Targeting Constant Money Growth at the Zero Lower Bound*

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Unconventional policy actions, including quantitative easing and forward guidance, taken during and since the financial crisis and Great Recession of 2007–09, allowed the Federal Reserve to influence long-term interest rates even after the federal funds rate hit its zero lower bound. Alternatively, similar policy actions could have been directed at stabilizing the growth rate of a monetary aggregate in the face of severe disruptions to the financial sector and the economy at large. A structural vector autoregression suggests it would have been feasible for the Fed to target the growth rate of a Divisia monetary aggregate once the federal funds rate had reached its zero lower bound and that doing so would have supported a stronger, more rapid recovery.

JEL Codes: E21, E32, E37, E41, E43, E47, E51, E52, E65.

1. Introduction

The financial crisis and Great Recession of 2007–09 seemingly required major changes in Federal Reserve (Fed) operating procedures. Pre-crisis, the Fed conducted monetary policy by targeting the interest rate on overnight, interbank loans: the federal funds rate. When the Fed wished to tighten monetary policy, it raised its target for the federal funds rate; conversely, when it wished to

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ease, it lowered its funds rate target. After the target was reduced to a range of 0 to 0.25 percent in December 2008, however, the zero lower bound (ZLB) on the federal funds rate forced the Fed to look for other ways of providing additional monetary stimulus to help output and employment recover and prevent inflation from falling further.

Bernanke (2012) describes two sets of tools that the Fed adopted, under his Chairmanship, to continue pursuing these goals. Multiple waves of large-scale asset purchases of U.S. Treasury bonds and government agency mortgage-backed securities, known more popularly as "quantitative easing" or "QE," aimed to put direct downward pressure on long-term interest rates. Meanwhile, "forward guidance," in the form of official policy statements, promised to keep short-term interest rates low for an extended period of time, even as the economy began to recover. These public statements were intended to reduce long-term rates further by working on the yield curve through expectational channels. Although these tactics kept the focus of Federal Reserve policy squarely on interest rates, the severity of the downturn caused the Fed's interventions in bond markets to grow enormously in size and scope while its communication strategy evolved into a program vastly more ambitious and complex than originally conceived.[1]

Viewed from a different angle, however, there may be less to distinguish between monetary policy before and after the crisis. This is because, in more normal times, any increase in the Fed's target for the federal funds rate still required open market operations that drained reserves from the banking system. This decrease in reserves worked through textbook channels to slow the growth rate of money and thereby dampened economic activity generally and slowed inflation specifically. Likewise, when the Fed lowered its target for the

[1]Bernanke, Reinhart, and Sack (2004) discuss alternative monetary policy strategies once the zero lower bound constraint binds. Written before the Great Recession, these options were examined because, under sustained low inflation, the zero lower bound was becoming more than a theoretical curiosity. One of the suggested strategies was to stimulate economic activity by increasing the size and altering the composition of the Federal Reserve's balance sheet in a manner that would raise asset values and reduce yields. The authors, however, do not consider the potential effects of changes in the quantity of money.

funds rate, it engineered the desired fall through open market operations that increased the supply of reserves, which caused broad money growth to accelerate with more rapid economic activity and inflation to follow. From this viewpoint, large-scale asset purchases might have worked mainly to increase the quantity of reserves supplied to the banking system, leading to faster money growth, higher output, and more stable inflation.[2] Forward guidance might have worked, as well, to convince the public that open market operations designed to stimulate broad money growth would continue even after the economy began to recover; working again through expectational channels, this more persistent increase in money growth might have contributed to a stronger economy right away. Taking a similar view, Taylor (2009) argues that the Federal Reserve might have conducted monetary policy in a more systematic fashion by switching to a version of Friedman's (1960) k-percent rule for constant money growth after the federal funds rate hit its zero bound in 2008.

If the monetary policy strategies available to the Fed before and after the recent financial crisis are similar in principle if not degree, it seems reasonable to ask whether the Fed could have responded to the economic downturn of 2007–09 by adopting a constant rate of money growth as an intermediate target rather than continuing to focus on interest rates. Moreover, if an alternative intermediate target of constant money growth had been chosen to guide the course of monetary policy, it must be asked whether that strategy would have made the U.S. economy's recovery from the Great Recession stronger or more rapid.

This paper investigates both questions by modifying the structural vector autoregression (SVAR) developed in Belongia and Ireland (2015, 2016b). Importantly, the SVAR brings data on both interest rates *and* money growth to bear in gauging the stance and consequences of Federal Reserve policy before, during, and since the financial crisis and Great Recession. The paper uses this model to

[2]See Orphanides and Wieland (2000) for an early theoretical treatment of the zero lower bound, motivated by the Japanese experience of the 1990s, that is consistent with this view. In their model, the central bank uses its influence over the monetary base to manage the federal funds rate during normal times, while targeting the monetary base even more aggressively to continue pursuing its stabilization goals in exceptional circumstances where short-term interest rates are constrained by the zero lower bound.

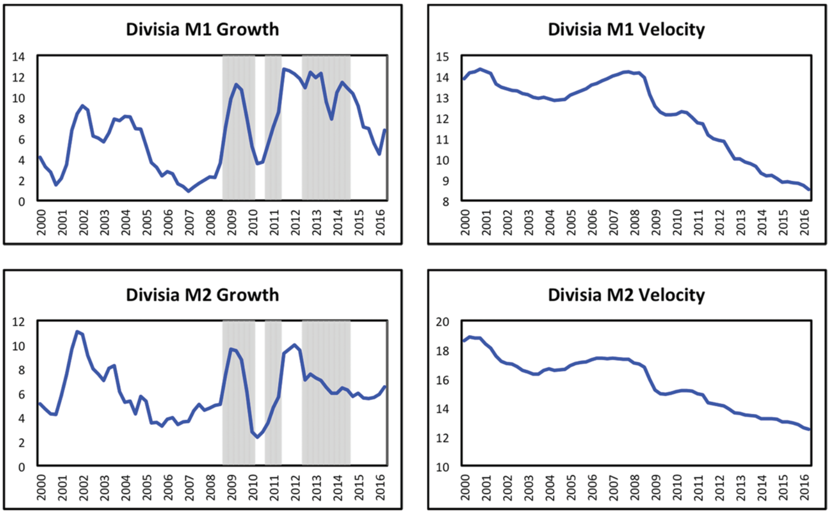
consider a range of counterfactual scenarios in which the Federal Reserve succeeds in maintaining a constant rate of broad money growth while its funds rate target is up against the zero lower bound.[3] Reassuringly, interest rates are often *higher* along their counterfactual paths than they were historically, suggesting that these alternative paths for money would have been feasible in practice. Indeed, in light of these counterfactual simulations, the persistence of extremely low interest rates after the end of the Great Recession could be seen as a consequence not of a dramatically expansionary monetary policy but, instead, of insufficiently accommodative rates of money growth. The declining velocities of the monetary aggregates observed during and since the financial crisis also play a role in shaping the results, which highlight the importance of maintaining robust rates of monetary expansion in the face of severe disruptions to the financial system and economic activity as a whole. Overall, the results provide evidence that the Fed could have successfully directed its efforts towards stabilizing money growth while the funds rate remained at its zero lower bound and, in so doing, generated more favorable economic outcomes.

2. Money, Output, and Prices Before, During, and Since the Crisis: An Overview

Before describing the model and presenting the results, this section provides an overview of the behavior of the monetary aggregates over the period from 2000 through 2016 and summarizes the reduced-form relationships between these measures of money and real GDP and the GDP deflator as indexes of aggregate output and prices. To begin, the two panels on the left-hand side of figure 1 plot year-over-year growth rates of the Divisia M1 and M2 monetary aggregates used throughout this study. The assets included in Divisia

[3]This analysis is therefore in much the same spirit of McCallum (1990), who examined whether a rule for growth in the monetary base could have prevented the Great Depression, and Bordo, Choudhri, and Schwartz (1995), who simulated the potential effects on output and inflation during the Depression under two variants of Friedman's k-percent rule. Although these studies show effects on nominal income or prices and output separately that are of different magnitudes, both suggest that economic performance under a money growth rule would have been substantially better than that depicted by the actual data.

Figure 1. Divisia Money Growth and Velocity



Notes: Panels on the left show year-over-year growth rates of the Divisia monetary aggregates, with periods of quantitative easing shaded. Panels on the right show the income velocities of the Divisia monetary aggregates.

M1 and M2 are the same as those in the Federal Reserve's official, simple-sum M1 and M2 measures of money. Both measures of Divisia money are compiled, however, using the economic aggregation techniques first outlined by Barnett (1980) and reviewed more recently in Barnett (2012). These techniques allow the Divisia monetary aggregates to accurately track the true flows of monetary services generated by their constituent assets, most of which pay interest at different rates. It accomplishes this in much the same way that more familiar macroeconomic quantity aggregates, such as real GDP, measure service flows generated by different goods and services based on the prices that demanders are willing to pay for those products. The Divisia monetary aggregates correct, as well, for distortions in the Federal Reserve's official monetary aggregates induced by the proliferation of deposit sweep programs, described by Cynamon, Dutkowsky, and Jones (2006). Prior to the financial crisis, these programs allowed banks to reduce their holdings of required reserves without changing the public's perception of the amount of funds held on deposit at those banks. Barnett et al. (2013) describe the construction of these Divisia monetary aggregates in full detail; the series themselves are available through the Center for Financial Stability's website.

The shaded portions of each panel on the left-hand side of figure 1 identify periods during which the Federal Reserve conducted its three waves of quantitative easing, operations that increased the Federal Reserve Bank of St. Louis's adjusted monetary base from \$872 billion in August 2008 to \$4,097 billion in August 2014. However, as the figure clearly shows, quantitative easing did not generate the same kind of explosive growth in broader measures of money. One reason for the disparate effects of large-scale asset purchases on the monetary base relative to broad monetary aggregates is the Federal Reserve's decision to begin paying interest on reserves. Ireland (2014) shows that the ability to pay interest on reserves gives the central bank a second instrument of monetary policy, one that works to shift the *demand* curve, rather than the supply curve, in the market for reserves. In particular, for any given level of the federal funds rate, movements from an initial equilibrium in which interest is not paid on reserves to a new equilibrium in which interest is paid on reserves at a rate that is very close to the target federal funds rate itself triggers a potentially large rightward shift in the demand curve for reserves. If the central bank then accommodates this increase in demand with an equally large increase in the supply of reserves, the monetary base can be expanded without generating additional broad money growth or inflation. Indeed, an increase in banks' holdings of excess reserves of close to \$2,700 billion accounts for about 84 percent of the increase in the adjusted monetary base between 2008 and 2014. Thus, it appears that to a large extent, quantitative easing simply accommodated the increased demand for reserves brought about by the Fed's new interest-on-reserves policy. Put another way, it seems that the Fed intentionally used interest on reserves to "sterilize" much of the increase in the base generated by quantitative easing.

Even though much of the effect of quantitative easing appears to have been absorbed by holdings of excess reserves, the left-hand panels of figure 1 also make clear that QE did have at least some expansionary effects on broader measures of money. Moving from the first half of the sample from 2000 through 2007 to the second half running from 2008 through the second quarter of 2016, average annual Divisia M1 growth increases from about 4.5 to 9 percent, while average annual Divisia M2 growth increases from slightly less than 6 to 6.75 percent. Nevertheless, whatever effects QE had on average rates of broad money growth, the pattern of money growth appears, overall, to have been "consistently inconsistent." Measured by either of the Divisia aggregates, money growth rose and then fell during QE1, accelerated throughout QE2, and finally drifted lower during much of QE3. The two panels on the right-hand side of figure 1, meanwhile, show that the downward trend in the income velocity of the Fed's official, simple-sum M2 measure studied by Anderson, Bordo, and Duca (2016) also appears in the velocities of the Divisia aggregates. This downward trend in velocity continues even after short-term interest rates reached their lower bound in 2008, a pattern consistent with Anderson, Bordo, and Duca's (2016) argument that flight-to-quality dynamics during and since the financial crisis increased the public's demand for the safe and liquid assets included in M1 and M2.

The implication of this first set of graphs is that Fed policy succeeded only partially in supporting the monetary system against the severe disruptions set off by the financial crisis of 2007–08 and the sharp downturn in aggregate economic activity that followed. Although the money supply did not fall during the Great Recession as Friedman and Schwartz (1963) show that it did during the Great Depression, the payment of interest on reserves appears to have impeded multiple waves of QE from generating consistent growth in broad monetary aggregates.[4] Any expansionary effects of quantitative easing were dampened further by a decline in velocity that called for even higher rates of money growth to stabilize nominal income and spending. Whatever indications of monetary ease were given by persistently low values of the funds rate or flattening of the yield curve, the data for money growth indicate a restrictive policy stance throughout much of the post-crisis period.

If the observed monetary growth rates are suggestive of policy actions that were insufficiently accommodative, it still is possible that more strenuous efforts to increase the growth rates of the broad monetary aggregates only would have led to further declines in

[4]See Currie (1934) for a much earlier analysis that emphasizes many of the same points made by Friedman and Schwartz (1963).

velocity, without noticeable effects on aggregate output and prices. The statistics in table 1, however, provide evidence to the contrary. This table reports correlations between real GDP, the GDP deflator, and each measure of money after the logarithms of all series are passed through the filter developed by Baxter and King (1999) to isolate fluctuations occurring at business-cycle frequencies corresponding to periods between eight and thirty-two quarters. These tables show that, in fact, modest correlations between money, output, and prices seen over an extended sample of quarterly data running from 1967:Q1 through 2016:Q2 become much stronger when recomputed using the data from 2000:Q1 through 2016:Q2 that are the principal focus here. The peak correlation between Divisia M1 and real GDP rises from 0.32 for the longer sample to 0.73 for the period since 2000; the strongest correlation between Divisia M1 and the deflator rises from 0.38 for the full sample to 0.77 since 2000. Likewise, for Divisia M2, its peak correlation with real GDP rises from 0.45 since 1967 to 0.69 since 2000, and its strongest correlation with the GDP deflator rises from 0.67 since 1967 to 0.81 since 2000.[5] Of course, these are only reduced-form statistics, yet they are, if anything, consistent with the presence of *stronger* links between money and economic activity during the period leading up to, during, and since the financial crisis and Great Recession, including the seven years during which the federal funds rate remained at its zero lower bound.

This preliminary look at the data, therefore, leads back to the questions that motivate this study. First, even with short-term interest rates near their zero lower bound, could the Fed have generated a higher and more stable rate of growth for a broad monetary aggregate since 2008? And, second, would the economic recovery have been stronger or more rapid had the Fed pursued this policy option instead of one with continued focus on interest rates? Answering these questions requires more structure to be imposed on a wider range of data. Hence, the analysis turns next to the structural VAR.

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[5]The lags at which peak correlations between money, output, and prices can be found also lengthen when moving from the longer sample to the most recent period. These changes in lag lengths follow broader trends documented and discussed by Belongia and Ireland (2015, 2016b, 2017).

Table 1. Correlations between the Cyclical Components of Real GDP, the GDP Deflator, and Lagged Divisia Money

k	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A. Real GDP, 1967:Q1–2016:Q2																
M1	−0.20	−0.18	−0.14	−0.08	−0.02	0.04	0.11	0.17	0.22	0.27	0.31	0.32	0.31	0.28	0.21	0.13
M2	−0.35	−0.31	−0.26	−0.19	−0.11	−0.03	0.06	0.15	0.25	0.34	0.41	0.45	0.45	0.40	0.32	0.21
B. GDP Deflator, 1967:Q1–2016:Q2																
M1	0.16	0.24	0.30	0.35	0.37	0.38	0.36	0.31	0.24	0.14	0.03	−0.09	−0.20	−0.30	−0.36	−0.40
M2	0.59	0.65	0.67	0.66	0.61	0.53	0.41	0.27	0.09	−0.09	−0.28	−0.44	−0.56	−0.63	−0.64	−0.61
C. Real GDP, 2000:Q1–2016:Q2																
M1	0.01	0.16	0.31	0.46	0.58	0.67	0.71	0.73	0.72	0.67	0.60	0.49	0.32	0.12	−0.08	−0.22
M2	0.36	0.47	0.58	0.66	0.69	0.66	0.59	0.50	0.40	0.28	0.16	0.01	−0.16	−0.35	−0.51	−0.59
D. GDP Deflator, 2000:Q1–2016:Q2																
M1	0.46	0.59	0.70	0.76	0.77	0.73	0.67	0.59	0.47	0.33	0.15	−0.03	−0.21	−0.34	−0.40	−0.39
M2	0.78	0.81	0.79	0.72	0.59	0.44	0.29	0.13	−0.04	−0.21	−0.38	−0.53	−0.62	−0.63	−0.55	−0.40

Note: Each entry shows the correlation between the cyclical component of real GDP or the GDP deflator in quarter t and the cyclical component of Divisia M1 or M2 in quarter $t-k$.

3. Interest Rates, Money, and Monetary Policy in a Structural VAR

The structural vector autoregression developed in Belongia and Ireland (2015, 2016b) describes the behavior of six variables: the GDP deflator, real GDP, the federal funds rate, a Divisia monetary aggregate and its associated user cost index, and a measure of commodity prices. Here, this model is modified and extended to address issues raised by the financial crisis, the Great Recession, and their aftermath, events which clearly set the more recent period apart from earlier episodes in U.S. monetary, financial, and economic history. The modified model estimated here retains the GDP deflator and real GDP as its measures of aggregate prices P_t and output Y_t and uses either Divisia M1 or M2 as the measure of money M_t. To distinguish more sharply between the demand for and supply of money, the model also continues to exploit information in the associated Divisia monetary user cost index U_t as explained in more detail below.

To capture more fully the effects that the Federal Reserve's large-scale asset purchases and forward guidance have had on the American economy through traditional interest rate channels, this study replaces the federal funds rate with either of two alternative interest rate measures R_t. The first alternative, Wu and Xia's (2016) measure of the shadow federal funds rate, is derived from a nonlinear model that accounts for the zero lower bound on the actual funds rate, but follows Black (1995) by using information in the term structure of interest rates to deduce the shadow rate—which may be negative—consistent with the behavior of longer-term bond yields. The second is a more direct measure of intermediate-term interest rates—the two-year U.S. Treasury yield—that, according to Swanson and Williams (2014), continued to reflect the effects of Federal Reserve policy actions through most of the ZLB period.[6] Finally, the modified model estimated here replaces the commodity price index with Gilchrist and Zakrajšek's (2012) measure X_t of the excess bond premium. Although the identification scheme

[6]Gertler and Karadi (2015), Gilchrist, López-Salido, and Zakrajšek (2015), and Hanson and Stein (2015) also use the two-year Treasury rate to help gauge the effects of Federal Reserve policy during and since the financial crisis and Great Recession.

outlined below makes no attempt to distinguish shocks originating in the non-bank financial sector from other non-policy shocks affecting the U.S. economy during the crisis, including this measure in the model's information set helps ensure that macroeconomic volatility due to financial stress before, during, and since the crisis does not get misattributed to monetary policy.

All variables enter the SVAR in logarithms, except for the interest rate, the Divisia monetary user cost, and the excess bond premium, which enter as decimals, e.g., $R_t = 0.05$ or $R_t = -0.01$ for an annualized shadow funds rate equal to +5 or −1 percent. Figure 2 plots all of the quarterly series. The data for real GDP, the GDP deflator, and the two-year Treasury yield are drawn from the Federal Reserve Bank of St. Louis's Federal Reserve Economic Data (FRED) database; those for the Divisia M1 and M2 quantity and user cost aggregates are from the Center for Financial Stability's website. The series for the shadow federal funds rate comes from Jing Cynthia Wu's webpage at the University of Chicago, and that for the excess bond premium from Simon Gilchrist's webpage at Boston University. The sample of data runs from 2000:Q1 through 2016:Q2, so as to focus on the lead-up to the financial crisis of 2007–08 and the Great Recession and slow recovery that followed, while also providing enough observations to estimate the parameters of the SVAR with a reasonable degree of precision.

Collecting the variables into the 6×1 vector

$$Z_t = \begin{bmatrix} P_t & Y_t & R_t & M_t & U_t & X_t \end{bmatrix}', \tag{1}$$

the structural model can be written as

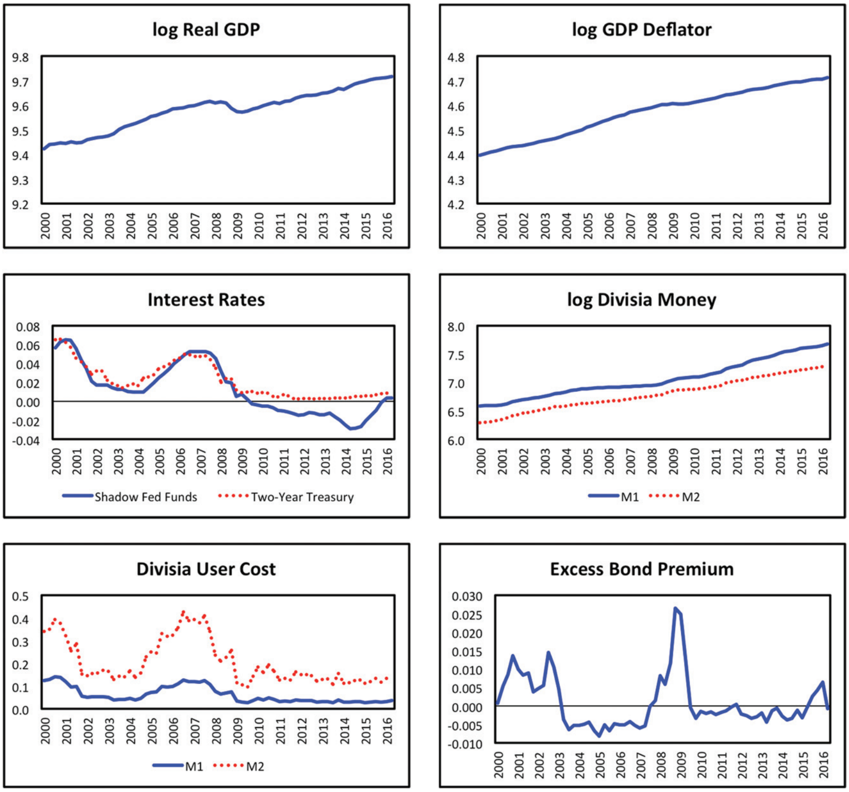
$$AZ_t = \mu + \Phi_1 Z_{t-1} + \Phi_2 Z_{t-2} + \varepsilon_t, \tag{2}$$

where A is a 6×6 matrix of impact coefficients, normalized to have positive elements along its diagonal, μ is a 6×1 vector of intercept terms, Φ_1 and Φ_2 are 6×6 matrices of autoregressive coefficients, ε_t is a 6×1 vector of serially and mutually uncorrelated structural shocks, normally distributed with zero means and

$$E\varepsilon_t\varepsilon' = I_6, \tag{3}$$

and I_6 is the 6×6 identity matrix. The short sample of data used to estimate the model dictates the choice to place two lags of Z_t on the

Figure 2. Data Used to Estimate the Vector Autoregressions



right-hand side of (2). Multiplying (2) by A^{-1} leads to the reduced form

$$Z_t = \nu + \Gamma_1 Z_{t-1} + \Gamma_2 Z_{t-2} + z_t, \tag{4}$$

where $\nu = A^{-1}\mu$, $\Gamma_1 = A^{-1}\Phi_1$, and $\Gamma_2 = A^{-1}\Phi_2$, and the 6×1 vector of zero mean disturbances $z_t = A^{-1}\varepsilon_t$ is such that

$$E z_t z_t' = \Omega = A^{-1}(A^{-1})'. \tag{5}$$

Since the reduced-form covariance matrix Ω has only twenty-one distinct elements, at least fifteen restrictions must be imposed on the thirty-six elements of A in order to identify the structural disturbances based on information in the data. A popular approach to solving this identification problem follows Sims (1980) by imposing a lower triangular structure on A so that, suppressing the intercept and autoregressive terms that appear in (2) to focus on the contemporaneous relationships between the observable variables and the structural disturbances, the model specializes to

$$\begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \begin{bmatrix} P_t \\ Y_t \\ R_t \\ M_t \\ U_t \\ X_t \end{bmatrix} = \begin{bmatrix} \varepsilon_t^p \\ \varepsilon_t^y \\ \varepsilon_t^{mp} \\ \varepsilon_t^{md} \\ \varepsilon_t^u \\ \varepsilon_t^x \end{bmatrix}. \tag{6}$$

With the variables ordered the same way in (6) as in (1), this identification scheme is based partly on the assumption that monetary policy shocks, measured by the third element ε_t^{mp} in the vector of structural disturbances ε_t, affect the aggregate price level and output with a one-period lag. Leeper and Roush (2003) note, however, that when a monetary aggregate also appears in the list of variables used to estimate the model, as is the case here, a triangular scheme that orders the interest rate behind prices and output but ahead of money also reflects assumptions that distinguish money supply from money demand. In particular, the third equation in (6) can be interpreted as a monetary policy rule of the same general form

$$a_{31}P_t + a_{32}Y_t + a_{33}R_t = \varepsilon_t^{mp} \tag{7}$$

as in Taylor (1993), which describes how the Federal Reserve sets its target for the interest rate with reference to the current period's values of aggregate prices and output. Under this interpretation, the money supply then adjusts elastically so as to satisfy the fourth equation in (6), which can be viewed as a flexibly parameterized money demand relationship,

$$a_{41}P_t + a_{42}Y_t + a_{43}R_t + a_{44}M_t = \varepsilon_t^{md}, \tag{8}$$

that links the nominal quantity of money demanded to the aggregate price level and aggregate output as scale variables and the interest rate as an opportunity cost variable.

Thus, while the lagged terms that appear implicitly in (6)–(8) and more explicitly in (2) allow for flexible dynamics between the lags of interest rates and money, the view of monetary policy reflected in this triangular specification resembles closely the one taken by the canonical New Keynesian model, as depicted in textbook presentations such as Galí's (2015): the Federal Reserve is described as targeting the interest rate based on output and inflation, leaving the money stock to expand or contract as needed to fully accommodate changes in money demand.[7] More generally, in the same language of Cushman and Zha (1997), Leeper and Roush (2003), Leeper and Zha (2003), and Sims and Zha (2006), the system in (6) identifies the first two elements of ε_t as disturbances to the sluggishly moving "production sector" of the economy and the last two elements of ε_t as shocks to a more quickly adjusting "information sector." The triangular scheme distinguishes these shocks from those to monetary policy and money demand, but does not assign any specific structural interpretation to them.

Belongia and Ireland (2015, 2016b) take an alternative approach to identifying structural shocks in systems like (2) and (3) by imposing additional restrictions on the money demand relationship in order to allow for a finite elasticity of money supply and, by extension, a richer set of interactions between interest rates and the money stock in shaping the effects of monetary policy disturbances. This alternative model, in the modified form used here, parameterizes A so that (2) becomes

$$\begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & a_{34} & 0 & 0 \\ -a_{44} & -a_{44} & 0 & a_{44} & a_{45} & 0 \\ -a_{54} & 0 & a_{53} & a_{54} & a_{55} & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \begin{bmatrix} P_t \\ Y_t \\ R_t \\ M_t \\ U_t \\ X_t \end{bmatrix} = \begin{bmatrix} \varepsilon_t^p \\ \varepsilon_t^y \\ \varepsilon_t^{mp} \\ \varepsilon_t^{md} \\ \varepsilon_t^{ms} \\ \varepsilon_t^x \end{bmatrix}, \quad (9)$$

[7]See Belongia and Ireland (2016a) for further elaboration on this New Keynesian interpretation of conventionally specified structural VARs, and for an explicit Bayesian comparison between the New Keynesian benchmark and an alternative that allows changes in the money stock to play a greater role, operating through "classical" channels of monetary transmission.

again suppressing explicit reference to the intercept and autoregressive terms to focus on the contemporaneous relationships between the observable variables and the structural shocks.

The first two equations in (9) impose the same timing restrictions used in the fully recursive, triangular model such that the aggregate price level and output respond to monetary policy (and other) shocks with a one-period lag. In defense of this timing assumption, note from table 1 that, for the sample period running from 2000:Q1 through 2016:Q2, correlations between the cyclical components of money and output and money and the price level are consistently negative, a reduced-form relationship more easily explained if monetary policy responds immediately to output and inflation than if output and inflation respond immediately to monetary policy. In (9) as in (6), therefore, ε_t^p and ε_t^y appear as shocks to a sluggish production sector, identified separately from shocks to monetary policy and money demand but not given any structural interpretation, for example, as shocks to aggregate supply and demand.

The third equation in (9) describes a monetary policy rule more general than (7) and takes the form

$$a_{31}P_t + a_{32}Y_t + a_{33}R_t + a_{34}M_t = \varepsilon_t^{mp}. \tag{10}$$

Following Ireland (2001), (10) can be interpreted as a generalized Taylor (1993) rule that includes the money stock together with the aggregate price level and output in the list of variables that Federal Reserve policymakers refer to when setting their interest rate target. Following Leeper and Roush (2003), (10) also can be interpreted as a monetary policy rule that features a finite elasticity of money supply, in contrast to the implicit assumption of infinite money supply elasticity reflected in (7), the original Taylor (1993) rule, and the standard New Keynesian model. Yet another interpretation, supported by the reduced-form connections between money, output, and prices shown in table 1, is that (10) captures simultaneous movements in the interest rate *and* money, both of which are important in transmitting the effects of monetary policy shocks through the economy.

Belongia and Ireland (2015) test the general specification in (10) against the more constrained alternative originally proposed by Sims (1986) and used more recently by Leeper and Roush (2003) and Sims and Zha (2006) in which $\alpha_{31} = \alpha_{32} = 0$, so that the price level and output are excluded from the monetary policy rule. Belongia and Ireland (2015, 2016b) work with this simpler version of the rule because, when using data from 1967:Q1 through 2007:Q4, imposing these constraints does not lead to statistically significant deterioration in the model's fit. As shown below, however, these constraints are rejected quite decisively in data from 2000:Q1 through 2016:Q2, reflecting mainly the Federal Reserve's attempts to use monetary policy to stabilize output over this most recent period. Hence, the more flexible specification is used here. Keating et al. (2014) and Arias, Caldara, and Rubio-Ramirez (2016) are two other papers that experiment, successfully, in bringing information in both interest rates and monetary aggregates to bear in identifying monetary policy shocks and estimating their effects on the economy.

The fourth equation in (9) draws on economic theory to parameterize the money demand relationship more tightly as

$$a_{44}(M_t - P_t - Y_t) + a_{45}U_t = \varepsilon_t^{md}. \tag{11}$$

Relative to (8) from the triangular model, (11) follows Cushman and Zha (1997) by imposing a unitary price elasticity, so that the demand for money is described explicitly as a demand for *real* cash balances. Here, again modifying the specification from Belongia and Ireland (2015, 2016b), a unitary income elasticity of money demand also is imposed; though not essential for identification, this constraint also helps distinguish between money demand and money supply, is not rejected by the data, and is consistent with theories of money demand that predict a stable relationship between monetary velocity and an opportunity or user cost variable. Finally, compared with (8), (11) replaces the interest rate R_t with the Divisia user cost index U_t, which measures the "price" of monetary services in a theoretically coherent way; interest rates, by contrast, are linked to the price of bonds as money substitutes.[8] Thus, drawing on the logic behind identification in more traditional simultaneous equation systems, (10) and (11) work to disentangle shocks to money supply from those to money demand, first, by using quantity-theoretic restrictions that associate "money supply" with nominal cash balances and "money demand" with real cash balances relative to income. These

[8]See Barnett (1978) and Belongia (2006) for more detailed discussions of this point.

shocks also are distinguished by including in the money supply rule the nominal interest rate as a variable that the Fed cares about and the Divisia user cost of money in the money demand equation as a variable that private depositors care about.

The fifth equation in (9),

$$a_{53}R_t + a_{54}(M_t - P_t) + a_{55}U_t = \varepsilon_t^{ms}, \tag{12}$$

describes how the private banking system, together with the Federal Reserve, create the liquid assets in the Divisia monetary aggregates. Belongia and Ireland (2014) and Ireland (2014) incorporate this "monetary system" into dynamic stochastic general equilibrium models in which bank deposits and currency substitute imperfectly for one another in providing monetary services, showing in particular how changes in interest rates get passed along to consumers in the form of a higher user cost of a Divisia monetary aggregate. Equation (12) adds flexibility to this simpler relationship implied by the DSGE models by allowing the quantity of real monetary services to affect the user cost as well, as it would if banks pass rising marginal costs along to consumers when they expand their scale of operation. Finally, the sixth equation in (9) treats the excess bond premium X_t as an information variable, able to respond instantaneously to all other disturbances that hit the economy. Although the shock ε_t^x that affects the bond premium before affecting all other variables is identified separately from the remaining elements of ε_t based on that timing assumption, it is not given a specific, structural interpretation here.[9]

Rubio-Ramirez, Waggoner, and Zha (2010, theorem 1, p. 673) provide sufficient conditions for global identification in structural VARs; the appendix verifies that these conditions hold with A parameterized as in (9). Hamilton (1994, ch. 11) and Lutkepohl (2006, ch. 9), meanwhile, show that even with the non-recursive restrictions

[9]Imposing additional assumptions that would allow the model to distinguish specific shocks that originate in the non-bank financial sector from others that affect measures of financial stress simply because they provide information about developments in the economy as a whole would be a useful extension in future work. Such an extension then could address more fully the specific role played by financial as well as monetary factors in shaping the Great Recession and the slow recovery that followed. Here, without those assumptions, the disturbance ε_t^x must be viewed as an amalgam of these more fundamental shocks.

imposed in (9), fully efficient estimates of the reduced-from intercept and autoregressive coefficients in (4) can be obtained by applying ordinary least squares separately to each equation. Estimates of the free parameters in A then can be obtained by maximizing a concentrated log-likelihood function, and estimates of the intercept and autoregressive coefficients in (2) recovered by multiplying (4) through by A. These estimates are summarized and discussed next. The estimated model then is used to assess the feasibility and desirability of policies the Federal Reserve might have used to stabilize the rate of money growth during and since the Great Recession.

4. Estimates and Counterfactuals

Tables 2 and 3 report estimates of key parameters from the matrix A of impact coefficients, focusing on the monetary policy and money demand relationships (7) and (8) from the triangular model and the monetary policy, money demand, and monetary system equations (10)–(12) from the non-recursive model. In the tables, these equations are written with the nominal interest rate R_t, nominal money M_t, or real money balances relative to income $M_t - P_t - Y_t$, and the Divisia user cost variable U_t isolated on their left-hand side. This re-formatting, however, is only to assist in interpreting the signs of the coefficients, as each relationship describes how all of its variables respond contemporaneously to one of the identified structural disturbances. It also would be possible to renormalize each equation by dividing through by the coefficient on its "left-hand-side" variable. But, as noted by Cushman and Zha (1997), maximum-likelihood estimation is invariant to such renormalizations, and in their original form the equations allow one to assess the importance of each variable individually. Standard errors for the estimated coefficients, also shown in the tables, are computed using the formulas from proposition 9.5 in Lutkepohl (2006, ch. 9, p. 373).[10]

[10]In interpreting these standard errors, one should keep in mind that sixty-six quarterly observations on six variables are being used to estimate a model with ninety-nine or ninety-six parameters: the six intercept terms, seventy-two autoregressive coefficients, and either twenty-one or eighteen distinct elements of the matrix A as shown in (6) or (9). Hence, the standard errors for some of these parameters are bound to be large.

Table 2. Estimated Impact Coefficients: Triangular Vector Autogression

	Shadow Federal Funds Rate/M1	**Shadow Federal Funds Rate/M2**
Monetary Policy	312.95R = 2.47P + 72.97Y (27.66) (75.39) (33.46)	315.88R = 14.26P + 78.68Y (27.92) (76.00) (33.82)
Money Demand	132.76M = 74.92P – 95.42Y – 80.51R (11.73) (75.68) (35.11) (39.76) L^* = 1594.53	180.01M = 100.75P – 65.49Y – 72.52R (15.91) (76.53) (35.01) (40.00) L^* = 1533.96
	Two-Year Treasury Rate/M1	**Two-Year Treasury Rate/M2**
Monetary Policy	352.94R = 120.74P + 106.18Y (31.20) (77.15) (34.17)	352.98R = 121.96P + 108.34Y (31.20) (77.87) (34.41)
Money Demand	131.79M = 75.13P – 100.10Y + 57.17R (11.65) (78.17) (36.53) (44.41) L^* = 1617.69	192.28M = 147.46P – 66.70Y – 118.34R (17.00) (79.68) (36.20) (45.35) L^* = 1557.01

Notes: The table reports estimates of the coefficients shown in equations (7) and (8) for the triangular model. Standard errors of the estimated parameters are in parentheses. L^* denotes the maximized value of the log-likelihood function.

Table 3. Estimated Impact Coefficients: Non-recursive Vector Autogression

	Shadow Federal Funds Rate/M1	**Shadow Federal Funds Rate/M2**
Monetary Policy	89.67R = –63.28P + 119.27Y + 114.35M (84.00) (77.75) (34.53) (20.79)	133.10R = –71.66P + 99.72Y + 143.43M (87.60) (82.67) (34.39) (34.38)
Money Demand	18.08(M – P – Y) = –134.09U (13.67) (11.94)	32.71(M – P – Y) = –38.72U (17.87) (3.46)
Monetary System	51.10U = 331.27R + 65.09(M – P) (17.66) (36.20) (27.77) $L^* = 1593.71$, $p = 0.65$	13.13U = 310.31R + 103.14(M – P) (5.14) (45.07) (39.72) $L^* = 1533.26$, $p = 0.71$
	Two-Year Treasury Rate/M1	**Two-Year Treasury Rate/M2**
Monetary Policy	218.53R = 36.77P + 145.93Y + 90.09M (68.97) (79.73) (35.32) (23.88)	233.26R = 23.07P + 127.21Y + 103.79M (79.18) (88.15) (34.94) (43.62)
Money Demand	20.17(M – P – Y) = –160.08U (13.69) (14.45)	36.66(M – P – Y) = –41.38U (17.40) (3.68)
Monetary System	46.46U = 294.06R + 94.11(M – P) (22.60) (50.70) (19.85) $L^* = 1615.77$, $p = 0.28$	6.31U = 293.23R + 157.99(M – P) (5.69) (60.30) (28.69) $L^* = 1556.03$, $p = 0.58$

Notes: The table reports estimates of the coefficients shown in equations (10)–(12) for the non-recursive structural model. Standard errors of the estimated parameters are in parentheses. L^* denotes the maximized value of the log-likelihood function; the p-values shown are for the likelihood-ratio test of the model's three over-identifying restrictions.

In tables 2 and 3 and throughout the analysis that follows, each specification is estimated four times, using either the shadow federal funds rate or the two-year U.S. Treasury yield to measure R_t and either Divisia M1 or M2 to measure M_t and U_t. While some differences do appear and are noted below, the main findings and conclusions are robust to these data choices. Thus, much of the discussion can focus on a benchmark set of results obtained when the model is estimated with the shadow funds rate, which by design is never constrained by the zero lower bound, and Divisia M1, which as shown in table 1 displays its peak correlations with aggregate output and prices at shorter lags, a distinct advantage given the relatively short sample period and the small number of lags included in the VAR.

For the triangular model, the estimated coefficients on the GDP deflator and real GDP in the monetary policy equations shown in table 2 have their expected signs, consistent with the interpretation of (7) as a variant of the Taylor (1993) rule for the interest rate. In the money demand relationship (8), however, the estimated coefficient on real GDP implies an income elasticity of money demand that is negative and statistically significant. This inverse relationship between nominal money and real output is what one would expect to see in a money *supply* function as opposed to a money demand curve. Thus, this finding suggests that excluding money from the monetary policy rule (7)—that is, assuming an infinitely elastic money supply schedule—forces the money demand relationship (8) to account for dynamics associated with both money supply and money demand. Although the triangular model is exactly identified and therefore “fits” the data as well as or better than any other, its failure to discriminate adequately between money supply and money demand points to the non-recursive model as a preferred alternative.

Since (9) imposes eighteen restrictions on the elements of A whereas only fifteen restrictions are needed for identification, the statistical adequacy of the over-identified, non-recursive specification can be tested by comparing its maximized log-likelihood function to that of the just-identified triangular model. Tables 2 and 3 do this and, in particular, the p-values shown in table 3 confirm that likelihood-ratio tests never reject their null hypothesis that the three additional constraints imposed by (9) relative to (6) are satisfied.

Table 4. Long-Run Monetary Policy Rules from Non-recursive Vector Autogression

Shadow Federal Funds Rate/M1	$\Delta M = -0.97\Delta P - 0.48\Delta Y - 0.13R + 0.10U + 0.05X$ (0.76) (0.30) (0.21) (0.11) (0.29)
Shadow Federal Funds Rate/M2	$\Delta M = -0.31\Delta P + 0.03\Delta Y - 0.10R - 0.01U + 0.08X$ (0.64) (0.24) (0.16) (0.03) (0.23)
Two-Year Treasury Rate/M1	$\Delta M = -1.03\Delta P - 1.10\Delta Y + 0.32R - 0.15U + 0.19X$ (1.00) (0.51) (0.42) (0.19) (0.39)
Two-Year Treasury Rate/M2	$\Delta M = -0.52\Delta P - 0.49\Delta Y - 0.21R - 0.01U + 0.23X$ (0.89) (0.50) (0.27) (0.05) (0.33)

Notes: The table reports estimates of the coefficients measuring the long-run monetary policy response of Divisia money growth to permanent changes in inflation, output growth, the nominal interest rate, the user cost of money, and the excess bond premium. Standard errors of the estimated coefficients are in parentheses.

Moving to the non-recursive model, therefore, requires no sacrifice in terms of statistical fit.

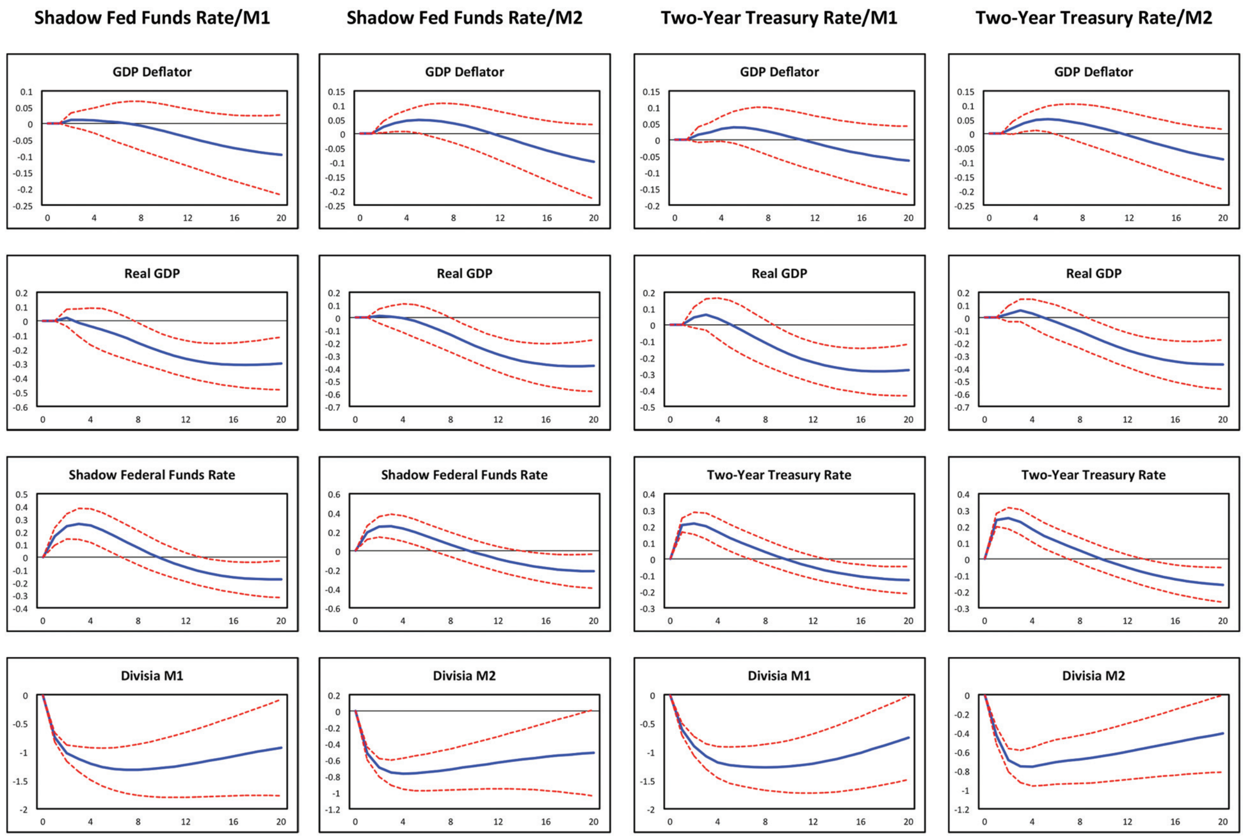
In table 3, all the estimated parameters from the non-recursive specification have their expected signs, the only exception being the negative—but statistically insignificant—coefficient on the aggregate price level in the monetary policy rule that appears when the model is estimated with data on the shadow funds rate. The Divisia user cost variable enters significantly into the money demand equation (11), and both the nominal interest rate and the real money stock significantly influence the user cost via the monetary system equation (12).

In fact, the estimated policy rules for the non-recursive model draw their strongest statistical connections between nominal money and real GDP. This finding is consistent with the interpretation that Federal Reserve policy actions, including quantitative easing, worked to increase the growth rates of the broad monetary aggregates in an attempt to stabilize output during and since the Great Recession. Building on this interpretation, table 4 displays "long-run" policy rules for nominal money growth derived from the estimated model, which take into account the autoregressive coefficients appearing in the matrices Φ_1 and Φ_2 from the structural model (2) as well as the impact coefficients from A. Computed as suggested by Sims and Zha (2006), each long-run coefficient measures the permanent, percentage-point increase in the growth rate of money that would be generated, according to the estimated policy rule, by a permanent, 1 percentage point increase in inflation or output growth or by a permanent, 1 percentage point increase in the nominal interest rate, user cost of money, or excess bond premium. Although large standard errors reflect considerable uncertainty surrounding the magnitudes of these long-run responses, the results from table 4 combine with those from table 3 to provide a consistent characterization of Federal Reserve policy over 2000–16 as one that took actions to increase the rate of money growth in response to declining output in the short run and declining output and inflation over longer horizons.

The solid lines in figure 3 plot impulse responses for the GDP deflator, real GDP, the nominal interest rate, and the Divisia money stock to a one-standard-deviation contractionary monetary policy shock, identified using the non-recursive model. The dashed lines, meanwhile, provide plus-and-minus one-standard-error bands around the impulse responses. These are computed, as suggested by Hamilton (1994, ch. 11, pp. 336–37), by treating each impulse response as a vector-valued function of the estimated VAR parameters and using the numerical derivatives of that function to convert standard errors for the parameters into standard errors for the impulse responses. For the benchmark case when data on the shadow federal funds rate and Divisia M1 are used to estimate the model, the monetary policy shock lifts the shadow rate by 25 basis points over the first four quarters; the rate remains higher for more than two years before falling back below its initial level in response to the lower levels of prices and output that also follow the unanticipated monetary tightening. Leeper and Zha (2003) point out that an impulse response with these properties captures the same short-run liquidity effect and longer-run expected inflation effect that Friedman (1968) and Cagan (1972) associate with monetary policy actions that decrease the money supply. In fact, as figure 4 also shows, the identified policy shock has large and persistent contractionary effects on the Divisia money stock. Real GDP responds to the disturbance with a lag, moving lower with effects that build over a period of three to four years.

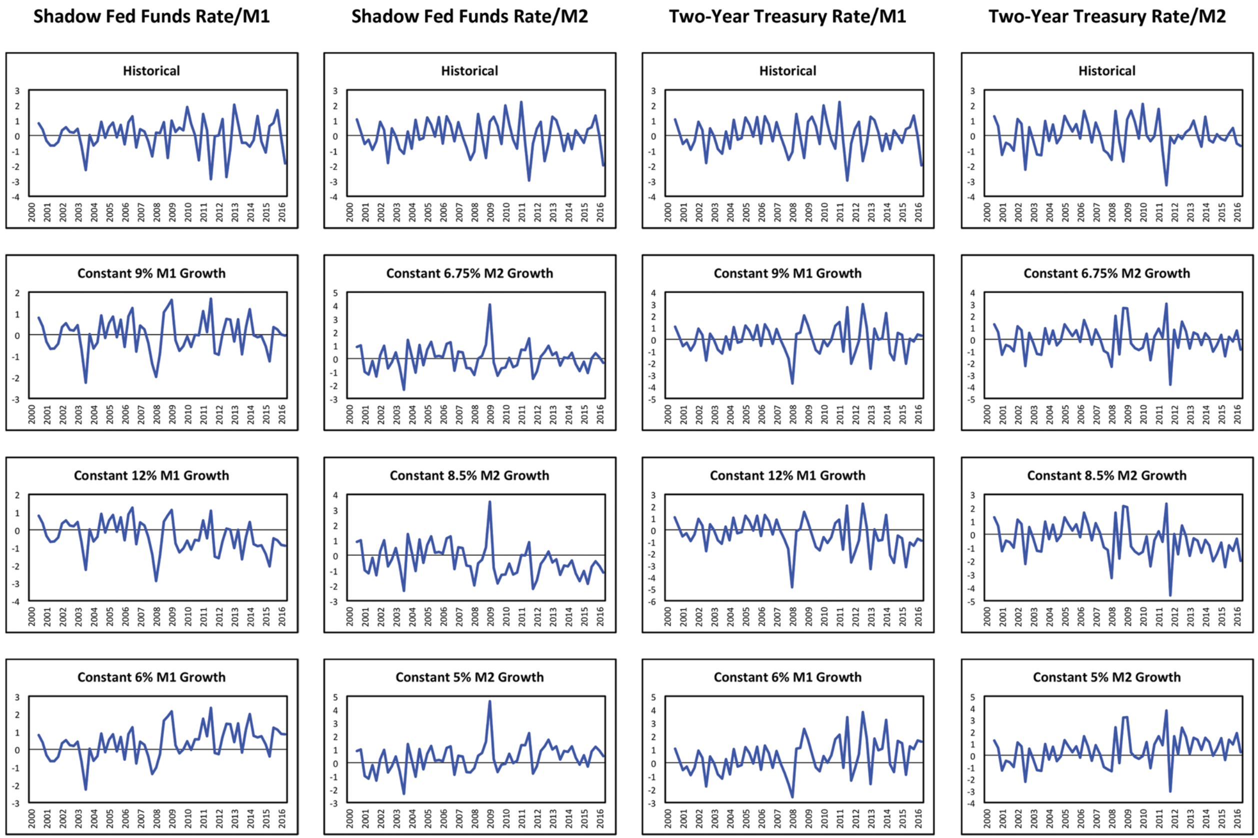
The impulse response for the GDP deflator exhibits a short-run "price puzzle," rising immediately after the shock before falling more

Figure 3. Impulse Response Functions



Note: Each panel shows the percentage-point response of the indicated variable to a one-standard-deviation monetary policy shock (solid line) together with plus-and-minus one standard error bands (dashed lines).

Figure 4. Monetary Policy Shocks: Historical and Counterfactual



Note: Panels show the historical path for the identified monetary policy shock and counterfactual paths required to support constant rates of money growth.

persistently later on.[11] The initial upward movement in the price level gets magnified when the two-year Treasury yield is used to measure the interest rate, suggesting that the shadow federal funds rate is more useful in identifying monetary policy shocks over the entire 2000–16 sample period.[12] The initial increase in prices also becomes larger when Divisia M2 replaces Divisia M1 as the measure of money. Across all four data sets, however, the effects of the monetary policy shock on the aggregate price level are small and imprecisely estimated. The absence of strong effects of monetary policy on inflation is, in fact, a feature that runs consistently through all of the results that follow.

Table 5 reports the fraction of the forecast error variances in real GDP and the GDP deflator attributable to monetary policy shocks, again identified with the non-recursive specification in (9). Although their standard errors, computed in the same way as for the impulse responses described above, are large, these variance decompositions attribute to monetary policy shocks about 20 percent of the forecast errors in real GDP over horizons of four to five years. By contrast, monetary shocks explain relatively little of the volatility in the GDP deflator.

As shown previously in figure 1, Divisia M1 and M2 grew at average annual rates of 9 and 6.75 percent, respectively, between 2008:Q1 and 2016:Q2. With stable velocity, of course, those rates of money growth would have translated into similarly robust rates of growth in nominal spending and resulted in much faster rates of real GDP growth and inflation than those seen historically. The substantial declines in velocity shown in the same figure, however, imply that even more rapid monetary expansion was needed to fully stabilize the economy. In addition, because money growth itself exhibited wide fluctuations about its mean, falling sharply in particular when the Fed briefly suspended its quantitative easing in 2010, monetary

[11] As shown in a previous draft of this paper, available as Belongia and Ireland (2016c), the price puzzle appears in the impulse response to an identified monetary policy shock even when an index of commodity prices is included in the list of series used to estimate the non-recursive model.

[12] This observation also is consistent with Swanson and Williams (2014), which shows that while the two-year Treasury yield reacted fully to Federal Reserve policy actions through 2010, the zero lower bound began constraining its movements in 2011.

Table 5. Forecast Error Variance Decompositions from Non-recursive Vector Autoregression

Quarters Ahead	Shadow Federal Funds Rate/M1		Shadow Federal Funds Rate/M2	
	GDP Deflator	**Real GDP**	**GDP Deflator**	**Real GDP**
2	0.23	0.12	1.05	0.05
	(0.88)	(0.70)	(1.78)	(0.44)
4	0.21	0.18	2.62	0.02
	(1.15)	(0.90)	(4.07)	(0.16)
8	0.08	2.11	2.20	1.56
	(0.32)	(5.34)	(4.61)	(4.20)
12	0.43	9.02	1.45	10.17
	(1.90)	(11.43)	(3.37)	(12.66)
16	1.63	17.83	1.83	21.39
	(5.24)	(15.54)	(2.72)	(16.17)
20	3.48	23.40	3.98	26.96
	(9.73)	(17.04)	(8.91)	(15.99)

Quarters Ahead	Two-Year Treasury Rate/M1		Two-Year Treasury Rate/M2	
	GDP Deflator	**Real GDP**	**GDP Deflator**	**Real GDP**
2	0.47	0.56	0.75	0.27
	(1.43)	(1.57)	(1.71)	(1.08)
4	1.37	0.60	3.04	0.47
	(3.18)	(2.09)	(4.51)	(1.87)
8	1.25	1.02	2.46	1.09
	(3.74)	(1.76)	(4.86)	(2.31)
12	0.79	5.99	1.59	7.37
	(2.43)	(8.28)	(3.52)	(9.93)
16	1.02	13.90	1.91	16.46
	(1.73)	(13.70)	(2.65)	(14.11)
20	1.94	19.68	3.91	22.02
	(4.95)	(15.37)	(7.55)	(15.00)

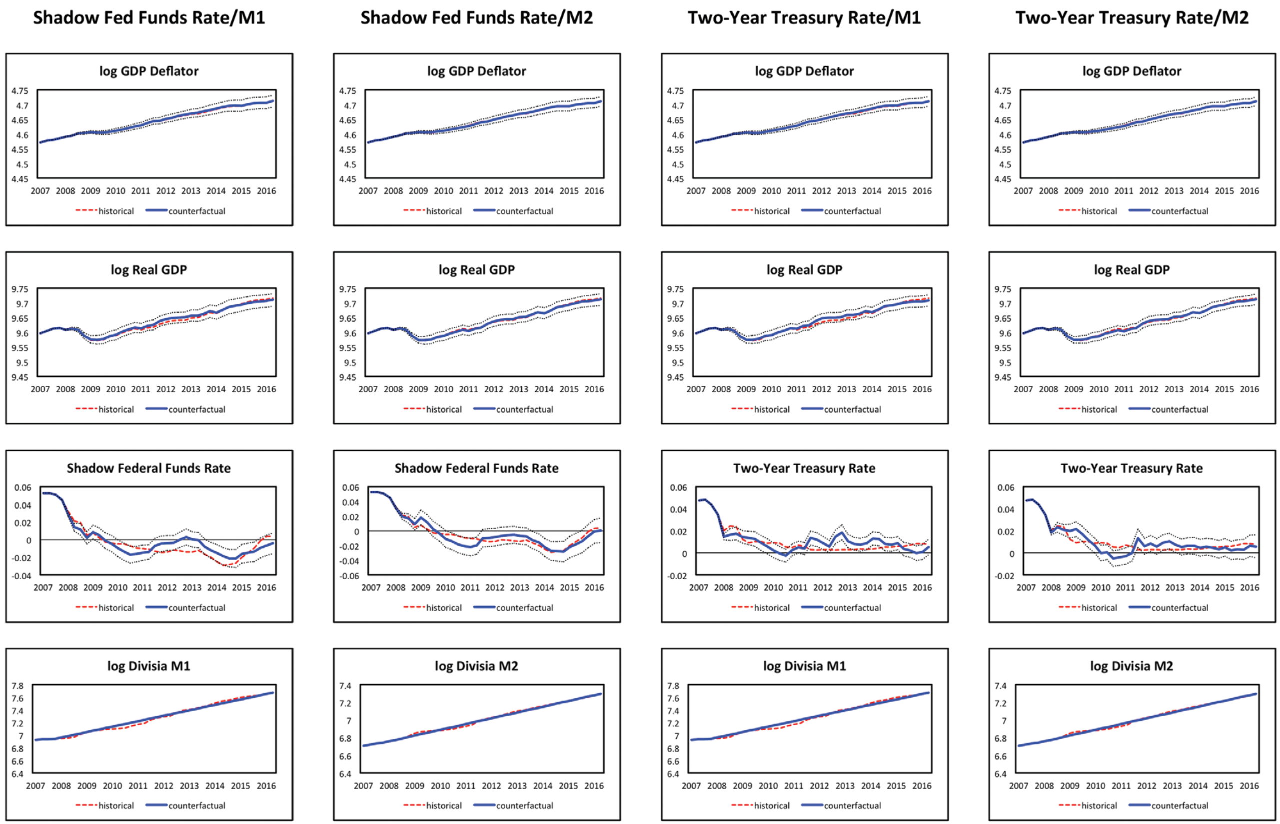
Note: Each entry shows the percentage of the forecast error variance in the GDP deflator or real GDP due to the identified monetary policy shock at the indicated horizon. Standard errors are in parentheses.

policy may have contributed to some of the slow growth and inflation experienced during the period of recovery from the Great Recession. Evidence on this conjecture can be seen in the top row of figure 4, which plots the historical series for monetary policy shocks implied by the estimated, non-recursive SVAR. Strikingly, most of the policy disturbances realized during 2009 and 2010 are *positive*: since shocks with this sign are associated with higher interest rates and slower rates of money growth, they signal that monetary policy was unexpectedly *tight* throughout this period. Along with the impulse responses in figure 3 and variance decompositions in table 5, therefore, the historical shocks in figure 4 show that, according to the estimated model, it was not until 2011 and 2012 that Federal Reserve policy began to lend full support to the economic recovery.

These observations suggest that the lesson drawn from U.S. monetary history by Friedman and Schwartz (1963) and Brunner and Meltzer (1968) continues to have relevance today. By interpreting low nominal interest rates as a sign of monetary ease and neglecting signs of tightness implied by a comparison of trends in money supply and money demand, it is possible to understand how the Federal Reserve contributed to the length and severity of the Great Depression and why the Fed behaved as it did during the Great Recession. But, again, these observations beg the following questions: Would switching to Milton Friedman's (1960) k-percent rule for constant money growth once the zero lower bound for the funds rate had been reached—an option specifically mentioned by Taylor (2009)—have been feasible? If so, would policy conducted according to that constant money growth rule have led to a more rapid, or at least a more stable, recovery and expansion following the recession? And would targeting faster rates of money growth have generated even more favorable outcomes?

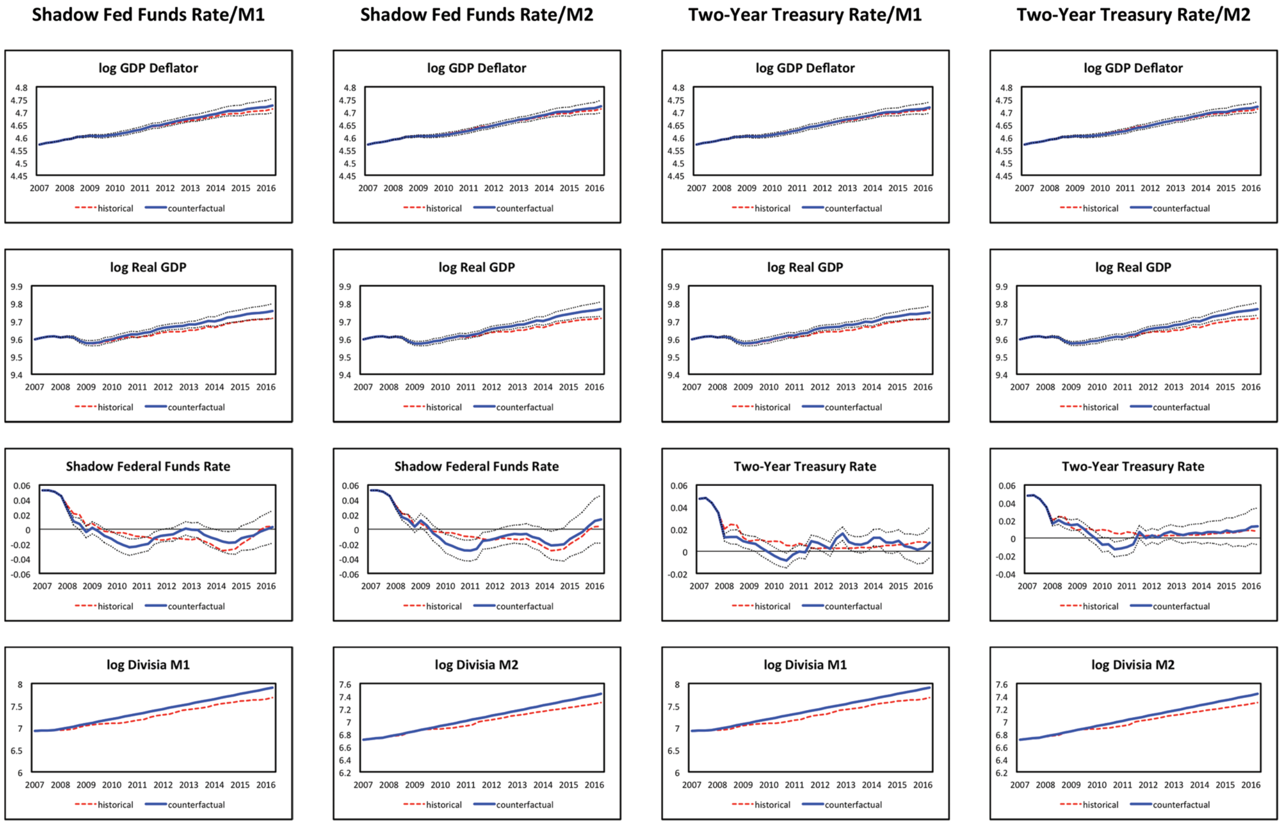
To answer these questions, figures 4–7 illustrate in detail and table 6 summarizes the results from three counterfactual experiments, in which the estimated non-recursive SVAR is used to simulate the effects of constant money growth rate policies. The remaining panels of figure 4 show the hypothetical series of monetary policy shocks from 2008:Q1 forward that, when fed through the estimated model, keep Divisia M1 or M2 growing along a constant path even as all other shocks take on their historical values. The first set of

Figure 5. Counterfactual Simulations: Constant 9 Percent M1 Growth or 6.75 Percent M2 Growth



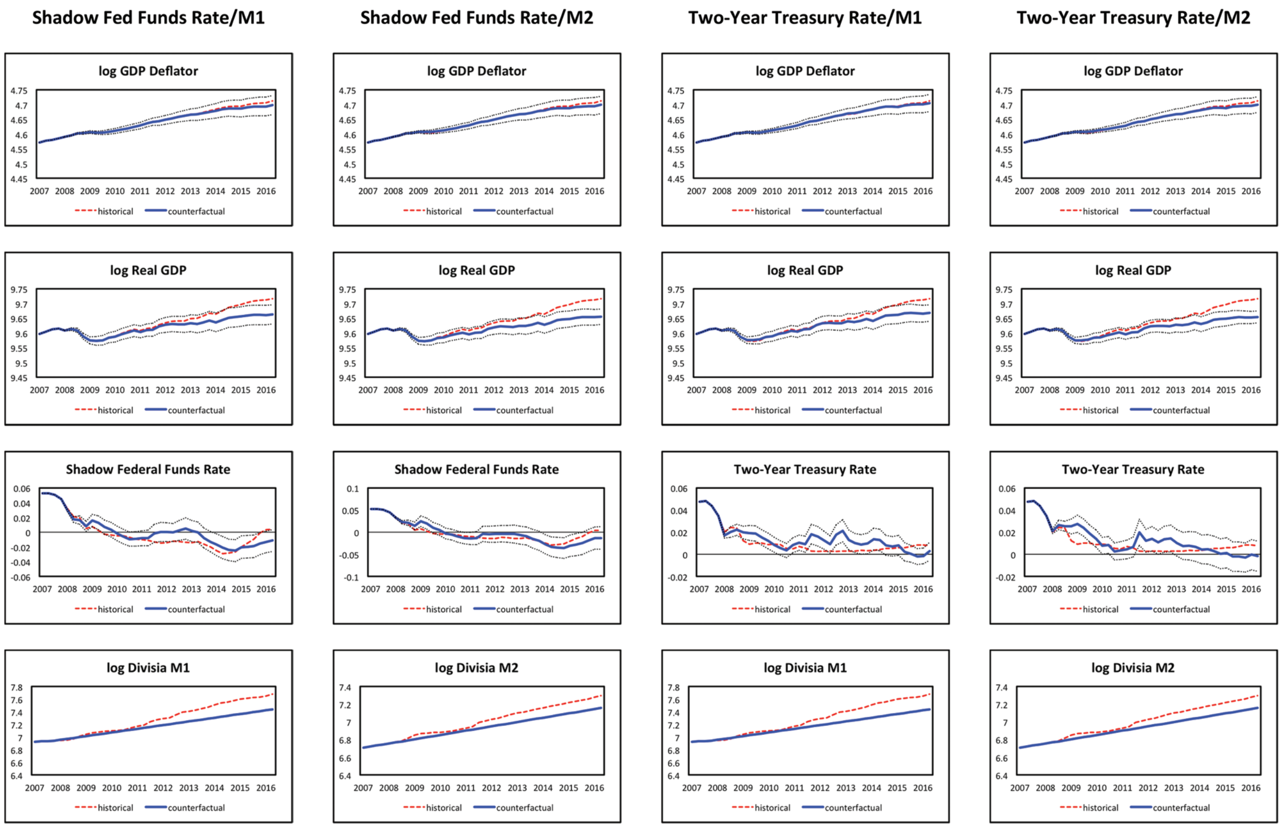
Note: Each panel shows the historical path (dashed line) for the indicated variable, together with the counterfactual path (solid line) of the same variable surrounded by plus-and-minus one standard error bands (dotted lines).

Figure 6. Counterfactual Simulations: Constant 12 Percent M1 Growth or 8.5 Percent M2 Growth



Note: Each panel shows the historical path (dashed line) for the indicated variable, together with the counterfactual path (solid line) of the same variable surrounded by plus-and-minus one standard error bands (dotted lines).

Figure 7. Counterfactual Simulations: Constant 6 Percent M1 Growth or 5 Percent M2 Growth



Note: Each panel shows the historical path (dashed line) for the indicated variable, together with the counterfactual path (solid line) of the same variable surrounded by plus-and-minus one standard error bands (dotted lines).

Table 6. Average Annual Growth Rates: Historical and Counterfactual

	Shadow Federal Funds Rate/M1			Shadow Federal Funds Rate/M2		
	GDP Deflator	**Real GDP**	**Divisia M1**	**GDP Deflator**	**Real GDP**	**Divisia M2**
2008:Q1–2016:Q2						
Historical	1.51	1.19	9.08	1.51	1.19	6.75
With Constant Money Growth	1.51	1.13	9.00	1.49	1.14	6.75
With Faster Money Growth	1.67	1.67	12.00	1.63	1.81	8.50
With Slower Money Growth	1.34	0.57	6.00	1.35	0.47	5.00
2010:Q1–2016:Q2						
Historical	1.63	2.04	9.46	1.63	2.04	6.65
With Constant Money Growth	1.62	1.92	9.00	1.59	1.98	6.75
With Faster Money Growth	1.84	2.59	12.00	1.80	2.83	8.50
With Slower Money Growth	1.41	1.23	6.00	1.38	1.13	5.00
	Two-Year Treasury Rate/M1			**Two-Year Treasury Rate/M2**		
	GDP Deflator	**Real GDP**	**Divisia M1**	**GDP Deflator**	**Real GDP**	**Divisia M2**
2008:Q1–2016:Q2						
Historical	1.51	1.19	9.08	1.51	1.19	6.75
With Constant Money Growth	1.50	1.10	9.00	1.49	1.14	6.75
With Faster Money Growth	1.58	1.58	12.00	1.62	1.82	8.50
With Slower Money Growth	1.42	0.62	6.00	1.37	0.46	5.00
2010:Q1–2016:Q2						
Historical	1.63	2.04	9.46	1.63	2.04	6.65
With Constant Money Growth	1.62	1.89	9.00	1.59	1.98	6.75
With Faster Money Growth	1.73	2.50	12.00	1.78	2.87	8.50
With Slower Money Growth	1.50	1.26	6.00	1.40	1.09	5.00

Note: Each entry reports the average annual growth rate of the indicated variable over the indicated period historically or under one of the counterfactual simulations with constant money growth.

simulations fixes the constant annual growth rate of money at 9 percent for Divisia M1 or 6.75 percent for Divisia M2. Thus, in these experiments, the average rate of money growth remains the same as it was historically, but the growth paths for money are completely smoothed out. The second set of simulations increases the constant rate of money growth to 12 percent for Divisia M1 or 8.5 percent for Divisia M2, to generate outcomes under distinctly more expansionary policies. The third set of simulations, conversely, decreases the constant rate of money growth to 6 percent for M1 or 5 percent for M2, to ask what might have happened if Federal Reserve policy had produced rates of monetary expansion that, while fully appropriate for normal times, would have been highly contractionary in the face of the flight-to-quality dynamics that, according to Anderson, Bordo, and Duca (2016), generated declines in velocity during and after the financial crisis and Great Recession. As shown in figure 4, these counterfactual scenarios rarely require monetary policy shocks much larger than those that were actually realized over the post-2008 period. On the other hand, the serial correlation that is clearly evident in the disturbances required to maintain the faster or slower rates of money growth make it unwise to expand the range of counterfactuals still further. As discussed by Leeper and Zha (2003), doing so would surely raise concerns, related to the Lucas (1976) critique, that a VAR with constant coefficients could not credibly address.

The various panels in figure 5 illustrate what would have happened, according to the estimated model, if the Fed had switched to a rule generating constant 9 percent M1 growth or 6.75 percent M2 growth starting in 2008:Q1. The panels in the third row reveal that interest rates would have had to decline more quickly than they did historically. Reassuringly, however, the counterfactual paths for the shadow federal funds rate never decline as far below zero as the actual historical path eventually does. In addition, all of the counterfactual interest rate paths—whether for the shadow funds rate or the two-year Treasury yield—lie *above* the actual paths for much of the period starting in 2011. Finally, while the counterfactual and actual paths for aggregate prices and output are generally quite similar, in cases where M1 is used to measure money, the policies of constant money growth do lead to somewhat higher levels of real GDP over the same period beginning in 2011. Through these results, the model provides evidence that the Fed could have used some combination of its existing policy tools—quantitative easing and forward guidance—to generate outcomes with more stable paths for money growth and, by doing so, produced macroeconomic outcomes no worse and possibly slightly better than those observed historically.

Naturally, the expansionary effects of monetary policy on real GDP become larger and more persistent in figure 6, where the constant rate of money growth increases to 12 percent for M1 and 8.5 percent for M2. Focusing on the benchmark case in which the model is estimated with data on the shadow funds rate and Divisia M1, the average annual growth rate of real GDP from 2008:Q1 through 2016:Q2 rises from its actual value of 1.19 percent to a hypothetical 1.67 percent with faster money growth; similarly, from 2010:Q1 through 2016:Q2, average real GDP growth increases from 2.04 percent historically to 2.59 under the counterfactual. And while maintaining this faster rate of money growth would have required interest rates to fall more quickly at the onset of the recession, beginning in 2011 the counterfactual interest rate paths lie above the historical ones. These results suggest that by switching to a constant money growth policy in 2008, as soon as the severity of the initial downturn had become apparent, the Fed could have provided additional monetary stimulus, in the form of more rapid money growth, that would have made the recovery stronger and faster.

Figure 7 shows what might have happened, instead, if the Fed had conducted monetary policy to maintain rates of money growth—6 percent for M1 or 5 percent for M2—which, though adequate for more normal times, would have proven far too slow in light of the declines in velocity that occurred during and since the financial crisis. According to the estimated model, average real GDP growth would have only been about 0.5 percent per year since 2008 had one of these policies been implemented. Also reversing the patterns shown in figure 6, interest rates would, according to the counterfactual simulations, today be *lower* under these slower rates of money growth. Overall, these results echo those of Friedman and Schwartz (1963) and Brunner and Meltzer (1968), by underscoring the need for a central bank to act aggressively to counteract the deflationary effects of increases in money demand that accompany severe financial and economic disruptions. They repeat the message of those same authors, too, by highlighting the danger of attempting to gauge the stance of monetary policy using interest rates alone. In the counterfactuals illustrated in figure 7, as in data from the Great Depression, persistently low nominal interest rates reflect monetary policy that has been too *tight*.

Figures 5–7 and table 6 also show the same, very modest, effects of monetary policy on the aggregate price level seen previously in the impulse responses and variance decompositions. The estimated model predicts, for example, that even with 12 percent M1 growth, the annual inflation rate would have been only 10 to 20 basis points higher than it was historically. Reynard (2007) argues that the lags between monetary policy actions and their effects on inflation have become too long to be captured by conventional VAR models like the one used here. Indeed, table 1 shows that these lags extend out to three or four years when measured by peak correlations between the cyclical components of Divisia money and the GDP deflator. But while a persistent shortfall in inflation below the Federal Reserve's 2 percent target may have been an inevitable consequence of the financial crisis and Great Recession, even the results obtained here suggest that the Fed could have at least moved inflation somewhat closer to target by generating faster growth in the quantity of money.

5. Conclusions and Implications

Could—and should—the Federal Reserve have attempted to stabilize the growth rate of a monetary aggregate once its target federal funds rate reached the zero lower bound in 2008? The analysis conducted here suggests that the answer to both questions is "yes." Counterfactual simulations conducted with a structural vector autoregression generate constant money growth rate paths that often require *smaller* downward interest rate movements than those observed historically, a finding that indicates that targeting money growth would have been a feasible policy option. Moreover, in these same simulations, constant money growth paths lead to a stronger and faster recovery in real GDP and a slightly higher rate of price inflation, results that support their desirability.

Targeting constant monetary growth at the zero lower bound likely would have other advantages, too, which the SVAR used here does not capture. As suggested by Taylor (2009), for example, targeting money growth would allow the Federal Reserve to continue conducting monetary policy in a systematic, rule-like fashion, even after the zero lower bound makes the prescription of more conventional interest rate rules difficult or impossible to follow. Related to this point, however, the results presented here support arguments made by Friedman and Schwartz (1963) and Brunner and Meltzer (1968) that, especially during sharp or extended cyclical downturns when deflationary expectations threaten to take hold, very low nominal interest rates no longer serve as an unambiguous sign that monetary policy is fully accommodative. Instead, environments of persistently low interest rates may mask indications given by slow rates of money growth that monetary policy is too restrictive or even outright contractionary.[13] Thus, by working harder to stabilize broad money growth, a central bank can continue to emphasize its commitment to stabilizing inflation and the real economy even when the zero lower bound constraint on interest rates appears to render standard policy strategies inoperable.

A standard criticism of targeting money growth is that it will increase the volatility of interest rates; however, as noted just above, the interest rate movements required to support hypothetical policies of constant money growth appear less extreme than those actually observed since 2008. This finding suggests that the Fed could use its existing policy tools within its existing policy framework to target money growth more closely and do so without any deleterious effects from alternative paths for interest rates. Presumably, with short-term policy rates at the zero lower bound, implementation of a constant money growth rate rule would involve increasing the rate of bond purchases when money growth temporarily falls below target and scaling back on QE when money growth exceeds the desired rate. On the other hand, the Federal Reserve's new interest-on-reserves policy, introduced at the same time it was conducting quantitative easing, clearly led to an increased demand for excess

[13]Even more broadly, these points reflect the difference between a "liquidity trap" and a "credit deadlock" as discussed by Laidler (2004) and Sandilands (2010). While the former has been central to most discussions of the efficacy of monetary policy during the Great Recession, the latter concept, which suggests an important role for monetary expansion in rekindling inflationary expectations, has received virtually no attention. An exception is Belongia and Ireland (2017).

reserves that weakened the link between changes in reserves brought about through traditional open market operations and subsequent changes in the broad monetary aggregates. This helps explain why, in figure 1, periods of quantitative easing did not always generate faster money growth and also provides a reason for the Fed to reconsider paying interest on reserves, should it aim to target money growth more closely in the future.

Finally, the empirical findings reported here illustrate a key role for changes in the quantity of money as well as interest rates in describing Federal Reserve policy and its effects on the U.S. economy over the period before, during, and since the financial crisis and Great Recession of 2007–09.[14] These findings, therefore, raise basic questions about the adequacy of state-of-the-art New Keynesian models, which capture only those effects working through traditional interest rate channels. At the same time, however, our empirical model itself has difficulty connecting historical monetary policy shocks and counterfactual monetary policy interventions to significant movements in the aggregate price level or inflation. These results highlight that understanding the full range of effects that monetary policy has on the economy remains nearly as elusive to us today as it did to Friedman (1968) nearly half a century ago. Perhaps, for this reason too, a constant money growth rate rule that attempts to remove monetary policy itself as a source of macroeconomic instability remains an attractive benchmark against which to judge more activist alternatives that try, but fail, to do more.

Appendix

This appendix verifies that, with the matrix of impact coefficients A parameterized as in (9), the structural VAR consisting of (2), (3), and (9) satisfies Rubio-Ramirez, Waggoner, and Zha's (2010, theorem 1, p. 673) sufficient condition for global identification. In light of (2), it is clear that the matrix A_0 from Rubio-Ramirez, Waggoner, and Zha's (2010, p. 668) equation (1) corresponds to the transpose of the matrix A used here. In addition, Rubio-Ramirez, Waggoner,

[14]Results in Romer (1992) indicate, similarly, that recovery from the Great Depression can be attributed to rapid growth in the money supply rather than fiscal measures or any self-correcting mechanism.

and Zha assume without loss of generality that the columns of A_0 are organized such that those containing fewer free parameters appear first. Employing the notation from Rubio-Ramirez, Waggoner, and Zha (2010, p. 678), therefore, the model used here implies

$$\begin{array}{ccccccc} & PS & PS & MD & MS & MP & IN \\ \\ P & a_{11} & a_{21} & -a_{44} & -a_{54} & a_{31} & a_{61} \\ Y & 0 & a_{22} & -a_{44} & 0 & a_{32} & a_{62} \\ U & 0 & 0 & a_{45} & a_{55} & 0 & a_{65} \\ R & 0 & 0 & 0 & a_{53} & a_{33} & a_{63} \\ M & 0 & 0 & a_{44} & a_{54} & a_{34} & a_{64} \\ X & 0 & 0 & 0 & 0 & 0 & a_{66} \\ \\ q_j & 5 & 4 & 4 & 3 & 2 & 0 \end{array},$$

where columns labeled *PS* correspond to the production sector; columns labeled *MD, MS,* and *MP* correspond to money demand, the monetary system, and monetary policy, respectively; and the column labeled *IN* corresponds to the information sector. As indicated in the final row, and as noted in the text, the total number of restrictions imposed is $q = 18 > 15$, so the necessary order condition for identification holds.

Continuing to use Rubio-Ramirez, Waggoner, and Zha's notation, the restriction matrices for this example are

$$Q_1 = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$Q_2 = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$Q_3 = \begin{bmatrix} -1 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$Q_4 = \begin{bmatrix} -1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$Q_5 = \begin{bmatrix} 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

and

$$Q_6 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

while the rank matrices are

$$M_1(A_0) = \begin{bmatrix} 0 & a_{22} & -a_{44} & 0 & a_{32} & a_{62} \\ 0 & 0 & a_{45} & a_{55} & 0 & a_{65} \\ 0 & 0 & 0 & a_{53} & a_{33} & a_{63} \\ 0 & 0 & a_{44} & a_{54} & a_{34} & a_{64} \\ 0 & 0 & 0 & 0 & 0 & a_{66} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$M_2(A_0) = \begin{bmatrix} 0 & 0 & a_{45} & a_{55} & 0 & a_{65} \\ 0 & 0 & 0 & a_{53} & a_{33} & a_{63} \\ 0 & 0 & a_{44} & a_{54} & a_{34} & a_{64} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$M_3(A_0) = \begin{bmatrix} -a_{11} & -a_{21} & 0 & 0 & a_{34}-a_{31} & a_{64}-a_{61} \\ 0 & -a_{22} & 0 & a_{54} & a_{34}-a_{32} & a_{64}-a_{62} \\ 0 & 0 & 0 & a_{53} & a_{33} & a_{63} \\ 0 & 0 & 0 & 0 & 0 & a_{66} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix},$$

$$M_4(A_0) = \begin{bmatrix} -a_{11} & -a_{21} & 0 & 0 & a_{34}-a_{31} & a_{64}-a_{61} \\ 0 & a_{22} & -a_{44} & 0 & a_{32} & a_{62} \\ 0 & 0 & 0 & 0 & 0 & a_{66} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix},$$

$$M_5(A_0) = \begin{bmatrix} 0 & 0 & a_{45} & a_{55} & 0 & a_{65} \\ 0 & 0 & 0 & 0 & 0 & a_{66} \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix},$$

and

$$M_6(A_0) = \begin{bmatrix} 0_{6\times 6} \\ I_6 \end{bmatrix},$$

where $0_{6\times 6}$ is a 6×6 matrix of zeros and I_6 is the 6×6 identity matrix. Since all of these rank matrices have rank equal to six, the conditions of Rubio-Ramirez, Waggoner, and Zha's (2010) theorem 1 are satisfied, and the model is globally identified. Similar analysis reveals that the model continues to be globally identified when either real GDP and the GDP deflator are excluded from the monetary policy rule, so that $a_{31} = a_{32} = 0$, or the income elasticity of money demand is estimated, so that $a_{42} \neq -a_{44}$ appears as a distinct parameter in the fourth column and second row of the matrix A in (9).

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