Macroeconomic Dynamics, **26**, 2022, 1923–1963. Printed in the United States of America.
doi:10.1017/S1365100521000158

NEWS SHOCKS AND THE EFFECTS OF MONETARY POLICY

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Traditionally identified monetary shocks in a structural vector autoregression (SVAR) model typically result in long-lasting effects on output and total factor productivity (TFP). In this paper, I argue that the typical monetary shock has been confounded with the news shock about future technology. I propose and implement a novel SVAR approach that effectively "cleans" the technology component from the traditional Cholesky monetary shock. With the new identification, I find that a monetary shock exerts smaller and less persistent effects on output and the level of measured TFP than a traditionally identified monetary shock. Finally, I show that the SVAR impulse responses can be replicated by augmenting the standard New Keynesian model with a time-varying inflation target and a non-Ricardian fiscal policy regime.

Keywords: Monetary Policy, News Shock, VAR Model, Fiscal Theory of Price Level.

1. INTRODUCTION

How does monetary policy affect the economy? Following the seminal work of Sims (1980), a long literature based on the structural vector autoregression (SVAR) model has been developed to explore the empirical effects of monetary policy on business cycles.[1] Nevertheless, identifying the monetary policy shock is by no means an easy task. One of the problems that present severe challenges to the identification of the monetary shock is the "foresight problem" [Ramey (2016)]. On the one hand, policymakers usually take into account their expectations about future economic developments when making monetary policy. On the other hand, shifts in the stance of monetary policy or other exogenous shocks may be anticipated by private agents in advance. The foresight of both the monetary authority and private agents needs to be taken into account when identifying the monetary policy shock [Jia (2019)].

Following Beaudry and Portier (2006), a burgeoning news shock literature has been developed which proposes anticipated total factor productivity (TFP) shocks

I owe my deepest gratitude to my Ph.D advisor at Southern Methodist University, Nathan Balke, for his continuous help and invaluable advice. I also thank Lian An, John Cochrane, Pavel Kapinos, Xiaohan Ma, Enrique Martinez-Garcia, Jian Wang, Mark Wynne as well as seminar participants at Federal Reserve Bank of Dallas, Canadian Economic Association Meeting and Southern Economic Association Meeting for their helpful comments and suggestions. I would like to thank the Research Enhancement Program at Texas State University for financial support. All remaining errors are mine alone. Address correspondence to: Ren Zhang, Department of Finance and Economics, McCoy College of Business Administration, Texas State University, 519 McCoy Hall, San Marcos, Texas, 78666, USA. e-mail: r_z79@txstate.edu. Phone:+1 (469) 394-3198.

1469-8056/21

as alternative persistent sources of macroeconomic fluctuations.[2] An anticipated TFP shock, also known as TFP news shock, is defined as a shock which predicts future technology movements without exerting any effect on current technology movements.[3] Recent papers, such as Kurmann and Otrok (2013) and Gambetti et al. (2017), suggest that monetary policy responds systematically to anticipated TFP shocks, and that the systematic monetary policy is essential in propagating the effects of a TFP news shock.

Given this, it is surprising that the existing SVAR literature has not considered the joint identification of monetary policy shocks and TFP news shocks. The potential risk associated with identifying the monetary policy shock and the TFP news shock one at a time is that the monetary policy shock can be confounded with the systematic monetary policy response to the TFP news shock. In light of this, this paper addresses the following research questions: Is the standard monetary policy shock identified by the recursive causal assumption confounded with the TFP news shock?[4] If it is, how do we effectively "clean" the TFP news component from the traditional monetary shock, so that we can disentangle the unanticipated monetary policy shock from the Fed's systematic monetary policy response to the news shock?

In this paper, I take the first step to address the above questions by proposing an alternative strategy to identify the monetary policy shock. In particular, I explicitly restrict the monetary shock to be independent of the TFP news shock as well as the unanticipated TFP shock. Following Barsky and Sims (2011), I identify the TFP news shock as the linear combination of the reduced-form innovations orthogonal to the unanticipated TFP shock which maximizes the sum of contributions to TFP forecast error variance over a finite horizon. The monetary policy shock is then identified as orthogonal to both the unanticipated and the anticipated TFP shock. Consistent with early studies in the literature, I also assume no contemporaneous effects of the monetary policy shock on TFP, real GDP, the price level, and commodity prices to achieve exact identification of the monetary shock. Implementing the novel approach in a six-variable SVAR model which includes TFP, real GDP, the GDP deflator, commodity prices, the Federal Funds rate, and the 10-year treasury bill rate yields the following results:[5]

First, the contractionary monetary shock identified by the traditional recursive causal approach looks similar to my negative TFP news shock; the impulse responses, the forecast error variance decompositions, and the historical realizations are very similar. For traditional identifications, the contractionary monetary shock induces a significant decline in TFP and accounts for around 45 percent of the variation in TFP at long horizons, just as a negative TFP news shock does in my identification. The correlation between the traditional monetary shock and the negative TFP news shock is as high as 0.90. This evidence suggests that the traditional monetary shock is confounded with the TFP news shock. The TFP news shock and my new monetary shock are independent by construction, and they together explain more than 97 percent of the variation in the traditional monetary shock. Thus, we can approximate the monetary policy shock identified by the traditional recursive causal assumption with a linear combination of the TFP news shock and the monetary policy shock identified by my new method. This evidence suggests that the new identification strategy developed in this paper has purified the monetary shock by effectively "cleaning" the TFP news component from the traditional monetary shock.

Second, the effects of my new monetary shock on TFP and real GDP differ from the corresponding effects of the traditional monetary shock. Unlike the traditional monetary shock, the new monetary shock exerts virtually no impact on the TFP series. This is plausible given that the measure of TFP used in this paper has already been adjusted for latent factor utilization and thus stripped of any systematic response to monetary policy.[6] Furthermore, the new monetary shock induces a smaller and less persistent effect on real output than the traditional monetary shock. Historically, economists have long observed that shifts in monetary policy are followed by significant and persistent fluctuations in output and inflation [e.g. Friedman and Schwartz (1963)]. Without controlling for the systematic monetary policy response to the TFP news shock, studies which identify the monetary policy shock with the traditional approach conclude that the monetary policy shock has a persistent effect on real output. The results in this paper show that the chronological order between the monetary policy action and the ensuing macroeconomic fluctuation does not necessarily imply a causal relationship. A third factor, the TFP news shock, is responsible for both the shifts in monetary policy stance and the subsequent macroeconomic fluctuations.

Third, the contractionary monetary shock identified by the new approach induces a Fisherian effect which raises the inflation rate in a hump-shaped pattern, while the interest rate and the inflation rate decrease in response to a positive news shock.[7] The Fisherian effect uncovered in this paper is consistent with the recent findings of Uribe (2018) who shows that a permanent tightening of monetary policy can lead to a higher inflation rate. Nevertheless, this contradicts the predictions of the standard New Keynesian dynamic stochastic general equilibrium (DSGE) models in which a tight monetary policy shock would cause an increase in the real interest rate and a decrease in the inflation rate. The standard New Keynesian model also envisages small and transitory effects of the news shock on the interest rate and the inflation rate. To provide an economic explanation for these documented empirical results, I construct a DSGE model that augments the standard New Keynesian model with a time-varying inflation target which allows the Fed to set the inflation target in response to their observation of the TFP news shock. I also assume in my DSGE model different policy coordination between the fiscal authority and the central bank from the standard New Keynesian model. Following the literature on the fiscal theory of the price level, I assume that fiscal policy determines the price level, while monetary policy provides any necessary backing to fiscal policy, which is known as the non-Ricardian fiscal policy regime. I find that we can largely replicate the empirical SVAR impulse responses by the DSGE model augmented with the time-varying inflation target and the non-Ricardian fiscal policy. The non-Ricardian fiscal policy is essential in explaining the Fisherian effect of the monetary policy shock, while the time-varying inflation target provides a systematic monetary policy channel for amplifying the effects of the news shock.

The closest papers to the current paper are Kurmann and Otrok (2013) and Gambetti et al. (2017). Like this paper, both of these papers argue that systematic monetary policy provides an important channel in amplifying the effects of the TFP news shock on output and inflation. However, rather than focusing solely on the TFP news shock as in previous studies, this paper distinguishes itself by moving one step further to evaluate the effects of the monetary shock conditional on the TFP news shock. With the new identification approach of the monetary shock, I conclude that the effects of the unanticipated monetary shock are small once the Fed's systematic response to the TFP news shock is taken into account. This paper is also connected to the large monetary SVAR literature which attempts to crack the foresight problem when identifying the monetary policy shock with a variety of approaches. The existing methods in this literature largely fall into three categories: (i) the factor-augmented vector autoregression model, which incorporates a large number of indicators into the SVAR model [e.g. Bernanke et al. (2005), Boivin et al. (2009) and Ahmadi and Uhlig (2015)]; (ii) the narrative approach, which infers the expectations of the central bank and the monetary policy shock from the economic forecasts of the Greenbook [e.g. Romer and Romer (2004), Coibion (2012)]; (iii) a combination of the high-frequency identification method and the proxy SVAR approach, which identifies the monetary shock by focusing on what happens to interest rates within a narrow window of time, say 30 min to one day, around a monetary policy announcement [e.g. Gertler and Karadi (2015), Nakamura and Steinsson (2018), Stock and Watson (2018)]. Compared to existing methodologies in the literature, my new approach has the advantage of identifying the anticipated TFP shock explicitly, which may shed some light on those DSGE studies that evaluate the effects of the TFP news shock and the monetary shock with a variety of nominal and real frictions [e.g. Christiano et al. (2010), Khan and Tsoukalas (2012), Schmitt-Grohé and Uribe (2012) and Kurmann and Otrok (2014)]. In this sense, this paper contributes to the literature by bridging the gap between the monetary SVAR literature and the TFP news shock literature. Finally, the Fisherian effect of the monetary shock uncovered in this paper is consistent with Uribe (2018), which lends empirical support to the the fiscal theory of the price level literature [e.g. Leeper (1991), Sims (1994), Woodford (1995), Cochrane (2011), Sims (2011), Sims (2013), Cochrane (2018*b*)].

The remainder of the paper proceeds as follows. Section 2 describes the benchmark empirical identification strategy. Data description and the main empirical results are reported in section 3. Section 4 explores the theoretical implications of the empirical findings by replicating the documented empirical results with a DSGE framework and Section 5 concludes.

2. EMPIRICAL STRATEGY

2.1. SVAR Model and the Traditional Identification Approach

Prior to introducing the new approach to identify the monetary shock, I start from a reduced-form VAR model expressed as equation (1):

$$y_t = \sum_{i=1}^{K} B_i y_{t-i} + u_t, \tag{1}$$

where y_t is a vector that contains endogenous variables, B_i denotes the coefficient matrix, and u_t corresponds to the regression residuals with the variance–covariance matrix $Var(u_t) = \Sigma$. Similar to Bernanke et al. (1997) and Kurmann and Otrok (2013), the endogenous vector, y_t, consists of six variables: TFP, real GDP, the GDP deflator, commodity prices, the Federal Funds rate, and the 10-year treasury bill rate.[8] Most of the endogenous variables are not stationary with long-run cointegration relationships among the variables. If the true cointegration relationships are both known and can be provided an economic interpretation, it should be appropriate to estimate a vector error correction model. However, when the true cointegration relationships are unknown and are not the main focus of the analysis, then imposing an inappropriate cointegration relationship can lead to biased estimates of the parameters and impulse responses. In this case, estimating a VAR model in levels is more appropriate which provides a consistent estimation of the parameters as argued in Ramaswamy and Sloek (1998). In my benchmark analysis, I remain ignorant about the true cointegration relationship and estimate a VAR model in levels.[9] I will show in the section of robustness checks that most of the empirical results are robust when estimating a vector error correction model instead.

The identification of the structural shocks amounts to searching for a mapping, A, between the regression residuals, u_t, and the structural shocks, ϵ_t, so that $u_t = A\epsilon_t$. By definition, the matrix A, also known as the impact matrix, must satisfy $\Sigma = E(A\epsilon_t\epsilon_t' A') = AA'$. However, as it is well known in the literature, these equations alone are insufficient to solve for a unique impact matrix. As a result, auxiliary restrictions on matrix A are necessary to identify the structural shocks.

Following Sims (1980), the standard restriction imposed on the impact matrix is that the impact matrix is lower triangular, which in practice can be obtained by taking a Cholesky decomposition of the variance–covariance matrix. This traditional identification method implies a "recursive causal order" where all the shocks that appear later in the ordering are assumed to have no contemporaneous effect on the variables before them. Similar to Bernanke et al. (1997), Christiano et al. (1999) and other previous work in the literature, I order the Federal Funds rate after TFP, real output, the GDP deflator, and commodity prices, so that the traditional monetary policy shock is assumed to affect these macro variables with a lag. If we denote the impact matrix associated with the traditional recursive causal approach with T, the matrix T can be formalized as equation (2), where the symbol “#” represents nonzero numbers and the monetary policy shock is identified by the fifth column of the matrix T:

$$T = \begin{bmatrix} \# & 0 & 0 & 0 & 0 & 0 \\ \# & \# & 0 & 0 & 0 & 0 \\ \# & \# & \# & 0 & 0 & 0 \\ \# & \# & \# & \# & 0 & 0 \\ \# & \# & \# & \# & \# & 0 \\ \# & \# & \# & \# & \# & \# \end{bmatrix}. \tag{2}$$

2.2. The New Identification Strategy

The recursive identification approach has become a standard way to identify the monetary shock. Although a long list of new methods has been developed in recent years, as surveyed in the previous section, the recursive approach is still the most widely used identification approach. The empirical effects of the macroeconomic shocks uncovered by this approach provide the cornerstone rationale behind New Keynesian DSGE models [Christiano et al. (2005)]. Given this, it is surprising that little attention has been paid to the fact that this popular procedure does not guarantee the independence between the unanticipated monetary shock and the technology shocks as usually assumed in theoretical models. One exception is Carlstrom et al. (2009) who demonstrate that the traditional monetary shock is confounded with the unanticipated technology shock in an SVAR model even if the underlying data generating process is a simple New Keynesian three-equation model. Furthermore, Beaudry and Portier (2006) illustrate that in a bivariate vector error correction system, the shock traditionally identified as the Cholesky monetary shock corresponds to the anticipated technology shock in a diffusion model. The anticipated technology shock acts like a news shock which predicts future technology movements without exerting any effect on current technology movements. It updates economic agents’ expectation of future technology movements. In light of the potential confounding problem discussed above, this paper introduces an alternative identification strategy where the monetary shock is explicitly restricted to be independent of both the unanticipated technology shock and the anticipated technology shock.

I follow the method proposed by Barsky and Sims (2011) to identify the technology shocks, the details of which will be discussed in section 2.2.1. The unanticipated technology shock is identified as the only shock which can affect TFP on impact. The anticipated technology shock is identified as the linear combination of the reduced-form innovations orthogonal to the unanticipated technology shock which maximizes the sum of contributions to TFP forecast error variance over a finite horizon. Consistent with other studies such as Beaudry and Lucke (2010) and Kurmann and Otrok (2013), Barsky and Sims (2011) uncover that the unanticipated technology shock alone typically explains around only 50 percent of the variation in the technology series at medium and long horizons. However, the news shock and the unanticipated technology shock together account for over 95 percent of TFP movements at all horizons. This evidence suggests that not all of the technology movements arrive as surprises and much of the future movement in technology can be anticipated in advance. It also indicates that the monetary shock that is identified to be orthogonal with the unanticipated and the anticipated technology shocks should also be largely independent of the technology as measured by TFP.

Conditional on the two identified technology shocks, the monetary shock needs to be a linear combination of the other non-technology shocks in the SVAR model. This guarantees the monetary shock to be independent of the technology shocks. To further determine the coefficients of such a linear combination and exactly identify the monetary shock, I employ the assumption that the unanticipated monetary shock exerts no effect on TFP, real GDP, the price level, and commodity prices on impact. The rationale for this is twofold: first, it has been long observed that the monetary shock affects macroeconomic variables with a lag. Second, it facilitates comparison between the new identification strategy and the traditional recursive identification method.

2.2.1. The identification of technology shocks: Barsky–Sims approach. Barsky and Sims (2011) assume that the evolution of the technology, a_t, proxied by the logarithm of TFP, follows:

$$a_t = v\,(L)\,\epsilon_t^{current} + d\,(L)\,\epsilon_t^{news}, \tag{3}$$

where the news shock, ϵ_t^{news}, and the unanticipated TFP shock, $\epsilon_t^{current}$, are uncorrelated; $v\,(L)$ and $d\,(L)$ are the lag polynomials with the restriction $d\,(0) = 0$. This restriction distinguishes the news shock, ϵ_t^{news}, that is revealed in t but affects TFP only in $t + 1$ or later, from the unanticipated TFP shock, $\epsilon_t^{current}$, that is revealed and affects TFP in t.

Since the unanticipated TFP shock is the unique contributor to contemporaneous technology movements, it is identified as the disturbance to the TFP equation and is associated with the first column of the lower triangular impact matrix, T, in equation (2). Moreover, equation (3) also presumes that the news shock and the unanticipated technology shock together are responsible for all variation in TFP at all horizons. However, in a multivariate SVAR setting, it is unrealistic to expect this assumption to hold at all horizons. Instead, the news shock is identified by picking an impact matrix, so that the news shock explains as much as possible the variation in the TFP series over a finite subset of horizons conditional on the unanticipated technology shock. Specifically, suppose the VAR model can be expressed in a moving average form:

$$y_t = \sum_{i=0}^{\infty} C_i u_{t-i}, \tag{4}$$

where C_i is the moving average coefficient matrix. Then the share of the forecast error variance of the k-th variable in y_t contributed by structural shock j up to horizon H is

$$\sum_{h=0}^{H} \Omega_{k,j}(h) = \sum_{h=0}^{H} \frac{e_k^{'}\left(\sum_{\tau=0}^{h} C_\tau T Q e_j e_j^{'} Q^{'} T^{'} C_\tau^{'}\right) e_k}{e_k^{'}\left(\sum_{\tau=0}^{h} C_\tau \Sigma C_\tau^{'}\right) e_k}, \tag{5}$$

where e_i is the selection vector with one in the i-th place and zero elsewhere, T is the lower triangular matrix in equation (2), and Q is an orthonormal rotation matrix.

The identification of the news shock is equivalent to finding a specific rotation matrix, Q, which rotates the old impact matrix, T, to the new impact matrix, $\tilde{A}$, i.e., $\tilde{A} = TQ$. Without loss of generality, I assume that the news shock is ordered last.[10] Accordingly, the last column of the rotation matrix, denoted by the vector q_6, is solved by maximizing the contribution of the news shock to TFP conditional on the unanticipated technology shock, which can be expressed as:

$$\begin{aligned} q_6 &= \arg\max \textstyle\sum_{h=0}^{H} \Omega_{1,6}(h) \\ s.t. \quad & q_6^{'} * q_6 = 1, q_6(1) = 0, \end{aligned} \tag{6}$$

where $q_6(1)$ represents the first element of the vector q_6, and the restriction $q_6(1) = 0$ ensures that the news shock induces no immediate response in TFP. Thus, the new impact matrix, $\tilde{A}$, is in the form of equation (7):

$$\tilde{A} = TQ = \begin{bmatrix} a_1 & 0 & 0 & 0 & 0 & 0 \\ a_2 & \# & \# & \# & \# & a_7 \\ a_3 & \# & \# & \# & \# & a_8 \\ a_4 & \# & \# & \# & \# & a_9 \\ a_5 & \# & \# & \# & \# & a_{10} \\ a_6 & \# & \# & \# & \# & a_{11} \end{bmatrix}, \tag{7}$$

where the rotation matrix, Q, is formalized as:

$$Q = \begin{bmatrix} 1 & 0_{1*4} & \multirow{2}{*}{q_6} \\ 0_{5*1} & Q^A_{5*4} & \end{bmatrix}. \tag{8}$$

The identified columns of the impact matrix, $\tilde{A}$, are denoted by a_i, $i = 1, 2, ..., 11$. The first column of the impact matrix, $\tilde{A}$, is associated with the unanticipated technology shock, while the last column corresponds to the technology news shock. The four columns in the middle of the impact matrix, $\tilde{A}$, are left undetermined. I use the symbol "#" to represent undetermined nonzero numbers. The shocks associated with these middle columns are independent of the two technology shocks and are left unidentified under the Barsky–Sims framework.

2.2.2. *The unanticipated monetary shock.*

The novel identification approach of the unanticipated monetary shock introduced in this paper stands on the shoulders of the Barsky–Sims identification strategy for technology shocks discussed above. The new monetary shock is identified to be orthogonal to both the unanticipated technology shock and the technology news shock. This suggests that the monetary shock should be a linear combination of the non-technology shocks associated with the four columns in the middle of the matrix $\tilde{A}$. To determine the four coefficients of the linear combination, we need to impose four additional zero restrictions on the monetary shock as is demonstrated in Rubio-Ramirez et al. (2010) and Binning (2013). Hence, I apply a set of widely used assumptions which restrict the monetary shock to exert no contemporaneous effect on the four macro variables in the SVAR model: TFP, real output, the price level, and commodity prices. This set of zero restrictions are consistent with the zero restrictions directly imposed on the traditional monetary shock. Thus, the key ingredient that distinguishes the new strategy from the traditional strategy is that the new strategy restricts the monetary shock to be independent of the TFP news shock. This facilitates the evaluation of the question of whether the traditional monetary shock has been confounded with the TFP news shock, which can be done by comparing the performance of the traditional monetary shock and the new monetary shock.

The new identification assumption implies an impact matrix in the form of equation (9), where the first and last columns of the impact matrix, N, correspond to the unanticipated technology shock and the anticipated technology shock, respectively, the fifth column identifies the monetary shock, and the other three columns are left undetermined. Thus, although this new identification scheme exactly identifies the technology shocks and the monetary policy shock, it is a partial identification strategy which only identifies three shocks:

$$N = \tilde{A}Q^* = \begin{bmatrix} a_1 & 0 & 0 & 0 & 0 & 0 \\ a_2 & \# & \# & \# & 0 & a_7 \\ a_3 & \# & \# & \# & 0 & a_8 \\ a_4 & \# & \# & \# & 0 & a_9 \\ a_5 & \# & \# & \# & a_{12} & a_{10} \\ a_6 & \# & \# & \# & a_{13} & a_{11} \end{bmatrix}, \tag{9}$$

To obtain the impact matrix N, I rotate the previous impact matrix $\tilde{A}$ with another auxiliary orthonormal rotation matrix Q^*, which is formalized as:

$$Q^* = \begin{bmatrix} 1 & 0_{1*4} & 0 \\ 0_{4*1} & Q^{*N}_{4*4} & 0_{4*1} \\ 0 & 0_{1*4} & 1 \end{bmatrix}, \tag{10}$$

where the first and last columns of Q^* are selection vectors. This design ensures that the first and the last columns of $\tilde{A}$ are left unrotated. As a result, the monetary shock is identified conditional on the technology shocks identified by the Barsky–Sims method. The last column of the submatrix Q^{*N}_{4*4} defines the unique linear combination of the four non-technology shocks and is determined by the assumption that the new monetary shock does not have any contemporaneous impact on the four variables ordered before it. Such an orthonormal rotation matrix, Q^*, can be obtained with the following algorithm:[11]

(1) Define a matrix $\tilde{B}$ as the four-by-four submatrix in the center of the impact matrix, $\tilde{A}$ (from the second row/column to the fifth row/column). Then calculate $\tilde{\Sigma}_B = \tilde{B}\tilde{B}'$;
(2) Take the Cholesky decomposition of $\tilde{\Sigma}_B$ so that $\tilde{\Sigma}_B = B_c B_c'$, where B_c is lower triangular;
(3) Derive Q^{*N}_{4*4} by $Q^{*N}_{4*4} = \tilde{B}^{-1} B_c$.

It is easy to verify that the rotation matrix, Q^*, acquired with the steps above guarantees that the impact matrix, N, is in the form specified in equation (9). This is because rotating the previous impact matrix, $\tilde{A}$, with the rotation matrix, Q^*, obtained from the above algorithm is equivalent to decomposing the matrix $\tilde{\Sigma}_B$ with the Cholesky decomposition method conditional on the identification of the unanticipated technology shock and the anticipated technology shock. The orthonormality of the rotation matrix, Q^*, gurantees $NN' = \Sigma$. Given that $\tilde{B}Q^{*N}_{4*4} = B_c$ is lower triangular, the fifth column of the impact matrix, N, satisfies the four zero restrictions imposed on the monetary shock.

3. EMPIRICAL RESULTS

3.1. Data

The baseline estimation of the empirical model uses quarterly data from 1962Q1 to 2007Q3. The sample ends immediately before the financial crisis to avoid the Great Recession period and the unconventional monetary policy era when the policy rate in the USA was stuck at the zero lower bound. In fact, it is difficult to think of the post-2007 data as being generated by the same stochastic processes as the sample before 2007. Nevertheless, I show later in the robustness check that all the results are robust even when extending the sample to 2018Q2.

The most critical data series needed to proceed is an empirical measure of aggregate technology. Since the identification of the monetary shock requires that the news shock is orthogonal to the observed technology, it is crucial that the empirical measure of technology adequately control for endogenous factors such as unobserved input variation. To address these issues, I adopt the Fernald (2014) quarterly TFP series which is available on the Federal Reserve Bank of San Francisco website. The indices are constructed using the methodology introduced in Basu et al. (2006) which exploits first-order conditions from a firm's optimization problem to correct for latent factor utilization. This TFP series arguably represents the state-of-the-art research in growth accounting and is thus preferable to a simple Solow residual measure for exogenous TFP.

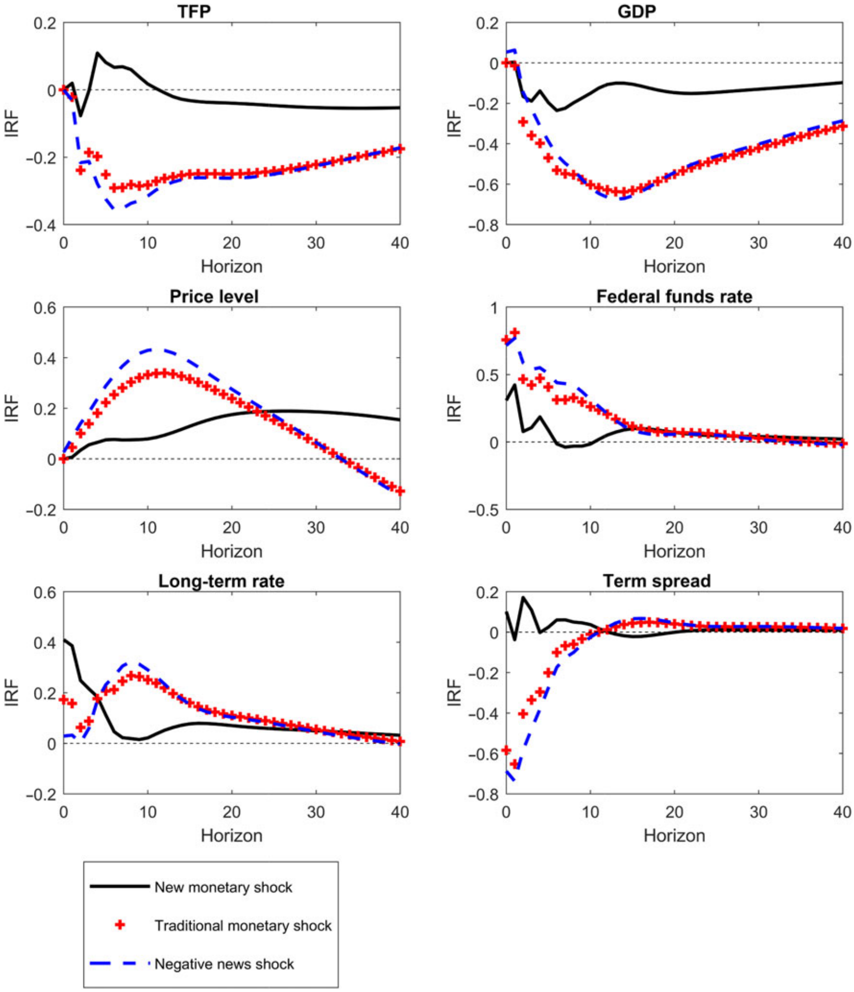
For the other indicators, I use real GDP as the output measure and the GDP deflator as the price measure. Commodity prices are proxied by the producer price index for crude materials for further processing. Following the previous literature, the four macroeconomic series (TFP, real GDP, the GDP deflator, and commodity prices) are taken in log-levels (multiplied by 100 to express the impulse response functions in percentage rates of variation). As in Bernanke et al. (1997), I also include the Federal Funds rate as the monetary policy rate and the 10-year treasury bill rate as the long-term rate. The long-term interest rate contains information on households' expectations about future economic developments which assists the identification of the anticipated TFP shock.

3.2. Results

I estimate the VAR model with four lags.[12] Figure 1 displays the impulse responses to 1 standard deviation of new monetary shock (black solid lines) and negative TFP news shock (blue dashed lines) as identified by the new identification approach. To facilitate comparison, I also plot in red "plus" lines the impulse responses to a 1 standard deviation traditional monetary shock identified by the recursive causal approach under the same VAR specification.[13] I also calculate the impulse responses of the term spread based on the impulse responses of the long-term interest rate and the impulse responses of the short-term interest rate. Including the results of the term spread facilitates in comparison with Kurmann and Otrok (2013), who argue that the TFP news shock is actually a (term structure)"slope shock." To save space, I omit the impulse responses of the commodity price index in Figure 1 given that the commodity price index is an auxiliary variable used as a proxy for unobserved inflation expectations in the VAR model.

The estimated effects of the traditional monetary shock are fairly standard. In response to a 1 standard deviation traditional monetary shock, the Federal Funds rate rises by 75 basis points which does not dissipate until 5 years later. Meanwhile, real output contracts persistently and reaches its trough of -0.63 percent 4 years after the initial shock. The price level responds in a hump-shaped pattern which rises until it reaches its peak in the eleventh quarter. This suggests that including a measure of commodity prices in my SVAR model does not solve the well-known "price puzzle" in the monetary SVAR literature (see Christiano et al. 1999 and Hanson 2004). Furthermore, consistent with Bernanke et al. (1997) and Kurmann and Otrok (2013), the traditional monetary shock leads to a moderate response in the long-term interest rate, and thus a significant decrease in the term spread. Last, but most puzzling, TFP contracts significantly and persistently in response to a traditional monetary shock. This evidence challenges the conventional belief that technology is exogenous and independent of an unanticipated monetary shock.

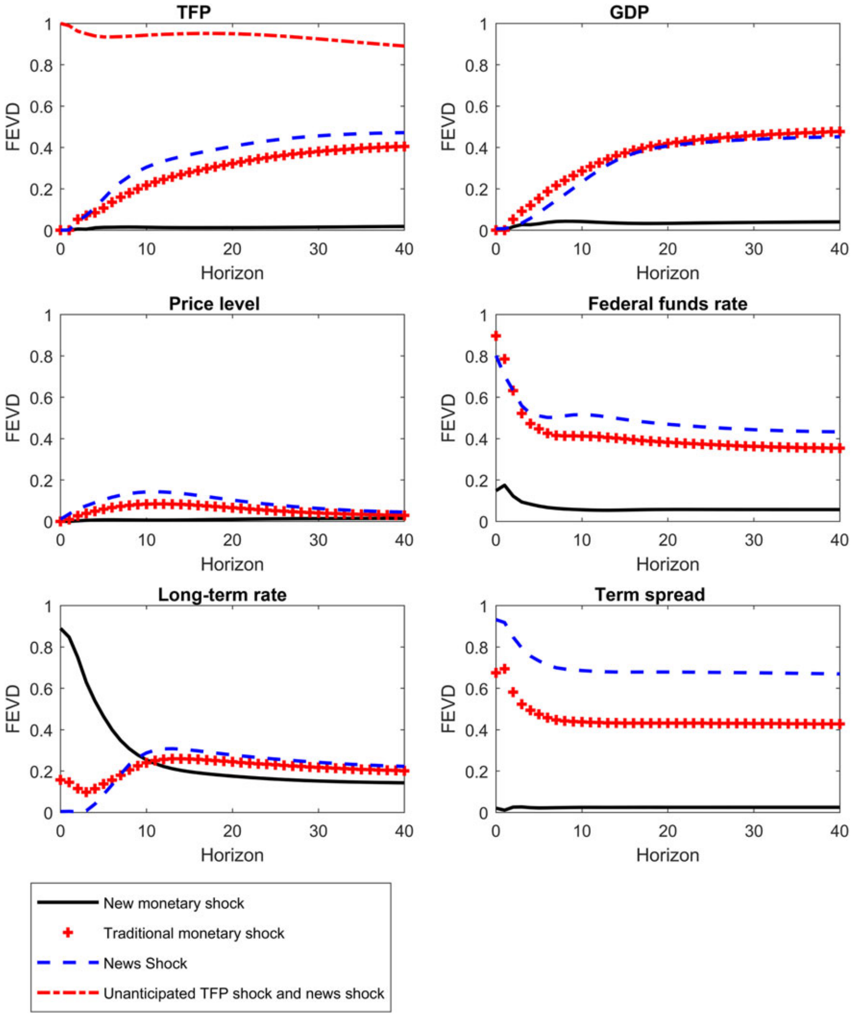
The new monetary shock, depicted in black solid lines, induces very different dynamics. To begin with, the Federal Funds rate increases by 31 basis points which endures for only five quarters. In contrast to the traditional monetary shock, the new monetary shock exerts an insignificant effect on the TFP series as predicted by most theoretical models; thus, the new identification strategy is more consistent with the exogeneity of TFP than the traditional methodology. Moreover, the new monetary shock also exerts a smaller and less persistent effect on output. GDP decreases to -0.24 percent at the six-quarter horizon and recovers



Note: New monetary shock: the impulse responses to 1 standard deviation of monetary shock identified conditional on the news shock by the method introduced in this paper; traditional monetary shock: the impulse repsonses to 1 standard deviation of monetary shock identified by the Cholesky decomposition method; negative news shock: the impulse responses to 1 standard deviation of contractionary news shock identified by the method proposed by Barsky and Sims (2011).

FIGURE 1. Impulse responses to one standard deviation shocks

beyond that. In contrast to traditional monetary theory and conventional SVAR findings, the new monetary shock does not have any deflationary effects. The price level grows slowly and never reverts following the rise in the policy rate. This result is consistent with the new empirical findings by Uribe (2018), who shows that a persistent tight monetary shock can lead to a higher inflation rate. In addition, unlike the traditional monetary shock, the long-term interest rate moves



Note: New monetary shock: the variation of the variables explained by the monetary shock identified conditional on the news shock by the method introduced in this paper; traditional monetary shock: the variance of the variables explained by the monetary shock identified by the Cholesky decomposition method; negative news shock: the volatility of the variables explained by the news shock identified by the method proposed by Barsky and Sims (2011); unanticipated TFP shock and news shock: the total variation contributed by the unanticipated and anticipated TFP shocks together.

FIGURE 2. Forecast error variance decomposition

together with the Federal Funds rate, so that the term spread responds little to the new monetary shock.

Figure 2 depicts the forecast error variance decomposition. As in Figure 1, the black solid lines represent the contribution of the new monetary shock, while the red plus lines are for the traditional monetary shock. Again the contribution of the traditional monetary shock is in line with the other studies in the monetary SVAR literature such as Bernanke et al. (1997), Cochrane (1998), and Christiano et al. (1999). The traditional monetary shock explains about 90 percent of the variation in the Federal Funds rate on impact, approximately 47 percent of the fluctuations in real GDP and 8 percent of the variation in the price level at medium and long horizons. Like Bernanke et al. (1997), the old monetary shock accounts for 20 percent of the movement in the long-term interest rate and 40 percent of the term spread. Finally, although the old monetary shock does not explain any contemporaneous TFP variation, as is assumed in the identification scheme, it is responsible for around 40 percent of the forecast error variance in TFP at horizons of 5 years and later.

The new monetary shock, by contrast, explains little of the variation in the TFP series. This is plausible given that the TFP data have already been adjusted for latent factor utilization. Meanwhile, it also contributes little to the price level and term spread. Nevertheless, this does not imply that the new monetary shock plays no role in the system. In fact, 15 percent of the contemporaneous forecast error variance in the monetary policy rate is attributable to the new monetary shock; this decreases to 6 percent in the long term. Contrary to the evidence of the traditional SVAR monetary shock, this suggests that most of the monetary policy stance shifts are not due to unanticipated monetary shocks but are the Fed's systematic response to economic fundamentals. The new monetary shock makes an even more significant contribution to the long-term interest rate and explains 89 percent of the long-term interest rate volatility on impact and 15 percent at longer horizons. Given that the long-term interest rate is the summation of the term premium and expectations about the future path of the short-term interest rates, the above results echo the argument of Gambetti et al. (2017) who suggests that the term premium serves as an essential channel in propagating the effect of monetary shocks on the long-term interest rate. Additionally, the new monetary shock is responsible for no more than 5 percent of the real output movements along all the horizons, which is much less than the contribution of the Cholesky monetary shock identified by the traditional method.

The TFP news shock explains around only 50 percent of the variance in TFP at longer horizons. In accordance with Barsky and Sims (2011) and Kurmann and Otrok (2013), the TFP news shock and the unanticipated TFP shock together explain over 95 percent of the TFP variation at most horizons. Moreover, the TFP news shock accounts for 40 percent of the GDP fluctuations, 14 percent of the price level variation, and 50 percent of the Federal Funds rate volatility at long horizons. Consistent with Kurmann and Otrok (2013), the news shock is also a shock to the slope of the term structure. It explains 93 percent of the contemporaneous variation in the term spread and remains above 65 percent at long horizons.

Another observation from Figures 1 and 2 that deserves special notice is that the impulse responses and the contribution of the traditional monetary shock (measured by the forecast error variance decomposition) are similar to those of

TABLE 1. Correlation between traditional monetary shock, TFP news shock, and new monetary shock.

	Traditional monetary shock	TFP news shock	New monetary shock
Traditional monetary	1	-0.90	0.41
TFP news		1	0
New monetary			1

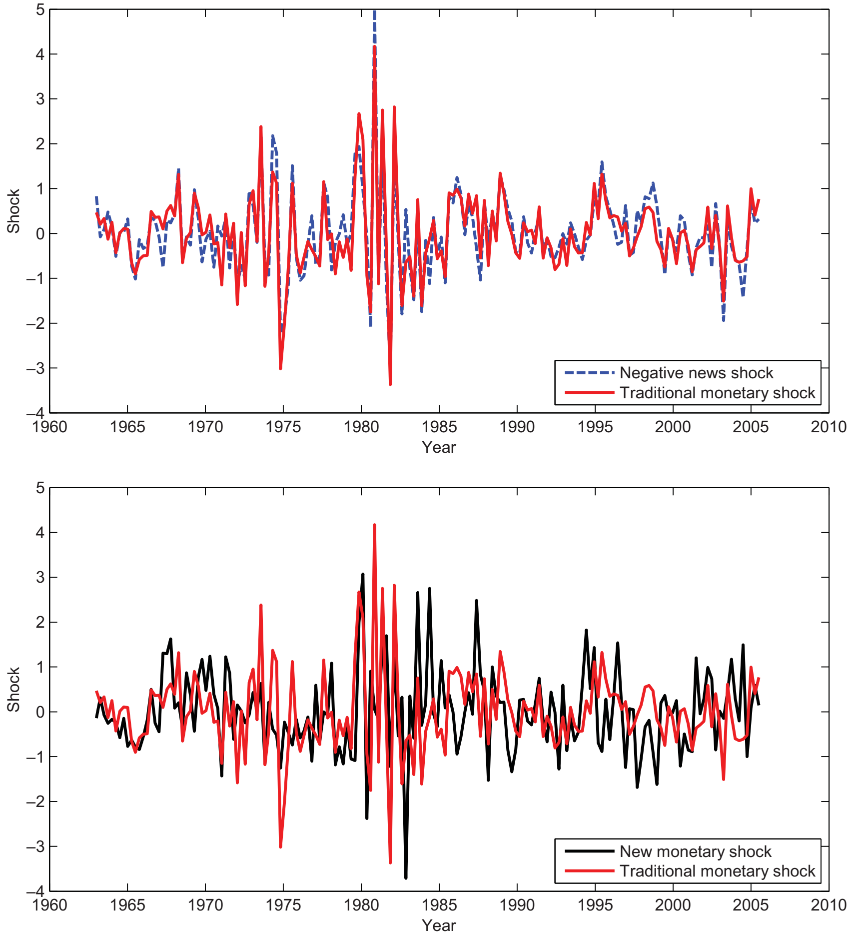
NOTES: The traditional monetary shock is identified by the recursive causal assumption. The TFP news shock and the new monetary shock are identified by the new identification approach with the same VAR specifications.

a negative news shock plotted in blue dashed lines. To further explore the information content of the traditional monetary shock, I examine its relationship with the TFP news shock and the new monetary shock. As reported in Table 1, the correlation between the traditional monetary shock and the TFP news shock is as high as -0.90. Moreover, Figure 3 shows that the historical plots of the traditional monetary shock track the negative news shock closely. This suggests that the traditional monetary shock is confounded with the TFP news shock. Besides, the correlation between the old monetary shock and the new monetary shock is 0.41. By a simple regression such as equation (11), I find that 97.5 percent of the variance in the traditional monetary shock, ϵ_t^c, can be explained by the regression equation, where 80.7 percent is contributed by the TFP news shock, ϵ_t^{news}, and the new monetary shock, ϵ_t^m, add another 16.8 percent:

$$\epsilon_t^c = \underset{(std:0.012)}{-0.90}\,\epsilon_t^{news} + \underset{(std:0.012)}{0.41}\,\epsilon_t^m + v_t. \tag{11}$$

Thus, the traditional monetary shock can be approximated by a linear combination of the new monetary shock and the TFP news shock. This implies that the effects of the traditional monetary shock are determined by both the news shock and the pure monetary shock. However, the effects of the TFP news component dominates the effects of the traditional monetary shock in my model for two reasons: first, the TFP news shock contributes much more to the variation in the traditional monetary shock than the new monetary shock. Second, the responses of macroeconomic indicators are much more persistent and significant to the news shock than the pure monetary shock as discussed above. Therefore, the dynamics normally attributable to the monetary shock in the SVAR literature actually come from the TFP news shock. The essence of the new identification strategy is that it “cleans” the TFP news component from the traditional monetary shock and isolates the pure monetary shock.

The above results shed some light on a few existing puzzles and debates in the monetary SVAR literature. For example, as discussed in Cochrane (1998), the traditional monetary shock usually exerts a very persistent effect in output. This paper demonstrates that this persistent impact on output is mainly due to the TFP news shock, while the output effect of the pure monetary shock is transient.



Note: The upper panel compares the historical plots of the monetary shock identified by the Cholesky decomposition method with the contractionary news shock identified by Barsky–Sims method; the lower panel plots the Cholesky monetary shock together with the monetary shock identified by the new method introduced in this paper.

FIGURE 3. Historical plots of the traditional monetary shock, the news shock and the new monetary shock

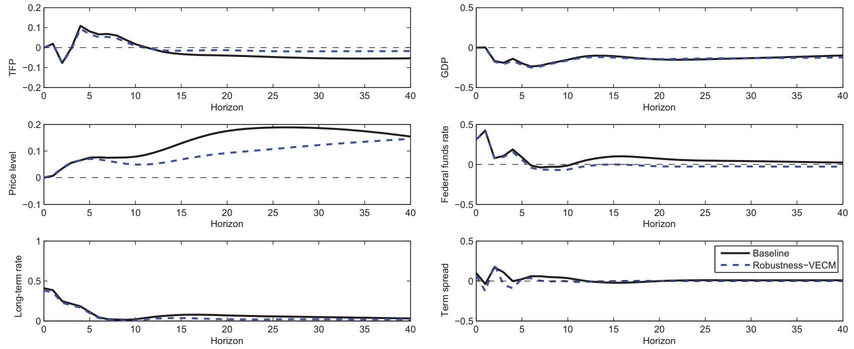
Moreover, the policy rate also responds persistently to the traditional monetary shock, which is considered as evidence of high monetary policy inertia by previous work. On the contrary, this paper illustrates that the policy rate responds more transiently to the monetary shock, while the persistence of the Federal Funds rate mostly comes from the Fed's response to the news of future productivity movements. Finally, the historical plots of the traditional monetary shock fluctuate with high volatility prior to the early 1980s and then become much more stable after the mid-1980s during the "Great Moderation" period.[14] Even so, having controlled for the TFP news shock, the volatility of the new monetary shock is stable along all the historical periods as shown in Figure 3. Thus, the new empirical evidence suggests that the high volatility of the Federal Funds rate prior to the 1980s mainly originates from the response of systematic monetary policy to the news shocks rather than from purely unanticipated monetary shocks.

To summarize, the above analysis shows that the new identification strategy has successfully restricted the monetary shock to be independent of TFP by separating the news shock from the traditional monetary shock. Under the new identification scheme, the monetary shock generates more reasonable effects on TFP, output, and the Federal Funds rate. The novel empirical evidence also sheds some light on several existing puzzles and debates in the monetary SVAR literature. Historically, economists have long observed that shifts in monetary policy stance are usually followed by significant macroeconomic fluctuations. With the traditional identification strategy, which fails to sufficiently capture the central bank's systematic responses to the technology news shock, one may conclude that it is the unanticipated monetary shocks that cause these significant macroeconomic fluctuations. The new identification strategy developed in this paper argues that the TFP news shocks contribute to both the shifts in monetary stance and the subsequent fluctuations in macroeconomic variables.

3.3. Robustness Checks

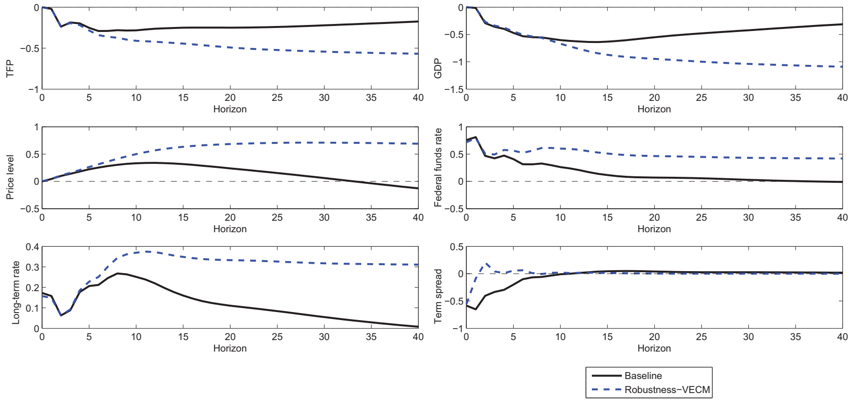
To check the robustness of the above results, I implement a set of experiments. First, one may argue that the data series such as TFP, real output, and the price level are not stationary, so that a vector error correction framework might be more appropriate in capturing the dynamics among the macroeconomic variables. The benchmark vector autoregression model can provide a consistent estimation of parameters when the true data generating process is a vector error correction model. Nevertheless, to address this argument more completely, I also estimate a vector error correction model with three cointegration relationships as indicated by the Johansen cointegration test. Figure 4 illustrates that the impulse responses to the new monetary shock are robust to the vector error correction specification. On the contrary, Figure 5 indicates that the effects of the monetary shock identified by the traditional Cholesky decomposition method are not robust. The impulse responses from the vector error correction model are more persistent than the corresponding responses generated by the baseline SVAR model.

Second, I extend the sample to 2018Q2 which also covers the period when the Federal Funds rate was at the zero lower bound. To capture the shifts in monetary stance caused by the Fed's unconventional monetary policy actions during the zero lower bound period, I also explore an alternative case which replaces the Federal Funds rate with the shadow funds rate data developed by Wu and Xia (2016). Figure 6 shows that the effects of the monetary shock identified by the new approach proposed by this paper are robust when extending the sample to 2018



Note: Baseline: the impulse responses to the new monetary shock gernerated by the vector autoregression model; robustness-VECM: the impulse responses to the new monetary shock generated by the vector error correction model with three cointegration relationships as suggested by Johansen cointegration test.

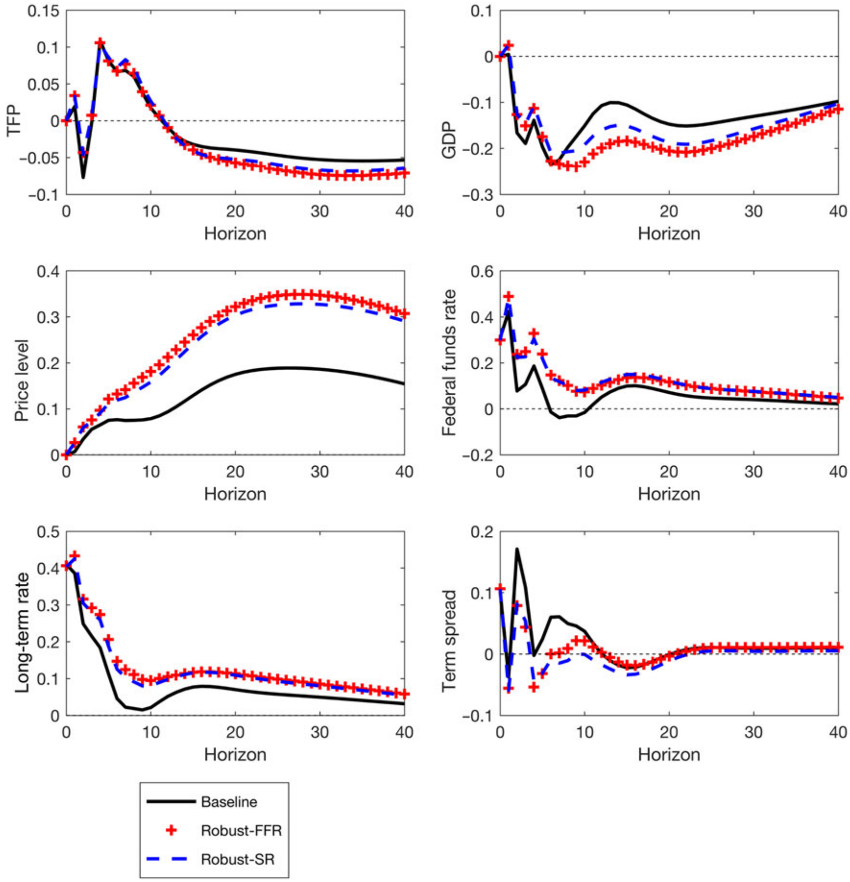
FIGURE 4. Impulse responses to the new monetary shock: robustness check I



Note: Baseline: the impulse responses to the traditional monetary shock under the vector autoregression model; robustness-VECM: the impulse responses to the traditional monetary shock under the vector error correction model with three cointegration relationships as suggested by Johansen cointegration test.

FIGURE 5. Impulse responses to the traditional monetary shock: robustness check I

using either the Federal Funds rate (labeled “Robust-FFR”) or the shadow funds rate (labeled “Robust-SR”) as the proxy for monetary policy. Moreover, similar to the baseline results, the correlation between the traditional monetary shock and the news shock is around 0.91, while the news shock and the new monetary shock together contribute approximately 99.6 percent of the variation in the traditional monetary shock. Such evidence indicates that the news shock is still confounded with the traditional Cholesky monetary shock even when including more recent data.



Note: Baseline: impulse responses to the new monetary shock under the baseline SVAR model estimated with data from 1962Q1 to 2007Q3; Robust-FFR: impulse responses to the new monetary shock under the baseline SVAR model estimated with data from 1962Q1 to 2018Q2; Robust-SR: impulse responses to the new monetary shock estimated with data from 1962Q1 to 2018Q2 under the SVAR model which adopts the shadow Federal Funds rate by Wu and Xia (2016) as a proxy for the monetary policy rate during the zero lower bound period.

FIGURE 6. Impulse responses to the new monetary shock: robustness check II

Third, recent papers such as Bouakez et al. (2017) and Kurmann and Sims (2017) argue that TFP series may be imprecise measures of technology due to measurement errors. It is worth pointing out that the Barsky and Sims (2011) approach adopted in my paper allows for the possibility that the TFP series may have some measurement error. This is why the unanticipated technology and anticipated technology shocks together do not explain all the variance of TFP. Kurmann and Sims (2017) argue that the effects of the Barsky and Sims (2011) TFP news shock are not robust to observation vintages in a four-variable SVAR model. In light of this, I re-estimate my SVAR model with the TFP series observed at various vintages from 2007 to 2018. The main empirical results such as “the impulse responses and the contribution of the traditional monetary shock are similar to those of a negative news shock” are robust for all data vintages and are available upon request.

Finally, some recent papers such as Moran and Queralto (2018) and Meier et al. (2020) find that TFP responds negatively to a tighter monetary policy shock consistent with my paper. They propose alternative stories to explain this evidence by arguing that the TFP series is not completely exogenous. Meier et al. (2020) argue that the TFP series of Fernald (2014) does not only measure the exogenous technology but also the markup dispersion that is negatively related to TFP but responds positively to their measure of monetary shock. However, a simple regression suggests a positive, rather than negative, long-run correlation between the TFP series and the markup dispersion.[15] In addition, the markup dispersion does not always respond positively to the monetary shock of Meier et al. (2020). Instead, I find that the Meier et al. (2020) monetary shock first raises the markup dispersion and then lower the markup dispersion after 16 quarters with the same local projection model as the one in Meier et al. (2020). The above evidence cast some doubts on the story introduced in Meier et al. (2020). In fact, the relationship between TFP growth and the growth rate of markup dispersion is estimated to be quite weak. The local projection model also predicts an insignificant markup dispersion response to my new monetary shock which suggests that the markup dispersion is largely exogenous to the new monetary shock. The identification approach in my paper is valid when markup dispersion is exogenous to the monetary policy shock or when it contributes little to TFP. In addition, Moran and Queralto (2018) argue that the monetary shock may have some effects on technology through an *R&D* channel. However, they do not evaluate how important the *R&D* channel is to propagate the effects of monetary shock in their SVAR model. If the *R&D* channel is indeed important, technology could be endogenous so that the assumptions of Barsky and Sims (2011) approach may not hold. Despite its importance, evaluating the importance of *R&D* channel and revising the Barsky and Sims (2011) approach to take account of this channel is beyond the discussion of my paper.

4. REPLICATING THE EMPIRICAL RESULTS: A DSGE MODEL

The preceding section shows that the new monetary shock induces quite different impulse responses from the traditional monetary shock. It also illustrates that the news shock accounts for around 50 percent of unpredictable movements in real GDP and the Federal Funds rate at long horizons. In this section, I investigate to what extent a standard New Keynesian model can replicate the responses to the news shock and the new monetary shock implied by the empirical model. In particular, (i) do these empirical results have implications for macroeconomic modeling? (ii) does the monetary shock in the standard model induce a Fisherian effect where an unanticipated rise in the policy rate leads to an increase in the inflation rate? and (iii) does the news shock in the theoretical model cause a significant drop in both the inflation rate and the Federal Funds rate on impact as in the SVAR model? This section addresses these questions by replicating the empirical impulse responses with an explicit New Keynesian framework.

Before introducing the details of the structural model, it deserves clarification that the target of the exercise in this section is not to demonstrate that the new VAR identification approach is adequate to recover shocks if the underlying data generating process is a DSGE model. More consistent with Christiano et al. (2005) and Kurmann and Otrok (2014), the goal is to show that the DSGE model is also able to generate similar impulse responses as the VAR impulse responses.[16] The exercise in this section may provide some guidance for future DSGE modeling.

4.1. Three-Equation Model

I adopt a prototypical New Keynesian three-equation model, which assumes that the economy can be summarized as follows:

$$x_t = \frac{1}{1+\phi}\mathbb{E}_t\left(x_{t+1}\right) + \frac{\phi}{1+\phi}x_{t-1} - \frac{\sigma\left(1-\phi\right)}{1+\phi}\left(i_t - \mathbb{E}_t\left(\pi_{t+1}\right) + g_t, \qquad \textbf{(12)}$$

$$\begin{aligned}\pi_t = &\frac{\beta}{1+\beta\gamma}\mathbb{E}_t\left(\pi_{t+1}\right) + \frac{\gamma}{1+\beta\gamma}\pi_{t-1} \\ &+ \frac{\left(1-\alpha\right)\left(1-\alpha\beta\right)}{\left(1+\beta\gamma\right)\alpha}\left[\frac{\chi-\left(\eta-1\right)}{\eta}x_t + \frac{\sigma^{-1}}{1-\phi}\left(x_t - \phi x_{t-1}\right)\right] + \mu_t, \qquad \textbf{(13)}\end{aligned}$$

$$i_t = \rho i_{t-1} + \left(1-\rho\right)\left(\pi_t^* + \chi_x x_t + \chi_\pi\left(\pi_t - \pi_t^*\right)\right) + \epsilon_t^m, \qquad \textbf{(14)}$$

where x_t denotes the output gap, π_t represents the inflation rate, i_t corresponds to the nominal interest rate, and π_t^* is the inflation target set by the central bank.[17]

Equation (12) describes a dynamic IS equation obtained from a linear approximation to households' optimal decision for both consumption and bond holdings, where the parameter σ denotes the intertemporal elasticity of substitution. The equation is obtained by assuming (external) habit formation in consumption, with the parameter ϕ characterizing the habits coefficient. Hence, the current output gap depends on both the expected future and lagged output gaps. The variable g_t in equation (12) is a function of potential output, y_t^*, which can be expressed as:

$$g_t = \frac{1}{1+\phi}\left[\left(y_{t+1}^* - \phi y_t^*\right) - \left(y_t^* - \phi y_{t-1}^*\right)\right]. \qquad \textbf{(15)}$$

Equation (13) is a New Keynesian Phillips curve which describes the inflation dynamics in the economy. It is derived from an economy with a continuum of monopolistically competitive firms, each facing a downward-sloping demand curve for its differentiated output. Prices are set with a Calvo-type rigidity where only a fraction (1-α) of firms are allowed to reoptimize their price in a given period. The firms that are not able to adjust their price optimally are assumed to update their price according to the previous quarters' aggregate inflation rate, with an indexation parameter γ. Additionally, habit formation also affects the Phillips curve, so that inflation does not only depend on the current output gap, x_t, but also the term $(x_t - \phi x_{t-1})$. Finally, the disturbance μ_t captures exogenous movement in the marginal cost of production.

Equation (14) specifies the monetary policy rule. The parameter ρ indicates the degree of monetary policy inertia. χ_x represents the central bank's response to the output gap, while χ_π characterizes the response to the deviation of inflation from the Fed's target. ϵ_t^m is the monetary shock which reflects the non-systematic part of monetary policy. The inflation target, π_t^*, is assumed to be constant in the baseline case but will be allowed to be time-varying later on. Furthermore, potential output, y_t^*, also depends on the technology a_t:

$$\left[\omega + \frac{1}{\sigma\,(1-\phi)}\right] y_t^* - (\omega + 1)\, a_t = \frac{\phi}{\sigma\,(1-\phi)} y_{t-1}^*, \tag{16}$$

where $\omega = \frac{\chi - (\eta - 1)}{\eta}$. Similar to Kurmann and Otrok (2014), I assume that the technology contains a transitory component, v_t, driven by the unanticipated technology shock and a more persistent component, d_t, driven by the news shock, ϵ_t^{news}. Specifically:

$$a_t = v_t + d_t, \tag{17}$$

$$v_t = \rho_v v_{t-1} + \sigma_v \epsilon_t^{current}, \tag{18}$$

$$(1 - \rho_{d0} L)\left(1 - \rho_{d1} L - \rho_{d2} L^2\right) d_t = c + \sigma_d \epsilon_{t-1}^{news}, \tag{19}$$

where L is the lag operator. Equations (17) to (19) represent a special case of the more general specification in equation (3) and are selected because they match the impulse responses of TFP to the unanticipated technology shock and the news shock in the SVAR model closely. To summarize, equations (12) to (19) consist of all the equations in the small-scale New Keynesian model which can be solved with the method proposed by Sims (2002).

4.2. Parameter Calibration and Estimation

The above model introduces the news shock into an otherwise standard New Keynesian model. As a result, all the parameters except for the news-shock-related parameters can be calibrated based on previous work in the literature. Table 2 reports the calibration of the structural parameters at a quarterly frequency where applicable. In the baseline model, the habit formation coefficient, ϕ, is calibrated to be 0.9 as estimated by Milani and Treadwell (2012) and Schmitt-Grohé and Uribe (2012). The higher habit formation coefficient likely reflects the fact that here habits need to capture the persistence of output in a model that abstracts from capital, investment, and a variety of adjustment costs that usually appear in a medium-sized DSGE model. The coefficient σ is assumed to be 5, so that the pseudo-intertemporal elasticity of substitution, $(1-\phi)\sigma$, equals 0.5. In line

TABLE 2. Parameter estimation and calibration.

Description	Parameter	Standard	Non-Ricardian
AR coefficient of trend in TFP	ρ_{d0}	0.54	0.54
AR coefficient of trend in TFP	ρ_{d1}	1.52	1.52
AR coefficient of trend in TFP	ρ_{d2}	-0.53	-0.53
Std. of the news shock	σ_d	0.08	0.08
Habit formation	ϕ	0.90	0.90
Intertemporal elasticity of substitution	σ	5	5
Households discount factor	β	0.99	0.99
Elasticity of substitution btw goods	θ	11	11
Price indexation	γ	0.35	0.35
Calvo coefficient	α	0.8	0.8
Labor share	η	1	1
Elasticity of labor supply	χ	0.6	0.6
MP inertia	ρ	0.72	0.72
MP inflation feedback	χ_π	1.5	0.3
MP output gap feedback	χ_x	0.3	0.3
Std. of the money shock	σ_m	0.12	0.12
Inflation target parameter	c_0	—	-17.88
Time-varying inflation target	c_1	—	43.05
Time-varying inflation target	c_2	—	-25.21
Inflation expectation	γ_π	—	-0.6

NOTES: The TFP parameters in the first four rows and the inflation parameters in the last four rows are estimated by impulse response matching. The rest of the parameters are calibrated to standard values in the DSGE literature.

with Milani and Treadwell (2012), the time preference parameter, β, is set to 0.99 implying a steady-state real interest rate of 4 percent per annum. The elasticity of substitution between the differentiated goods is fixed at 11, so that the steady-state markup $1/(\theta - 1) = 0.1$ which is consistent with the estimation in Basu and Fernald (1997). Similar to Christiano et al. (2005), the Calvo coefficient, α, is fixed at 0.8 which implies that the intermediate goods producer on average has to wait five quarters for a chance to reoptimize their prices. Following Milani and Treadwell (2012), the inflation indexation parameter, γ, is calibrated to 0.35, so that the Phillips curve is mostly forward-looking. In addition, the labor supply elasticity, χ, is pinned down as 0.6. Finally, I presume that the production function is constant returns to scale and accordingly the labor share $\eta = 1$.

The monetary policy coefficients are calibrated to standard values. The monetary policy inertia parameter, ρ, is calibrated to 0.72 which indicates a moderately persistent adjustment of the monetary policy. The inflation response coefficient, χ_π, is set to 1.5 while the output gap feedback coefficient, χ_x, is fixed at 0.3 based on the estimation in Milani and Treadwell (2012). As a result, the central bank is committed to fighting more aggressively against the inflation gap than the output gap, which satisfies the so-called Taylor principle and ensures the determinacy of the model. The standard deviation of the monetary shock is calibrated to 0.12, so that the contemporaneous response of the Federal Funds rate matches with the related response to the new SVAR monetary shock.[18]

Except for Kurmann and Otrok (2014), no previous study has identified the parameters in equation (19) which determines the effect of the news shock on technology. Hence, these parameters, included in vector $\theta_d = [\rho_{d0}, \rho_{d1}, \rho_{d2}, \sigma_d]$, are estimated to match the SVAR impulse response of TFP to the news shock. Specifically, the parameter vector, θ_d, is solved for by minimizing the distance between the impulse response of TFP to the news shock implied by equations (17) to (19), $\Psi(\theta_d)$, and the empirical counterpart from the SVAR, Ψ_{VAR}, for the entire 40-quarter horizon. Formally,

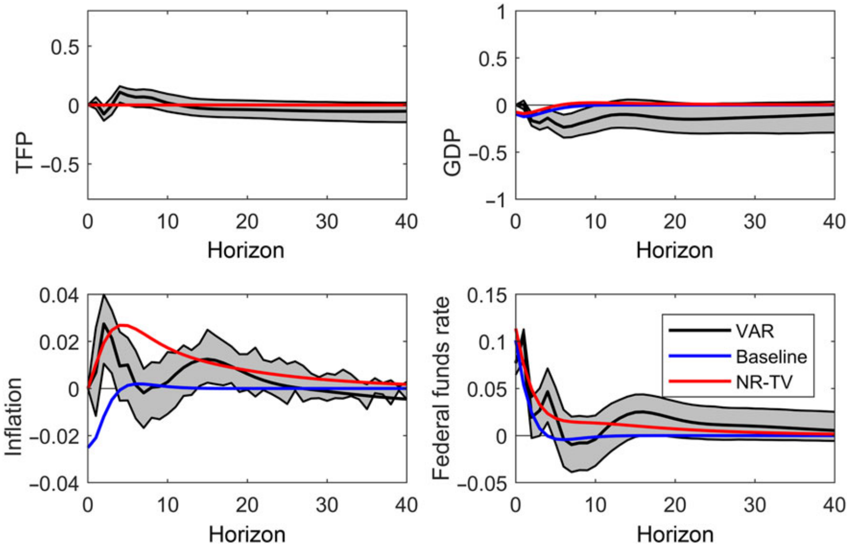
$$\theta_d^* = \arg\min_{\theta_d} \left[\Psi_{VAR} - \Psi(\theta_d)\right]' \hat{W}_\theta^{-1} \left[\Psi_{VAR} - \Psi(\theta_d)\right], \tag{20}$$

where the weighting matrix, $\hat{W}_\theta$, is a diagonal matrix with the bootstrapping sample variance of the empirical impulse response Ψ_{VAR}, constructed by the method developed in Kilian (1998), along the diagonal. The estimated value of the standard deviation of the news shock is $\sigma_d = 0.08$ which is close to that estimated in Kurmann and Otrok (2014). Moreover, $\rho_{d0} = 0.54$, $\rho_{d1} = 1.52$, and $\rho_{d2} = -0.53$ which implies that the model-implied response of TFP to a news shock is very persistent. The half-life of the TFP response starting from the maximum is 44 quarters. With this parameter estimation, the theoretical response of TFP to the news shock matches with the corresponding SVAR response closely.

4.3. Results of the Baseline New Keynesian Model

Figure 7 documents the theoretical impulse responses to the monetary shock implied by the baseline model in blue lines. To facilitate comparison, I plot the SVAR impulse responses in black lines, with the shaded gray areas representing the associated 1 standard deviation confidence bands from the bias-corrected bootstrap procedure of Kilian (1998). The DSGE monetary shock exerts no effect on the technology, which lies well inside the narrow confidence band. This is because both the DSGE model and the SVAR model assume exogenous technology process. Moreover, the DSGE model predicts a transient decrease in output and a temporary increase in the Federal Funds rate, both of which replicate the SVAR responses fairly well. Nevertheless, the baseline model fails to match the empirical inflation response that is calculated by the growth rate of the price impulse responses of the SVAR model. Instead of a hump-shaped rise in the inflation rate, the theoretical model predicts that the inflation rate would decrease significantly on impact and stay negative for more than five quarters after the initial monetary shock.

Figure 8 reports the impulse responses to the TFP news shock which predicts that the technology will be permanently higher. As in Figure 7, the blue lines depict the impulse responses generated by the baseline model, which shows that the performance of the theoretical model in replicating the effects of the SVAR news shock is mixed. On the one hand, the dynamics of TFP and output are properly replicated, both of which exhibit a hump-shaped pattern and stay in the



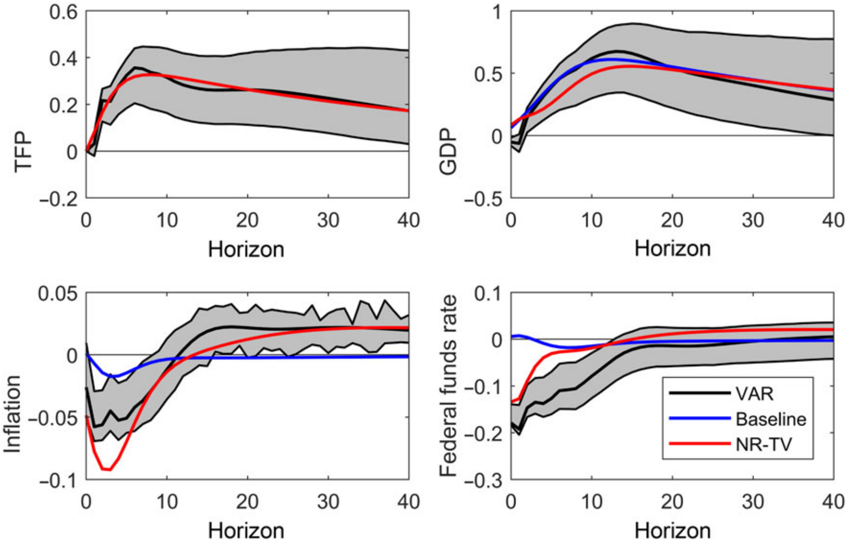
Note: VAR: the empirical impulse responses to the new monetary shock; baseline: the impulse responses to the monetary shock implied by the baseline DSGE model; NR-TV: the impulse responses to the monetary shock implied by the DSGE model augmented with time-varying inflation target under non-Ricardian regime. The shaded area plots the 68% confidence band of the empirical SVAR impulse responses estimated by the method of Kilian (1998).

FIGURE 7. Response to the monetary shock from the DSGE model

central areas of the confidence bands. On the other hand, the model matches the empirical responses of the inflation rate and the Federal Funds rate poorly. Both the inflation rate and the Federal Funds rate respond little on impact and react with much smaller magnitude than the corresponding SVAR responses at all horizons. As a result, it fails to generate the significant contemporaneous decrease in the real interest rate to the news shock as in the SVAR responses where the nominal interest rate plummets more sharply than the inflation rate.

4.4. Discussion

It is not surprising that the standard New Keynesian model has difficulty in matching all the SVAR responses to the new identification scheme, given that several of the impulse responses based on the new identification are substantially different from the traditional identification. Nevertheless, observing the gap between the SVAR responses and the standard New Keynesian model's implied responses provides some useful insights. To match the SVAR responses and thus evaluate the factors underlying the empirical results, it is essential to reexamine the determination of the price level under the standard New Keynesian framework and explore additional channels to amplify the systematic monetary policy response to the news shock.



Note: VAR: the empirical impulse responses to the TFP news shock; baseline: the impulse responses to the TFP news shock implied by the baseline DSGE model; NR-TV: the impulse responses to the TFP news shock implied by the DSGE model augmented with time-varying inflation target under the non-Ricardian regime. The shaded area plots the 68% confidence band associated with the empirical SVAR impulse responses estimated by the method of Kilian (1998).

FIGURE 8. Response to the TFP news shock from the DSGE model

Standard New Keynesian models assume that the monetary authority takes an "active" monetary policy which provides the "nominal anchor" by systematically raising the policy rate more than one-for-one with inflation. This active monetary policy induces a unique non-explosive inflation path where the price level jumps to the equilibrium level when a monetary shock occurs. Fiscal policy adjusts "passively" to the monetary shock which provides an aggressive "backing" to ensure that the government budget constraint holds for any equilibrium price path. The combination of active monetary policy and passive fiscal policy implies that the inflation rate responds to the monetary policy shock but not to the other shocks immediately. On the one hand, the assumption is inconsistent with the SVAR assumption that the price level responds to the monetary policy shock with a lag. On the other hand, it does not allow the news shock to induce an immediate response in the inflation rate as in the SVAR model. As a result, I consider an alternative policy coordination in determining the price level, which assumes that fiscal policy is implemented "actively" and determines the equilibrium price level, while monetary policy adjusts "passively" to support the equilibrium path. The combination of an active fiscal policy and a passive monetary policy is known as the "non-Ricardian regime" in the literature of the fiscal theory of price level determination [e.g. Leeper (1991), Sims (2011), and Cochrane (2018*b*)].

The "non-Ricardian regime" assumption, as illustrated in the appendix, does not require the monetary policy reacts aggressively to the inflation movements as suggested by the Taylor principle ($\chi_\pi > 1$). It implies that unexpected inflation is entirely determined by changing expectations about the future discounted primary surpluses. When assuming away the fiscal backing of the monetary policy as in Cochrane (2014), the primary surpluses, a proxy for the fiscal stance defined as the tax revenue minus the government expenditure excluding interest payments, do not respond to the monetary shock.[19] As such, the monetary shock exerts no contemporaneous effect on the inflation rate dynamics. Unlike the monetary shock, the positive technology shock can raise the tax revenue through expanding the tax base. The positive TFP news shock would raise the expectation of discounted future primary surpluses and thus results in an unexpected deflation. Motivated by this idea, I assume that the unexpected inflation conditional on the monetary shock and the news shock is linearly related to the TFP news shock as follows:

$$\mathbb{E}\left(\pi_t|\Omega_{t-1}, \epsilon_t^m, \epsilon_t^{news}\right) - \mathbb{E}\left(\pi_t|\Omega_{t-1}\right) = \gamma_\pi \sigma_d \epsilon_t^{news}, \tag{21}$$

where γ_π is negative, σ_d is the standard deviation of the news shock, and Ω_{t-1} represents the information available at period $t-1$. Equation (21) indicates that the inflation rate responds to the news shock on impact but reacts to the monetary shock with a lag. This is consistent with my identification strategy in the SVAR model. It is worth noting that equation (21) also allows other shocks, such as price shocks and output shocks, to contribute to unexpected inflation as well. However, we focus on the news shock and the monetary shock only in the discussion. As a result, I deviate from the standard New Keynesian model by deviating from the Taylor principle and include equation (21) in the model.

In addition, I also follow Ireland (2007) and augment the monetary policy rule with an endogenous time-varying inflation target which allows the central bank to systematically adjust its inflation target in response to the expectation of current and future technology movements. The endogenous inflation target amplifies the systematic monetary policy response to the news shock which could help match the significant and persistent empirical interest response to the news shock seen in the empirical analysis but is missing from a standard New Keynesian model.[20] As argued in Ireland (2007), the idea of relating the central bank's inflation target to the technology factors is a way to formalize the narratives of Blinder (1982), Hetzel (1998), and Mayer (1999) which all attribute the upward secular trend in inflation prior to the 1980s to a systematic tendency for monetary policy to translate the short-run price pressures set off by adverse supply shocks into more persistent movements in inflation itself. This represents part of an effort by policymakers to avoid at least some of the contractionary impacts those shocks would otherwise have had on the real economy. The idea is also in line with Bomfim and Rudebusch (2000) and Orphanides and Wilcox (2002) which suggest that the Fed took advantage of favorable supply-side disturbances in the post-1980 period to "opportunistically" work the inflation rate back down. In particular, I assume that

$$\pi_t^* = c_0 a_t + c_1 \mathbb{E}_t\left(a_{t+1}\right) + c_2 \mathbb{E}_t\left(a_{t+2}\right) + \epsilon_t^{\pi^*}, \tag{22}$$

where a_t is TFP and $\epsilon_t^{\pi^*}$ represents the non-technology determinants of the inflation target. Equation (22) allows the central bank to set the inflation target according to its expectation of future technological progress in the next two quarters, while at the same time preserves the parsimony of the model formulation.

I estimate the new parameters, γ_π, c_0, c_1, c_2, in equations (21) and (22), by matching the model-implied impulse responses with the corresponding SVAR impulse responses using equation (20). To be comparable to the baseline model, I set all the other parameters in the model to the same values as the baseline model.[21] Table 2 lists the estimation results of these parameters. The estimated unexpected inflation parameter $\gamma_\pi = -0.6$, so that the positive news shock lowers the unexpected inflation rate, which is consistent with the prediction by the government valuation equation under the non-Ricardian regime. The time-varying inflation target coefficients are $c_0 = -17.88$, $c_1 = 43.05$, and $c_2 = -25.21$, which when summed are equal to -0.04. The negative value of the summation $\Sigma_{i=0}^{2} c_i$ implies that the monetary authority would lower its long-run inflation target if TFP permanently increased. This is consistent with Blinder (1982), Hetzel (1998) and Mayer (1999) as well as the "opportunistic disinflation" argument by Bomfim and Rudebusch (2000) and Orphanides and Wilcox (2002) mentioned above. Furthermore, as demonstrated in Leeper (1991), unlike the baseline model, monetary policy responds to inflation fluctuations less aggressively under the non-Ricardian regime, so that the inflation feedback parameter χ_π in the monetary policy rule has to be smaller than 1. By assuming that the central bank places equal emphasis on the output gap and the inflation gap, I recalibrate the inflation feedback parameter χ_π as $\chi_\pi = \chi_x = 0.3$ which guarantees the determinacy of the model.

The red lines (labeled "NR-TV") in Figure 7 depict the impulse responses to the monetary shock in the standard three-equation model augmented with a time-varying inflation target under the non-Ricardian regime. On the one hand, the empirical impulse responses of TFP and output are well replicated by the theoretical model as in the baseline case. On the other hand, the fit of the impulse responses of the inflation rate and the interest rate are significantly improved compared to the baseline model. Under the non-Ricardian regime, the inflation rate rises to the monetary shock in a hump-shaped pattern which nicely captures the shape of the corresponding SVAR response. With the same degree of monetary policy inertia, the interest rate responds to the monetary shock more persistently, which matches the empirical response of the interest rate more closely than the baseline model. This slower reversion of the policy rate arises mainly because the Fed is not under the deflationary pressure caused by the contractionary monetary shock under the non-Ricardian regime.

Figure 8 displays the theoretical impulse responses to the favorable TFP news shock in red lines (labeled "NR-TV"). The responses of TFP and output stay in the middle of the shaded area and match the SVAR responses closely as in the baseline case. The inflation rate falls immediately following the news shock and exhibits a downward hump-shaped pattern as in the empirical responses. It tracks the empirical responses closely at horizons except for a very short run where it overshoots the empirical response. Furthermore, the Federal Funds rate drops sharply on impact as a result of the decline in the inflation target following the news shock. The contemporaneous decrease in the nominal interest rate exceeds the immediate fall in the inflation rate, so that the real interest rate decreases in response to the news shock as implied by the SVAR model. The theoretical response of the policy rate moves along the upper limit of the 68% confidence interval for the first eight quarters and then stays in the middle of the shaded area thereafter.

In summary, all the empirical responses can be largely replicated by the three-equation New Keynesian model augmented with a time-varying inflation target under the non-Ricardian regime. In Appendix C, I also separately evaluate the contribution of each of the two mechanisms by considering models which augment the baseline model either with solely the time-varying inflation target or with only the non-Ricardian regime. I find that both the time-varying inflation target and the non-Ricardian regime are essential in fitting the interest rate response to the news shock. In addition, the Fisherian effect of the monetary shock is solely due to the non-Ricardian regime. Nevertheless, there are two relevant points that deserve mentioning. First, I only focus on exploring the effects of the news shock and the monetary shock in both the empirical SVAR model and the DSGE model. The effects of other shocks are beyond the discussion of this paper. In particular, although I discuss the non-Ricardian regime in this section, I do not either include a fiscal variable in my SVAR model as many other papers in the monetary SVAR literature or explicitly model the behaviour of fiscal policy as in most New Keynesian DSGE models. The purpose of introducing the non-Ricardian regime is to motivate equation (21) which provides an alternative way to determine the price level in the spirit of Cochrane (2011) and is more consistent with the SVAR findings. I leave the study of the fiscal variables and the fiscal shocks for future research. Second, the purpose of introducing the theoretical model in this section is to show that it is possible to generate similar impulse responses as the empirical SVAR impulse responses with a DSGE model. However, there can be other explanations for the novel empirical evidence in this paper, which opens a promising avenue for future studies.

5. CONCLUSION

A central question of monetary economics is measuring the effects of the monetary policy. Quantifying the effects, however, requires disentangling endogenous and exogenous changes in the policy instrument. The traditional approach to identify and estimate the effects of monetary policy shocks maintains a recursive causal assumption with the policy rate ordered after output and price. This paper challenges the conventional wisdom by arguing that the traditional monetary shock has been confounded with the news component of technology. I design a novel identification strategy that effectively "cleans" the news component from the traditional monetary shock. With the new method, I find that most of the shifts in the stance of monetary policy are contributed by the Fed's systematic responses to the current and expected future economic activities rather than the purely exogenous monetary policy shock as suggested by the traditional monetary SVAR models. Furthermore, the new monetary shock has smaller and less persistent effects on output and inflation.

Economists have long observed that shifts in monetary policy stance are followed by significant and persistent fluctuations in output and inflation. With the recursive causal identification strategy which fails to sufficiently capture the central bank's systematic responses to the technology news shock, the traditional identification approach concludes that these macroeconomic fluctuations are mostly caused by the unanticipated monetary shock. The new identification strategy developed in this paper argues that it is the TFP news shocks that are responsible for both the shifts in monetary policy stance and the subsequent macroeconomic fluctuations.

Finally, this paper shows that the contractionary monetary shock induces a Fisherian effect which raises the inflation rate in a hump-shaped pattern similar to Uribe (2018), while the interest rate and the inflation rate decrease in response to a positive news shock. In an attempt to provide an economic explanation for these documented empirical results, I construct a DSGE model which augments the standard New Keynesian model with a time-varying inflation target and a non-Ricardian fiscal regime. With the DSGE model, I find that the non-Ricardian regime, which assumes away fiscal backing to monetary policy, is essential to explain the Fisherian effect of monetary policy. On the other hand, allowing the Fed's inflation target to respond to the expectation of future technology provides a systematic monetary policy channel for amplifying the effects of the TFP news shock, which is essential in replicating the effects of the TFP news shock predicted by the SVAR model.

There are some directions for future research. The current paper takes the first step to disentangle the unanticipated monetary shock from the endogenous response of monetary policy to the TFP news shock. Recent studies also highlight the importance of other news shocks identified with the maximum forecast error variance decomposition approach in the spirit of Barsky and Sims (2011), such as the risk news shock [Pinter et al. (2013)], the fiscal news shock (Ben Zeev and Pappa (2017)), the monetary news shock [Kapinos (2011) and Ben Zeev et al. (2020)], and the investment-specific news shock [Ben Zeev and Khan (2015) and Ma (2018)]. The approach proposed in this paper provides a way to combine the zero restriction method with the maximum forecast error variance decomposition approach. As a result, it can potentially be generalized to identify the unanticipated monetary shock (or other structural shocks) to be independent of multiple news shocks, which is left for future research.

NOTES

1. See e.g. Christiano et al. (1999), Romer and Romer (2004), Bernanke et al. (2005), Uhlig (2005), Antolín-Díaz and Rubio-Ramírez (2018), An et al. (2020) and Balke et al. (*inpress*).

2. See e.g. Jaimovich and Rebelo (2009), Beaudry and Lucke (2010), Barsky and Sims (2011), Schmitt-Grohé and Uribe (2012), Blanchard et al. (2013), Kurmann and Otrok (2013), Nam and Wang (2015), Forni et al. (2017) and Pinter (2018).

3. This paper will use "TFP news shock" and "anticipated TFP shock" interchangeably.

4. There are also other approaches available to identify the monetary shock in the SVAR literature, such as the sign restriction method, the long-run restriction method, the narrative method, and so forth. However, rather than exploring all the existing identification strategies, this paper solely focuses on the most widely used identification approach which assumes a recursive causal relationship among shocks, where the shocks ordered later can only affect the variables before them with a lag. I will refer to the monetary shock identified by the recursive causal assumption as the traditional monetary shock in this paper.

5. The SVAR specification that I consider in this paper is fairly standard and is similar to Bernanke et al. (1997), Kurmann and Otrok (2013) and Pinter (2018) among others.

6. The TFP series is estimated following the method in Fernald (2014) and are available at the Federal Reserve Bank of San Francisco (https://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tfp/).

7. The Fisherian effect is different from the "price puzzle." The latter implies that the inflation rate only rises in the very short run but would decrease later on.

8. I deviate from Bernanke et al. (1997) by replacing the oil price in their paper with the TFP series, since my focus is more on the technology shock than the oil price shock.

9. By estimating a VAR model in levels, I assume that the nonstationary variables such as the price level and the GDP level are of the same order of integration, which is supported by the augmented Dickey–Fuller test. This is also the reason that I include the price level instead of the inflation rate in my VAR model.

10. Barsky and Sims (2011) order the news shock second. The position of the news shock does not matter for its identification. I order the news shock last to make it more convenient to introduce the new identification approach of the monetary shock in the next subsection.

11. An alternative way to impose general zero restrictions is by the QR decomposition method described in Rubio-Ramirez et al. (2010). However, it is not straightforward to combine the QR decomposition method with the approach that identifies the news shock by maximizing the forecast error variance decomposition.

12. AIC suggests three lags. However, the AIC for the model with four lags is only slightly higher than its counterpart with three lags. Here, I follow the traditional VAR literature and employ a lag length of 1 year. However, all the results are robust for different specification of lag structures.

13. The confidence intervals of the impulse responses are standard but omitted here to facilitate comparison of the impulse responses to the three shocks in the same figure. I will display the confidence intervals of the impulse responses to the new monetary shock and the TFP news shock in Figures 7 and 8 when comparing the VAR responses with the DSGE responses. The confidence intervals of the impulse responses to the traditional monetary shock are similar to those of the TFP news shock and are available upon request.

14. Similar results can be found in other works like Christiano et al. (1999).

15. I thank Dr. Matthias Meier for generously sharing their markup dispersion data with me.

16. Kurmann and Otrok (2014) show that a DSGE model with nominal rigidities and a standard parametrization along the lines of Smets and Wouters (2007) is unable to replicate the VAR responses to the TFP news shock. As a result, this paper pursues alternative deviations from standard DSGE models.

17. Similar New Keynesian models can be found in Woodford (2003), Milani and Treadwell (2012), Zhang et al. (*inpress*) among others. The full description of the economy underlying the DSGE model is available in Appendix A.

18. The interest rate data used in the SVAR model are the annualized Federal Funds rate. However, the DSGE model is designed to be quarterly. As a result, the interest rate response of the SVAR model is divided by 4 to be comparable with the corresponding interest rate response of the DSGE model.

19. The primary surpluses is a proxy for the fiscal policy, which is defined as the tax revenue minus the government expenditure excluding interest payments. Appendix B demonstrates this point with the government debt valuation equation under a frictionless model where the real interest rate is constant. In New Keynesian models, the real interest rate changes when monetary policy changes which will have a discount rate effect on the present value of government debt. To avoid the extra complexity of taking account of such an effect, I follow Cochrane (2014) and implicitly assume that the monetary policy shock leads to slight fiscal backing which cancels out the discount rate effect.

20. See Christiano et al. (2010) and Kurmann and Otrok (2014) among others.

21. Using impulse response matching to estimate the parameters will help match the inflation and interest rate responses to the news shock but not the other impulse responses. In particular, the estimation of the inflation target parameters, c_0, c_1, and c_2, does not affect the effect of the TFP news shock on TFP, which is governed by the parameter vector θ_d estimated by equation (20).

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APPENDIX A: DSGE MODEL

This section outlines the model economy underlying the three equations, which consists of representative households, representative finished-goods-producing firms, and a continuum of intermediate-goods-producing firms indexed by $i \in [0, 1]$.

A.1. Representative Household

Each household solves the following optimization problem:

$$\underset{C,L,B}{\text{Max}} \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t - \phi C_{t-1})^{1-\sigma^{-1}}}{1-\sigma^{-1}} - \frac{L_t^{1+\chi}}{1+\chi} \right], \tag{A1}$$

subject to the period budget constraint:

$$C_t + \frac{B_t}{P_t} = W_t L_t + \frac{(1+R_{t-1})\, B_{t-1}}{P_t} + \frac{D_t}{P_t} - T_t. \tag{A2}$$

Each household acquires utility from consumption C_t and disutility from hours of labor supplied L_t. The utility function is characterized by external habit formation where the degree of habit formation is measured by the parameter ϕ. The coefficient β means the discount factor, σ and χ are the elasticities of intertemporal substitution and of labor supply. Expected discounted lifetime utility is maximized subject to the budget constraint (A2) where B_t denotes nominal bond holdings, P_t denotes the aggregate price level, W_t the nominal wage, R_t the nominal interest rate, D_t the dividend from household-owned firms, and T_t the net transfers.

A.2. Final-Goods-Producing Firm

The final good producers maximize profits by solving:

$$\underset{y_{i,t}}{\text{Max}}\ P_t y_t - \int_0^1 P_{i,t} y_{i,t} di, \tag{A3}$$

subject to the constraint:

$$y_t = \left(\int_1^0 y_{i,t}^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}, \tag{A4}$$

where equation (A4) implies that the final good is a constant elasticity of substitution (CES) aggregate of the intermediate goods $y_{i,t}$ and θ is the elasticity of substitution between intermediate goods. By solving the final producers' problem, a downward-sloping demand curve for each intermediate good can be derived as expressed in equation (A5):

$$y_{i,t} = \left(\frac{p_{i,t}}{p_t}\right)^{-\theta} y_t. \tag{A5}$$

A.3. Intermediate-Goods-Producing Firm

The intermediate goods sector is characterized by a continuum of monopolistically competitive firms. Prices are sticky and determined by the Calvo pricing model: each firm has a probability of $(1-\alpha)$ to reoptimize its price each period. Those firms who are not allowed to optimize use the indexation rule suggested by Christiano et al. (2005):

$$log\left(p_{i,t}\right) = log\left(p_{i,t-1}\right) + \gamma\pi_{t-1}, \tag{A6}$$

where γ gauges the degree of indexation to past inflation. Based on the pricing assumption above, the intermediate producers' demand function would be

$$y_{i,t} = \left[\left(\frac{p_{i,t}}{P_{t+\tau}}\right)\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\gamma}\right]^{-\theta} Y_{t+\tau}. \tag{A7}$$

Moreover, the production function of the intermediate goods is assumed as $y_{i,t} = A_t\left(L_t^i\right)^{\eta}$ where A_t denotes the TFP level and η accounts for diminishing returns to scale. Accordingly, the intermediate goods producers solve the problem below:

$$\begin{aligned}\underset{p_t^*}{\text{Max}}\ \mathbb{E}_t \sum_{\tau=0}^{\infty} \frac{(\alpha\beta)^{\tau}\lambda_{t+\tau}}{\lambda_t} &\left\{ p_t^*\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\gamma}\left[\frac{p_t^*}{P_{t+\tau}}\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\gamma}\right]^{-\theta} Y_{t+\tau}\right. \\ &\left. - W_{t+\tau}\left[\left(\frac{p_t^*}{P_{t+\tau}}\left(\frac{P_{t+\tau-1}}{P_{t-1}}\right)^{\gamma}\right)^{-\theta}\frac{Y_{t+\tau}}{A_{t+\tau}})\right]^{\frac{1}{\eta}}\right\},\end{aligned} \tag{A8}$$

where p_t^* denotes the optimal price to be chosen and λ_t indicates the shadow price of the households' optimization problem.

A.4. Monetary Policy Rule

The central bank conducts monetary policy following the modified Taylor rule:

$$i_t - \pi_t^* = \rho\left(i_{t-1} - \pi_{t-1}^*\right) + (1-\rho)\left[\chi_{\pi}\left(\pi_t - \pi_t^*\right) + \chi_x x_t\right] + \epsilon_t^m, \tag{A9}$$

$$\pi_t^* = c_0 a_t + c_1\mathbb{E}_t\left(a_{t+1}\right) + c_2\mathbb{E}_t\left(a_{t+2}\right) + \epsilon_t^{\pi^*}, \tag{A10}$$

$$m_t = \rho_m m_{t-1} + \epsilon_t^m, \tag{A11}$$

according to which it raises or lowers the nominal interest rate in response to the output gap x_t, the inflation target π_t^*, and the deviation of current inflation from the inflation target $\pi_t - \pi_t^*$. The monetary policy rule is assumed to be persistent, where the degree of monetary inertia is measured by the parameter ρ. Finally, I assume that the inflation target that the monetary policy set reacts to the current and expected future technology as expressed in (A10).

APPENDIX B: PRICE DETERMINATION UNDER NON-RICARDIAN REGIME

The key equation that determines the equilibrium path of the price level under the non-Ricardian regime is the government debt valuation equation which is derived from the household's optimization problem in a frictionless model.[22] The equation states that the real value of the government liability equals the present value of the primary surpluses that will pay off the liability:

$$\frac{B_{t-1}}{P_t} = \mathbb{E}_t\left(\sum_{j=0}^{\infty}\beta^j S_{t+j}\right), \tag{B1}$$

where B_{t-1} refers to the nominal bond sales at the beginning of period t, the real primary surpluses, S_t, measures the fiscal policy stance which equals the tax revenue T_t minus the government expenditure excluding interest payment G_t, P_t denotes the price level, and $\beta = 1/(1+r)$ is a constant real interest rate. Given that the level of bond holding B_{t-1} is predetermined, equation (B1) implies that the price level is determined by the current primary surpluses, S_t, and the expectation of future primary surpluses, $\mathbb{E}_t\left(S_{t+j}\right)$: when $\mathbb{E}_t\left(\sum_{j=0}^{\infty}\beta^j S_{t+j}\right)$ increases, the price level P_t falls. To explore how the primary surpluses affects the unexpected inflation, I transform equation (B1) into:

$$\frac{B_{t-1}}{P_{t-1}}\left(\mathbb{E}_t - \mathbb{E}_{t-1}\right)\left(\frac{P_{t-1}}{P_t}\right) = \left(\mathbb{E}_t - \mathbb{E}_{t-1}\right)\sum_{j=0}^{\infty}\beta^j S_{t+j}, \tag{B2}$$

where B_{t-1} is predetermined, $\left(\mathbb{E}_t - \mathbb{E}_{t-1}\right)\left(\frac{P_{t-1}}{P_t}\right)$ represents the inverse of the unexpected inflation rate, and $\left(\mathbb{E}_t - \mathbb{E}_{t-1}\right)\left(S_{t+j}\right)$ is affected by news about future primary surpluses when $j > 1$.

Equation (B2) indicates that unexpected inflation is negatively related to the expectation change to the path of the primary surpluses. This equation holds under both the Ricardian policy coordination, as assumed in the standard New Keynesian model, and the non-Ricardian policy coordination studied in the fiscal theory of price level determination literature. The main ingredient that distinguishes between the two types of policy coordination is what drives the movements in primary surpluses. The Ricardian policy coordination assumes that the primary surpluses are endogenously determined by the monetary policy. In other words, the fiscal policy, proxied by the primary surpluses S_t, provides backing to the monetary policy. As a result, the monetary policy shock determines unexpected inflation through its effects on the primary surpluses. The non-Ricardian policy coordination assumes that the primary surpluses are exogenous to the monetary policy. As a result, the unexpected inflation rate is unresponsive to the monetary shock, since the primary surpluses do not respond to the monetary shock. We can formalize this idea by the following equation:

$$\mathbb{E}\left(\pi_t|\Omega_{t-1}, \epsilon_t^m\right) - \mathbb{E}\left(\pi_t|\Omega_{t-1}\right) = 0., \tag{B3}$$

where Ω denotes the information set that the economic agents have. In fact, equation (B3) is consistent with the zero restrictions that are usually imposed in SVAR models: the monetary shock does not have any contemporaneous effect on the inflation rate.

In this paper, I assume non-Ricardian policy coordination where the primary surpluses are exogenous to the monetary shock. Moreover, I highlight that the state of technology which boosts the output level should raise the total tax revenue. As a result, a positive TFP news shock which raises the expectation of future technology would lift up the the expectation of future primary surpluses $(\mathbb{E}_t - \mathbb{E}_{t-1})\left(S_{t+j}\right)$. The rise in $(\mathbb{E}_t - \mathbb{E}_{t-1})\left(S_{t+j}\right)$ would decrease the unexpected inflation $\pi_t - \mathbb{E}_{t-1}\left(\pi_t\right)$ as predicted by equation (B2). Based on the discussion above, I assume that:

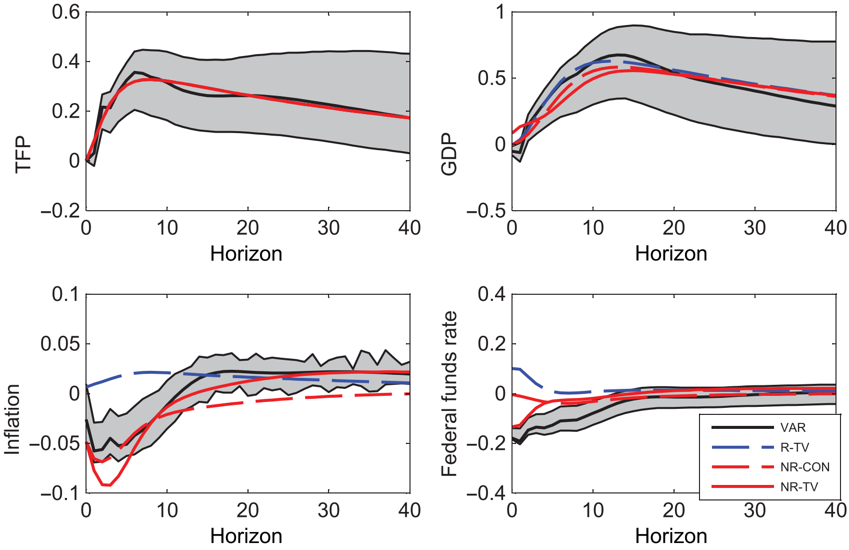
$$\mathbb{E}(\pi_t|\Omega_{t-1}, \epsilon_t^m, \epsilon_t^{news}) - \mathbb{E}(\pi_t|\Omega_{t-1}) = \gamma_\pi \sigma_d \epsilon_t^{news}. \quad \textbf{(B4)}$$

APPENDIX C: TIME-VARYING INFLATION TARGET AND NON-RICARDIAN REGIME

In the paper, I show that the time-varying inflation target and the non-Ricardian regime are helpful in replicating the empirical responses. To separately evaluate the contribution of each of these two mechanisms, in this subsection, I consider models which augment the baseline model either with solely the time-varying inflation target or with only the non-Ricardian regime. With parameters calibrated to the same values as before, Figure C1 and C2 display the impulse responses, respectively, to the news shock and the monetary shock by these models. Specifically, the blue dashed lines plot the results by the model with the time-varying inflation target under the Ricardian regime (labeled “R-TV”); the red dashed lines display the impulse responses by the model with constant inflation target under the non-Ricardian regime (labeled “NR-CON”); and the red solid lines represent the outcome by the model with time-varying inflation target under the non-Ricardian regime (labeled “NR-TV”). By comparing the dashed lines with the red solid lines, there are two points to highlight.

First, the time-varying inflation target alone is not sufficient for the standard model to match the interest rate response to the news shock. The red dashed lines (labeled “NR-CON”) in Figure C1 show that with a constant inflation target, unlike the NR-TV model, the NR-CON model is not able to generate the significant contemporaneous decrease in the interest rate response to the news shock. This verifies that the time-varying inflation target provides an essential channel for amplifying the systematic monetary policy response to the news shock. Nevertheless, the endogenous inflation target alone is insufficient to replicate the systematic monetary policy rate response to the news shock either. As depicted by the blue dashed lines (labeled “R-TV”) in Figure C2, the interest rate rises, instead of decreases, to the news shock in the Ricardian regime model with the time-varying inflation target. This is because the inflation feedback coefficient in the monetary policy rule $\chi_\pi > 1$ under the Ricardian regime, so that the lower inflation target caused by the positive news shock induces the central bank to raise the policy rate. Therefore, both the time-varying inflation target and the non-Ricardian regime are essential in fitting the interest rate response to the news shock.

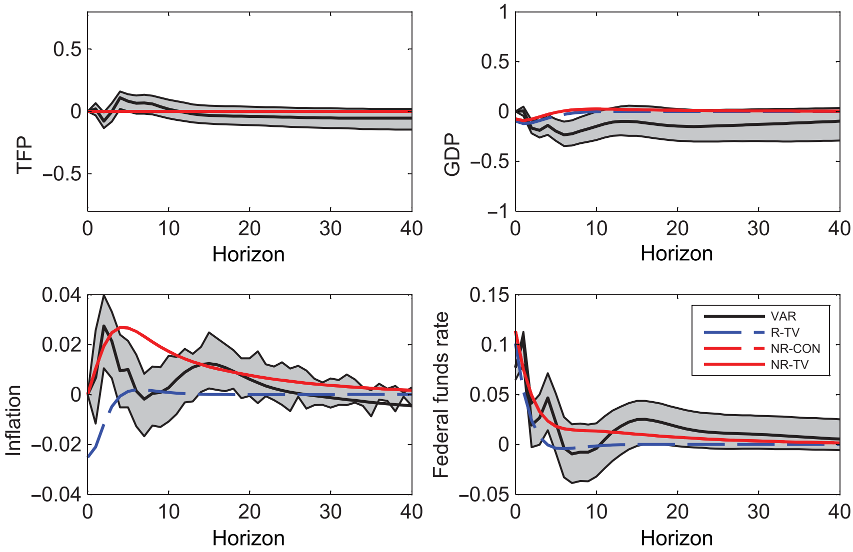
Second, the Fisherian effect of the monetary shock is solely due to the non-Ricardian regime. The blue dashed lines (labeled “R-TV”) in Figure C2 show that under the Ricardian regime, the monetary shock induces a significant fall in the inflation rate on impact which



Note: VAR: the empirical impulse responses to the TFP news shock; R-TV: the impulse responses to the TFP news shock implied by the DSGE model augmented with time-varying inflation target under the Ricardian regime; NR-CON: the impulse responses to the TFP news shock implied by the DSGE model with constant inflation target under the non-Ricardian regime; NR-TV: the impulse responses to the TFP news shock implied by the DSGE model augmented with time-varying inflation target under the non-Ricardian regime. The shaded area plots the 68% confidence band of the empirical SVAR impulse responses estimated by the method of Kilian (1998).

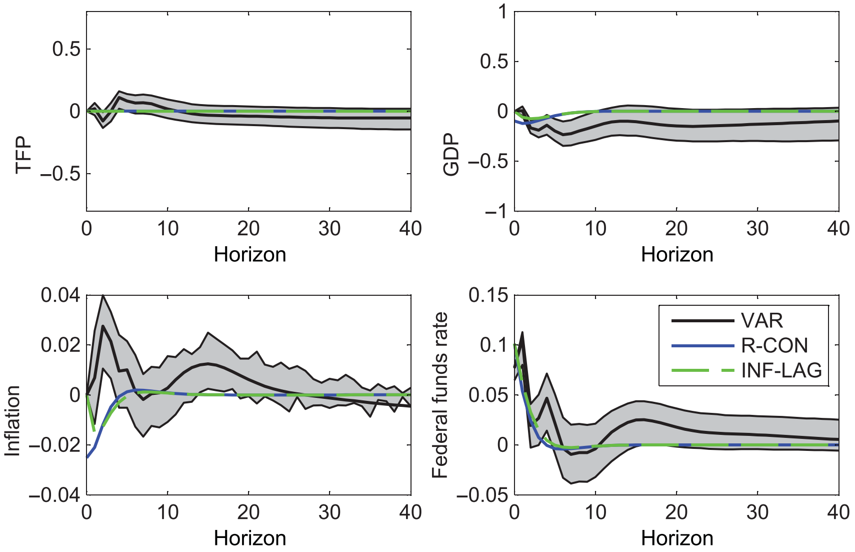
FIGURE C1. Response to the TFP news shock, sensitivity analysis

reverts to zero in the sixth quarter even with the time-varying inflation target. This fails to match the empirical inflation response. However, the R-TV inflation response to the monetary shock is almost parallel with the corresponding SVAR response in the first five quarters. Thus, it is worthwhile to explore whether it is the initial fall in the inflation response that makes it difficult for the Ricardian regime model to replicate the inflation response. To assess the validity of this argument, I consider a way to impose the zero restrictions on the monetary shock in the baseline model by assuming an information lag following Christiano et al. (2005). In particular, I assume that consumption and prices in the theoretical model are decided before the realization of the monetary shock, so that the inflation rate and the output gap do not respond contemporaneously to the monetary shock. The green lines (labeled “INF-LAG”) in Figure C3 depict the impulse responses to the monetary shock in the Ricardian regime model with an information lag. Even with zero restrictions imposed on the monetary shock as in Christiano et al. (2005), the inflation rate still decreases with respect to the monetary shock in a downward, instead of upward, hump-shaped pattern in the Ricardian model. Therefore, the non-Ricardian regime is essential for the standard three-equation model to replicate the inflation response to a monetary shock.



Note: VAR: the empirical impulse responses to the monetary shock; R-TV: the impulse responses to the monetary shock implied by the DSGE model augmented with time-varying inflation target under the Ricardian regime; NR-CON: the impulse responses to the monetary shock implied by the DSGE model with constant inflation target under the Non-Ricardian regime ; NR-TV: the impulse responses to the monetary shock implied by the DSGE model augmented with time-varying inflation target under the Non-Ricardian regime. The shaded area plots the 68% confidence band of the empirical SVAR impulse responses estimated by the method of Kilian (1998).

FIGURE C2. Response to the monetary shock, sensitivity analysis



Note: VAR: the empirical impulse responses to the monetary shock; NR-CON: the impulse responses to the monetary shock implied by the baseline DSGE model with constant inflation target under the Non-Ricardian regime ; INF-LAG: the impulse responses to the monetary shock implied by the DSGE model assuming that the monetary policy takes effects with an information lag. The shaded area plots the 68% confidence band of the empirical SVAR impulse responses estimated by the method of Kilian (1998).

FIGURE C3. Response to the monetary shock: information lag