollary 1. *(**Imperfect Information IRFs**) With imperfect information, investment is affected by both the conventional and information channels, which move in opposite directions:*

$$\psi \frac{\partial \Delta k_{t+1}}{\partial u_0} = \begin{cases} -1 + (1+\psi)(1+\psi)\lambda \frac{\tau_u}{\tau_u + \tau_s} & t = 0 \\ (1+\psi)\rho^t (1-\lambda)^t \lambda \frac{\tau_u}{\tau_u+\tau_s} & t \geq 0 \end{cases} \tag{13}$$

This corollary has two main implications. First, even pure monetary policy shocks have information effects since the private sector cannot tell them apart from shocks to the natural rate. When a pure shock happens, the households partially interpret it as change in the natural rate and reacts accordingly in her investment decision. Accordingly, on impact, the negative investment effect of a rise in the real rate through the cost of funds is partially mitigated, or even overturned by the positive shift in the expectation of the household about the natural rate. Moreover, since the household's beliefs are persistent, the information effect persists over time and decays at an exponential rate.

The second implication is that both the strength and the persistence of the information effects of a pure monetary policy shock on investment depends on how precise the household's information is absence of the information revealed by the policy rate. In particular, if s_t is infinitely precise, then the agent know the natural rate and fully attributes any unexpected change in the policy rate to a pure monetary policy shock.

3.3 What do Fed. Information Shocks Identify?

In our empirical section, after decomposing our raw monetary surprises, we also provided impulse responses of aggregate variables to the information component of these shocks. In this section, we revisit those impulse responses from the lens of our model. In particular, here we characterize what information shocks are according to the model, and how one should interpret the impulse responses to these shocks.

In our simple model, if we were to implement our identification strategy within our model, the raw monetary surprises are the part of the real rates that are orthogonal to the private sectors projections about it. Formally, let u_t^{raw} denote this shock at time t, then

$$\begin{aligned} u_t^{\text{raw}} &\equiv r_t - \mathbb{E}_{t-1}^h[r_t] \\ &= \underbrace{u_t}_{\text{pure MP shock}} + \underbrace{r_t^n - \mathbb{E}_{t-1}^h[r_t^n]}_{\text{Fed info. shock}} \end{aligned} \tag{14}$$

The decomposition shows that our identification strategy for the raw monetary shocks decomposes these surprises to the pure monetary policy shock and a residual that is the forecast error of the private sector about r_t^n that we have referred to as the Fed. information shock in our empirical section.

An important observation here is that Fed information shocks are endogenous objects within the model and are determined by the evolution of the private sectors beliefs about natural rate of the economy. In particular, using Equation (11) we can express these forecast errors in terms of the exogenous shocks in the economy:

$$\begin{aligned} u_t^{\text{info}} &\equiv r_t^n - \mathbb{E}_{t-1}^h[r_t^n] \\ &= (1-\lambda)u_{t-1}^{\text{info}} + \underbrace{v_{r,t}}_{\text{shock to } r_t^n} - \underbrace{\lambda \frac{\tau_s}{\tau_u + \tau_s} v_{s,t-1}}_{\text{lagged noise shock}} - \underbrace{\lambda \frac{\tau_u}{\tau_u + \tau_s} u_{t-1}}_{\text{lagged pure MP shock}} \end{aligned} \tag{15}$$

This decomposition show that even in this simple model, the Fed information shock has several moving parts. Therefore, impulse responses to "Fed info shocks" can represent any combination of several effects that stem from each of the shocks above. First, it could be a response to the shock to the natural rate. Second, it could be a response to the lagged noise in the public signal, or third, a response to lagged pure MP shock. Figure (8) shows the impulse responses of investment to both purified monetary shocks as well as the information shock.

4 Conclusion

We document that the effect of monetary policy on aggregate investment has changed since 1990s. While the conventional interest rate channel is the main transmission mechanism of monetary policy to investment in the period before, investment is heavily affected by the Fed information effects in the period after.

We then provide a model that incorporates these two channels in order to study their interaction. In our model, agents do not observe the fundamental shocks of the economy, and use the policy rates to infer about the natural rate of interest in the economy. When the Fed targets the natural rate more precisely in its rule, even after a pure monetary policy shock the agents respond more strongly to the shock as if it is an information shock.

The confusion of the private sector about the natural rate, and their demand for information about the state the economy is key in how strong these information effects are. We use this mechanism to study the effect of independent communication strategies of the Fed on the strength of the information effect. When the Fed is more effective in communicating its information through these independent strategies, the information effects are smaller since agents are less likely to confuse a purified shock with information about the state of the economy.

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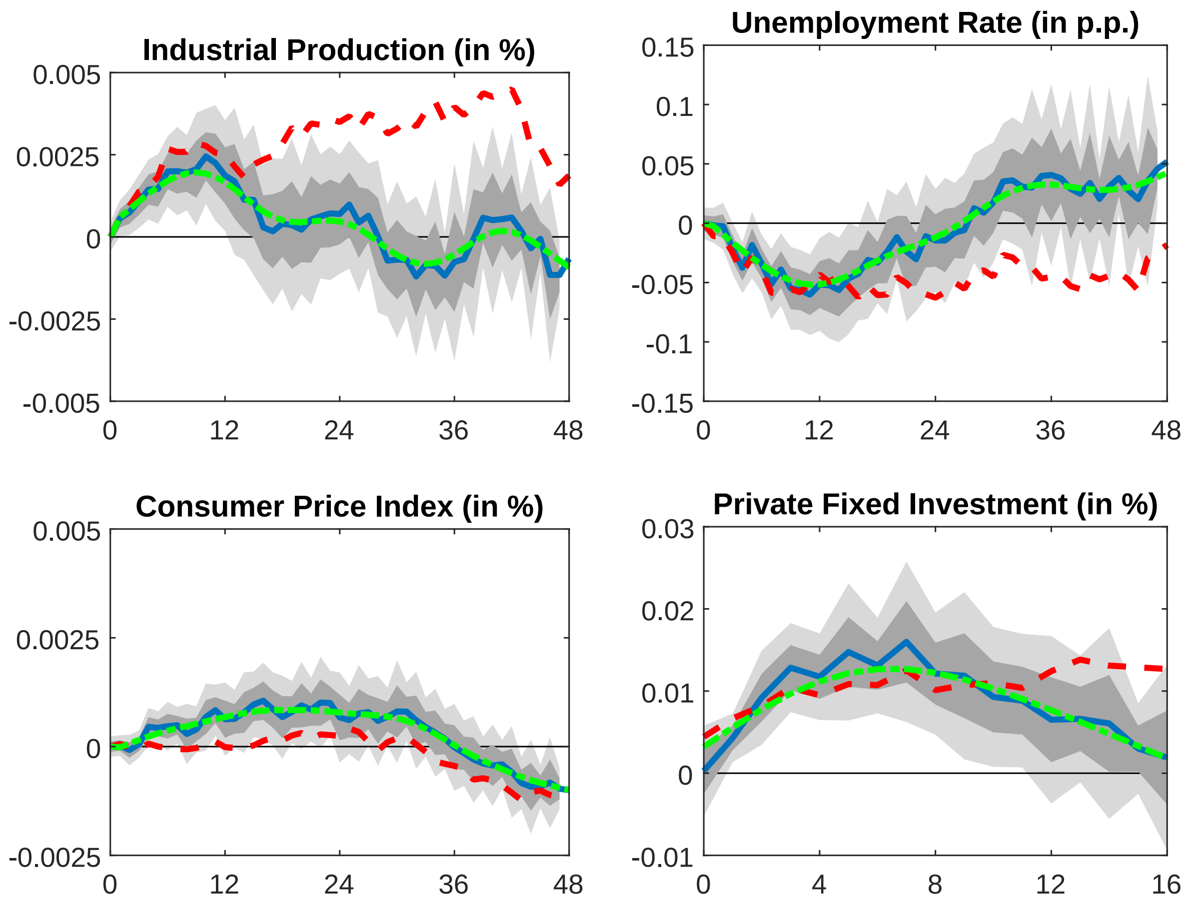
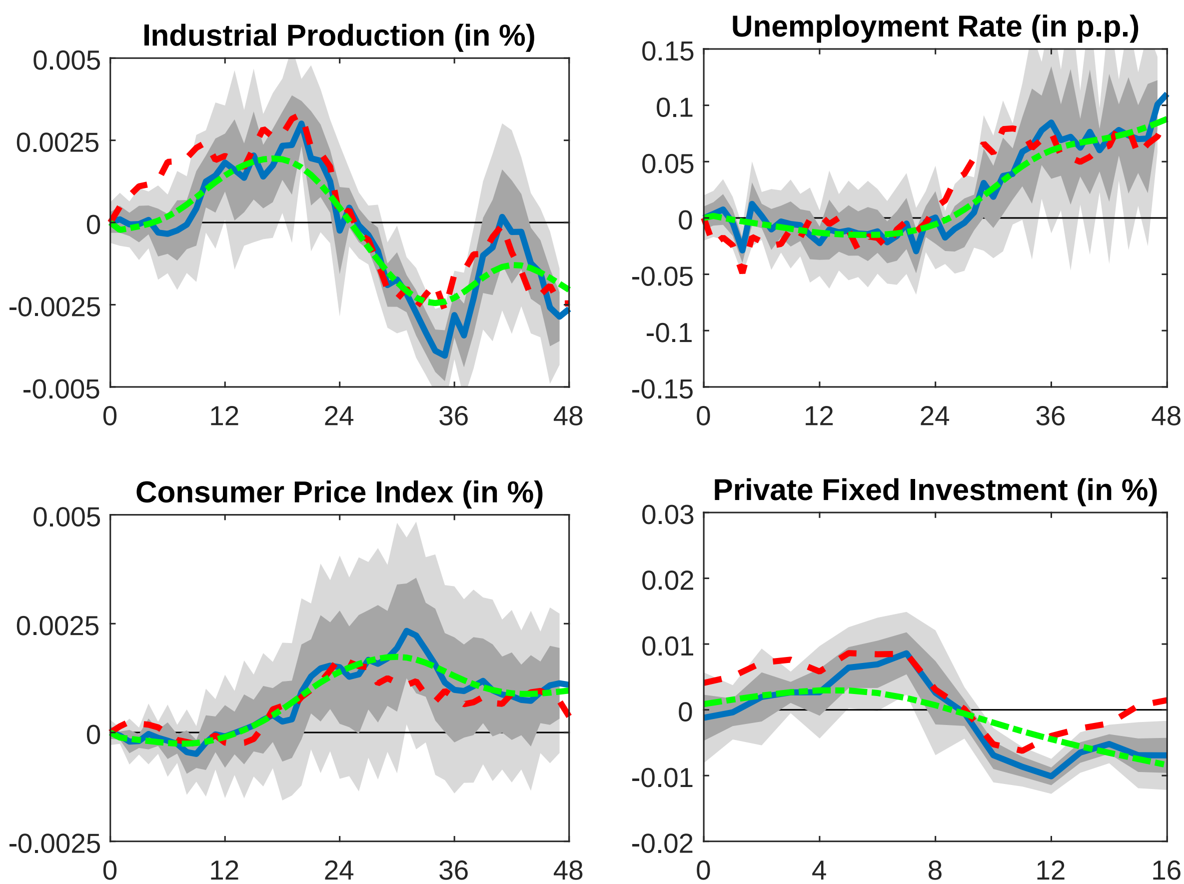
Figure 1: Impulse Responses to Contractionary Monetary Policy: 1983:M01–2007:M12



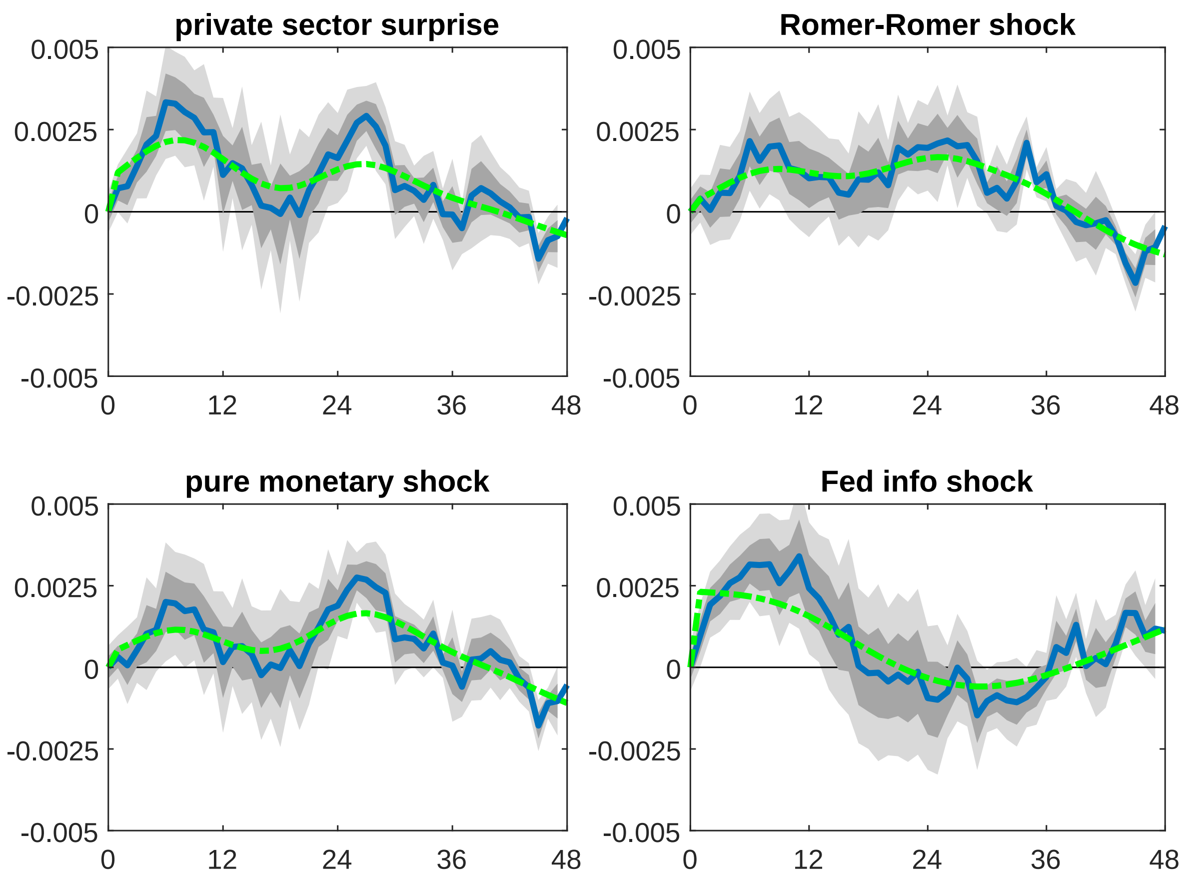
Notes: Impulse responses to a one standard deviation contractionary monetary shock estimated from Equation (3). The solid blue line shows the response to a private sector monetary surprise. Dark and light gray-shaded areas are corresponding 1-standard error and 2-standard error confidence bands, respectively, based on Newey and West (1987) standard errors. Private sector monetary surprises are unexpected changes in the intended federal funds rate after controlling for private sector forecasts from the Blue Chip Economic Indicators estimated from Equation (1). The green dash-dot line shows the same impulse response as the solid blue line estimated by smooth local projections (Barnichon and Brownlees, 2019). The red dashed line shows the impulse response to a Romer and Romer (2004)-shock reestimated on observations from the current sample period using the updated and extended dataset by Wieland and Yang (2020). Frequency of data is monthly except for quarterly data on private fixed investment. All regressions estimated on sample 1983:M01–2007:M12.

Figure 2: Impulse Responses to Contractionary Monetary Policy: 1983:M01–1996:M06



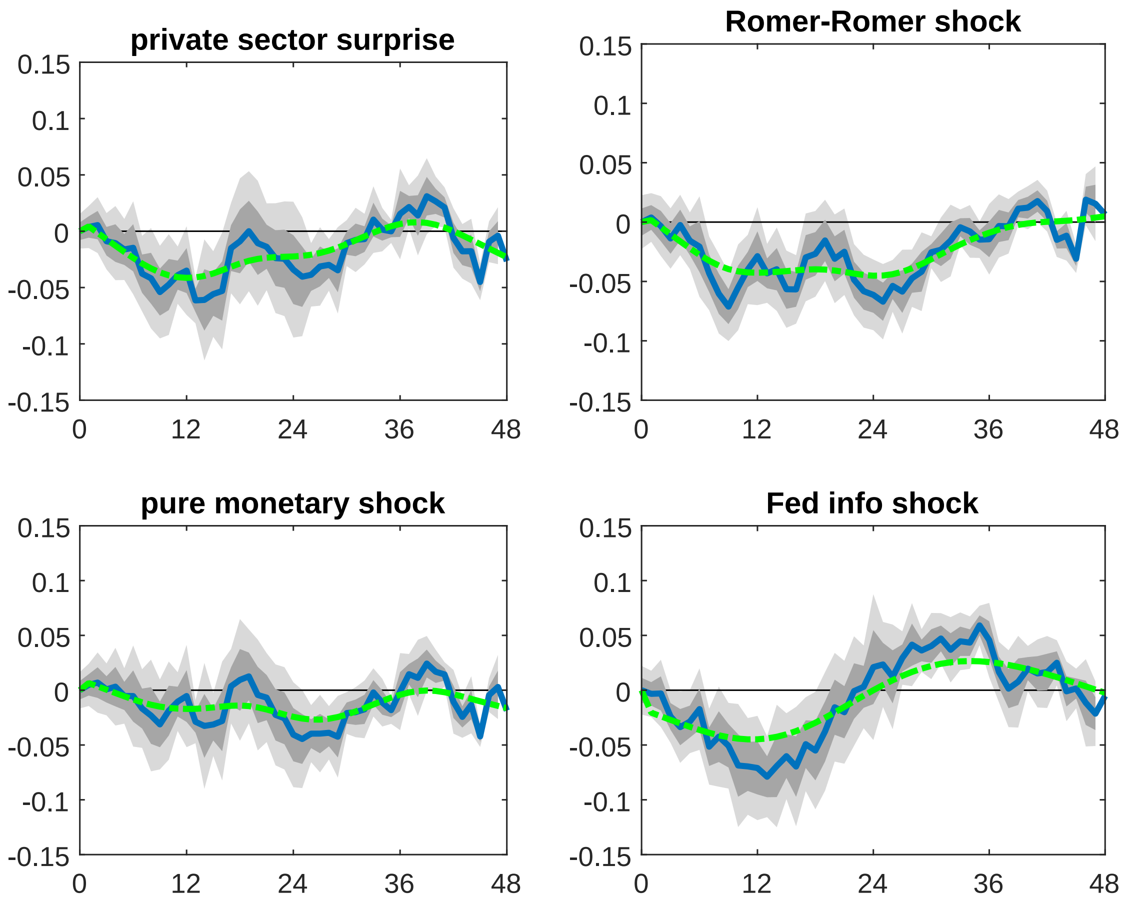
Notes: Impulse responses to a one standard deviation contractionary monetary shock estimated from Equation (3). The solid blue line shows the response to a private sector monetary surprise. Dark and light gray-shaded areas are corresponding 1-standard error and 2-standard error confidence bands, respectively, based on Newey and West (1987) standard errors. Private sector monetary surprises are unexpected changes in the intended federal funds rate after controlling for private sector forecasts from the Blue Chip Economic Indicators estimated from Equation (1). The green dash-dot line shows the same impulse response as the solid blue line estimated by smooth local projections (Barnichon and Brownlees, 2019). The red dashed line shows the impulse response to a Romer and Romer (2004)-shock reestimated on observations from the current sample period using the updated and extended dataset by Wieland and Yang (2020). Frequency of data is monthly except for quarterly data on private fixed investment. All regressions estimated on sample 1983:M01–1996:M06.

Figure 3: Effects of Monetary Policy on Industrial Production: 1996:M07–2007:M12



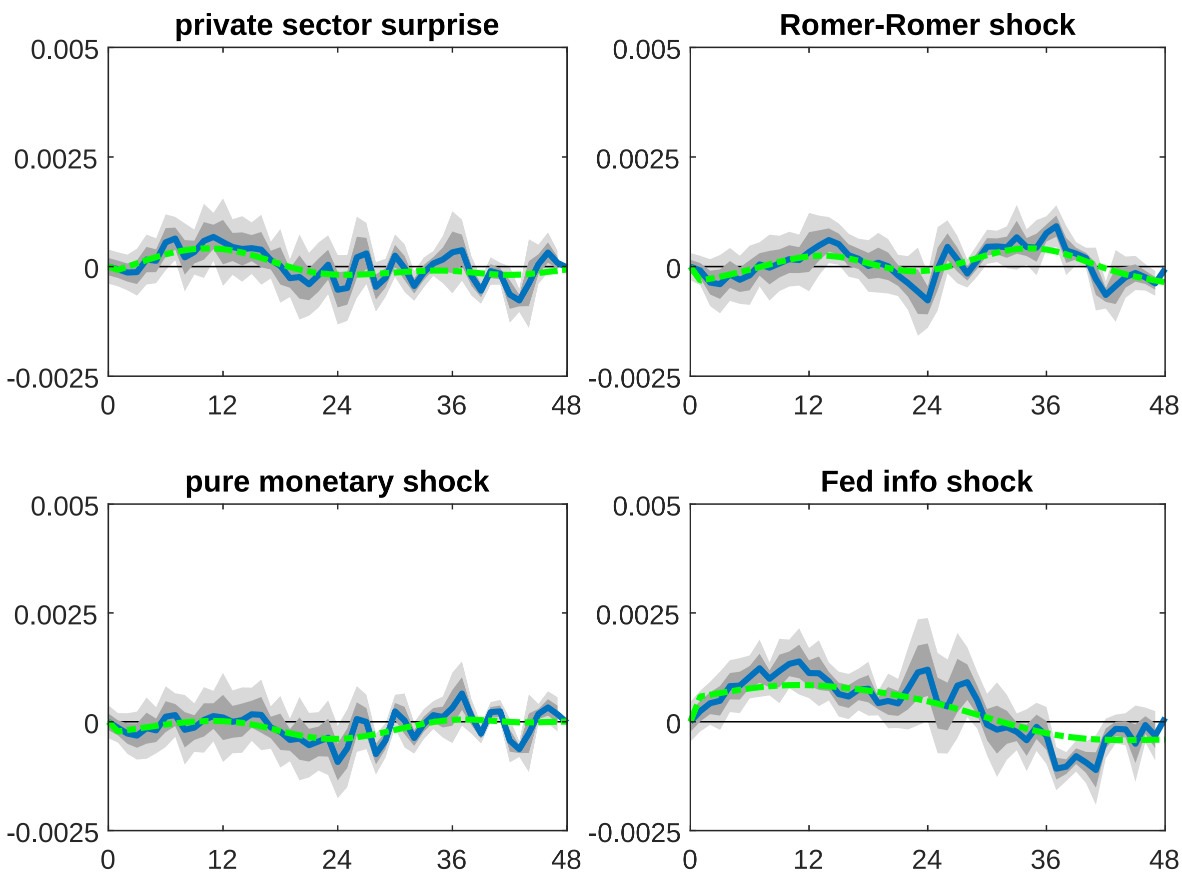
Notes: Impulse responses a one standard deviation contractionary monetary shock estimated from Equation (3). The solid blue line in each panel shows the response of industrial production to a given monetary surprise. Dark and light gray-shaded areas are corresponding 1-standard error and 2-standard error confidence bands, respectively, based on Newey and West (1987) standard errors. The green dash-dot line shows the same impulse response as the solid blue line estimated by smooth local projections (Barnichon and Brownlees, 2019). Private sector monetary surprises are unexpected changes in the intended federal funds rate after controlling for private sector forecasts from the Blue Chip Economic Indicators estimated from Equation (1). Romer and Romer (2004)-shocks are reestimated on observations from the current sample period using the updated and extended dataset by Wieland and Yang (2020). Pure monetary shocks are private sector monetary surprises after controlling for the role of the Fed's private information in these surprises, estimated as the residual of Equation (2). Fed information shocks are that part of private sector monetary surprises explained by the Fed's private information, estimated as the fitted value of Equation (2). Frequency of data is monthly. All regressions estimated on sample 1996:M07–2007:M12.

Figure 4: Effects of Monetary Policy on Unemployment: 1996:M07–2007:M12



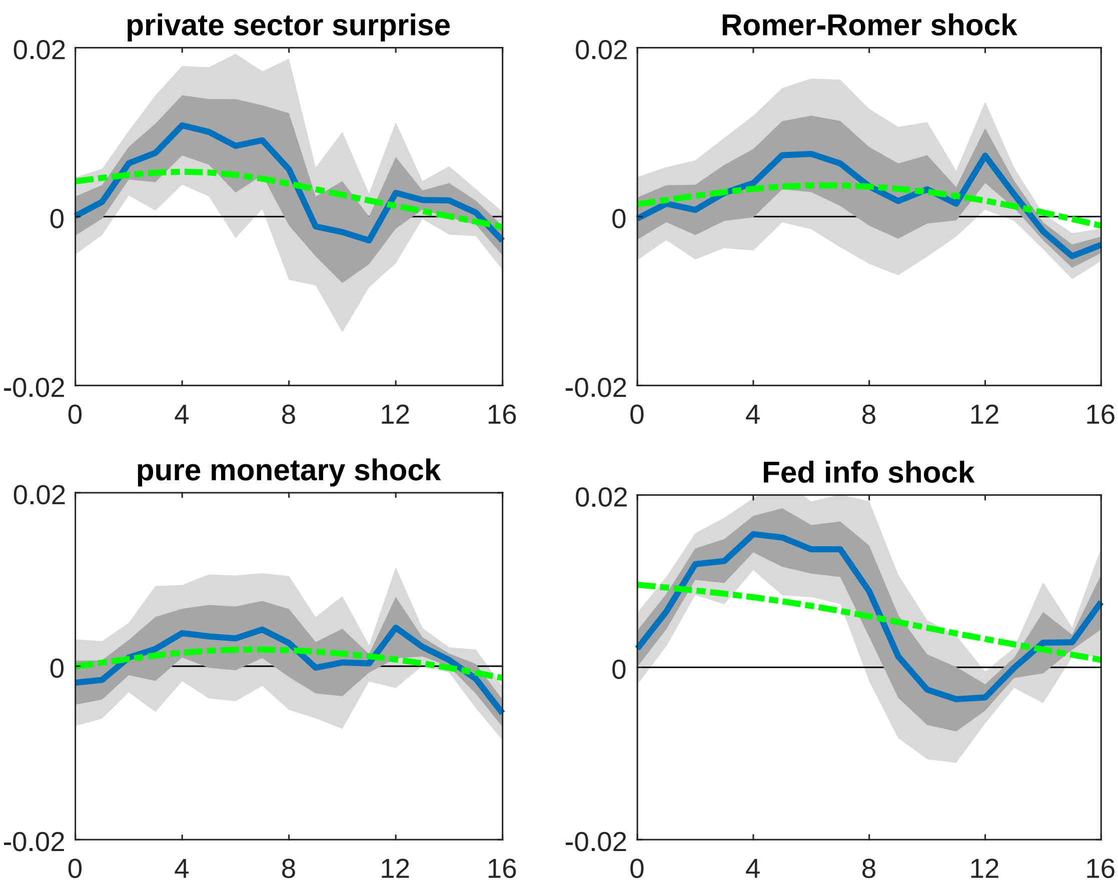
Notes: Impulse responses a one standard deviation contractionary monetary shock estimated from Equation (3). The solid blue line in each panel shows the response of the unemployment rate to a given monetary surprise. Dark and light gray-shaded areas are corresponding 1-standard error and 2-standard error confidence bands, respectively, based on Newey and West (1987) standard errors. The green dash-dot line shows the same impulse response as the solid blue line estimated by smooth local projections (Barnichon and Brownlees, 2019). Private sector monetary surprises are unexpected changes in the intended federal funds rate after controlling for private sector forecasts from the Blue Chip Economic Indicators estimated from Equation (1). Romer and Romer (2004)-shocks are reestimated on observations from the current sample period using the updated and extended dataset by Wieland and Yang (2020). Pure monetary shocks are private sector monetary surprises after controlling for the role of the Fed's private information in these surprises, estimated as the residual of Equation (2). Fed information shocks are that part of private sector monetary surprises explained by the Fed's private information, estimated as the fitted value of Equation (2). Frequency of data is monthly. All regressions estimated on sample 1996:M07–2007:M12.

Figure 5: Effects of Monetary Policy on Consumer Prices: 1996:M07–2007:M12



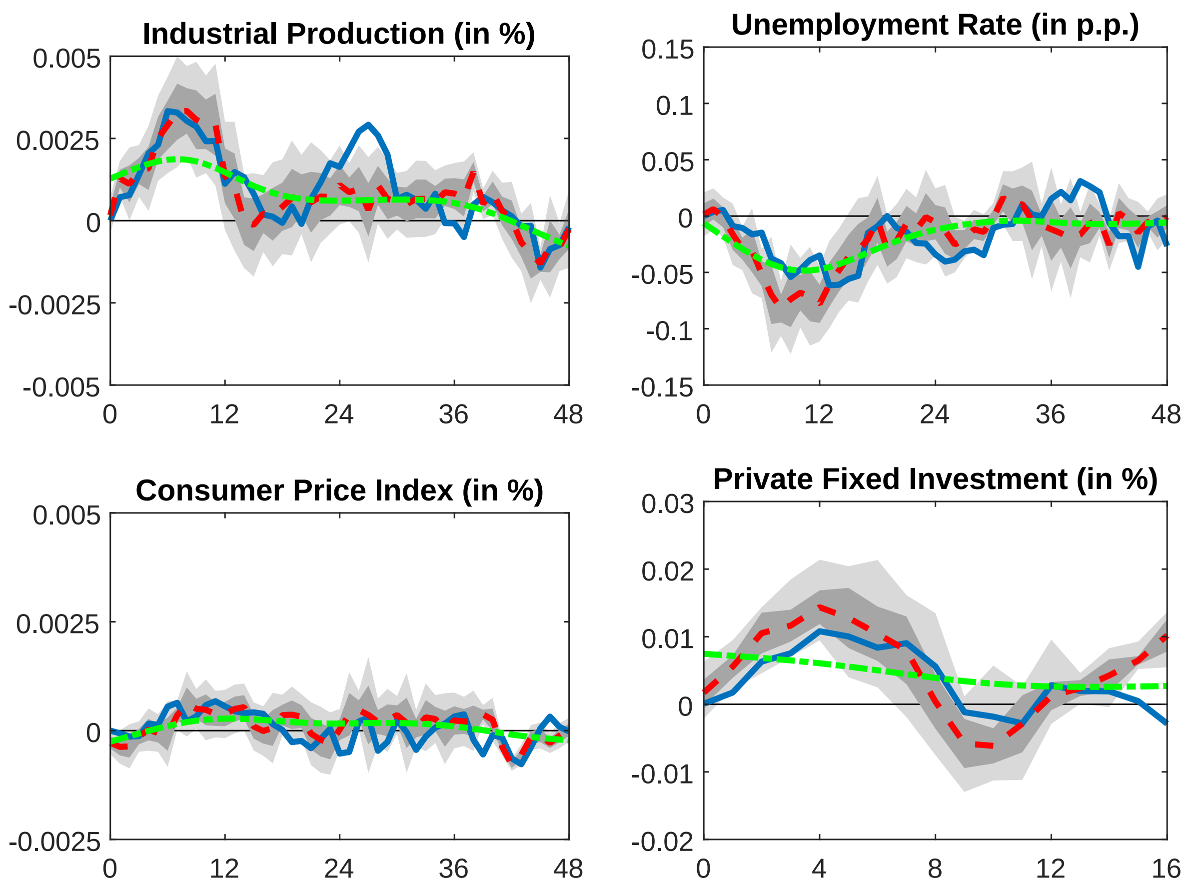
Notes: Impulse responses a one standard deviation contractionary monetary shock estimated from Equation (3). The solid blue line in each panel shows the response of the consumer price index to a given monetary surprise. Dark and light gray-shaded areas are corresponding 1-standard error and 2-standard error confidence bands, respectively, based on Newey and West (1987) standard errors. The green dash-dot line shows the same impulse response as the solid blue line estimated by smooth local projections (Barnichon and Brownlees, 2019). Private sector monetary surprises are unexpected changes in the intended federal funds rate after controlling for private sector forecasts from the Blue Chip Economic Indicators estimated from Equation (1). Romer and Romer (2004)-shocks are reestimated on observations from the current sample period using the updated and extended dataset by Wieland and Yang (2020). Pure monetary shocks are private sector monetary surprises after controlling for the role of the Fed's private information in these surprises, estimated as the residual of Equation (2). Fed information shocks are that part of private sector monetary surprises explained by the Fed's private information, estimated as the fitted value of Equation (2). Frequency of data is monthly. All regressions estimated on sample 1996:M07–2007:M12.

Figure 6: Effects of Monetary Policy on Investment: 1996:Q3–2007:Q4



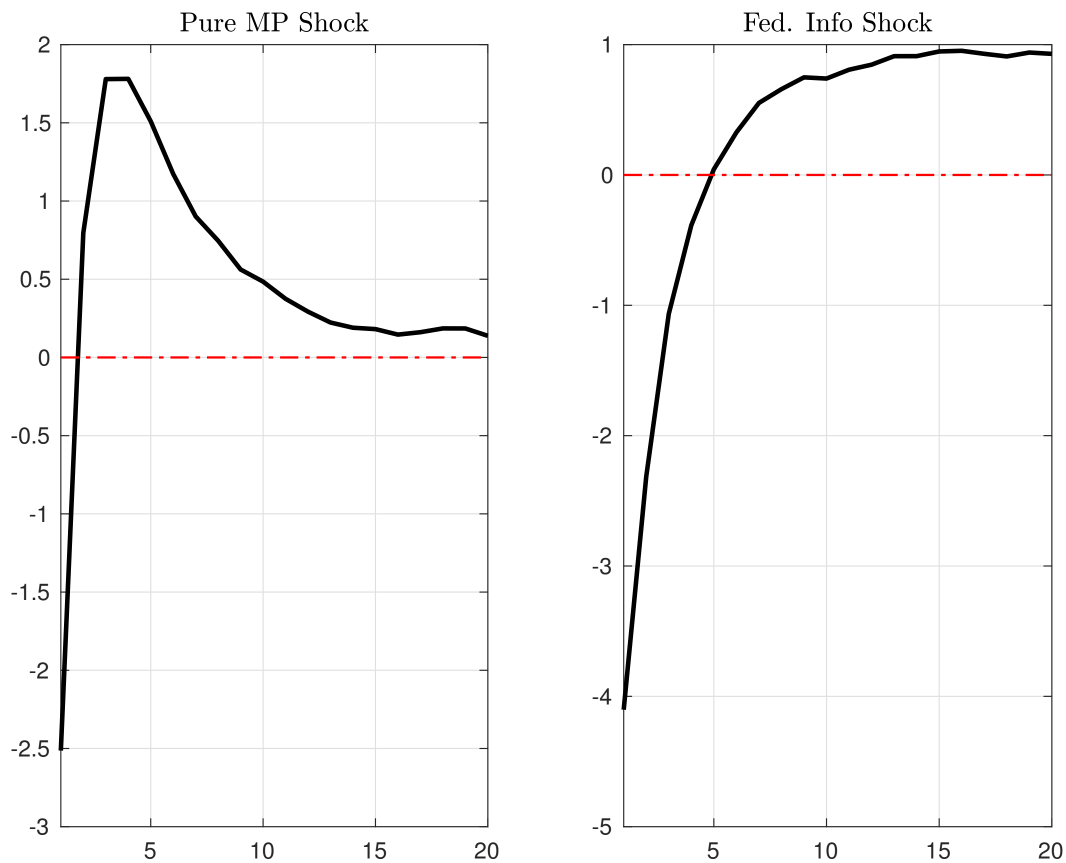
Notes: Impulse responses a one standard deviation contractionary monetary shock estimated from Equation (3). The solid blue line in each panel shows the response of non-residential private fixed investment to a given monetary surprise. Dark and light gray-shaded areas are corresponding 1-standard error and 2-standard error confidence bands, respectively, based on Newey and West (1987) standard errors. The green dash-dot line shows the same impulse response as the solid blue line estimated by smooth local projections (Barnichon and Brownlees, 2019). Private sector monetary surprises are unexpected changes in the intended federal funds rate after controlling for private sector forecasts from the Blue Chip Economic Indicators estimated from Equation (1). Romer and Romer (2004)-shocks are reestimated on observations from the current sample period using the updated and extended dataset by Wieland and Yang (2020). Pure monetary shocks are private sector monetary surprises after controlling for the role of the Fed's private information in these surprises, estimated as the residual of Equation (2). Fed information shocks are that part of private sector monetary surprises explained by the Fed's private information, estimated as the fitted value of Equation (2). Frequency of data is quarterly. All regressions estimated on sample 1996:M07–2007:M12.

Figure 7: Comparison to High-Frequency Identification: 1996:M07–2007:M12



Notes: Impulse responses to a one standard deviation contractionary monetary shock estimated from Equation (3). The solid blue line shows the response to a private sector monetary surprise . Private sector monetary surprises are unexpected changes in the intended federal funds rate after controlling for private sector forecasts from the Blue Chip Economic Indicators estimated from Equation (1). The red dashed line shows the impulse response to raw high-frequency monetary policy shocks provided by Jarociński and Karadi (forthcoming). Dark and light gray-shaded areas are corresponding 1-standard error and 2-standard error confidence bands, respectively, based on Newey and West (1987) standard errors. The green dash-dot line shows the same impulse response as the red dash-dot line estimated by smooth local projections (Barnichon and Brownlees, 2019). Frequency of data is monthly except for quarterly data on private fixed investment. All regressions estimated on sample 1996:M07–2007:M12.

Figure 8: Model-Implied Investment IRFs



Notes: The left figure shows the impulse response of investment in the model to a pure contractionary monetary policy shock. Investment goes down on impact due to conventional effects and expands in later periods due to information effects as the private sector partially interprets the monetary shock as an endogenous response of the Fed to a natural rate shock. The right panel shows the impulse response function of investment to an "information shock", which is identified as the predicted component of regressing raw monetary policy shocks on the Fed's forecasts of the natural rate. Investment goes up in the long-run as these shocks are correlated with the increase in the natural rate. The Fed info effect only front-loads this response.