



The transmission of monetary policy shocks through the markets for reserves and money

Michael T. Belongia^a, Peter N. Ireland^{b,*}

^a Professor Emeritus of Economics, University of Mississippi, Box 1848, University, MS 38677, United States

^b Department of Economics, Boston College, 140 Commonwealth Avenue, Chestnut Hill, MA 02467, United States

ARTICLE INFO

JEL Classifications:

E31
E32
E41
E43
E51
E52

Keywords:

Bank reserves
Divisia money
Monetary policy shocks
Quantitative easing
Structural VAR

ABSTRACT

This paper identifies supply and demand curves for bank reserves and a Divisia aggregate of monetary services within a structural vector autoregressive time-series model. Estimated over four sample periods spanning 1967 through 2020, the model illustrates how monetary policy actions can be interpreted with reference to their initial impact on bank reserves and the federal funds rate and their subsequent effects on Divisia money, nominal consumption spending, the aggregate nominal price level, and the unemployment rate. Model estimates attribute strong inflationary effects to monetary policy in the late 1960s and 1970s and also show that changes in the supply of reserves associated with the Fed's large-scale asset purchases since 2008 worked, as intended, to offset deflationary pressures and reduce unemployment. The model describes a much richer monetary policy process than one focused on interest rates alone.

1. Introduction

For nearly four decades, the Federal Reserve has implemented monetary policy by setting a target for the federal funds rate. The federal funds rate, however, never has been administered directly by the Fed. Instead, as the interest rate charged by one bank to another on overnight loans of reserves – deposits held by banks at the Fed – the funds rate must adjust to equilibrate supply and demand in the market for reserves. Thus, while it has been standard practice to refer to the funds rate as the Fed's policy instrument, the endogenous nature of the funds rate suggests it is better characterized as an intermediate target.

The Fed's ability to hit that target rests, ultimately, on its status as the monopoly supplier of bank reserves and its willingness to adjust that supply, either to move the funds rate to a new target value or to offset any change in the demand for reserves that would otherwise move the funds rate away from the target value. More specifically, when the Fed conducts an open market purchase and uses its monopoly power to increase the supply of reserves, it initiates a process of bank deposit creation that at first accelerates growth in the broader monetary aggregates and, after some lag, growth in the dollar volume of spending by households and firms. Although the way this increase in nominal spending breaks down into changes in real economic activity versus inflation appears to vary over time, a long tradition in economics running from Hume ([1752] 1987) to Lucas (1972) associates unexpected monetary expansions with

The authors would like to thank two anonymous referees and conference participants at the American Institute for Economic Research and the Mercatus Center at George Mason University for extremely helpful comments on previous versions of this paper.

* Corresponding author.

E-mail address: peter.ireland@bc.edu (P.N. Ireland).

<https://doi.org/10.1016/j.jmacro.2024.103590>

Received 16 June 2023; Received in revised form 19 December 2023; Accepted 7 February 2024

Available online 10 February 2024

0164-0704/© 2024 Elsevier Inc. All rights reserved.

increases in output and employment in the short run, followed by a rise in prices in the long run.

Surprise increases in the supply of reserves also are widely believed to generate a “liquidity effect” that not only reduces the federal funds rate, but also decreases nominal interest rates along the entire yield curve.¹ As discussed by [Belongia and Ireland \(2021\)](#), however, the most recent New Keynesian models go much further, eschewing explicit consideration of bank reserves and the monetary aggregates altogether and choosing instead to describe the effects of monetary policy actions exclusively through the effects they have on the current value of the federal funds rate and its expected future path. As emphasized by [Leeper and Roush \(2003\)](#), taking the New Keynesian view also amounts to assuming that the Federal Reserve and banking system act, in unison, to make the supply curves for reserves and money infinitely elastic at the targeted funds rate over periods as long as a quarter year. Absent from this view is any role for changes in the public’s demand for reserves to influence the funds rate or any response by the Fed to such changes. Assuming the public’s demand for reserves is stable or the Federal Reserve’s supply of reserves is infinitely elastic precludes any consideration of how quantity variables might transmit the effects of monetary policy actions through channels apart from the federal funds rate alone.

Taking the New Keynesian view, therefore, makes it particularly difficult to rationalize the Federal Reserve’s large-scale asset purchases – known popularly as “quantitative easing” or “QE” – conducted while the federal funds rate target lies in a range near zero. One conjecture is that the Fed conducts QE for signaling purposes alone, to reinforce expectations that the federal funds rate will remain “lower for longer” and thereby deliver additional monetary stimulus through the New Keynesian interest rate channel. According to New Keynesian theory, however, the asset purchases themselves, and the dramatic increases in the dollar volume of bank reserves that they require, have no direct effects on inflation or unemployment.

These considerations beg several questions, most importantly whether it is accurate to describe the Federal Reserve’s behavior as one that supplies bank reserves elastically, an assumption that might allow the stance of its monetary policy to be described with exclusive reference to the federal funds rate. It also is interesting to ask whether there is any evidence to suggest that changes in the supply of bank reserves during and after the zero-interest period of 2008–15 had effects of their own on broad monetary growth, nominal spending, inflation, and unemployment. Finally, it is worthwhile to ask, as [Fama \(2013, p.191\)](#) does, whether the observed co-movement between the federal funds rate and nominal interest rates at longer maturities reflects “a powerful Fed” that exerts considerable control over longer-term interest rates by targeting the funds rate or a “passive Fed” that simply adjusts the funds rate target to maintain alignment with longer-term rates.

To help answer these questions, this paper estimates a structural vector autoregression (VAR) that makes distinctions between the Federal Reserve’s supply of and the banking system’s demand for reserves and between the public’s demand for and banking system’s supply of the monetary services provided by the safe and highly liquid assets comprising the M2 aggregate. Finding that the Federal Reserve’s supply of reserves function is upward-sloping, that variations in quantity aggregates have effects on economic activity independent of any influence associated with variations in the funds rate alone, or that monetary policy actions that affect the funds rate do not invariably produce similar movements in longer-term nominal rates would call for a richer view of how Federal Reserve actions affect real variables in the short run and nominal magnitudes in the long run.

The model is estimated separately with four samples of monthly data that correspond to periods across which the Federal Reserve changed the basic features of its approach to managing the supply of bank reserves while the banking system, likewise, appears to have changed its approach to managing its demand for reserves.² Over all four periods, 1967:01 – 1979:09, 1983:01 – 1994:12, 1995:01 – 2007:12, and 2009:01 – 2020:02, the model succeeds in identifying upward-sloping supply curves and downward-sloping demand curves linking reserves to the federal funds rate and the Divisia M2 monetary aggregate to its own user-cost dual. For only one period, beginning in 1983:01 and running through 1994:12, are the estimates in any way consistent with the infinitely-elastic reserves supply curve imposed, implicitly, by the popular view that summarizes the Federal Reserve’s policy stance using observations on the funds rate alone.

Over the other three sample periods, parameter estimates and impulse responses generated from the model provide a consistent view that associates surprise monetary expansions with both an increase in the supply of bank reserves and a decrease in the federal funds rate. Across all sample periods, these expansionary monetary policy shocks generate faster growth in Divisia M2 and nominal spending. And while the responses of inflation and unemployment to these identified monetary policy disturbances change across sample periods, the estimates for the most recent 2009:01 – 2020:02 period show prices rising and unemployment falling as bank reserves and Divisia M2 increase after an expansionary shock, even as the funds rate was constrained by its zero lower bound. Of course, it is possible that these effects on inflation and unemployment reflect a signaling channel rather than a direct impact of changes in reserves on macroeconomic conditions. But while the estimates from the early samples confirm that monetary policy shocks trigger liquidity effects on longer-term interest rates, these effects disappear in the data after 1995. Altogether, the results show that the Federal Reserve delivered additional monetary stimulus through its control of quantity variables despite the constraints imposed by the zero lower bound on its federal funds rate target. The results also highlight the difficulties in detecting strong effects of QE on longer-term interest rates.

In modeling the supply of and demand for reserves to gauge the stance of monetary policy and estimate its effects, this paper finds

¹ For more discussion and evidence on this issue, see [Fama \(2013\)](#).

² [Dutkowsky and VanHoose \(2017\)](#), [Goodhart \(2017\)](#), and [Ryan and Whelan \(2023\)](#) present more detailed theoretical and empirical analyses linking regime changes in the Federal Reserve’s policies of reserves supply to important shifts in banks’ reserves demand, with particular emphasis on comparing pre- and post-2009 data. The empirical analysis here confirms that these regime shifts have occurred and highlights, as well, that similar though perhaps less dramatic regime changes appear repeatedly throughout the years since 1967.

its closest antecedents in [Gordon and Leeper \(1994\)](#) and [Smith \(2019\)](#).³ [Gordon and Leeper \(1994\)](#) identify supply and demand curves for reserves in a structural VAR estimated with monthly data from 1982:12 through 1992:04, and supply and demand curves for M2 in a separate model estimated over the same period. Their results indicate that variations in output and the aggregate price level over that period can be associated with monetary policy shocks emanating from either the market for reserves or M2. Both of their models prove less successful, however, at distinguishing between reserves or M2 supply and demand over an earlier period running from 1971:01 through 1979:09. The single model developed here, by contrast, combines equations for the supply of and demand for reserves and Divisia M2 to link explicitly the market for reserves to the market for broader monetary services. This single model works, in addition, to provide a theoretically consistent interpretation of the data from sample periods spanning the much longer period from 1967:01 through 2020:02.

[Smith \(2019\)](#) uses a small-scale VAR to identify a liquidity effect through which changes in the supply of reserves affect the opportunity cost to banks of holding reserves, a cost measured by the spread between the federal funds rate and the interest rate paid by the Fed to banks on excess reserves. Estimated over a short sample of weekly data running from October 2017 through November 2018, [Smith's \(2019\)](#) results imply the existence of a downward-sloping demand curve for reserves over a very recent sample period.⁴ When estimated within the larger model developed here, a similar demand curve for reserves appears over a longer sample of post-2008 data. In addition, the larger VAR provides estimates of the effects that unexpected changes in reserves supply have had, not only on the spread between the federal funds rate and the interest rate on excess reserves, but also on the Divisia M2 monetary aggregate, nominal personal consumption expenditures, the aggregate nominal price level, and the unemployment rate.

Thus, [Gordon and Leeper \(1994\)](#), [Smith \(2019\)](#), and this paper all imply that fully understanding monetary policy and its effects on the economy requires a more detailed analysis of reserves supply and demand and cannot be achieved by examining the behavior of the federal funds rate alone. Also, as noted above, [Fama \(2013\)](#) expresses skepticism as to whether the observed co-movement between the federal funds rate and longer-term nominal interest rates reflects the Federal Reserve's ability to influence longer-term rates via its federal funds rate targeting procedures. The results here confirm his suspicions by showing that while monetary policy disturbances affecting the funds rate do have similar effects on longer-term rates in data samples ending before 1995, these effects disappear in more recent data. Yet, the results presented here add considerable nuance by also showing that these same monetary policy disturbances *have* affected nominal spending, the aggregate price level, and the unemployment rate since 1995. Once again, therefore, a model that includes data on reserves and Divisia money provides a description of monetary policy that is much richer than those based on interest rates alone.

Finally, the results here join those presented in a large literature that shows how “measurement matters” in efforts to link changes in a broad monetary aggregate to changes in key macroeconomic variables including – but not limited to – real GDP growth, inflation, and nominal spending growth as their sum. [Barnett \(1980, 1982\)](#) explains the rationale for using a superlative (Divisia) index to measure a monetary aggregate and describes how the index is constructed. [Barnett \(2012\)](#) provides a recent and comprehensive discussion of Divisia monetary aggregation and its usefulness in monetary policy analysis. [Chrystal and MacDonald \(1994\)](#) coin the phrase “Barnett critique” to explain why the statistical relations between money and other variables predicted by macroeconomic theory appear stronger when Divisia monetary aggregates replace their “simple-sum” counterparts in estimating and testing these relations. [Belongia \(1996\)](#) and [Hendrickson \(2014\)](#) revisit a series of results from widely-cited studies in monetary economics to illustrate the relevance of the Barnett critique. [El-Shagi et al. \(2015\)](#), [Binner and Kelly \(2017\)](#), [Ghosh and Bhadury \(2018\)](#), [Tang et al. \(2020\)](#), [Dery and Serletis \(2021\)](#), [El-Shagi \(2021\)](#), [Ghosh and Adil \(2023\)](#), and [Molinas et al. \(2023\)](#) present more recent examples. Most directly related to the post-2009 results presented here, [Keating et al. \(2019\)](#) and [Bordo and Duca \(2023\)](#) emphasize how shifts in Divisia money growth can be used to track the changing stance of monetary policy during periods when the Federal Reserve used large-scale asset purchases to provide additional stimulus while holding its traditional federal funds rate target in a range near the zero lower bound. The analysis here complements and extends all of this previous work by combining specifications for the public's demand for and the banking system's supply of the monetary services measured by the Divisia monetary aggregates with descriptions of the Federal Reserve's supply of and the banking system's demand for reserves to provide a more detailed view of how Federal Reserve policy actions influenced macroeconomic outcomes through the effects on the markets for reserves and money both before and since 2009.

2. The data

Because so few recent studies of monetary policy and its effects use data on bank reserves, it is useful to start by describing these data and their sources. For samples starting in 1967 and running through 2007, the data used here are compiled by the Federal Reserve Bank of St. Louis and made available through the Bank's FRED database. They are described by [Anderson and Rasche with Loesel](#)

³ [Ramey \(2016\)](#) surveys the broader literature that identifies and estimates the effects of monetary policy and other macroeconomic shocks.

⁴ [Bräuning \(2017\)](#) uses a single-equation regression model to estimate a liquidity effect of exogenous changes in reserves, identified using changes in the Treasury General Account, on the federal funds rate with daily data from September 2013 through June 2018. Like those in [Smith \(2019\)](#), these results imply the existence of a downward-sloping demand curve for reserves, but stop short of tracing out the effects of reserves supply shocks on other monetary and macroeconomic variables as is done here. [Smith and Valcarcel \(2023\)](#) detect evidence of time-variation in the size of identified liquidity effects in weekly data from September 2014 through August 2019, depending on whether the Fed was reinvesting fully the proceeds from its maturing assets or allowing those assets to “run off” of its balance sheet; [Lu and Valcarcel \(2023\)](#) extend this analysis to cover the second episode of “quantitative tightening” that began in 2022. Again, the focus of these papers is on interest rates and other measures of financial conditions rather than macroeconomic variables.

(2003) and displayed in the top left-hand panel of Fig. 1. These data are seasonally adjusted and adjusted, as well, for changes in statutory reserve requirements and for the effects of deposit sweep programs. As Anderson and Rasche (2001) explain, these programs allowed banks, beginning in 1995, to circumvent statutory reserve requirements by reclassifying for regulatory purposes their customers' demand deposits as savings deposits.

Unfortunately, the St. Louis Fed discontinued reporting its adjusted reserves series in November 2019. For samples starting after 2008, therefore, an alternative series on reserves is constructed by subtracting figures for the currency component of M1 provided by the Federal Reserve Board's H.5 release from figures on the monetary base provided by the Board's H.3 data release. FRED reports historical time series for both sets of figures. The result is a series for the base that is not seasonally adjusted. The top right-hand panel of Fig. 1, however, shows that the massive post-2008 expansion of the Fed's balance sheet, by itself, appears to have eliminated any signs of seasonal fluctuations in this measure of reserves.

Initial inspection of the monthly reserves data in the top two panels of Fig. 1 illustrate several important changes in the Fed's approach to reserves supply management and, more generally, monetary policy implementation. The behavior of these data and what is known about changes in the Fed's approach to monetary policy suggest breaking the full period from 1967:01 through 2020:02 into four subsamples.⁵ The remaining panels of Fig. 1 identify the four periods while zooming in to provide more detailed views of the data.

The first period runs from 1967:01 through 1979:09 and is distinguished by the Great Inflation of the 1970s. Because the Fed is generally believed to have switched tactics between 1979:10 through 1982:12, a change that allowed more volatility in the federal funds rate in order to exercise greater control over the supply of bank reserves, this short transition period is excluded from the analysis here.⁶ Therefore, the second period runs from 1983:01 through 1994:12. As shown in the graphs from the middle row of Fig. 1, both of these periods feature robust growth in bank reserves. In fact, reserves grew at an average annual rate of more than 8 percent from 1983 through 1994, faster than the 5.5 percent rate from 1967 through 1979. This basic fact underscores the need for a model that distinguishes between exogenous changes in the supply of reserves undertaken to adjust the federal funds rate to a new target value and changes in supply undertaken to counter any changes in reserves demand that would otherwise take the funds rate away from its target value. By accounting for changes in reserves demand as well as reserves supply when measuring the effects that monetary policy has on inflation and other key macroeconomic variables, the model can capture channels of monetary policy transmission apart from looking at the federal funds rate in isolation.

In sharp contrast to these two early samples, the bottom left-hand panel of Fig. 1 shows that the St. Louis measure of reserves grew at an average annual rate of less than 1 percent over the third sample period, 1995:01 – 2007:12. Since, as noted above, this series already is adjusted for the effects of sweep programs, the data suggest that these programs formed only part of banks' efforts to economize on their holdings of reserves during this period. Again, this observation points clearly to the need to distinguish between changes in the demand for as well as the supply of reserves when gauging the effects of monetary policy on the economy. The top left-hand panel of Fig. 1 also shows sharp spikes in the quantity of reserves held by banks around the year 2000 calendar change and the 2001 terrorist attacks. Since these large but transitory shifts in reserves supply clearly were intended to accommodate equally large shifts in reserves demand, the spikes are removed from the data by interpolating the St. Louis series between 1999:08 and 2000:03 and again between 2001:08 and 2001:12. The smoothed series is shown in the bottom left-hand panel and these are the data used to estimate the model.

Likewise, the initial upward spike in the Federal Reserve Board's measure of reserves in 2008 shown in the top right-hand panel of Fig. 1 was accompanied by the introduction of interest payments by the Fed to banks on their holdings of required and excess reserves.⁷ As Ireland (2019) explains in more detail, interest on reserves was, at first, meant to allow the Fed to expand its emergency lending programs in the wake of the failure of Lehman Brothers and the bailout of AIG in the fall of 2008 without fueling inflation. The payment of interest on reserves accomplished this by bolstering reserves demand to match the necessary increase in reserves supply. Hence, the fourth and final sample period begins in 2009:01, following the transition to the new policy regime featuring interest on excess reserves, and continues through 2020:02. Thus, this period still covers virtually all of the interval, from November 2008 through October 2014, when the Fed was conducting three rounds of quantitative easing, as well as an overlapping but longer period, from mid-December 2008 through mid-December 2015, when the federal funds rate target was held in a range near zero.

Over this period following the 2008 transition to the new regime with interest on reserves, the dollar volume of reserves rose dramatically from \$886 billion in 2009:01 to a peak of \$2.85 trillion in 2014:08. Even with the subsequent reduction to \$1.74 trillion in 2020:02, reserves still grew, on average, at a 6 percent rate over the 11 years in total. This recent growth was much faster than in the years from 1995 through 2007 immediately preceding the financial crisis. The recent growth, however, was *slower* than the average growth rate from 1983 through 1994 and only slightly faster than the average growth rate from 1967 through 1979. Once more, these comparisons suggest that only a model capable of disentangling reserves supply and demand can make sense of all these data.

Fig. 2 plots the other series used to estimate the model developed next. All series are drawn from FRED, except those for Divisia M2

⁵ The 1967:01 starting date is determined by the availability of the data on Divisia M2, described below; the 2020:02 ending date is chosen to avoid distortions associated with the Covid-19 pandemic. Results quite similar to those presented below also can be derived using data on the St. Louis measure of reserves throughout at the cost of ending the sample period in 2019:11.

⁶ See Cook (1989) and Gilbert (1994) for detailed discussions and analyses of Federal Reserve policy during this 1979–82 episode. Although the Federal Reserve announced a shift to targeting paths for the monetary aggregates in October 1979, there is evidence to suggest that, in practice, interest rate targeting never was abandoned.

⁷ As noted above, Dutkowsky and VanHoose (2017), Goodhart (2017), and Ryan and Whelan (2023) focus in particular on this regime change brought about through the payment of interest on reserves and the coincident shift in banks' demand for reserves that it triggered.

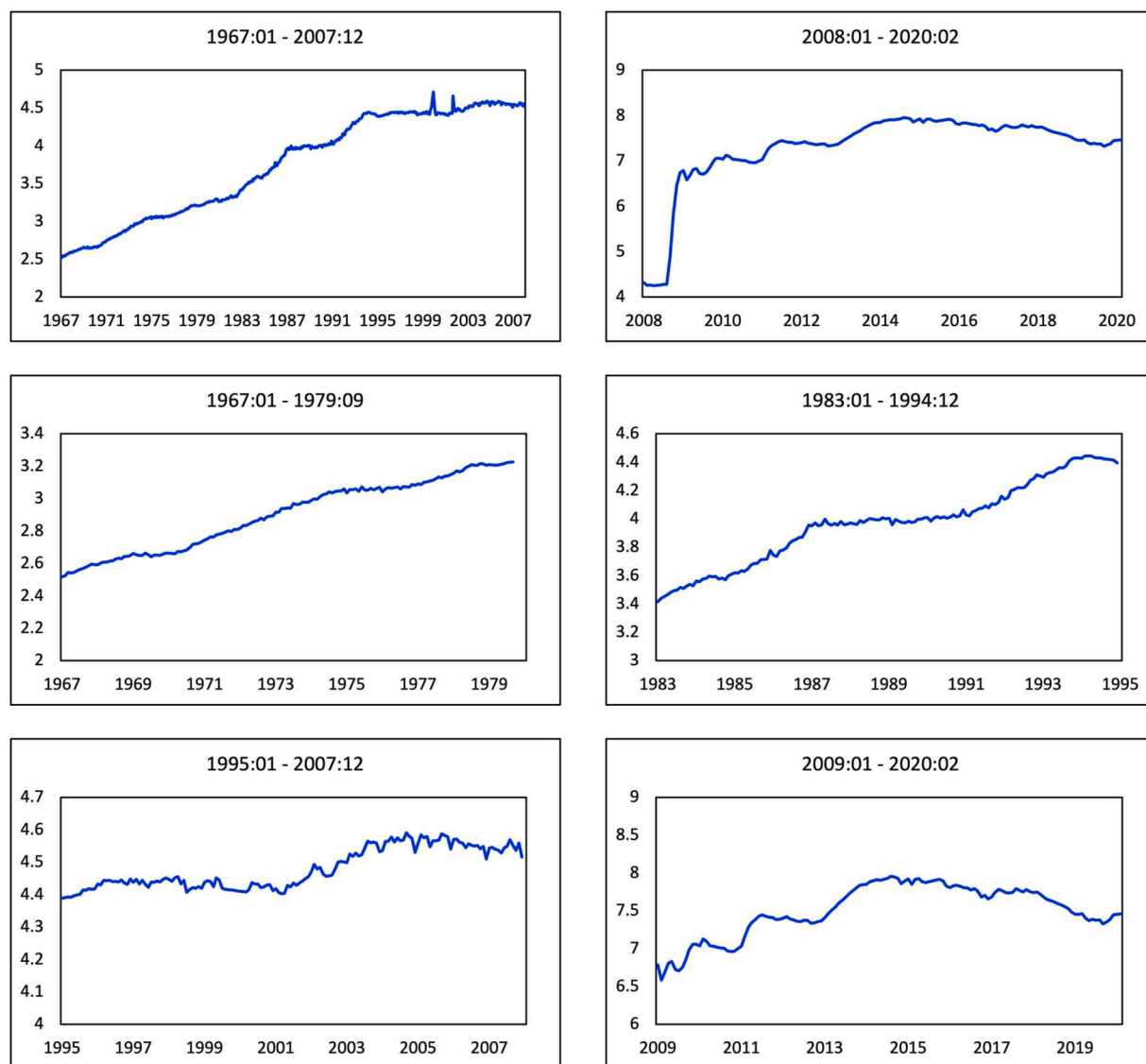


Fig. 1. Bank Reserves. The top two panels plot the series for bank reserves, adjusted by the Federal Reserve Bank of St. Louis for changes in reserve requirements over the period from 1967 through 2007 and as reported by the Federal Reserve Board from 2008 through 2020. The remaining panels plot the series used to estimate the structural VAR over the indicated subsamples. All series are in natural logarithms.

and its user cost, which are available through the website of the Center for Financial Stability. The aggregate price level is measured by the price index for personal consumption expenditures (PCE). It, as well as the unemployment rate and nominal personal consumption expenditures, is seasonally adjusted. As shown by the units along the graphs' vertical axes, the series for the PCE index and PCE itself enter the model in logs; the unemployment rate enters as a decimal.

As explained below, the federal funds rate is used together with the measures of reserves to characterize monetary policy for the first three sample periods. In the fourth, post-2008 sample, the spread between the funds rate and the interest rate paid by the Fed on excess reserves replaces the funds rate as a measure of the opportunity cost to banks of holding reserves. The bottom right-hand panel of Fig. 2 shows that, in fact, the interest rate on excess reserves exceeds the funds rate for most of the 2009:01 – 2020:02 sample period, making this spread negative until the end of 2018.⁸ Throughout, the interest rate or interest rate spread enters the model as a decimal; none of these interest rate data require seasonal adjustment.

The Divisia M2 aggregate, described by Barnett et al. (2013), accounts for monetary services generated by the same safe and highly

⁸ Ireland (2014) shows that banks' demand for reserves remains finite and well-defined, even when the opportunity cost becomes zero or negative, if there are other resource or regulatory costs of holding reserves.

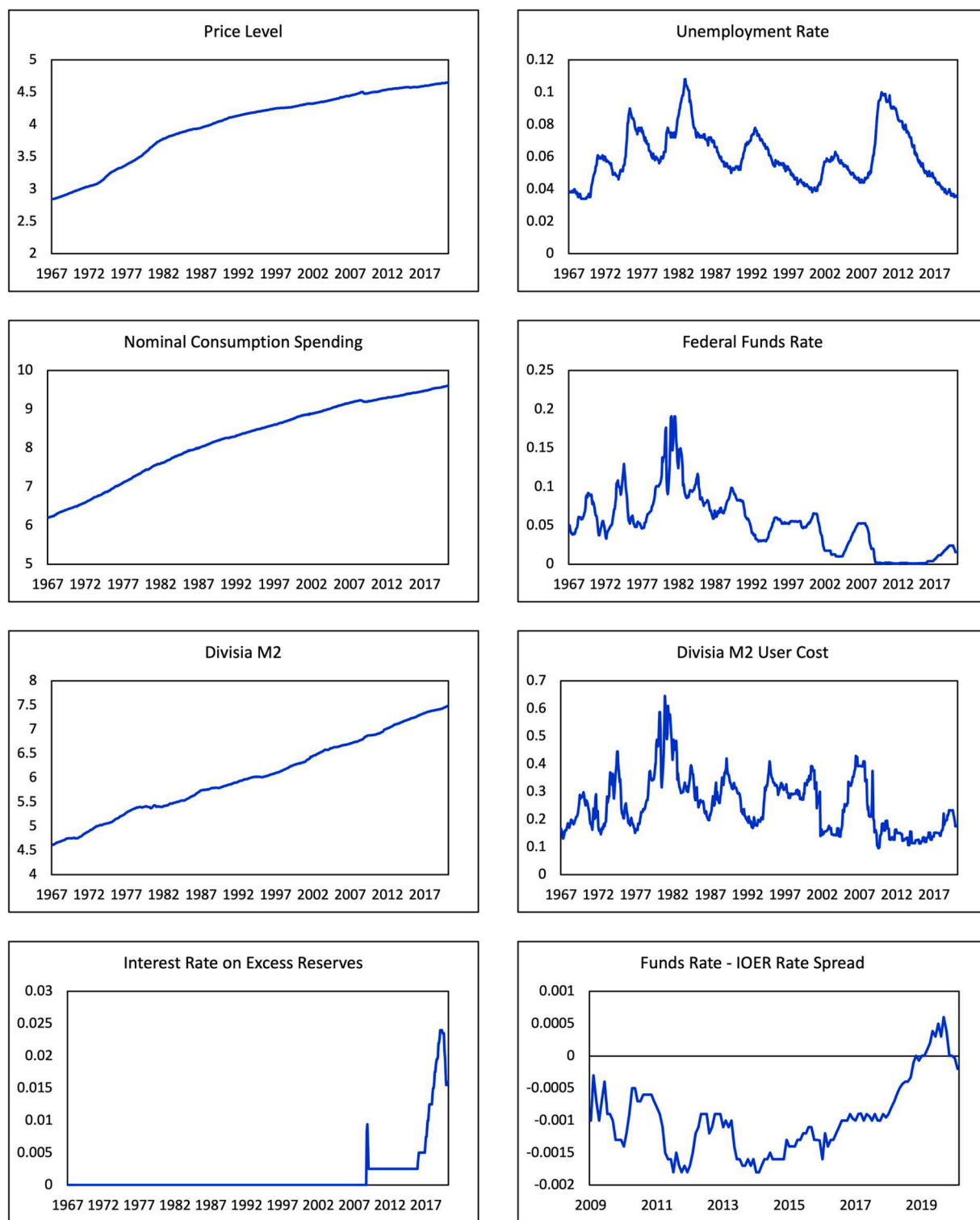


Fig. 2. Additional Data used to Estimate Structural VAR. The PCE price index, personal consumption expenditures, and Divisia M2 are in natural logarithms.

liquid assets – currency, travelers checks, demand deposits, other checkable deposits, savings deposits, retail money market mutual fund shares, and small time deposits – included in the Federal Reserve’s simple-sum M2 aggregate. The Divisia alternative improves on the simple-sum aggregate by using economic index number theory to exploit information contained in the spreads between interest

rates on benchmark illiquid assets and the various components of M2. These spreads account for differential flows of monetary services provided by different liquid assets that substitute for one another, imperfectly, in portfolios held by households and firms.⁹ Construction of Divisia M2 yields, as an equally valuable by-product, a price dual measuring the user cost of the quantity aggregate; this also is plotted in Fig. 2.¹⁰ The Divisia M2 quantity aggregate enters the model in logs and the Divisia M2 user cost appears as a decimal; both series are constructed with seasonally adjusted data.

3. The model

3.1. The pre-2008 samples

For the three sample periods before 2008, the monthly model describes the behavior of $n = 7$ variables: the PCE price index P_t , the unemployment rate U_t , nominal consumption spending C_t , the federal funds rate R_t , bank reserves H_t , the Divisia M2 aggregate of monetary services M_t , and the associated Divisia M2 user cost UC_t . The 7×1 vector

$$X_t = [P_t \ U_t \ C_t \ R_t \ H_t \ M_t \ UC_t]'$$

collects and orders these variables. The structural model takes the form

$$AX_t = \mu + \sum_{j=1}^q A_j X_{t-j} + \varepsilon_t, \quad (1)$$

for $t = 1, 2, \dots, T$, where $q = 3$ is the maximum lag length, T is the sample size, A is an $n \times n$ matrix of impact parameters, μ is an $n \times 1$ vector of intercept coefficients, each A_j , $j = 1, 2, \dots, q$, is an $n \times n$ matrix of autoregressive coefficients, and ε_t is an $n \times 1$ vector of serially uncorrelated structural shocks with mean zero and covariance matrix I_n , the $n \times n$ identity matrix.¹¹

The reduced form implied by (1) is

$$X_t = \nu + \sum_{j=1}^q \Phi_j X_{t-j} + u_t, \quad (2)$$

where $\nu = A^{-1}\mu$, $\Phi_j = A^{-1}A_j$ for all $j = 1, 2, \dots, q$, and $u_t = A^{-1}\varepsilon_t$ is an $n \times 1$ vector of statistical innovations that satisfies

$$Eu_t u_t' = (A^{-1})(A^{-1})' = \Omega.$$

Since the reduced-form covariance matrix Ω has only $n(n+1)/2 = 28$ distinct elements, at least 21 restrictions must be imposed on the 49 elements of A in order to identify the structural disturbances in ε_t based on information contained in the data. Belongia and Ireland (2015, 2016, 2018) show how some of these restrictions can be used to distinguish more clearly between the supply of and demand for the Divisia monetary aggregates; here, these ideas are extended to model more fully how the supply of and demand for reserves shape the effects that monetary policy has on the economy.

Temporarily suppressing the intercept and autoregressive terms that appear in (1) to focus on the contemporaneous relationship $AX_t = \varepsilon_t$ between the observable variables and the structural disturbances, suppose in particular that

$$\begin{bmatrix} a_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -a_3 & a_2 & 0 & 0 & 0 & 0 & 0 \\ -a_5 & -a_6 & a_4 & 0 & 0 & 0 & 0 \\ -a_8 & a_9 & 0 & a_7 & -a_{10} & 0 & 0 \\ 0 & 0 & 0 & a_{12} & a_{11} & -a_{11} & 0 \\ 0 & 0 & -a_{13} & 0 & 0 & a_{13} & a_{14} \\ a_{17} & 0 & 0 & -a_{16} & 0 & -a_{17} & a_{15} \end{bmatrix} \begin{bmatrix} P_t \\ U_t \\ C_t \\ R_t \\ H_t \\ M_t \\ UC_t \end{bmatrix} = \begin{bmatrix} \varepsilon_t^1 \\ \varepsilon_t^2 \\ \varepsilon_t^3 \\ \varepsilon_t^{pp} \\ \varepsilon_t^{hd} \\ \varepsilon_t^{md} \\ \varepsilon_t^{ms} \end{bmatrix}. \quad (3)$$

The restrictions imposed on A by (3) allocate the model's seven equations into three blocks. The first block, consisting of the top

⁹ See Barnett (1980, Barnett, 1982, 2012) for more detailed descriptions of the theory that underlies Divisia monetary aggregates and their construction.

¹⁰ See Belongia (2006) and Belongia and Ireland (2006, 2019) for theoretical and empirical analyses of the Divisia monetary user-cost dual as an opportunity cost measure in estimated money demand equations and as a direct measure of inflation-tax effects of monetary policy in a dynamic, stochastic business cycle model without nominal price and wage rigidities.

¹¹ The choice of maximum lag $q = 3$ is dictated mainly by the relatively short length of each of the four samples. The parameter estimates reported and discussed below are generally robust to variations in q ; models with longer lags produce impulse responses that are similar, as well, but feature wiggles and jagged oscillations that are symptomatic of overfitting.

three rows, reflects a timing assumption: that the macroeconomic variables P_t , U_t and G_t react to shocks from the monetary sectors with a one-month lag. While these assumptions help identify structural disturbances to the monetary sectors, they leave the first three elements of the vector ε_t with only a general interpretation as shocks to goods and labor markets that *do* affect these variables within the month. Meanwhile, the second block, consisting of the next two rows, describes supply and demand in the market for reserves; and the third block, consisting of the last two rows, describes the demand for and supply of monetary services as measured by Divisia M2.

In particular, the fourth row of (3) describes a monetary policy rule of the form

$$a_7 R_t - a_{10} H_t = a_8 P_t - a_9 U_t + \varepsilon_t^{mp}. \quad (4)$$

The left-hand side of this equation associates tighter monetary policy with both a higher federal funds rate and a diminished supply of reserves. The right-hand side allows the Federal Reserve to adjust its policy stance within the month to changes in aggregate prices and unemployment. In fact, in the special case where $a_{10} = 0$, (4) collapses to a rule, similar to [Taylor's \(1993\)](#), for setting the funds rate with reference to inflation and unemployment. As noted by [Gordon and Leeper \(1994\)](#), [Leeper \(1995\)](#), and [Leeper and Roush \(2003\)](#), therefore, the more general rule in (4) highlights that the popular approach of describing monetary policy using the federal funds rate alone imposes implicitly the assumption that the Fed sets a perfectly elastic supply curve for reserves over the course of each month. The more flexible specification in (4) allows this hypothesis to be tested, by examining whether estimates of a_{10} appear significantly greater than zero. In any case, if the Fed tightens policy within the month in response to higher inflation or lower unemployment, estimates of a_8 and a_9 should be positive as well.

The fifth row of (3) describes the demand for nominal reserves as depending proportionally on nominal money as a scale variable and inversely on the federal funds rate as an opportunity cost:

$$a_{11}(H_t - M_t) = -a_{12}R_t + \varepsilon_t^{hd}. \quad (5)$$

Thus, following [Meigs \(1962\)](#), [Morrison \(1966\)](#), and [Burger \(1971\)](#), the model depicts banks' optimizing behavior as determining the ratio of reserves to a broader concept of money that includes deposits as a function of the nominal interest rate.¹²

Several aspects of the specification for reserves demand in (5) deserve further discussion. First, both the supply curve (4) and the demand curve (5) link the quantity of reserves H_t to the federal funds rate R_t . The two curves are distinguished partly through exclusion restrictions that allow the price level P_t and the unemployment rate U_t to shift the supply curve but not the demand curve and the monetary aggregate M_t to shift the demand curve but not the supply curve. The two curves are distinguished, as well, by the unitary scale elasticity restriction in (5) that links the real variable $H_t - M_t$, that is, the inverse of the money multiplier, to the federal funds rate. This additional, quantity-theoretic restriction turns out to be important: without it, both (4) and (5) relate the nominal quantity of reserves to the federal funds rate, and the resulting parameter estimates make it difficult, theoretically, to interpret either equation as describing reserves supply or demand and, empirically, to distinguish between them.

Second but related, while the unitary scale elasticity imposed in (5) is crucial for identifying distinct reserves supply and demand curves, this restriction is imposed only on the impact coefficients from the matrix A in (1) and shown in more detail in (3). The autoregressive coefficients from the matrices A_j , $j = 1, 2, \dots, q$, in (1) are unconstrained, allowing for a more flexible response of the money multiplier to shocks of all kinds after a one-month lag. Thus, the model is not inconsistent with the richer dynamics of the money multiplier that appear both in theory and evidence supplied by [Dutkowsky and VanHoose \(2017\)](#), [Goodhart \(2017\)](#), and [Ryan and Whelan \(2023\)](#). Moreover, the emphasis that all of these studies place on regime shifts is reflected here, as well, by an estimation strategy that specifically accounts for changes in both Federal Reserve policy and bank behavior over several distinct subsamples.

Third and finally, even as the model developed here goes beyond previous VAR studies, including [Gordon and Leeper \(1994\)](#), [Belongia and Ireland \(2015, 2016, 2018\)](#), and [Smith \(2019\)](#), by describing separately the markets for bank reserves and liquidity services measured by a broader monetary aggregate, it nevertheless stops short of considering the full range of margins along which optimal bank decision-making take place. It would be useful, for instance, to expand the VAR still further, to account for the changes in lending that [Dia \(2013\)](#) and [Dutkowsky and VanHoose \(2017\)](#) find important in describing banks' process of adjustment to shocks. Adding bank loans and other related variables to the model would be a challenge, however, given the short length of each of the four data samples used here.¹³

The sixth row of (3) describes the public's demand for monetary services,

$$a_{13}(M_t - C_t) = -a_{14}U_t + \varepsilon_t^{md}, \quad (6)$$

using the same form implied by the theoretical model from [Belongia and Ireland \(2019\)](#), in which the monetary services provided by a range of liquid assets, paying interest at different rates, enters together with consumption into a representative household's utility function. This model implies a unitary scale elasticity of money demand, and thereby links the ratio of nominal money to nominal consumption spending to the user cost aggregate as the corresponding opportunity cost variable. Finally, the seventh row of (3),

¹² Recall from the discussion of the data above that reserves and Divisia M2, together with the price level and personal consumption expenditures, enter the model in logs, while the unemployment rate, the federal funds rate, and the M2 user costs enter in levels as decimals.

¹³ Bayesian methods, following [Leeper, Sims and Zha \(1996\)](#) or the least absolute shrinkage and selection (LASSO) approach pioneered by [Tibshirani \(1996\)](#) and [Hsu, Hung, and Chang \(2008\)](#) and used by [El-Shagi \(2021\)](#) to study the effects of monetary policy shocks might prove useful in meeting this challenge.

$$a_{15}UC_t = a_{16}R_t + a_{17}(M_t - P_t) + \varepsilon_t^{ms}, \quad (7)$$

describes the banking system's supply of monetary services, building on the stylized model of deposit creation appearing in [Belongia and Ireland's \(2014\)](#) New Keynesian model. There, banks hold reserves to support the process of deposit creation; perfect competition in the banking system then implies that changes in the federal funds rate, as the opportunity cost of holding reserves, get passed along to consumers in the form of a higher user cost of money. Here, as in [Belongia and Ireland \(2015, 2016, 2018\)](#), the specification is extended to allow an increase in the supply of real monetary services to increase the user cost as well, as it would if banks' deposit-creation activities feature decreasing instead of constant returns to scale.¹⁴

The net product of these individual specifications is that, in (3), ε_t^{mp} is the identified shock to the Fed's monetary policy via reserves supply, ε_t^{hd} is the shock to banks' reserves demand, ε_t^{md} is a shock to the public's demand for monetary services, and ε_t^{ms} is a shock to banks' supply of those same monetary services. Rather than focusing on a change in the federal funds rate alone, the model highlights how the demands and supplies of reserves and Divisia monetary services interact to shape how Federal Reserve policy actions influence aggregate activity.

As noted by [Hamilton \(1994, pp.331–2\)](#) and [Lütkepohl \(2006, pp.372–3\)](#), the model can be estimated by maximum likelihood through a two-step procedure that begins by applying ordinary least squares to each of the equations in the reduced form and computing

$$\hat{\Omega} = \frac{1}{T} \sum_{t=1}^T \hat{u}_t \hat{u}_t',$$

where $\hat{u}_t$ is the vector of residuals from (2). Then, the parameters of A can be found by maximizing the concentrated log likelihood function

$$\ln(A) = \frac{T}{2} \left\{ -n \ln(2\pi) + \ln(|A|^2) - \text{trace}[(A' A) \hat{\Omega}] \right\}.$$

[Lütkepohl \(2006, pp.373\)](#) also provides formulas for computing the standard errors of the elements of A . Meanwhile, [Rubio-Ramírez, Waggoner, and Zha's \(2010, pp.673–4\)](#) theorems 1 and 3 can be applied to show that the restrictions imposed on A in (3) are sufficient to identify all of the model's parameters. With the diagonal elements of A normalized to be positive, the economic interpretations of (4)–(7) suggest that estimates of the parameters a_8 , a_9 , a_{10} , a_{12} , a_{13} , a_{14} , a_{16} and a_{17} should all be positive, or at least non-negative.¹⁵

3.2. The post-2008 sample

As suggested earlier, analysis of data from the most recent sample period is complicated by two factors. First, the Federal Reserve introduced interest on reserves in October 2008, expanding greatly banks' demand for reserves even as the Fed was acting, at the same time, to greatly increase the quantity of reserves supplied through emergency lending programs following the failure of Lehman Brothers and the bailout of AIG. Second, from December 2008 through December 2015, the Fed's target for the federal funds rate was constrained by the zero lower interest rate bound.

In principle, a nonlinear model might be able track the data throughout the transition to the new policy regime with interest on reserves and accommodate, as well, a nonnegativity constraint on the funds rate. Here, however, the basic features of the model developed above – including its linearity – are preserved in order to interpret both pre and post-2008 data within a common analytic framework. As noted above, this goal is accomplished mainly by starting the post-2008 sample in 2009:01, implicitly treating 2008:01 – 2008:12 similarly to the earlier 1979:10 – 1982:12 episode, as a volatile transition period quite different from what came both before and after. For the 2009:01 – 2020:02 sample, in addition, the spread between the federal funds rate and the interest rate paid by the Fed on excess reserves, denoted by RI_t , replaces the federal funds rate itself to measure banks' opportunity cost of holding reserves. [Smith \(2019\)](#) uses a smaller VAR to identify the effect that changes in the supply of reserves have had on this interest rate spread; the larger model used here characterizes the effects that the same changes in reserves supply have on Divisia M2 money growth and macroeconomic variables as well.

With the 7×1 vector of observables redefined as

$$X_t = [P_t \quad U_t \quad C_t \quad RI_t \quad H_t \quad M_t \quad UC_t]',$$

the structural model (1) and reduced form (2) appear exactly as before. The specification for A introduced in (3), however, also is modified so that

¹⁴ Here, again at the cost of placing further demands on the data, it would be useful to extend this stylized model of deposit creation, perhaps along the lines suggested by [Dia \(2013\)](#), [Dutkowsky and VanHoose \(2017\)](#), and [Ryan and Whelan \(2023\)](#), to account for changes in bank lending and other margins of substitution on the asset and liability sides of the typical bank's balance sheet.

¹⁵ See [Rubio-Ramírez, Waggoner, and Zha \(2010, p.671\)](#) for a discussion of normalization rules for structural VARs. Here, as in their more general analysis, requiring the diagonal elements of A to be positive simply determines the "sign of each equation," since multiplying any one of (4)–(7) by -1 flips the expected sign of each coefficient but does not change the economic interpretation of the equation itself.

$$\begin{bmatrix} a_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -a_3 & a_2 & 0 & 0 & 0 & 0 & 0 \\ -a_5 & -a_6 & a_4 & 0 & 0 & 0 & 0 \\ a_8 & -a_9 & 0 & 0 & a_7 & 0 & 0 \\ 0 & 0 & 0 & a_{11} & a_{10} & -a_{10} & 0 \\ 0 & 0 & -a_{12} & 0 & 0 & a_{12} & a_{13} \\ a_{16} & 0 & 0 & -a_{15} & 0 & -a_{16} & a_{14} \end{bmatrix} \begin{bmatrix} P_t \\ U_t \\ C_t \\ RI_t \\ H_t \\ M_t \\ UC_t \end{bmatrix} = \begin{bmatrix} \varepsilon_t^1 \\ \varepsilon_t^2 \\ \varepsilon_t^3 \\ \varepsilon_t^{mp} \\ \varepsilon_t^{hd} \\ \varepsilon_t^{md} \\ \varepsilon_t^{ms} \end{bmatrix}. \quad (8)$$

The first three rows of (8) assume again that the macroeconomic variables P_t , U_t , and C_t react to shocks from the monetary sectors with a one-month lag. The last four rows describe the supply of and demand for reserves and monetary services as

$$a_7 H_t = -a_8 P_t + a_9 U_t + \varepsilon_t^{mp}, \quad (9)$$

$$a_{10}(H_t - M_t) = -a_{11} RI_t + \varepsilon_t^{hd}, \quad (10)$$

$$a_{12}(M_t - C_t) = -a_{13} UC_t + \varepsilon_t^{md}, \quad (11)$$

and

$$a_{14} UC_t = a_{15} RI_t + a_{16}(M_t - P_t) + \varepsilon_t^{ms}. \quad (12)$$

Of these equations, only the monetary policy rule (9) differs substantially from its analog (4) for the pre-2008 model. With a_7 normalized to be positive, the policy response coefficients a_8 and a_9 both should be nonnegative, assuming the Fed reacts to lower inflation and higher unemployment by expanding the supply of bank reserves via quantitative easing. In addition, a positive realization of the policy shock ε_t^{mp} is interpreted in (9) as an unexpected monetary *easing*, whereas in the more conventional rule based on Taylor's (1993) in (4), a positive realization of ε_t^{mp} corresponds to a surprise policy tightening. Despite these differences, the new policy rule (9), is in the same spirit as (4). It interprets the Fed's large-scale asset purchases and the subsequent partial unwinding of those purchases for the 2009:01 – 2020:02 sample period as monetary policy actions that have their effects on money growth, nominal spending, inflation, and unemployment through the effects they have, first, on the supply of bank reserves.

The reserves demand and money supply Eqs. (10) and (12) coincide with their earlier formulations (5) and (7), except that the interest rate spread RI_t replaces the federal funds rate R_t in measuring the opportunity cost to banks of holding reserves. The money demand Eq. (11), meanwhile, remains exactly the same as (6). Just as before, the model's parameters can be estimated via maximum likelihood according to the two-step procedure outlined by Hamilton (1994) and Lütkepohl (2004) and the application of Rubio-Ramírez et al. (2010) results to confirm that all of the parameters from the matrix A in (8) are identified. Finally, as before, theory suggests that the remaining parameters in (9)–(12) should be non-negative when the diagonal elements of A are normalized to be positive.

4. Results

Table 1 presents maximum likelihood estimates of the key parameters from the matrix A and their standard errors for all four sample periods. Its top left-hand panel confirms that, for the 1967:01 – 1979:09 period, the effects of monetary policy can be described through the interaction of an upward-sloping supply curve and a downward-sloping demand curve for reserves. In particular, the coefficient on reserves in the estimated monetary policy rule is positive and statistically significant, while the coefficient on the funds rate in the demand curve for reserves is negative and significant. By contrast, neither the price level P nor the unemployment rate U enters significantly into the monetary policy rule. And while the estimated coefficient on unemployment is negative as expected, the estimated coefficient on the price level takes the wrong sign and associates a rise in inflation with a lower setting for the funds rate and a larger quantity of reserves supplied. Meanwhile, all coefficients in the Divisia money demand and supply equations have their expected signs and are statistically significant.

The top right-hand panel of Table 1, meanwhile, shows that 1983:01 – 1994:12 is the one sample period out of four during which monetary policy might be described somewhat accurately by an interest rate rule of the form suggested by Taylor (1993). Perhaps this is not surprising, as Taylor (1993) introduces his rule as one that tracks the path for the federal funds rate well over the period from 1987 through 1992.¹⁶ But while the estimated coefficients on P and U both take their expected signs over this period, only the unemployment rate enters the policy rule significantly. In addition, though the coefficient on reserves is insignificant, it continues to take the expected, positive sign, allowing the policy rule to be interpreted as a weakly upward-sloping supply curve for reserves as opposed to a rule for setting the funds rate alone. For this second sample period, the interest elasticity of reserves demand again appears

¹⁶ And perhaps it should be emphasized as well that the findings here, showing that the Fed did *not* follow a rule like Taylor's (1993) before 1983 or after 1994, remain fully consistent with Taylor's (2009) subsequent assertion that U.S. monetary policy would have supported better macroeconomic outcomes before 1983 and after 1994 if the Fed *had* followed his rule over those periods.

Table 1
Parameter Estimates and Standard Errors.

	1967:01 – 1979:09	1983:01 – 1994:12
Monetary Policy	271.11R = -102.59P - 79.43 U + 111.33H (42.01) (67.27) (55.84) (22.15)	429.33R = 82.01P - 176.39 U + 29.25H (35.25) (71.45) (65.15) (22.29)
Reserves Demand	101.41(H-M) = -155.72R (23.84) (63.91)	82.22(H-M) = -77.02R (9.07) (113.31)
Money Demand	27.78(M-C) = -68.32UC (15.95) (3.99)	43.77(M-C) = -66.40UC (17.87) (4.09)
Money Supply	16.69UC = 122.82R + 397.98(M-P) (6.13) (25.72) (23.93)	25.16UC = 67.38R + 416.89(M-P) (6.28) (39.20) (25.27)
	1995:01 – 2007:12	2009:01 – 2020:02
Monetary Policy	631.99R = -27.72P + 41.32 U + 63.52H (199.31) (55.87) (73.45) (14.99)	34.42H = -40.04P - 62.13U (2.13) (74.86) (78.79)
Reserves Demand	53.66(H-M) = -646.28R (17.43) (198.81)	9.93(H-M) = -8111.45RI (3.05) (501.16)
Money Demand	1.64(M-C) = 59.20UC (24.07) (3.64)	11.85(M-C) = -83.69UC (36.23) (5.47)
Money Supply	17.24UC = 419.02R + 292.47(M-P) (6.69) (78.16) (17.06)	16.98UC = 662.02RI - 344.55(M-P) (11.50) (684.99) (21.36)

negative, though it, too, becomes statistically insignificant. And, for this second period as for the first, the coefficients describing the behavior of Divisia money have their expected signs as well.

The bottom left-hand panel of Table 1 suggests that monetary policy over the 1995:01 – 2007:12 period departs systematically from a Taylor rule once again. Neither P nor U enters significantly into the estimated policy rule: the coefficients are small in magnitude, and neither has the correct sign. Instead, through the positive and statistically significant coefficient on H in the rule, policy again is described more accurately by an upward-sloping supply curve for reserves. Meanwhile, the demand for reserves is estimated to have become more elastic as the level of interest rates declined over the late 1990s and early 2000s. For this period only, the model struggles in its description of Divisia money demand. In the estimated money demand curve, the coefficient on the log money-consumption ratio is quite small and the user cost elasticity takes the incorrect sign. The coefficients describing Divisia money supply, however, retain their expected signs and statistical significance.

The most recent data, from 2009:01 – 2020:02, present the linear model with its biggest challenge. In general, however, the estimates reported in the bottom right-hand panel of Table 1 appear sensible. Once again, neither macroeconomic variable enters significantly into the monetary policy rule. For this most recent sample period with the modified rule (9), therefore, the estimates indicate that the Fed did not adjust either the pace of its large-scale asset purchase programs or the subsequent, partial unwinding of those programs on a monthly basis in response to contemporaneous movements in inflation or unemployment. Consistent with earlier results from Bräuning (2017) and Smith (2019), the estimates here imply that banks' demand curve for reserves became highly elastic as the opportunity cost of holding reserves fell dramatically after 2008 but continued to slope downward even over this most recent period. For this most recent period, a downward-sloping money demand curve reappears. But while the estimated money supply relation continues to associate an increase in the user cost of Divisia money UC with an increase in the opportunity cost of reserves RI , it unexpectedly links an increasing Divisia user cost to a decrease in the volume of real monetary services produced by the banking system.

Overall, however, the estimates from Table 1 highlight the model's success in providing a consistent interpretation of data from all four samples in terms of the supplies of and demands for bank reserves and Divisia monetary services. Figs. 3 and 4 go further, to illustrate with impulse responses how these supplies and demands interact to shape the effects of identified monetary policy shocks. As noted above, the two monetary policy rules (4) and (9) adopt different normalizations, so that a positive value of ϵ_t^{mp} corresponds to a surprise monetary tightening in the three pre-2008 samples but a surprise easing in the post-2008 sample. To facilitate comparison, the impulse responses shown in Figs. 3 and 4 correspond to those generated by expansionary policy throughout, that is, to values of ϵ_t^{mp} equal to -1 standard deviation pre-2008 and $+1$ standard deviation post-2008. Each panel surrounds the estimated impulse response with standard error bands, computed numerically from the estimated VAR coefficients using the delta method. These bands show that the estimated response of each variable to the identified monetary policy shock typically lies more than one standard deviation away from zero and often lies more (although sometimes only slightly more) than two standard deviations from zero.¹⁷

Fig. 3 shows that across all four sample periods, the expansionary monetary policy shock generates an immediate increase in reserves with a liquidity effect that lowers the federal funds rate in each of the pre-2008 samples and reduces the spread between the funds rate and the interest rate on excess reserves in the post-2008 sample. The same expansionary policy shock works, invariably and as expected, to increase the Divisia M2 monetary aggregate and reduce the user cost dual.

Fig. 4, meanwhile, reveals that nominal consumption spending rises consistently as well, almost immediately during the 1983:01 –

¹⁷ Additional precision in the estimation of these impulse response functions might also be obtained, as suggested above, through the use of Bayesian priors or the LASSO method.

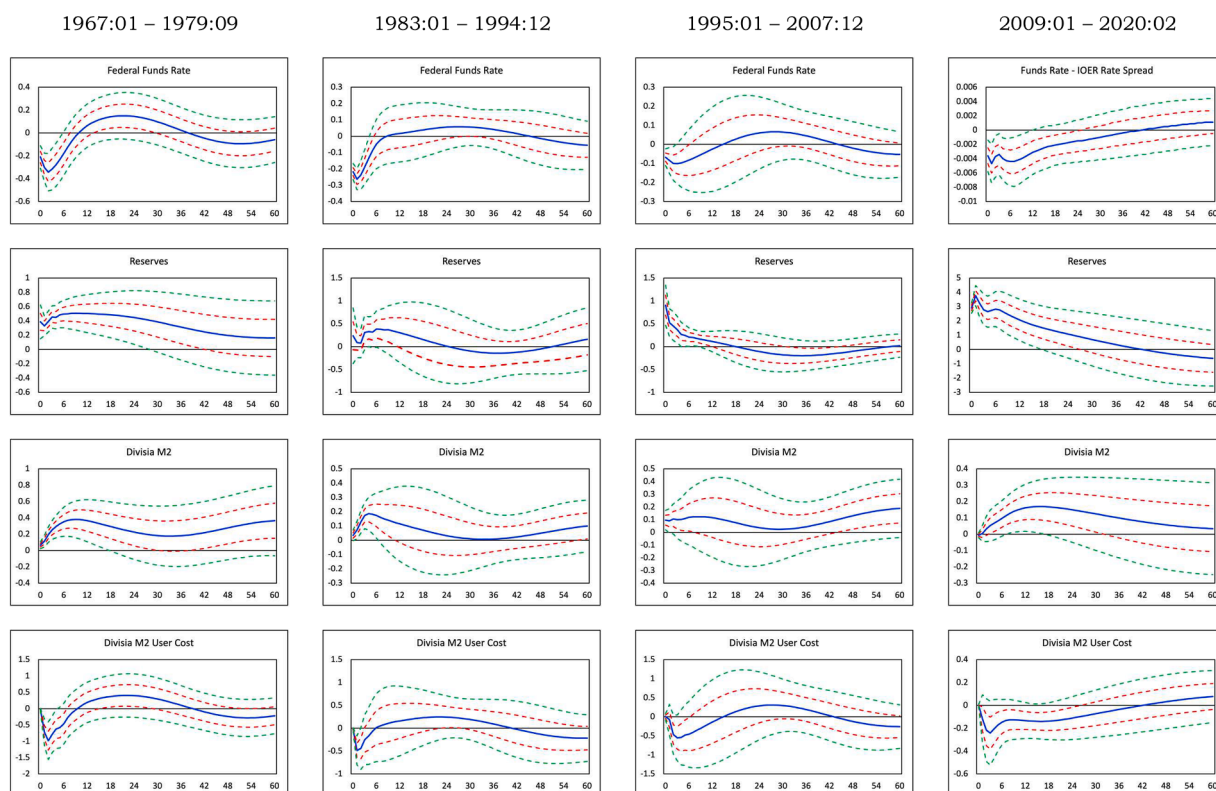


Fig. 3. Impulse Responses. Each panel shows the percentage-point response of the indicated variable to a one-standard-deviation expansionary monetary policy shock during the indicated subsample, surrounded by one- and two-standard-error bands.

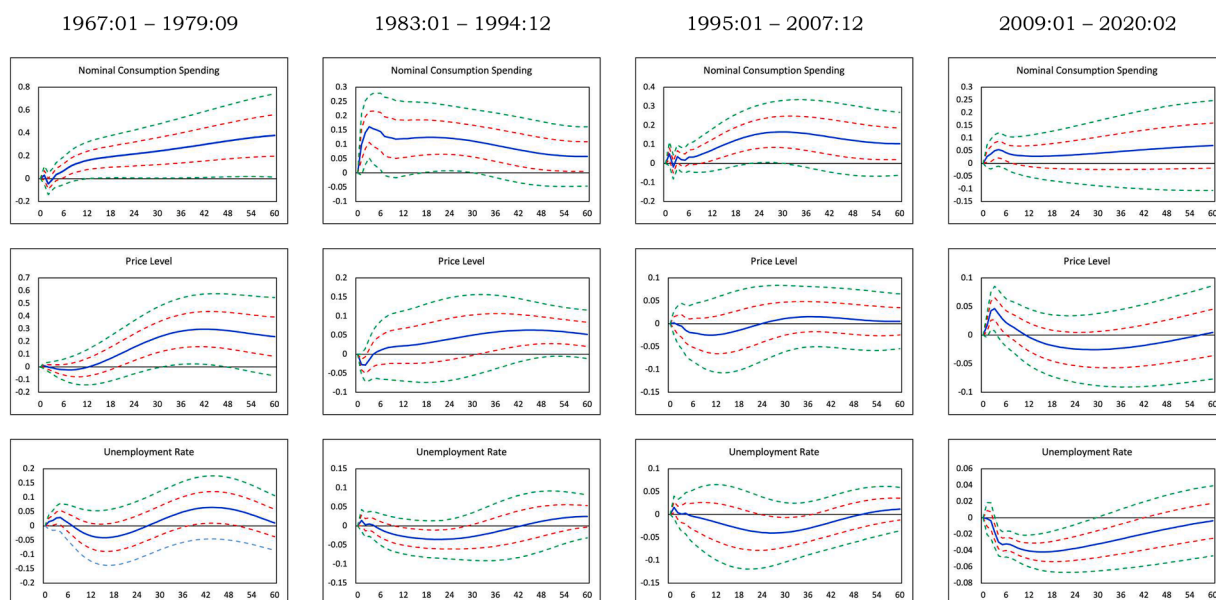


Fig. 4. Impulse Responses. Each panel shows the percentage-point response of the indicated variable to a one-standard-deviation expansionary monetary policy shock during the indicated subsample, surrounded by one- and two-standard-error bands.

1994:12 sample period but with a slight lag during the three periods before and since. Greater variation across samples appears in the responses of the aggregate nominal price level and unemployment rate to the expansionary policy shock.

For the period 1967:01 – 1979:09, the monetary policy shock has its largest effects on the price level, which rises strongly and

persistently after a lag of 12 months. The unemployment rate traces a less discernable pattern, falling as expected only at horizons of 8–26 months following the shock. Overall, this period stands out as one in which, as suggested by the models of [Kydland and Prescott \(1977\)](#) and [Barro and Gordon \(1983\)](#), the Federal Reserve's attempts to exploit a perceived Phillips curve tradeoff led mostly to higher inflation instead of lower unemployment.

Stronger effects of monetary policy shocks on unemployment appear, however, when estimated for the 1983:01 – 1994:12 and 1995:01 – 2007:12 sample periods. For the earlier episode, monetary policy shocks continue to have persistent effects on the price level. For the later period, on the other hand, instability in the Phillips curve appears again, though characterized in this case by the absence of a strong effect of monetary policy shocks on inflation.

Most notably, however, an expansionary policy shock during the recent sample period, running from 2009:01 through 2020:02, displays strong and rapid responses in both the nominal price level and the unemployment rate, in the expected positive and negative directions. Thus, when viewed in terms of their effects, first on the market for reserves and then on the market for Divisia monetary services, the estimated model shows that the Fed's large-scale asset purchases also had their desired macroeconomic impacts, offsetting deflationary pressures and stimulating employment during and after the financial crisis and Great Recession of 2007–9 and slow recovery that followed.

[Table 2](#) shows the results of forecast error decompositions, with each entry reporting the fraction of unexpected volatility in each observable variable, over horizons short and long, attributable to identified monetary policy shocks. Consistent with the parameter estimates from [Table 1](#), only for the sample period spanning 1983:01 and 1994:12 do monetary policy shocks manifest themselves mainly through unexpected movements in interest rates. Indeed, for all other periods, movements in the quantity of reserves appear more important. Consistent with the impulse response analysis from [Fig. 3](#), monetary policy shocks generate considerable volatility in Divisia M2 and nominal consumption spending. And while monetary policy shocks contribute importantly to price-level fluctuations during the earliest, 1967:01 – 1979:09 sample, they also account for a sizable share of the movements in unemployment observed over the most recent, 2009:01 – 2020:02, period.

While data on longer-term interest rates are not needed to identify monetary policy shocks within the VAR, impulse responses of these rates to monetary policy shocks can be estimated outside the model using local projection methods developed by [Jordà \(2005\)](#). To motivate this exercise, [Fig. 5](#) plots data on the one, three, five, and ten-year Treasury constant maturity rates, originally reported in the Federal Reserve Board's H.15 release and available as historical time series through FRED. The graphs in the top two rows reveal that over the years, interest rates on Treasury securities with different terms to maturity move together, not only with one another but also with the federal funds rate shown previously in [Fig. 2](#). The graphs in the bottom two rows illustrate this same co-movement in a different way, showing that while spreads between longer-term Treasury rates and the federal funds rate vary in their size and persistence over time, they always revert back to their longer-run means. Conventionally, the linkage of Treasury rates to movements in the funds rate is interpreted as a sign of the Fed's ability to control market rates more generally.

[Fama \(2013, p.191\)](#), however, offers two plausible interpretations of this co-movement. One is the conventional perspective of a “powerful Fed,” capable of using its influence over the federal funds rate to exercise control over longer-term rates as well. Alternatively, the co-movement could reflect adjustments to the federal funds rate target by a “passive Fed” reacting to economic forces that shift longer-term rates first. Consistently across all four sample periods, the expansionary monetary policy shocks identified from the VAR already have been shown to trigger a liquidity effect that lowers the federal funds rate. Tracing out their effects on longer-term rates via local projections will shed light on whether the liquidity effect extends farther out along the yield curve, thereby helping to answer [Fama's \(2013\)](#) query as to how strong the Fed's influence over longer-term interest rates has been.

Following the general approach to local projection described by [Ramey \(2016, p.84\)](#), the response of $Y_{i,t+k}$ the i -year Treasury rate $k = 0, 1, 2, \dots$ months after a monetary policy shock ε_t^{mp} at time t is estimated from the slope coefficient $\theta_{i,k}$ in the regression

$$Y_{i,t+k} = \alpha_{i,k} + \theta_{i,k} \varepsilon_t^{mp} + \sum_{j=1}^{q_y} \beta_{i,j,k} Y_{i,t-j} + \sum_{j=1}^{q_x} \Gamma_{i,j,k} X_{t-j} + \xi_{i,t+k}$$

of the long-term rate at time $t+k$ on a constant, the time t monetary policy shock, $q_y = 3$ lags of the long-term rate itself, and $q_x = 3$ lags of each in the 7×1 vector of variables X_t used to estimate the VAR. Thus, in the regression, $\alpha_{i,k}$, $\theta_{i,k}$, and each $\beta_{i,j,k}$ are scalar coefficients, while each $\Gamma_{i,j,k}$ is a 1×7 vector of slope coefficients on variables in X_{t-j} . [Fig. 6](#) plots these impulse responses, surrounded again by one- and two-standard-error bands, now computed using [Newey and West's \(1987\)](#) correction to account for serial correlation in the multi-step forecast error $\xi_{i,t+k}$.

The graphs in the first two columns of [Fig. 6](#) show evidence of strong and persistent liquidity effects on longer-term rates over both the 1967:01 – 1979:09 and 1983:01 – 1994:12 sample periods. On impact, the expansionary monetary policy shock reduces Treasury rates at all maturities. Longer-term rates remain below their initial levels for 8 to 17 months over the first sample period and nearly two years over the second period, before turning higher, presumably reflecting the impact of higher expected inflation. The absolute magnitude of both the short-run liquidity effect and the longer-run expected inflation effect dampens as the maturity lengthens, but remains sizable even for the ten-year Treasury rate.

Evidence of the liquidity effect disappears, however, in the 1995:01 – 2007:12 data sample. Graphs in the third column of [Fig. 6](#) show that the effects of monetary policy shocks on longer-term interest rates are small in magnitude. In general, however, the same expansionary monetary policy shock that lowers the federal funds rate in [Fig. 3](#) works, instead, to increase longer-term interest rates during this period.

Likewise, in the fourth column of [Fig. 6](#), it is difficult to see any sign of a strong effect of monetary policy shocks on longer-term

Table 2
Forecast Error Variance Decompositions.

1967:01 – 1979:09							
k	P	U	C	R	H	M	UC
3	0.1	0.7	0.6	43.7	43.8	14.7	20.2
12	0.3	1.6	7.0	24.8	69.3	41.1	14.3
24	3.0	3.5	20.2	22.9	64.7	34.2	13.7
36	16.6	3.0	29.1	19.4	53.7	30.0	13.4
48	28.2	6.3	36.5	16.7	44.4	28.0	12.1
60	31.9	7.1	42.4	16.4	36.9	28.7	12.6
1983:01 – 1994:12							
k	P	U	C	R	H	M	UC
3	2.2	0.7	7.0	77.5	3.3	8.2	6.7
12	0.9	2.9	14.9	20.5	9.8	14.9	2.3
24	1.2	9.6	17.4	12.5	4.3	7.6	3.3
36	2.5	7.1	19.8	11.9	3.5	6.2	3.6
48	4.3	4.2	19.6	8.7	3.3	5.3	2.8
60	5.9	4.2	18.0	7.7	2.6	5.3	3.3
1995:01 – 2007:12							
k	P	U	C	R	H	M	UC
3	0.0	1.0	1.7	31.1	49.8	7.0	4.2
12	1.4	0.5	2.5	8.2	44.0	7.0	6.4
24	1.3	3.0	9.3	4.0	21.8	4.8	3.7
36	1.1	6.5	15.7	5.4	18.0	4.2	5.0
48	1.2	7.2	18.0	5.4	19.4	4.9	4.8
60	1.1	7.0	18.5	5.7	18.7	7.7	5.2
2009:01 – 2020:02							
k	P	U	C	RI	H	M	UC
3	3.7	0.1	1.2	15.1	90.3	0.3	1.8
12	2.9	24.8	2.4	18.5	57.0	5.6	6.0
24	2.5	34.2	2.0	20.4	47.8	9.6	8.5
36	3.2	31.3	2.2	18.4	37.7	9.3	8.3
48	3.1	26.3	2.9	16.6	32.0	8.0	7.4
60	2.6	22.6	3.7	16.2	30.1	6.9	7.4

Note: Each entry shows the percentage of the k-month-ahead forecast error variance in the indicated variable attributed to monetary policy shocks over the indicated sample period.

interest rates over the most recent, 2009:01 – 2020:02 period. One- through ten-year Treasury rates do appear to fall on impact following an expansionary monetary policy shock. But these initial movements are very small – between one and three basis points – and are quickly followed by reversals that send longer-term rates above their pre-shock levels. This behavior is in contrast to the bending of the yield curve that had been a goal of quantitative easing.

This set of results confirms Fama's (2013) suspicion that the Fed's influence over longer-term nominal interest rates is much weaker than commonly believed, particularly over the years since 1995 when, as shown in Fig. 5, interest rate spreads became increasingly persistent. Recall from Fig. 3, however, that the identified monetary policy shocks still appear to have strong effects on nominal spending for both post-1995 sample periods, and on the price level and unemployment rate, as well, post-2009. From this perspective, the Fed remains "powerful," in the sense that it is able to affect macroeconomic conditions, even without exerting strong effects on longer-term Treasury rates. From this same perspective, however, the Fed's power over economic activity comes from its ability to influence quantity magnitudes.

Finally, Wu and Xia (2016) take an alternative approach to account for the Federal Reserve's efforts to deliver additional monetary stimulus through forward guidance and quantitative easing over the period from 2009 through 2015, when the federal funds rate target itself was held in a narrow range close to zero. Using a nonlinear model of the term structure, together with data on long-term interest rates, they estimate a "shadow federal funds rate," shown in the left-hand panel of Fig. 7, that falls below zero in response to these unconventional policy actions before 2015 but resumes tracking the actual funds rate after its lift-off from the zero lower bound. The right-hand panel of Fig. 7 plots the impulse response of Wu and Xia's shadow rate to identified monetary policy shock from the VAR estimated here, computed again using the local projection method. Quite strikingly, the pattern displayed by this impulse response – showing evidence of an initial liquidity effect that lowers the shadow federal funds rate followed by an eventual expected inflation effect that raises the shadow funds rate – resembles closely those shown previously, in the top row of Fig. 3, for the federal funds rate itself during each of the three pre-2008 subsamples. These results, too, highlight that patterns of monetary transmission look similar, pre- and post-2008, when they are described with reference quantity variables as well as interest rates.

5. Conclusion

The results just presented illustrate that Federal Reserve monetary policy and its effects can be described, over an extended period spanning 1967 through 2020, with consistent reference to the supplies of and demands for bank reserves and Divisia money. These results provide an account of the past that is broader and richer than those that gauge the stance of monetary policy based on interest rates alone. Indeed, even as they show how monetary policy and its effects have evolved over time, these results confirm that monetary

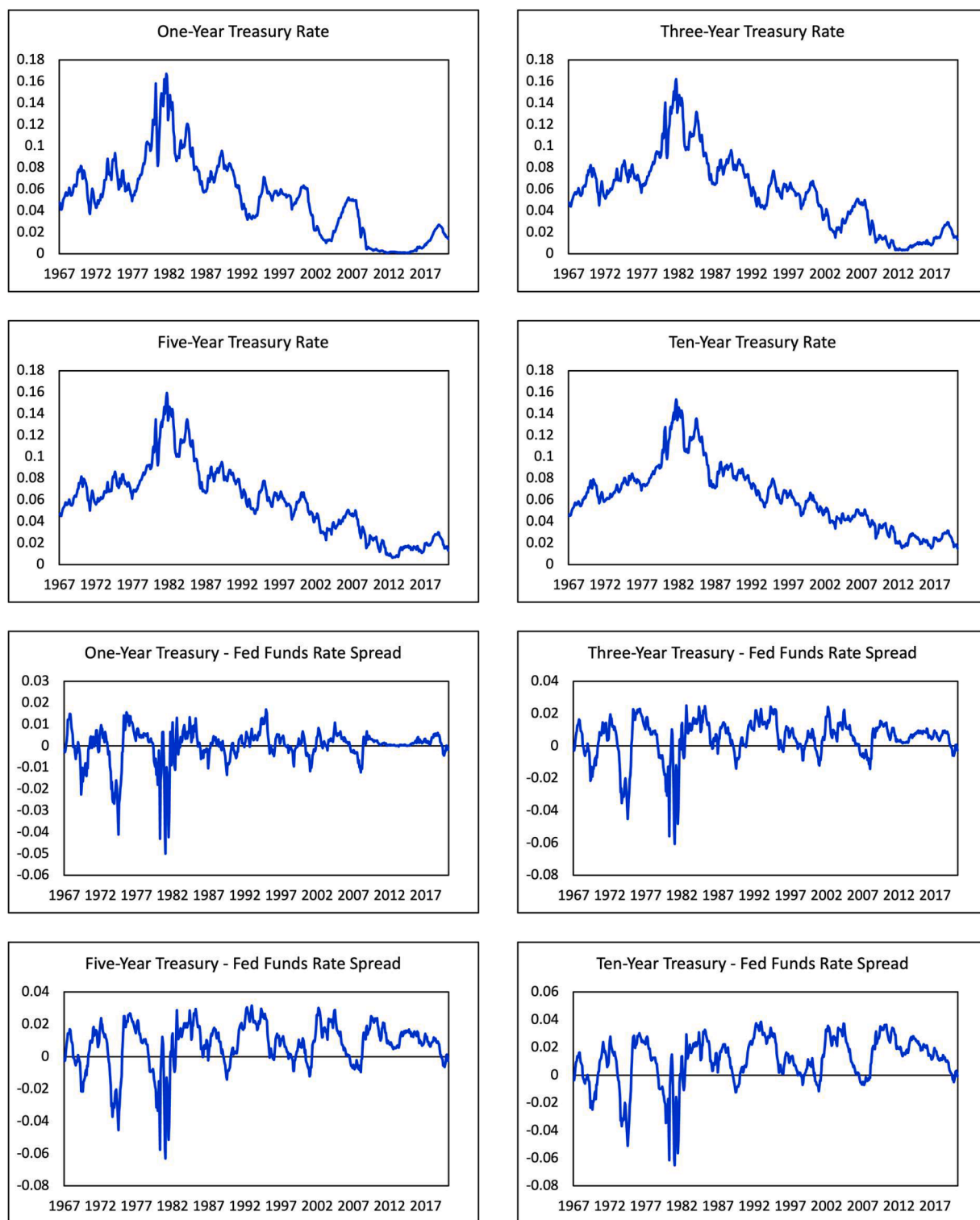


Fig. 5. Term Structure Data.

policy adjustments typically reveal themselves through changes in the supply of reserves as well as the federal funds rate target.

Among these results, perhaps the most striking show that changes in the quantity of bank reserves over the 2009:01 – 2020:02, featuring three rounds of quantitative easing and their unwinding, had their desired effects on nominal spending, inflation, and

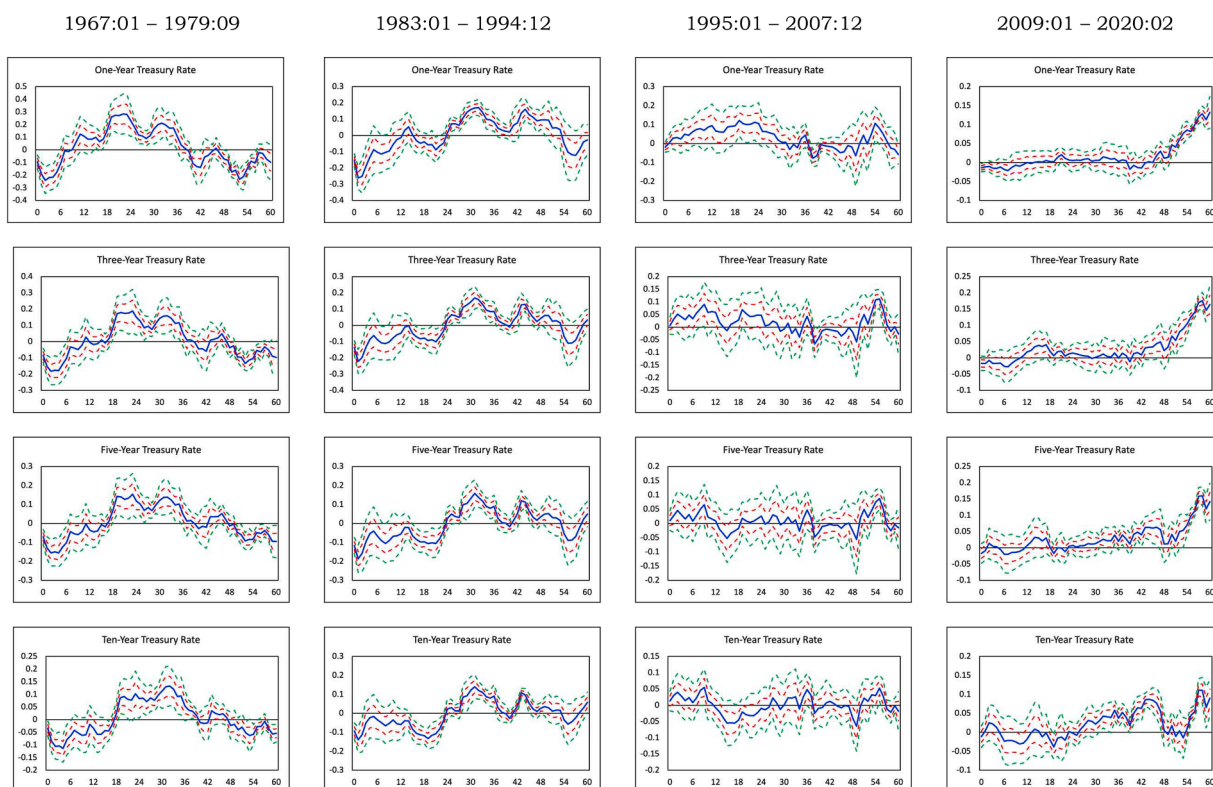


Fig. 6. Impulse Responses. Each panel shows the percentage-point response of the indicated Treasury rate to a one-standard-deviation expansionary monetary policy shock during the indicated subsample, surrounded by one- and two-standard-error bands.

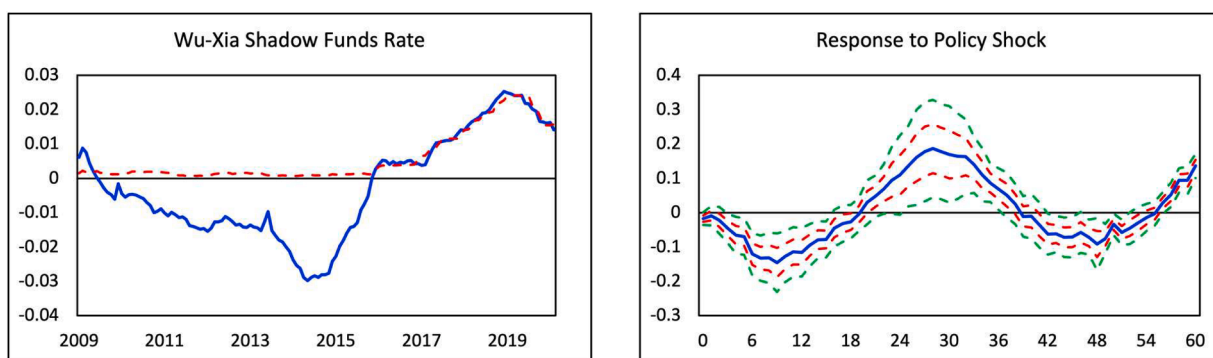


Fig. 7. Shadow Federal Funds Rate. The left-hand panel compares the Wu-Xia (2016) shadow federal funds rate (solid line) to the effective federal funds rate (dashed line), with both series plotted as decimals. The right-hand panel shows the percentage-point response of the shadow funds rate to a one-standard-deviation expansionary monetary policy shock, surrounded by one- and two-standard-error bands.

unemployment. These effects may simply reflect a signaling channel, through which they were used to make clear that the federal funds rate would remain lower for longer following the financial crisis and Great Recession of 2007–9. This interpretation is challenged, however, by additional estimates suggesting that QE had, at the same time, little or no effect on longer-term interest rates. A simpler and more compelling interpretation, therefore, is that these changes in reserves worked more directly to stimulate broad money growth and, in turn, nominal spending and other key macroeconomic variables, just as they have, historically, when the federal funds rate was unencumbered by the zero lower bound.

Altogether, these results suggest that it would be helpful for the Fed to reframe its asset purchase programs with at least some reference to their implications for the supply of bank reserves and their effects on broad money growth.¹⁸ By doing so, monetary policymakers could downplay the importance of the zero lower interest rate bound and emphasize that their policies operate through the same channels to help them achieve the same stabilization goals in both good times and bad. The broader view of monetary policy and how it works provided here becomes especially useful if, as seems likely, the zero lower bound becomes a recurrent constraint on the Fed's funds rate target.

Declaration of competing interest

None

Data availability

Data will be made available on request.

References

- Anderson, R.G., Rasche, R.H., 2001. Retail Sweep Programs and Bank Reserves, 1994-1999. *Federal Reserve Bank of St. Louis Review* 83, 51-72.
- Anderson, R.G., Rasche, R.H., Loesel, J., 2003. A Reconstruction of the Federal Reserve Bank of St. Louis Adjusted Monetary Base and Reserves. *Federal Reserve Bank of St. Louis Review* 85, 39-69.
- Barnett, W.A., 1980. Economic monetary aggregates: an application of index number and aggregation theory. *J. Econom.* 14, 11-48.
- Barnett, W.A., 1982. The optimal level of monetary aggregation. *J. Money Credit Bank.* 14, 687-710.
- Barnett, W.A., 2012. *Getting It Wrong: How Faulty Monetary Statistics Undermine the Fed, the Financial System, and the Economy*. MIT Press, Cambridge.
- Barnett, W.A., Liu, Jia, Mattson, Ryan, van den Noort, Jeff, 2013. The new CFS Divisia monetary aggregates: design, construction, and data sources. *Open Econ. Rev.* 24, 101-124.
- Barro, R.J., Gordon, D.B., 1983. A positive theory of monetary policy in a natural rate model. *J. Polit. Econ.* 91, 589-610.
- Beckworth, D., 2017. Permanent versus temporary monetary base injections: implications for past and future fed policy. *J. Macroecon.* 54, 110-126.
- Belongia, M.T., 1996. Measurement matters: recent results from monetary economics reexamined. *J. Polit. Econ.* 104, 1065-1083.
- Belongia, M.T., 2006. The neglected price dual of monetary quantity aggregates. In: Belongia, Michael T., Binner, Jane M. (Eds.), *Money, Measurement and Computation*. Palgrave, New York, pp. 239-253.
- Belongia, M.T., Ireland, P.N., 2006. The own-price of money and the channels of monetary transmission. *J. Money Credit Bank.* 38, 429-445.
- Belongia, M.T., Ireland, P.N., 2014. The Barnett critique after three decades: a new Keynesian analysis. *J. Econom.* 183, 5-21.
- Belongia, M.T., Ireland, P.N., 2015. Interest rates and money in the measurement of monetary policy. *J. Bus. Econ. Stat.* 33, 255-269.
- Belongia, M.T., Ireland, P.N., 2016. Money and output: Friedman and Schwartz revisited. *J. Money Credit Bank.* 48, 1223-1266.
- Belongia, M.T., Ireland, P.N., 2017. Circumventing the zero lower bound with monetary policy rules based on money. *J. Macroecon.* 54, 42-58.
- Belongia, M.T., Ireland, P.N., 2018. Targeting constant money growth at the zero lower bound. *Int. J. Central Bank.* 14, 159-204.
- Belongia, M.T., Ireland, P.N., 2019. The demand for Divisia money: theory and evidence. *J. Macroecon.* 61, 103128.
- Belongia, M.T., Ireland, P.N., 2021. A classical view of the business cycle. *J. Money Credit Bank.* 53, 333-366.
- Belongia, M.T., Ireland, P.N., 2022. A reconsideration of money growth rules. *J. Econ. Dyn. Control* 135, 104312.
- Binner, J.M., Kelly, L.J., 2017. Modelling money shocks in a small open economy: the case of Taiwan. *Manchester School* 85 (S1), 104-120.
- Brauning, F., 2017. The Liquidity Effect of the Federal Reserve's Balance Sheet Reduction on Short-Term Interest Rates. *Current Policy Perspectives Paper* 18-1. Federal Reserve Bank of Boston, Boston.
- Bordo, M.D., John, V.D., 2023. Money matters: broad Divisia money and the recovery of GDP from the COVID-19 recession. Working Paper 2306. Dallas: Federal Reserve Bank of Dallas, May.
- Burger, A.E., 1971. *The Money Supply Process*. Wadsworth Publishing Company, Belmont, CA.
- Chrystal, K.A., MacDonald, R., 1994. Empirical evidence on the recent behavior and usefulness of simple-sum and weighted measures of the money stock. In: *Federal Reserve Bank of St. Louis Review*, 76, pp. 73-109.
- Cook, T., 1989. Determinants of the federal funds rate: 1979-1982. *Federal Reserve Bank of Richmond Econ. Rev.* 75, 3-19.
- Dery, C., Serletis, A., 2021. Interest rates, money, and economic activity. *Macroecon. Dyn.* 25, 1842-1891.
- Dia, E., 2013. How do banks respond to shocks? A dynamic model of deposit-taking institutions. *J. Bank. Finance* 37, 3623-3638.
- Dutkowsky, D.H., VanHoose, D.D., 2017. Interest on reserves, regime shifts, and bank behavior. *J. Econ. Bus.* 91, 1-15.
- El-Shagi, M., 2021. When does monetary measurement matter (most)? *Macroecon. Dyn.* 25, 240-256.
- El-Shagi, M., Giesen, S., Kelly, L.J., 2015. The quantity theory revisited: a new structural approach. *Macroecon. Dyn.* 19, 58-78.
- Fama, E.F., 2013. Does the Fed control interest rates? *Review Asset Pricing Stud.* 3, 180-199.
- Ghosh, T., Hasan Adil, M., 2023. Money's predictive role in output: evidence from recent data. *Appl. Econ.* 55 (38), 4415-4440.
- Ghosh, T., Bhadury, S., 2018. Money's causal role in exchange rate: do Divisia monetary aggregates explain more? *Int. Rev. Econ. Finance* 57, 402-417.
- Gilbert, R.A., 1994. A case study in monetary control: 1980-82. In: *Federal Reserve Bank of St. Louis Review*, 76, pp. 35-58.
- Goodhart, C.A.E., 2017. The determination of the money supply: flexibility versus control. *Manchester School* 85 (S1), 33-56.
- Gordon, D.B., Leeper, E.M., 1994. The dynamic impacts of monetary policy: an exercise in tentative identification. *J. Polit. Econ.* 102, 1228-1247.
- Hamilton, J.D., 1994. *Time Series Analysis*. Princeton University Press, Princeton.
- Hendrickson, J.R., 2014. Redundancy or mismeasurement? A reappraisal of money. *Macroecon. Dyn.* 18, 1437-1465.
- Hsu, N.-J., Hung, H.-L., Chang, Y.-M., 2008. Subset selection for vector autoregressive processes using lasso. *Comput. Stat. Data Anal.* 52, 3645-3657.
- Hume, D., 1987. *Of Money*. In: *Essays: Moral, Political, and Literary*, 1777 Edition, 1752. Liberty Fund, Indianapolis, pp. 281-294.
- Ireland, P.N., 2014. The macroeconomic effects of interest on reserves. *Macroecon. Dyn.* 18, 1271-1312.
- Ireland, P.N., 2019. Interest on reserves: history and rationale, complications and risks. *Cato J.* 39, 327-337.
- Jordà, Ò., 2005. Estimation and inference of impulse responses by local projection. *Am. Econ. Rev.* 95, 161-182.

¹⁸ Beckworth (2017), Belongia and Ireland (2017, 2018, 2022), Keating, Kelly, Smith, and Valcarcel (2019), and Bordo and John, 2023 provide additional results to support this idea: that when federal funds rate target is constrained by the zero lower bound the Fed could communicate its policy intentions more clearly by emphasizing its ability to control the monetary base and influence broader measures of the money stock.

- Keating, J.W., Kelly, L.J., Lee Smith, A., Valcarcel, V.J., 2019. A model of monetary policy shocks for financial crises and normal conditions. *J. Money Credit Bank.* 51, 227–259.
- Kydland, F.E., Prescott, E.C., 1977. Rules rather than discretion: the inconsistency of optimal plans. *J. Polit. Econ.* 85, 473–491.
- Leeper, E.M., 1995. Reducing our ignorance about monetary policy effects. *Federal Reserve Bank of Atlanta Econ. Rev.* 80, 1–38.
- Leeper, E.M., Roush, J.E., 2003. Putting the ‘M’ back in monetary policy. *J. Money Credit Bank.* 35 (2), 1217–1256.
- Leeper, E.M., Sims, C.A., Zha, T., 1996. What does monetary policy do? *Brookings Pap. Econ. Act* (2), 1–63.
- Lu, Y., Valcarcel, V.J., 2023. A tale of two tightenings. Manuscript. University of Texas at Dallas, Dallas.
- Lucas Jr., R.E., April 1972. Expectations and the neutrality of money. *J. Econ. Theory* 4, 103–124.
- Lütkepohl, H., 2006. *New Introduction to Multiple Time Series Analysis*. Springer-Verlag, Berlin.
- Meigs, A.J., 1962. *Free Reserves and the Money Supply*. University of Chicago Press, Chicago.
- Molinas, L.A., Binner, J.M., Tong, M., 2023. Do Divisia monetary aggregates help forecast exchange rates in a negative interest rate environment? *Eur. J. Finance* 29 (7), 780–799.
- Morrison, G.R., 1966. *Liquidity Preferences of Commercial Banks*. University of Chicago Press, Chicago.
- Newey, W.K., West, K.D., May 1987. A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica* 55, 703–708.
- Ramey, V.A., 2016. Macroeconomic Shocks and Their Propagation. In: Taylor, J.B., Uhlig, H. (Eds.), *Handbook of Macroeconomics*, 2A. Elsevier, Amsterdam, pp. 71–162.
- Rubio-Ramírez, J.F., Waggoner, D.F., Zha, T., 2010. Structural vector autoregressions: theory of identification and algorithms for inference. *Rev. Econ. Stud.* 77, 665–696.
- Ryan, E., Whelan, K., 2023. A model of QE, reserve demand, and the money multiplier. *J. Money Credit Bank.* 55, 407–439.
- Smith, A.L., 2019. Do changes in reserve balances still influence the federal funds rate? *Federal Reserve Bank of Kansas City Econ. Rev.* 104, 5–24.
- Smith, A.L., Valcarcel, V.J., 2023. The financial market effects of unwinding the Federal Reserve’s balance sheet. *J. Econ. Dyn. Control* 146, 104582.
- Tang, B., Yemba, B., Chang, D., 2020. Divisia monetary aggregates and US GDP nowcasting. *Appl. Econ.* 32 (32), 3538–3554.
- Taylor, J.B., 1993. Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy* 39, pp. 195–214.
- Taylor, J.B., 2009. *Getting Off Track: How Government Actions and Interventions Caused, Prolonged, and Worsened the Financial Crisis*. Hoover Institution Press, Stanford.
- Tibshirani, R., 1996. Regression shrinkage and selection via the Lasso. *J. R. Stat. Soc. Series B* 58 (1), 267–288.
- Wu, J.C., Xia, F.D., 2016. Measuring the macroeconomic impact of monetary policy at the zero lower bound. *J. Money Credit Bank* 48, 253–291.