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ARTICLE

Monetary policy and economic fluctuations†

Cosmas Dery[1] and Apostolos Serletis[2]

[1]Department of Economics and International Business, Sam Houston State University, Huntsville, TX, USA
[2]Department of Economics, University of Calgary, Calgary, AB, Canada
Corresponding author: Apostolos Serletis; Email: Serletis@ucalgary.ca

Abstract

We assess the responses of output and inflation to monetary policy shocks in the context of a Bayesian, monetary structural vector autoregressive model. We allow money supply and leverage measures to enter into the interest rate policy rule and use an identification approach that is by construction devoid of any price puzzles. We provide a comprehensive comparison between monetary policy shocks under a policy regime that follows a standard Taylor rule and those that augment the standard reaction function of the central bank with measures of leverage and the money supply. We find that contractionary monetary policy is more pronounced and persistent when the reaction function of the central bank is augmented with measures of money and leverage than when the reaction function follows a typical Taylor rule. Our results support the use and inclusion of monetary aggregates in monetary policy and business cycle analysis.

Keywords: Monetary policy shocks; Divisia monetary aggregates; output; inflation

1. Introduction

Financial intermediaries issue deposit liabilities which are included in measures of the money supply. However, money supply measures have been largely ignored in recent monetary policy and business cycle analysis. Leeper and Roush (2003, p. 1) observed that the main reason that money has conspicuously disappeared from monetary policy analyses since the beginning of the Taylor rule era is that "in the most widely used models of monetary policy, the money stock is redundant for determining output and inflation once the short-term nominal interest rate is present. The near universal adoption of interest rate instruments by central banks, coupled with the belief that actual central bank behavior is well modeled by a policy rule that sets the interest rate as a function of only output and inflation, has led to an emphasis on theoretical models in which the money supply is infinitely elastic." However, Dery and Serletis (2021) showed that the predictive power of Divisia monetary aggregates is not adsorbed by the presence of the interest rate, confirming the assertion of McCallum and Nelson (2011, p. 147) that, "too much in the reaction to problems in measuring money has taken the form of abandoning the analysis of monetary aggregates, and too little has taken the form of more careful efforts at improved measurement."

Financial intermediaries also issue leverage to acquire assets in excess of net worth. The importance of leverage to business cycles and economic stability became particularly obvious in 2007–2008, when record high leverage led to the global financial crisis. In particular, prior to the global financial crisis, (then) major Wall Street investment banks (Bear Stearns, Goldman Sachs, Morgan Stanley, Merrill Lynch, and Lehman Brothers) together averaged leverage ratios of 30 to 1, up from 20 to 1 in 2003, but never previously in the history of the US leverage had exceeded

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30 to 1—see Barnett (2012) for an excellent discussion. In this regard, Adrian and Shin (2010) argue that "the evidence points to financial intermediaries adjusting their balance sheets actively, and doing so in such a way that leverage is high during booms and low during busts." In fact, as Geanakoplos (2012, p. 389) puts it, "leverage can be more important to economic activity and prices than interest rates, and more important to manage."

In this paper, we augment the policy reaction function of the monetary authority with measures of leverage and the money supply and assess the dynamic effects of monetary policy shocks on key macroeconomic variables. We also investigate the proportion of macroeconomic variations that can be attributed to monetary policy shocks when the policy function is augmented with leverage and money. We make a comprehensive comparison between the effects of monetary policy shocks and other shocks, such as demand and supply shocks, when the monetary authority's policy reaction function includes leverage and money measures against a policy reaction function that follows a standard Taylor rule. The dual and related questions of the dynamic effects of monetary policy on the economy and how much of the variation in output and inflation can be explained by monetary policy shocks have drawn a lot of research attention but are yet without a clear consensus. For example, while Sims (1992), Leeper et al. (1996), Bagliano and Favero (1998), Christiano et al. (1999), Kim (1999), Belongia and Ireland (2015, 2016, 2018), and Arias et al. (2019), among others, all find significant output contractions in response to contractionary monetary policy, Uhlig (2005) finds evidence to the contrary; evidence which suggests that contractionary monetary policy could actually be associated with output expansions. In a similar vein, while there exists evidence suggesting that monetary policy shocks account for a significant fraction of the variation in output [see, e.g., Faust (1998) and Christiano et al. (2005)], Leeper et al. (1996), Cushman and Zha (1997), and Kim (1999), all find small real effects.

More recently, Baumeister and Hamilton (2018) use a Bayesian structural vector autoregressive (VAR) model and also find that monetary policy shocks are relatively unimportant in explaining key macroeconomic variations compared to demand and supply shocks. Estimating a 3- and a 6-variable model, Baumeister and Hamilton (2018) find that monetary policy shocks account for less than 5% of the variation in output and inflation and that the dynamic responses of output and inflation to monetary policy shocks are also short-lived. Their 3-variable model consists of the output gap, the inflation rate, and the federal funds rate, while their 6-variable model augments the 3-variable model with the yield spread between Baa corporate and 10-year Treasury bonds, the Commodity Research Bureau (CRB) commodity spot price index, and average hourly earnings of production and nonsupervisory employees. However, the Baumeister and Hamilton (2018) model, like most models in this branch of the literature, is based on the new Keynesian approach to macroeconomics, according to which monetary policy is expressed in terms of interest rate rules of the type proposed by Taylor (1993). This approach ignores the financial intermediary sector, assuming that financial firms play a passive role that the central bank uses as a channel to implement monetary policy. However, as policy rates around the world reached the zero lower bound in the aftermath of the global financial crisis and during the coronavirus pandemic, banks and a number of market-based financial intermediaries, and in particular security broker-dealers, have attracted a great deal of attention. There is an almost universal agreement that the global financial crisis originated in the banking system.

With financial firms issuing leverage and also deposit liabilities which are included in measures of the money supply, the question then is whether there is a useful role of leverage and the aggregate quantity of money in monetary policy and business cycle analysis. To answer this question, we augment the reaction function of the monetary authority with leverage and money supply measures and assess the dynamic effects of monetary policy shocks on the economy relative to other shocks and the standard Taylor rule case. We complement and extend the literature that advocates for the inclusion of money and leverage measures in the analysis of monetary policy and business cycles. In particular, we estimate a 6-variable Bayesian monetary structural VAR that combines sign restrictions and other prior information, as in Baumeister and Hamilton (2018).

We augment the policy function with those financial variables that attracted most of the attention in the aftermath of the global financial crisis and during the coronavirus pandemic—financial intermediary leverage and money supply measures—and assess the response of output and inflation to monetary policy shocks, identifying monetary policy shocks with innovations in the federal funds rate, as in Sims (1992) and Bernanke and Blinder (1992). However, we allow money supply and leverage measures to enter into the interest rate policy rule, as in Leeper and Roush (2003), Belongia and Ireland (2015, 2016), and Dery and Serletis (2021). Moreover, we use an identification approach that is by construction devoid of any price puzzle particularly at shorter horizon, as in Baumeister and Hamilton (2018). By combining pure sign restrictions with other prior information, the Baumeister and Hamilton (2018) approach also avoids the Preston (1978) "model identification problem," as well as other concerns raised by Fry and Pagan (2011) and Danne (2015).

In this regard, Leeper and Roush (2003) argue for and include money measures in their analysis of monetary policy, but they use simple-sum monetary aggregates that have been shown to be inferior to Barnett's (1980) Divisia monetary aggregates. See Barnett and Chauvet (2011), Hendrickson (2014), Serletis and Gogas (2014), Belongia and Ireland (2014, 2015, 2016), Ellington (2018), Dai and Serletis (2019), Serletis and Xu (2020, 2021, 2023), and Xu and Serletis (2022), among others, regarding the superiority of the Divisia monetary aggregates over the simple-sum aggregates. More recently, Belongia and Ireland (2015, 2016, 2018) and Dery and Serletis (2021) use Divisia monetary aggregates, at different levels of aggregation, in the identification of monetary policy shocks. These papers, however, have all been plagued with the usual price puzzle, where a contractionary monetary policy shock tends to induce inflation rather than deflation. By construction, the Baumeister and Hamilton (2018) approach that we use is devoid of a price puzzle, even though their system ignores the increasing importance of money and leverage in the analysis of monetary policy.

In terms of the dynamic responses of output and inflation to identified monetary policy shocks, we find that a central bank with the standard Taylor rule as its reaction function tends to have a more benign impact on output and inflation. The contemporaneous declines in output and inflation following a contractionary monetary policy shock are 0.08% and 0.04%, respectively. However, when the policy function is augmented with a measure of money and leverage, a similar monetary policy shock has more pronounced effects on output and inflation. Specifically, on impact such a shock produces an output contraction of 0.46%, 0.34%, and 0.33%, respectively, with the Divisia M3, Sum M2, and Divisia M4 monetary aggregates, while the corresponding reduction in inflation is 0.23%, 0.21%, and 0.19%, respectively. Thus, in terms of dynamic responses to a comparable monetary policy shock, the dynamic responses of the augmented model are more pronounced and persistent than the standard Taylor type rule without money and leverage.

In addition, we find that when the monetary authority's reaction function follows a standard Taylor rule, monetary policy shocks explain a trivial fraction of the variation in output and inflation. However, augmenting the standard Taylor rule with a measure of money and leverage improves the ability of monetary policy to account for variations in output and inflation. Moreover, even thought monetary policy shocks are dominated by aggregate demand and supply shocks in explaining key macroeconomic variations, including a measure of money and any measure of leverage in the reaction function of the policymaker improves the ability of monetary policy shocks to account for variations in output and inflation relative to a model without money and leverage.

The rest of the paper is organized as follows. Section 2 presents and discusses the six-variable, Bayesian, monetary structural VAR that combines sign restrictions and other prior information, as in Baumeister and Hamilton (2018), and allows leverage and money supply measures to enter into the identification. It shows how we identify supply shocks, demand shocks, and monetary policy shocks. Section 3 discusses the data, which covers the 1986:q1 to 2021:q1 period, a period that includes the global financial crisis and its aftermath as well as the COVID-19 pandemic.

Section 4 pertains to estimation issues, and Section 5 presents the empirical results in terms of impulse response functions and forecast error variance decomposition. The final section briefly concludes regarding the implications of our research for monetary theory and the conduct of monetary policy.

2. A structural VAR model of monetary policy

We begin with a typical structural model of the form:

$$\boldsymbol{A}\boldsymbol{z}_t = \boldsymbol{B}\boldsymbol{z}_{t-1} + \boldsymbol{u}_t \tag{1}$$

where $\boldsymbol{z}_t$ is an $n \times 1$ vector of variables and $\boldsymbol{A}$ is $n \times n$ matrix of contemporaneous structural coefficients. $\boldsymbol{z}_{t-1}$ is $k \times 1$ vector (where $k = mn + 1$) containing a constant and m lags of $\boldsymbol{z}_t$. $\boldsymbol{u}_t$ is an $n \times 1$ vector of structural disturbances with variance covariance matrix $\boldsymbol{D}$.

Given (1), the reduced form is

$$\boldsymbol{z}_t = \boldsymbol{\Phi}\boldsymbol{z}_{t-1} + \boldsymbol{\varepsilon}_t$$

where

$$\boldsymbol{\Phi} = \boldsymbol{A}^{-1}\boldsymbol{B}$$

and

$$\boldsymbol{\varepsilon}_t = \boldsymbol{A}^{-1}\boldsymbol{u}_t.$$

We denote the vector of the unknown elements of $\boldsymbol{A}$, $\boldsymbol{B}$, and $\boldsymbol{D}$ by $\boldsymbol{\theta}$. Even though the VAR parameters ($\boldsymbol{\Phi}$ and $\boldsymbol{\Omega} = E(\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}_t')$) can easily be estimated using Ordinary Least Square (OLS) regression, the structural parameters in $\boldsymbol{\theta}$ will require additional assumptions regarding the structural model. There are several ways of achieving structural identification, the most popular of which is the recursive or Cholesky identification. A more recent and promising approach, championed by Faust (1998), Canova and De Nicolo (2002), and Uhlig (2005), is to specify the direction of the impact of a shock of interest—see Fry and Pagan (2011) for a detailed review of identification by pure sign restrictions. Despite the appealing simplicity and mostly theoretical grounding of pure sign restrictions, this approach suffers from some criticisms, including the Preston (1978) "model identification problem," as noted by Fry and Pagan (2011) and Danne (2015). As noted by Danne (2015, p. 11), "Uhlig's (2005) and Rubio-Ramirez's et al. (2010) rejection method are particularly prone to this 'model identification problem.'" This problem refers to the fact that there are many models with identified parameters that rationalize the data. Thus, summarizing the responses using for instance the median response and conventional error bands represents the spread of the responses distribution across these models. Also, Wolf (2020, 2022) illustrates, based on the true structure being a standard new Keynesian model, how sign restrictions alone may be unable to identify the effects of shocks to monetary policy; he shows how the shocks the econometrician identifies may actually be combinations of different types of structural disturbances.

We follow Baumeister and Hamilton (2015, 2018), who based on Bayesian optimal statistical decision theory utilize both information on the signs and magnitudes of the shocks of interest to achieve both parameter and model identification, thereby avoiding the Preston (1978) model identification problem and the Fry and Pagan (2011) and Danne (2015) criticisms that the median impulse response functions from a pure sign restriction structural VAR are not model-specific. Also, by using sign restrictions together with other prior information, we reduce the chances of the occurrence of scenarios as noted by Wolf (2020, 2022). In what follows, we provide a brief exposition of the Baumeister and Hamilton (2018) approach. This section borrows from Baumeister and Hamilton (2015) and Baumeister and Hamilton (2018), Sections 2 and 3.

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Suppose $\boldsymbol{Y}_t = \left(\boldsymbol{y}_1', \boldsymbol{y}_2', \ldots, \boldsymbol{y}_T'\right)'$ is the vector of data. The likelihood function $p\left(\boldsymbol{Y}_t \,|\boldsymbol{\theta}\right)$ can be written as:

$$p\left(\boldsymbol{Y}_t \,|\boldsymbol{\theta}\right) = (2\pi)^{Tn/2} \left|\det\left(\boldsymbol{A}\left(\boldsymbol{\theta}\right)\right)\right|^T \left|\boldsymbol{D}(\theta)\right|^{-T/2}$$
$$\times \exp\left[-\frac{1}{2}\sum_{t=1}^{T}\left(\boldsymbol{A}\left(\boldsymbol{\theta}\right)\boldsymbol{z}_t - \boldsymbol{B}\left(\boldsymbol{\theta}\right)\boldsymbol{z}_{t-1}\right)' \boldsymbol{D}\left(\boldsymbol{\theta}\right)^{-1}\left(\boldsymbol{A}\left(\boldsymbol{\theta}\right)\boldsymbol{z}_t - \boldsymbol{B}\left(\boldsymbol{\theta}\right)\boldsymbol{z}_{t-1}\right)\right]$$

for $\boldsymbol{u}_t \sim \mathcal{N}(\boldsymbol{0}, \boldsymbol{D})$, where $\left|\det\left(\boldsymbol{A}\right)\right|$ is the absolute value of the determinant of $\boldsymbol{A}$. For a prior distribution $p\left(\boldsymbol{\theta}\right)$,

$$p(\boldsymbol{\theta} \,|\boldsymbol{Y}_t) = \frac{p(\boldsymbol{Y}_t \,|\boldsymbol{\theta})p(\boldsymbol{\theta})}{\int p(\boldsymbol{Y}_t \,|\boldsymbol{\theta})p(\boldsymbol{\theta})d\boldsymbol{\theta}}$$

is the Bayesian posterior distribution. Let $\boldsymbol{\Psi}_s$ be the nonorthogonalized impulse response function at horizon s from the VAR. Then,

$$\boldsymbol{\Psi}_s = \frac{\partial \boldsymbol{z}_{t+s}}{\partial \boldsymbol{\varepsilon}_t}.$$

We are interested in the dynamic effects of the jth structural shock on the ith variable denoted by $h_{ij}^s\left(\boldsymbol{\theta}\right)$ which is the (i, j) element of the matrix $\boldsymbol{H}_s$, where

$$\boldsymbol{H}_s = \boldsymbol{\Psi}_s \boldsymbol{A}^{-1}.$$

Given an $s \times 1$ vector $h_{ij}\left(\boldsymbol{\theta}\right)$ and a quadratic loss function, the estimated solution according to Baumeister and Hamilton (2018) is the posterior mean. That is,

$$\hat{h}_{ij} = \underset{\hat{h}_{ij}}{\operatorname{argmin}} \int \left[\hat{h}_{ij} - h_{ij}\left(\boldsymbol{\theta}\right)\right]' \boldsymbol{W}\left[\hat{h}_{ij} - h_{ij}\left(\boldsymbol{\theta}\right)\right] p\left(\boldsymbol{\theta} \,|\boldsymbol{Y}_t\right) d\boldsymbol{\theta}$$

and $\hat{h}_{ij} = h_{ij}^*$ where $h_{ij}^* = \int h_{ij}\left(\boldsymbol{\theta}\right) p\left(\boldsymbol{\theta} \,|\boldsymbol{Y}_t\right) d\boldsymbol{\theta}$ and $\boldsymbol{W}$ is a positive definite $s \times s$ weighting matrix. Baumeister and Hamilton (2018) also show that for a weighted absolute value loss function, the optimal impulse response function is the posterior median of $h_{ij}^s\left(\boldsymbol{\theta}\right)$. Lastly, Baumeister and Hamilton (2018) show that conditional on $\boldsymbol{\theta}$, the s-period ahead forecast error can be written as:

$$\boldsymbol{z}_{t+s} - \widehat{\boldsymbol{z}}_{t+s} = \boldsymbol{H}_0\left(\boldsymbol{\theta}\right)\boldsymbol{u}_{t+s} + \boldsymbol{H}_1\left(\boldsymbol{\theta}\right)\boldsymbol{u}_{t+s-1} + \cdots + \boldsymbol{H}_{s-1}\left(\boldsymbol{\theta}\right)\boldsymbol{u}_{t+1}$$

with mean square errors (MSE)

$$E\left[\left(\boldsymbol{z}_{t+s} - \widehat{\boldsymbol{z}}_{t+s}\right)\left(\boldsymbol{z}_{t+s} - \widehat{\boldsymbol{z}}_{t+s}\right)' \,|\boldsymbol{\theta}\right] = \sum_{j=1}^{n} \boldsymbol{Q}_{js}\left(\boldsymbol{\theta}\right) \quad \text{and} \quad \boldsymbol{Q}_{js}\left(\boldsymbol{\theta}\right) = d_{ij}\left(\boldsymbol{\theta}\right)\sum_{k=0}^{s-1} h_j(k, \boldsymbol{\theta})h_j(k, \boldsymbol{\theta})'$$

where $d_{ij}\left(\boldsymbol{\theta}\right)$ is the (i, j) element of $\boldsymbol{D}$. The contribution of shock j to the s-period ahead MSE of the ith element of y_{t+s} is the (i, j) element of $\boldsymbol{Q}_{js}\left(\boldsymbol{\theta}\right)$.

3. The data

We use quarterly data for the USA, over the period from 1986:q1 to 2021:q1, to investigate how augmenting a standard Taylor rule with monetary aggregates and leverage measures affects the significance of monetary policy shocks in explaining key macroeconomic variations. The Bayesian structural VAR model consists of six variables—the output gap, y_t, inflation rate, π_t, federal funds rate, i_t, credit spread, cs_t, growth rate of commercial bank leverage, l_t, and the growth rate of a monetary aggregate, μ_t. With regard to the choice of the monetary aggregate, we follow Dery and Serletis (2021) and use the Center for Financial Stability (CFS) broad Divisia monetary aggregates, Divisia M3 and Divisia M4. However, we also provide a comparison with the Fed's broad simple-sum monetary aggregate, the Sum M2 aggregate.

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It should be noted that the Divisia M4- monetary aggregate, being the broadest monetary aggregate that excludes Treasury bills, could be argued to be the most appropriate monetary aggregate for monetary policy and business cycle analysis, since excluding Treasury bills will exclude the effects of fiscal policy. However, we use the Divisia M3 aggregate, instead of the Divisia M4- aggregate, as the comprehensive empirical analysis in Dery and Serletis (2021) supports the Divisia M3 aggregate. We also use the Divisia M4 aggregate, which is the broadest Divisia monetary aggregate, in order to provide a comparison with the Sum M2 monetary aggregate, which is the broadest simple-sum monetary aggregate constructed by the Federal Reserve.

The Divisia monetary aggregates, as constructed by Barnett (1980), are based on Diewert's (1976) class of superlative quantity index numbers. In deriving the Divisia indices, the (simple-sum) assumption of perfect substitutability of the monetary components is relaxed and a weighting scheme based on monetary component user costs is used instead—see Barnett et al. (2013) for more details. The commercial bank leverage series is calculated using data from the Board of Governors of the Federal Reserve System. All the other variables, except for the Divisia monetary aggregates, are obtained from the Federal Reserve Economic Database (FRED). The Divisia monetary aggregates are from the Centre for Financial Stability.

The output gap, y_t, is defined as the log difference between actual output and potential output scaled by 100; we use real GDP to measure output. The inflation rate, π_t, is the year-on-year log difference of the consumer price index scaled by 100, while i_t and cs_t are the yearly percentage changes of the Wu and Xia (2016) effective shadow federal funds rate and the credit spread, respectively. We define the credit spread as the difference between Moody's seasoned Baa corporate bond yield and the yield on 10-year Treasury constant maturity. μ_t is the yearly growth rate of the relevant monetary aggregate. l_t is measured as the yearly growth rate of commercial bank leverage. We follow Adrian et al. (2014) and define leverage as the ratio of total financial assets to total net financial assets. In calculating net financial assets, we follow Istiak and Serletis (2017) and exclude total miscellaneous liabilities from total liabilities of commercial banks. As Istiak and Serletis (2017) argue, this avoids extreme leverage values as well as negative leverage in some quarters.

In Figures 1 and 2, we present the levels (relative to the 1986:q1 value) and growth rates, respectively, of the Divisia M3, Divisia M4, and Sum M2 monetary aggregates over the sample period from 1986:q1 to 2021:q1. As can be seen, the aggregates are clearly distinguishable in both log levels and growth rates. In what follows, we investigate whether the differences in levels and growth rates of these aggregates, as shown in Figures 1 and 2, matter for the identification of monetary policy shocks. In a similar fashion, in Figures 3 and 4, we present the levels (again relative to the 1986:q1 value) and growth rates, respectively, of the commercial bank leverage, as well as broker-dealer leverage, shadow bank leverage, and household leverage.

4. Estimation

We estimate the structural monetary VAR model with four (quarterly) lags. In using the Baumeister and Hamilton (2015, 2018) approach, we are able to combine sign restrictions and other prior information, as well as zero restrictions to identify aggregate supply shocks, aggregate demand shocks, and monetary policy shocks. Specifically,

$$\boldsymbol{z}_t = \begin{bmatrix} y_t \\ \pi_t \\ i_t \\ cs_t \\ l_t \\ \mu_t \end{bmatrix} \quad \text{and} \quad \boldsymbol{A} = \begin{bmatrix} 1 & -a_{12} & 0 & 0 & 0 & 0 \\ 1 & -a_{22} & -a_{23} & 0 & 0 & 0 \\ -a_{31} & -a_{32} & 1 & 0 & -a_{35} & -a_{36} \\ -a_{41} & -a_{42} & -a_{43} & 1 & -a_{45} & -a_{46} \\ -a_{51} & -a_{52} & -a_{53} & -a_{54} & 1 & -a_{56} \\ -a_{65} & -a_{62} & -a_{63} & -a_{64} & -a_{65} & 1 \end{bmatrix}$$

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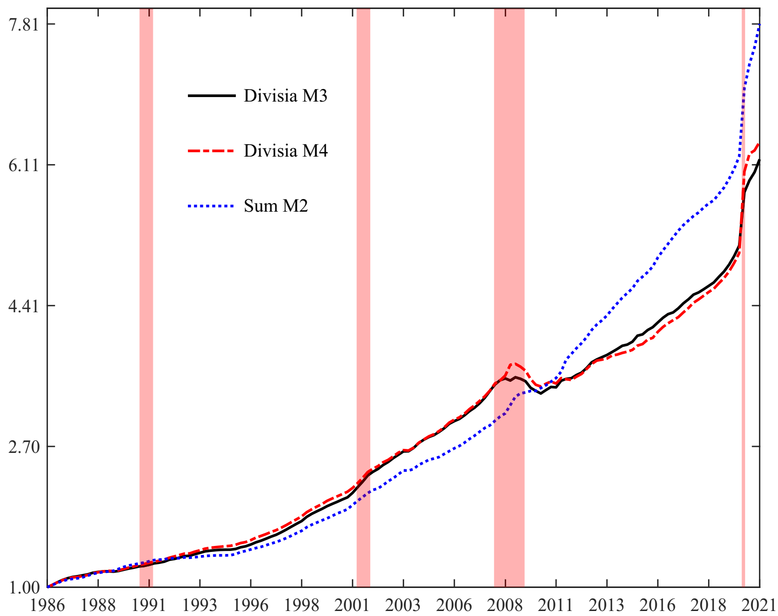

Figure 1. Broad monetary aggregates. This figure plots the level of the Divisia M3, Divisia M4, and Sum M2 monetary aggregates. Vertical shaded bars are National Bureau of Economic Research (NBER) recession dates.

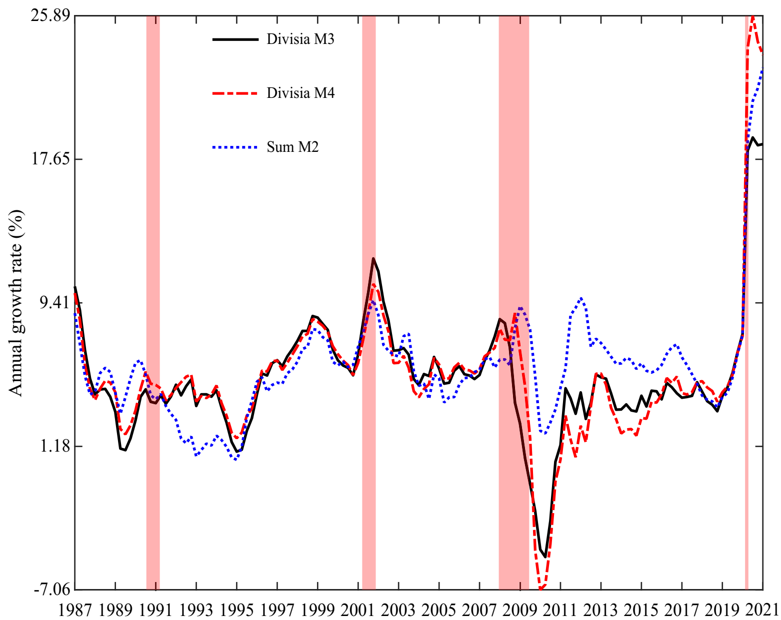

Figure 2. Annualized growth rates of broad monetary aggregates. Vertical shaded bars are NBER recession dates.

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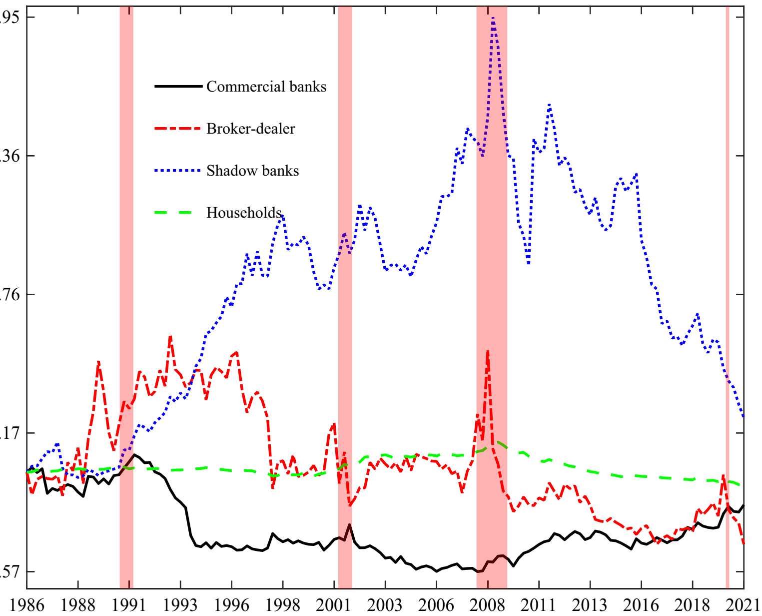

Figure 3. Leverage measures. This figure plots the level of four alternative leverage measures relative to their 1986:q1 value. Vertical shaded bars are NBER recession dates.

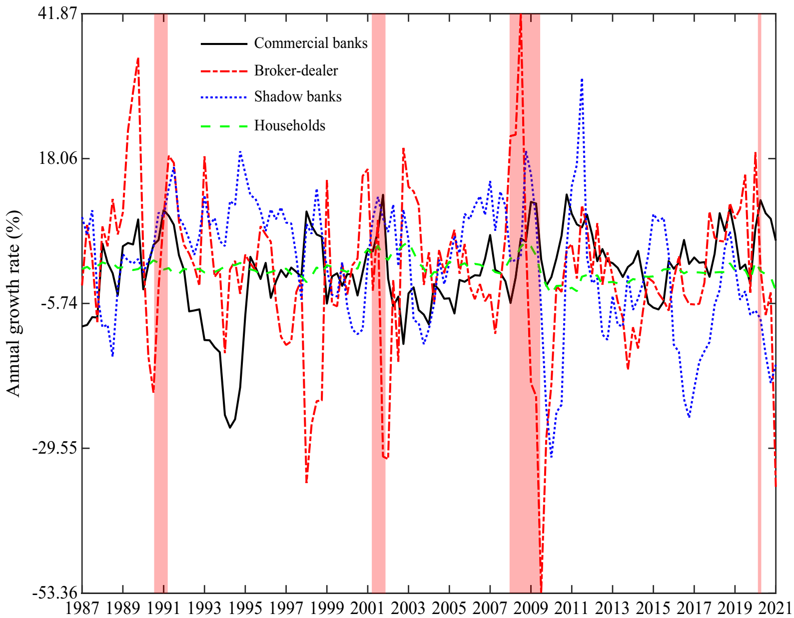

Figure 4. Annualized growth rates of leverage measures. Shaded bars are NBER recession dates.

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Table 1. Summary of sign restrictions and prior information of the model. Distribution is Student's *t* test with 3 degrees of freedom

Parameter	Meaning	Prior mode	Prior scale	Sign restrictions
a_{12}	Effect of inflation on supply	2	0.4	$a_{12} \geq 0$
a_{22}	Effect of inflation on demand	0.75	0.4	None
a_{23}	Effect of fed funds rate on demand	−1	0.4	$a_{23} \leq 0$
ψ^y	Fed's response to output	0.5	0.4	$\psi^y \geq 0$
ψ^π	Fed's response to inflation	1.5	0.4	$\psi^\pi \geq 0$
ψ^l	Fed's response to leverage growth	0.02	0.4	None
ψ^μ	Fed's response to money growth	0.2	0.4	$\psi^\mu \geq 0$
ρ	Interest rate smoothing	0.5	0.2	$0 \leq \rho \leq 1$

so that the system of equations of interest consists of a Phillips curve, an aggregate demand curve, and a monetary policy rule given by:

$$y_t = c^s + a_{12}\pi_t + [b^s]'z_{t-1} + u_t^s \tag{2}$$

$$y_t = c^d + a_{22}\pi_t + a_{23}i_t + [b^d]'z_{t-1} + u_t^d \tag{3}$$

$$i_t = c^{mp} + a_{31}y_t + a_{32}\pi_t + a_{35}l_t + a_{36}\mu_t + [b^{mp}]'z_{t-1} + u_t^{mp} \tag{4}$$

where u_t^s is the supply shock, u_t^d is the demand shock, and u_t^{mp} is the monetary policy shock. In equation (2), supply depends on the inflation rate, π_t, while in equation (3) we distinguish demand by making it depend on the inflation rate, π_t, as well as the interest rate, i_t. In equation (4), the monetary policy shock is interpreted as one which causes the Fed to adjust its policy rate in response to changes in the output gap, y_t, the inflation rate, π_t, the leverage growth rate, l_t, and the money growth rate, μ_t. As already noted, we use the Fed's Sum M2 aggregate and the CFS broad Divisia M3 and Divisia M4 aggregates as our measures of money and commercial bank leverage as our measure of leverage.

The version of equation (4) that is estimated is

$$i_t - \bar{\imath} = (1-\rho)\psi^y y_t + (1-\rho)\psi^\pi(\pi_t - \pi^*) + \rho(i_{t-1} - \bar{\imath}) + (1-\rho)\psi^l l_t + (1-\rho)\psi^\mu \mu_t + u_t^{mp} \tag{5}$$

where ψ^y, ψ^π, ψ^l, and ψ^μ are the Fed's long run responses to output, inflation, leverage growth, and money growth, respectively. π^* and $\bar{\imath}$ are the inflation rate and federal funds rate targets, respectively. ρ is the smoothing parameter reflecting the Fed's desire to implement changes gradually. Equation (5) is the same as in Baumeister and Hamilton (2018) except that it is augmented with leverage and a monetary aggregate.

In Table 1, we summarize the sign restrictions and prior information of the model. We follow Baumeister and Hamilton (2018), and references therein, to use the prior information as shown in Table 1 except for the prior regarding the Fed's response to leverage growth and money growth. The priors for the Fed's response to leverage growth and money growth are obtained from OLS regressions of the effective shadow federal funds rate on the output gap, inflation, leverage, and money. These OLS regressions show that the Fed's response to output is roughly 0.5, the response to inflation is 1.5, the response to leverage growth is 0.02, and the Fed's response to money growth is 0.2.

In addition to the priors on the parameter mode, we also use prior information on signs as shown in the last column of Table 1. Specifically, we restrict the effect of inflation on supply to be nonnegative, while the effect of the federal funds rate on demand is negative. Also, the responses of the Fed to output, inflation, and money growth are expected to be nonnegative, while the

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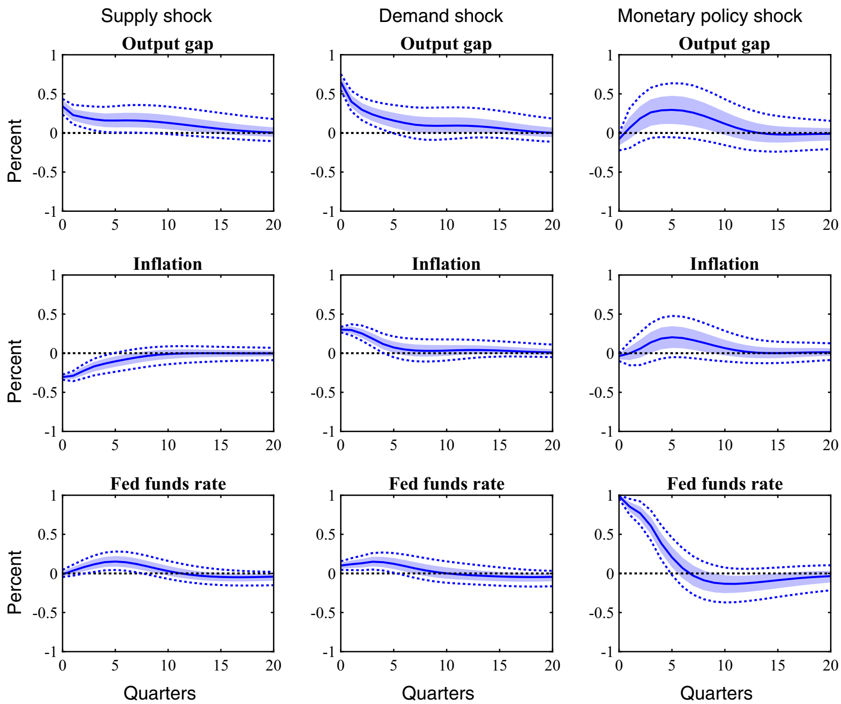

Figure 5. Impulse responses of the Baumeister and Hamilton (2018) type model without money and leverage. For each response, the shaded area shows the 68% credibility region, while the dashed lines show the 95% confidence bands of the median response (solid blue line).

response of the Fed to leverage growth is unconstrained. For the interest rate smoothing parameter, we follow Baumeister and Hamilton (2018), Lubik and Schorfheide (2004), and Del Negro and Schorfheide (2004) and use a beta distribution with mean 0.5 and standard deviation 0.2. For all the other parameters not shown in Table 1, we follow Baumeister and Hamilton (2018) and use Student's t test prior centered at 0 and an uninformative scale of 1.

All estimated results are based on 2 million draws from the posterior distribution of the structural parameters with the first 1 million as burn-in. We conducted the Geweke (1992) convergence diagnostics of the relevant parameters of the model as indicated in Table 1 and confirm that we are drawing from the same stationary distribution. The Geweke diagnostics essentially take two nonoverlapping parts of the Markov chain and compare the means of both parts. Basically, we tested for equality of means of the first 10% of the Markov chain and the last 50% of the chain. The test statistic is a standard Z-score with the standard errors adjusted for autocorrelation. Thus, being unable to reject the null of equality of means (say at the 5% significance level) implies that we are drawing from the same stationary distribution.

5. Empirical evidence

We begin by showing results of a Baumeister and Hamilton (2018) type model without money and leverage. This is a representative model according to which the behavior of the monetary authority is captured by the standard Taylor rule. Specifically, the Fed adjusts its policy rate in response to changes in output and inflation.

Figure 5 presents the impulse responses of a Baumeister and Hamilton (2018) type model without money and leverage. The model is estimated with the output gap, the inflation rate, the shadow

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federal funds rate, the credit spread, the CRB commodity spot price index, and average hourly earnings of production and nonsupervisory employees, over the period from 1986:q1 to 2021:q1. For each response, the shaded area shows the 68% credibility region, while the dashed lines show the 95% confidence bands of the median response. The response of the output gap to a contractionary monetary policy shock is not statistically significant at the 5% level. This is also the case for the response of the inflation rate to a monetary policy shock. The variance decomposition of the model attributes 2% of the variation in output and 1% of the variation in inflation to the monetary policy shock after 1 year (see the top panel of Table 3). Using this standard Taylor rule to capture the behavior of the monetary authority, it appears that monetary policy shocks are trivial in accounting for macroeconomic variations.

Our aim in this paper is to show that augmenting the policy function of the monetary authority with measures of money and leverage improves the role of monetary policy shocks in accounting for macroeconomic variations. By construction, sign restrictions and in particular the use of prior information eliminate the price puzzle that most of the monetary VAR literature has been plagued with. For this reason we do not use the commodity price index, since this variable is mostly included in VAR analyses as a means of dealing with the price puzzle—see Sims (1992) and Belongia and Ireland (2015, 2016). Instead, we use commercial bank leverage as a means of capturing the importance of financial intermediaries in monetary policy and business cycles. In our monetary model, we also replace the average hourly earnings of production and nonsupervisory employees with a monetary aggregate reflecting our desire to give a more prominent role to monetary aggregates in explaining business cycles. Thus, the only difference between our preferred monetary model and the Baumeister and Hamilton (2018) type model is the presence of money and leverage in the standard Taylor rule.

5.1. Impulse response functions

We now turn to an analysis of the effects of money and leverage in the identification of monetary policy shocks and assess the relative importance of supply, demand, and monetary policy shocks in affecting key macroeconomic variations. In doing so, while we estimated the augmented model with the Divisia M3, Divisia M4-, Divisia M4, and Sum M2 monetary aggregates, for brevity we only report results with the Divisia M3 and Sum M2 aggregates, as the results with the Divisia M4- and Divisia M4 monetary aggregates are similar to those with the Divisia M3 aggregate. In Figures 6 and 7, we present the impulse responses of the output gap, the inflation rate, and the federal funds rate to demand, supply, and monetary policy shocks when we allow the Divisia M3 (in Figure 6) and the Sum M2 (in Figure 7) monetary aggregates and commercial bank leverage to enter the monetary policy rule. As in Figure 5, for each response, the shaded area shows the 68% credibility region, while the dashed lines show the 95% confidence band of the median response.

As shown in column 1 and 2 of Figures 6 and 7, both a positive supply shock and an expansionary demand shock generate statistically significant responses in the output gap and inflation similar to those in Figure 5. The dynamic effects of a contractionary monetary policy shock on output and inflation are shown in column 3 of Figures 6 and 7. In comparison to the nonmonetary model in Figure 5, the effects of a monetary policy shock on output and inflation are statistically significant with persistence varying from one to three-quarters depending on the measure of money. The statistically significant output contraction and deflationary episode associated with a contractionary monetary policy shock in our monetary model are more consistent with theory and many empirical studies—see, for example, Sims (1992), Leeper et al. (1996), Bagliano and Favero (1998), Christiano et al. (1999), Kim (1999), Belongia and Ireland (2015, 2016, 2018), and Arias et al. (2019), among others.

It is important to notice that the method of identification using sign restrictions, short-run restrictions, prior information, and allowing money and leverage to enter the Taylor-type policy

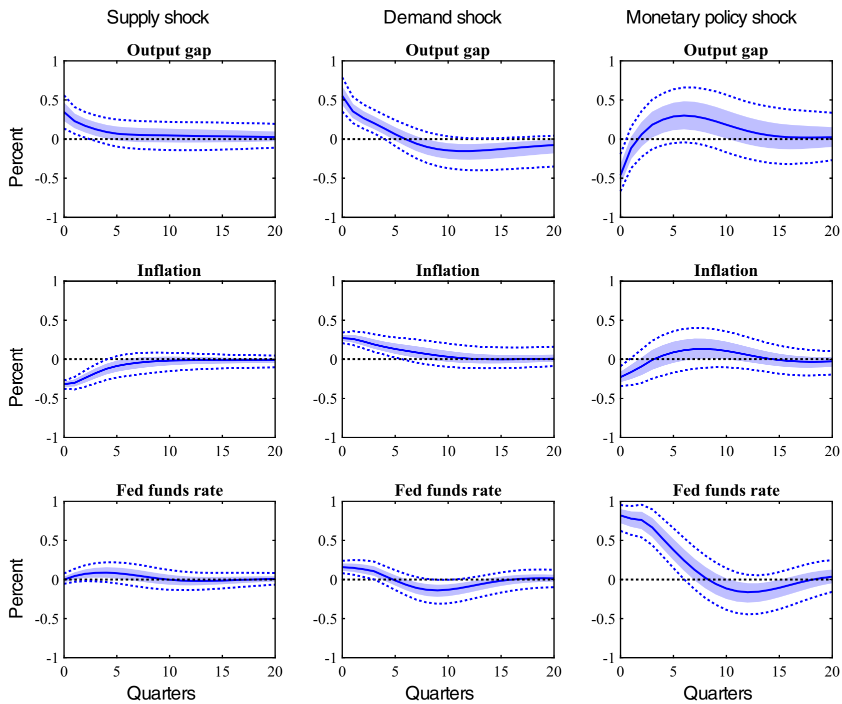

Figure 6. Impulse responses of the monetary model with Divisia M3. For each response, the solid blue line is the median response, the shaded area shows the 68% credibility region, while the dashed lines show the 95% confidence bands of the median response.

rule is by construction devoid of the usual price puzzle that many empirical models normally generate in this literature. For instance, Belongia and Ireland (2015, 2016, 2018) allow Divisia money to enter into a typical Taylor rule and produce theoretically consistent results with regard to the response of output to a contractionary monetary policy shock, but their model exhibits a price puzzle. Dery and Serletis (2021) also estimate a Taylor-type policy rule with Divisia money allowing for GARCH behavior in the structural shocks. Their results regarding the effect of a monetary policy shock on prices shows a puzzle. Using the Baumeister and Hamilton (2015, 2018) approach, we achieve both model and parameter identification, thereby avoiding the Preston (1978) "model identification problem," which as noted by Fry and Pagan (2011) and Danne (2015) is one of the major failings of the pure sign restrictions approach. The adopted empirical approach produces theoretically consistent results marked by the absence of the usual price puzzle. The absence of the price puzzle is by construction and a characteristic of the Baumeister and Hamilton (2018) approach. Even though our analysis and conclusions are based on 95% confidence intervals, if one were to focus instead on the 68% credibility region (shaded regions in Figures 5–7), we note that a contractionary monetary policy generates a statistically significant increase in output at longer forecast horizons. We also observe a price puzzle at longer horizons in the nonmonetary model (Standard Taylor rule), but the incidence of a statistically significant price puzzle at longer horizons is not recorded in the models augmented with money and leverage. We think that this supports the findings of Chen and Valcarcel (2021) who concluded that the identification of monetary policy shocks based on innovations in the shadow fed funds rate produces a price puzzle at longer horizons, but the use of monetary aggregates like the Divisia M4 eliminates such a puzzle. However, output puzzles do exist, as the output responses to a contractionary monetary policy shock are significant and positive at longer horizons. This could be because the contractionary

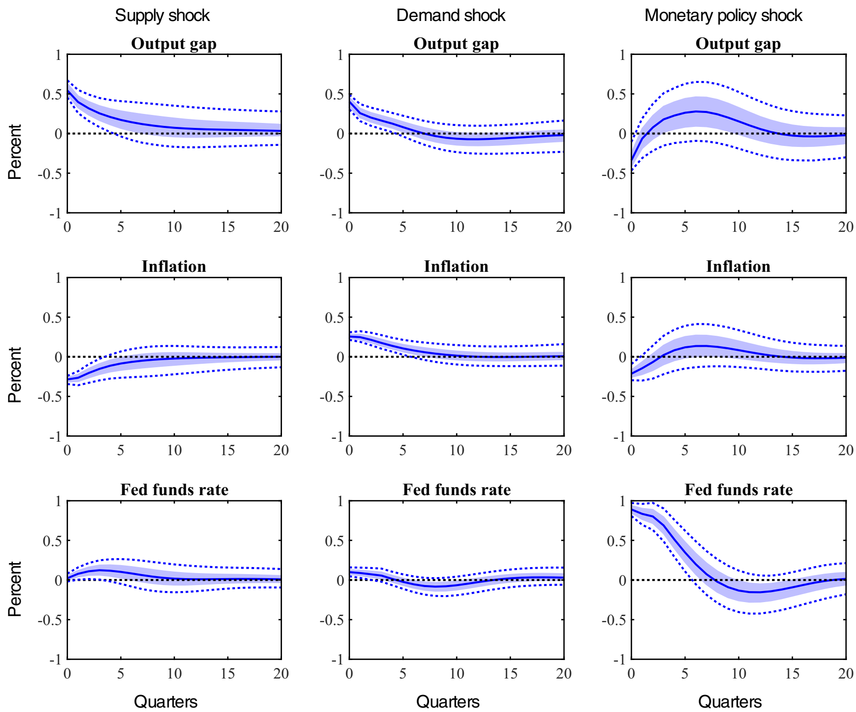

Figure 7. Impulse responses of the monetary model with Sum M2. For each response, the shaded area shows the 68% credibility region, while the dashed lines show the 95% confidence bands of the median response (solid blue line).

policy might be associated with a decline in expected inflation. If the expected inflation effect is dominant, interest rates will eventually decline and cause positive output responses at longer horizons.

In the first subplot of Figure 8, we present the cumulative responses of output and inflation to a contractionary monetary policy shock with the Divisia M3 and Sum M2 monetary aggregates and commercial bank leverage entering into the monetary policy rule. We also show the responses of output and inflation to a contractionary monetary policy shock emanating from the standard Taylor rule. As can be seen in the top panel of Figure 8, the contraction in output is more pronounced in the models with money and leverage compared to the model without money and leverage (standard Taylor rule). We present a similar comparison in the bottom panel of Figure 8 in terms of the response of inflation to a contractionary monetary policy shock. As can be seen, all the models with money and leverage generate more pronounced deflation relative to the standard Taylor rule. In unreported results, we compared each monetary model's output and inflation responses to the standard Taylor rule responses with their corresponding 95% confidence bands and confirm that there is significant overlap of the confidence bands and that there are also differences in the confidence regions. In Table 2, we provide a t test of differences in means of the relevant impulse responses. Specifically, we are testing the null hypothesis that the impulse response of each monetary model on average is statistically different from the impulse response of the standard Taylor rule without money and leverage. Hence, this test assists us in examining the assertion that the mean of an impulse response from the augmented model is not equal to the mean of an impulse response of the standard Taylor rule.

Both Figure 8 and Table 2 provide evidence that empirical models measuring the macroeconomic effects of central bank policy should capture a measure of money and leverage. Our evidence is supportive of Leeper and Roush (2003), and Belongia and Ireland (2015, 2016, 2018)

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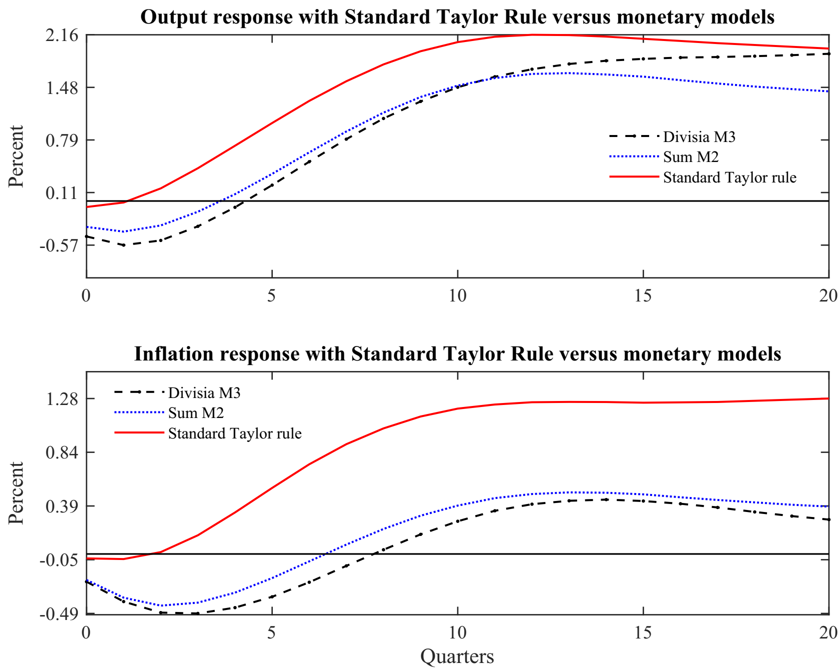

Figure 8. Comparison of the median output and inflation responses to a contractionary monetary policy shock.

who have argued for or provided evidence supporting the inclusion of monetary aggregates in interest rate-based monetary policy rules.

5.2. Variance decomposition

Another key area of interest is the examination of the proportion of the variation in a variable of interest that can be explained by a particular identified shock. In Table 3, we present the estimated contribution of each structural shock (supply shocks (SS), demand shocks (DS), and monetary policy shocks (MPS)) to the 4- and 20-quarters ahead median squared forecast error of each variable of interest (output gap, the inflation rate, and the federal funds rate) in bold and also expressed as a percent of the total MSE in squared brackets. We also provide the 95% credibility intervals in parentheses. Our format for reporting the variance decomposition follows closely the format of Baumeister and Hamilton (2018), since our paper is related to theirs and we intend to report the results in a comparable manner.

As can be seen in Table 3, the model with the Divisia M3 aggregate and commercial bank leverage allows monetary policy shocks to explain thrice (6%) as much of the variation in output compared to the standard Taylor rule which would only ascribe 2% of the variation in output to monetary policy shocks after 1 year. In fact, 5 years after the shock, monetary policy shocks identified with Divisia M3 and commercial bank leverage account for 8% of the variation in output compared to 5% in the case of the standard Taylor rule. It should be noted that there are overlaps in the 95% credibility intervals among the competing models. Generally, the models with money and leverage indicate that monetary policy shocks explain a higher proportion of macroeconomic variations. Also, the model with the Divisia M3 monetary aggregate marginally improves the explanatory power of monetary policy shocks for both output and inflation variations compared to the models with Sum M2. Generally, a model augmented with any measure of money

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Table 2. Test of significant difference between impulse responses of the various models. This is a t test testing the null hypothesis of the difference between the impulse response of any two models is on average indistinguishable

Null: Mean responses are equal	p-Value
Output responses	
Standard Taylor rule and Sum M2	0.032
Standard Taylor rule and Divisia M3	0.082
Inflation responses	
Standard Taylor rule and Sum M2	0.000
Standard Taylor rule and Divisia M3	0.000

Table 3. Variance decomposition of the monetary and nonmonetary models. The estimated contribution of each structural shock to the 4- and 20-quarter-ahead median squared forecast error of each variable in bold and expressed as a percent of total MSE in brackets. 95% credibility intervals are provided in parentheses. The top panel (Standard Taylor rule) is the Baumeister and Hamilton (2018) type model without money and leverage. Divisia M3 and Sum M2 are the monetary models with Divisia M3 and Sum M2, respectively, entering the policy function. The measure of leverage is commercial bank leverage

	4 quarters ahead			20 quarters ahead		
	SS	DS	MPS	SS	DS	MPS
Standard Taylor rule						
Output gap	**0.5** [21%]	**1.48** [62%]	**0.06** [2%]	**0.89** [23%]	**1.80** [47%]	**0.18** [5%]
	(0.21, 1.06)	(0.99, 2.39)	(0.01, 0.25)	(0.29, 3.24)	(1.08, 4.6)	(0.02, 0.77)
Inflation	**0.51** [40%]	**0.56** [44%]	**0.02** [1%]	**0.60** [35%]	**0.67** [39%]	**0.07** [4%]
	(0.30, 0.92)	(0.31, 1.04)	(0.00, 0.11)	(0.33, 1.39)	(0.36, 1.61)	(0.01, 0.36)
Fed funds rate	**0.08** [8%]	**0.17** [16%]	**0.71** [69%]	**0.29** [15%]	**0.33** [17%]	**0.79** [41%]
	(0.01, 0.28)	(0.03, 0.45)	(0.51, 1.03)	(0.05, 1.00)	(0.08, 1.13)	(0.54, 1.26)
Divisia M3						
Output gap	**0.42** [18%]	**1.35** [60%]	**0.13** [6%]	**0.62** [13%]	**2.06** [44%]	**0.36** [8%]
	(0.10, 1.00)	(0.82, 2.22)	(0.04, 0.30)	(0.20, 1.83)	(1.11, 5.38)	(0.09, 1.28)
Inflation	**0.54** [41%]	**0.63** [48%]	**0.04** [3%]	**0.62** [34%]	**0.82** [45%]	**0.10** [6%]
	(0.25, 1.07)	(0.31, 1.20)	(0.01, 0.13)	(0.28, 1.55)	(0.37, 2.33)	(0.02, 0.44)
Fed funds rate	**0.04** [4%]	**0.20** [17%]	**0.81** [69%]	**0.13** [6%]	**0.53** [25%]	**0.97** [46%]
	(0.00, 0.23)	(0.04, 0.55)	(0.51, 1.24)	(0.02, 0.64)	(0.15, 1.76)	(0.58, 1.77)
Sum M2						
Output gap	**0.93** [37%]	**1.19** [47%]	**0.08** [3%]	**1.22** [28%]	**1.62** [37%]	**0.25** [6%]
	(0.51, 1.71)	(0.70, 2.08)	(0.02, 0.24)	(0.61, 3.75)	(0.86, 4.48)	(0.05, 1.04)
Inflation	**0.33** [25%]	**0.87** [66%]	**0.03** [3%]	**0.42** [22%]	**1.07** [57%]	**0.09** [5%]
	(0.15, 0.69)	(0.53, 1.47)	(0.01, 0.10)	(0.18, 1.44)	(0.60, 2.74)	(0.02, 0.41)
Fed funds rate	**0.07** [6%]	**0.11** [9%]	**0.83** [71%]	**0.18** [8%]	**0.36** [18%]	**0.97** [47%]
	(0.00, 0.26)	(0.03, 0.33)	(0.58, 1.24)	(0.03, 0.89)	(0.10, 1.41)	(0.63, 1.65)

(Divisia or Sum M2) and leverage explains a slightly higher variation in output and inflation than the standard Taylor rule without money and leverage.

Monetary policy shocks when the Divisia M3 monetary aggregate and leverage are included in the policy rule are almost as important as supply shocks are in explaining the mean-squared error of the 5-year ahead forecast of output. While demand shocks and supply shocks dominate monetary policy shocks in explaining the variations in output and inflation, the explanatory power of monetary policy shocks generally improves if the monetary authority policy function is augmented with a monetary aggregate and leverage. Monetary policy shocks also explain a slightly higher percentage of the variation in the fed funds rate when the model is augmented with money and leverage. We conclude that a model with money is preferred to a model without money in terms of its ability to explain key macroeconomic variations. We provide evidence in support of Belongia and Ireland (2015, p. 268) who "call into question the conventional view that the stance of monetary policy can be described with exclusive reference to its effects on interest rates and without consideration of simultaneous movements in the monetary aggregates" and Chen and Valcarcel (2021) who advocate for Divisia monetary aggregates as policy indicators (not necessarily as instruments) in order to reconcile empirical results with macroeconomic theoretical predictions.

We note that our sample period (1986:q1 to 2021:q1) represents a period during which the Fed de-emphasized money growth targets and has gradually and finally discontinued reporting target ranges for all other monetary aggregates since 2000. However, as Chen and Valcarcel (2021, pp. 2) recently put it, "the 2007 Financial Crisis and the following protracted effective-lower-bound (ELB) period highlighted some shortcomings of the information content that the federal funds rate alone provides about monetary transmission." As such, we have considered and shown how an augmented policy rule can capture the behavior of the central bank relative to the standard Taylor rule. Also with the emergence of new policy tools (unconventional tools such as quantitative easing/tightening), it is possible to discount any apparent shortcomings of interest rate targeting. However, as Belongia and Ireland (2015, p. 255) recently put it, "the new policy initiatives can be characterized simply as conventional attempts to increase money growth," and it is thus worth exploring augmented Taylor rules for monetary and business cycle analysis.

6. Conclusion

In this paper, we use the approach proposed by Baumeister and Hamilton (2015, 2018) to estimate a Bayesian monetary structural VAR in an attempt to assess the relative importance of supply, demand, and monetary policy shocks in affecting macroeconomic variations. The model is identified based on sign restrictions and other prior information as well as short-run restrictions, thereby avoiding the Fry and Pagan (2011) and Danne (2015) criticisms regarding the pure sign restrictions identification approach. In this regard, Wolf (2020, 2022) illustrates, based on the true structure being a standard new Keynesian model, how sign restrictions alone may be unable to identify the effects of shocks to monetary policy; he shows how the shocks the econometrician identifies may actually be combinations of different types of structural disturbances. We reduce such concerns as in Wolf (2020, 2022) by combining both sign restrictions and other prior information in the identification process. Following Leeper and Roush (2003), and more recently Belongia and Ireland (2015, 2016, 2018) and Dery and Serletis (2021), we allow monetary aggregates and leverage to enter into the identification of monetary policy shocks.

In terms of the dynamic response of the economy to identified monetary policy shocks, we find that a central bank with the standard Taylor rule as its reaction function tends to have a more benign impact on output and inflation. However, when the policy function is augmented with a measure of money and leverage, monetary policy shocks have more pronounced effects on output and inflation. We produce theoretically consistent results and corroborate the findings of Barnett (2016), Jadidzadeh and Serletis (2019), Keating et al. (2019), and Chen and Valcarcel (2021) who all either argue for or provide evidence in support of the use of broad Divisia monetary aggregates in the analysis of monetary policy.

Overall, the paper complements and extends the literature that advocates for the use of properly constructed monetary aggregates such the Divisia monetary aggregates and leverage measures

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in monetary policy and business cycle analysis. It provides evidence of how the inclusion of money and leverage measures in traditional interest rate monetary policy rules increases the relative importance of monetary policy shocks. Given the new wave of interest in the role of central banks in affecting macroeconomic outcomes particularly the current inflation crisis, this paper provides evidence that augmented Taylor rule may better capture the reaction function of the monetary authority relative to the standard Taylor rule. The paper highlights that there is information content of monetary aggregates and leverage useful for the identification and transmission of monetary policy in empirical models.

We have used a constant parameter structural VAR model. The use of a time-varying parameter approach might be useful as leverage and Divisia money may have varying importance in the policy reaction at different stages of the business cycle. In this regard, the Primiceri (2005) model is promising as it captures a possible time-varying behavior of the underlying structure in multivariate data and has become very popular in macroeconomics. Another important reason for using this model is that this model has the capacity to improve the precision of estimation for the sample period that includes periods of extremely low interest rates as it has been in the USA for most of the period in the aftermath of the global financial crisis—see Nakajima (2011) for a detailed discussion.

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