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A Model of Monetary Policy Shocks for Financial Crises and Normal Conditions

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Abstract

Deteriorating economic conditions in late 2008 led the Federal Reserve to lower the target federal funds rate to near zero, inject liquidity into the financial system through novel facilities, and engage in large scale asset purchases. The combination of conventional and unconventional policy measures prevents using the effective federal funds rate to assess the effects of monetary policy in samples that extend beyond 2008. This paper develops an approach to identify the effects of monetary policy shocks in such instances. We employ a newly created broad monetary aggregate to elicit the effects of monetary policy shocks both prior to and after 2008. Our model is bolstered by its ability to produce plausible responses to monetary policy shocks free from price, output, and liquidity puzzles that have plagued other approaches.

Keywords: Structural Vector Autoregressions (SVARs), Monetary policy shocks, output puzzle, price puzzle, liquidity puzzle, financial crisis, monetary aggregates, DSGE models

JEL classification codes: E3, E4, E5

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1 Introduction

What are the macroeconomic effects of monetary policy? Prior to 2008, two conclusions had emerged from a voluminous literature addressing this question. First, the effective federal funds rate is the single best indicator of the stance of monetary policy in the post 1965 period. Second, unexpected increases in this policy rate decrease output and prices. In a classic paper which served to advance this consensus, *Monetary policy shocks: What have we learned and to what end?*, Christiano, Eichenbaum, and Evans (1999) thoroughly investigate one of the most widely used methods for identifying monetary policy shocks. Their empirical findings provide strong support for the identifying assumption that the central bank adjusts the federal funds rate in response to changes in output and prices but can only affect these variables with a lag.¹

Unfortunately, this approach to identifying the effects of monetary policy shocks can not be extended past 2008. The effective federal funds rate is no longer indicative of changes in the stance of monetary policy following the protracted 7 year period of being stuck as its lower bound. Moreover, in light of this lower bound constraint on rates, the Federal Reserve engaged in a number of unconventional policies including the creation of several liquidity facilities and large scale asset purchases.

Our objective is therefore to develop a model of monetary policy shocks which can be employed in samples that include the 2008 Financial Crisis and in normal conditions while maintaining the timing assumption advocated in Christiano et al. (1999). To reach this end, we develop a VAR model which uses a broad monetary aggregate (Divisia M4, or DM4 hereafter) as the policy indicator. This approach is supported by the following four findings. First, unexpected changes in monetary policy in our money-based model do not generate the output, price, or liquidity puzzles prevalent to this literature. Second, during normal conditions, policy shocks from our money-based model have similar effects to those found in the fed funds-based model of monetary policy that was widely used prior to the lower bound on that rate being effectively met. Third, our approach to identifying the effects of monetary policy shocks produces plausible responses which are robust in samples that include or exclude the 2008 financial crisis. Fourth, policy shocks have significant effects on output and prices. Therefore, abandoning the federal funds rate framework doesn't lead to fundamentally different conclusions regarding the effects of monetary policy.

¹This assumption is inspired by earlier work including Bernanke and Blinder (1992), Gertler and Gilchrist (1994), Eichenbaum and Evans (1995), Christiano, Eichenbaum, and Evans (1996), and Bernanke and Mihov (1998a).

One concern raised by our approach is that the Federal Reserve has not shown any inclination towards using the DM4 aggregate as a policy instrument. This could, for example, call into question our interpretation of the shocks we identify as monetary policy shocks. But we believe our approach minimizes this concern. First, using an empirically-sensible calibration for a fairly standard New-Keynesian structural model, we show that the dynamic responses following a monetary policy shock to an interest rule can be replicated by an appropriately parameterized money growth rule reacting solely to inflation and output. This suggests that a broad monetary aggregate can be used as an indicator of monetary policy in a recursive VAR for the purpose of identifying monetary policy shocks, even if the central bank follows an interest rate rule. Indeed, we also find that the dynamic responses to a policy shock from our money-based VAR model are remarkably similar to responses found in the fed funds-based VAR model over the pre-2008 sample. Furthermore, when we extend our money-based model to the post 2008 period, our identified monetary policy shocks align well with the narrative regarding the timing of sharp changes in the Federal Reserve's quantitative easing programs.

Of course, we are not the first to propose using a monetary aggregate as the policy indicator in a recursive VAR. The thorough analysis conducted by Christiano et al. (1999) seemingly closed the book on such specifications due to the puzzling responses of output, prices, interest rates, or other monetary aggregates in response to monetary policy shocks identified when M1 or M2 is the policy indicator. However, our approach employs a newly-developed, broader DM4 aggregate which has not been previously employed as a policy indicator in the monetary VAR literature.

Several factors lead us to work with DM4 as our policy indicator. First, the M4 aggregate includes assets that were especially targeted by the Federal Reserve's liquidity facilities such as institutional deposits, overnight and term repurchase agreements, commercial paper, and treasury securities. Second, we utilize the Divisia variety of M4 which is expenditure weighted and accompanied by a corresponding user cost which correlates closely with the federal funds rate prior to the zero lower bound period and remains well defined after 2008. Finally, the most compelling reason that leads us to use this aggregate is the absence of puzzling responses to monetary policy shocks that appear when the more popular M2 aggregate is employed in its place. Our DSGE model supports these empirical findings and provides one interpretation of the diverging success of these monetary aggregates to identify monetary policy shocks without producing puzzles.

The remainder of the paper is organized as follows. Section 2 presents a small-scale New-Keynesian model with a monetary aggregate to study the effects of monetary policy shocks under both interest rate and money rules for describing monetary policy. Section 3 undertakes an empirical investigation in which, motivated by our theoretical analysis, we modify and extend the classic approach to identifying monetary policy shocks with Divisia M4 as the policy indicator. We also explore the robustness of our results to a monthly specification, for which the recursive assumption may be considerably more palatable, and compares our model to the shadow-rate approach to circumventing the zero lower bound. Section 4 concludes with an overview of the results and directions for future work.

2 Monetary policy shocks in a NK model with money

This section uses a small-scale New-Keynesian model of the business cycle to assess whether the dynamics that ensue after a monetary policy shock to an estimated interest rate rule can be characterized by a money growth rule. Trivially, the household's money demand equation defines a level of nominal balances that can support any equilibrium under an interest rate rule. However, we ask the distinct question: Can a nominal money growth rule reacting only to price inflation and economic activity – excluding an independent reaction to interest rates – replicate the dynamic responses to a monetary policy shock under an interest rate rule? This class of rules is consistent with the central bank's information set in a recursive VAR with output and prices ordered ahead of the policy indicator. We find that for estimated interest rate rules, which feature a high-degree of interest-rate inertia, an appropriately parameterized nominal money growth rule can closely replicate the impulse responses of output, prices, money, and interest rates in our small scale model.

2.1 A Small-Scale DSGE Model

This section describes the sticky price model we use as our laboratory to assess the effects of monetary policy shocks under different policy rules. In the appendix the model is derived in detail however here we only present the relevant log-linear model equations.

$$y_t = \frac{1}{1+h} \mathbb{E}_t y_{t+1} + \frac{h}{1+h} y_{t-1} - \frac{1-h}{1+h} (r_t - \mathbb{E}_t \pi_{t+1}) \quad (2.1)$$

$$m_t = \frac{1+\chi(1-h)}{(1+\chi)(1-h)} y_t - \frac{h}{(1+\chi)(1-h)} y_{t-1} - \eta r_t \quad (2.2)$$

$$\pi_t = \pi_{t-1} + \kappa \left(\frac{1}{1+h} y_t - \frac{h}{1+h} y_{t-1} \right) + \beta \mathbb{E}_t (\pi_{t+1} - \pi_t) \quad (2.3)$$

In the above equations, y_t is economy wide output, π_t denotes the quarterly inflation rate, r_t is the nominal interest rate on one-period bonds, and m_t denotes real money balances. Equation 2.1 is the household's Euler equation which relates the habit-adjusted rate of output growth to the real return on a 1-period bond. Equation 2.2 is the household's money demand equation in which $\eta > 0$ is the interest semi-elasticity which is pinned-down for a given value of $\chi > 0$ which calibrates the elasticity of the amount of time the household must allocate to shopping with respect to the velocity of money. Equation 2.3 summarizes the pricing decision that firms face. The parameter $0 < \beta < 1$ is the household's discount factor. The parameter $\kappa = (1-\alpha)(1-\beta\alpha)/\alpha$ is the slope of the Phillips curve, in which $1-\alpha$ is the probability that any given firm is able to reoptimize its price this period. We assume that firms who are not able optimally to set their prices index their prices according to last period's inflation rate. This assumption, that prices are indexed to lagged inflation, is important for generating empirically plausible dynamics to a monetary policy shock (Christiano, Eichenbaum, and Evans, 2005).

One deviation from the standard models, found for example in Woodford (2003) and Gali (2008), is that a broad measure of money is specified in our model as a CES aggregate of currency and interest bearing assets as in Belongia and Ireland (2014). This adjustment is made to allow for a more direct comparison to the monetary aggregate used as the policy indicator in our VAR model. Although the micro-foundations of monetary aggregation are more clearly spelled out with this specification, equation 2.2 shows that after log-linearizing, the money demand equation that results is isomorphic to those found in textbooks.²

The model is closed with a specification of monetary policy which we assume can be described by an interest rate feedback rule in the spirit of a Taylor (1993) rule. However, we include output growth as opposed to the output gap to align the rule with the information set of the Federal Reserve

²However, we show in Section 3.6 that our approach to modeling the monetary aggregate is useful for understanding our empirical findings relative to the previous literature which has used monetary aggregates to identify policy shocks.

in our VAR model:

$$r_t = \rho r_{t-1} + (1 - \rho)(\phi_\pi \pi_t + \phi_y (y_t - y_{t-1})) + \varepsilon_t^{mp}, \quad (2.4)$$

where ε_t^{mp} is an i.i.d. monetary policy shock. Similarly, we allow for monetary policy to be described by a nominal money growth rule

$$\mu_t = \bar{\rho} \mu_{t-1} - (1 - \bar{\rho})(\bar{\phi}_\pi \pi_t + \bar{\phi}_y (y_t - y_{t-1})) + \bar{\varepsilon}_t^{mp}, \quad (2.5)$$

where $\mu_t = m_t - m_{t-1} + \pi_t$.

2.2 Approximating Monetary Policy Shock Dynamics

We now turn to the question of whether the effects of policy shocks under an interest rate rule can be approximated by policy shocks under a money growth rule. Furthermore, we restrict the policy rules we consider to be consistent with the recursive ordering in our VAR which orders output and prices ahead of the policy indicator. Our results in this section indicate that we are able to qualitatively approximate the responses of the economy under all the interest rate rules considered. However, we show that our quantitative success depends on the degree of inertia in the underlying Taylor rule. Rules with greater inertia are better approximated by money growth rules. Given the existing evidence that there was a large amount of inertia in interest rate rules over the 1967-2007 period a money-growth rule may be a viable alternative indicator for monetary policy in our VAR model over this sample.

The calibration of the model is standard. Each period is assumed to equal 1-quarter and therefore the household's discount factor $\beta = 0.99$. The slope of the Phillips curve is governed by $\alpha = 0.75$ implying an average duration of prices equal to one year which is consistent with the micro evidence presented in Nakamura and Steinsson (2008). The degree of habit persistence $h = 0.65$ as estimated in Christiano et al. (2005). The interest semi-elasticity of money demand is set to $\eta = 1.9$ as estimated in Ireland (2009). This value is also consistent with the VAR evidence presented by Christiano et al. (2005) which suggests that the short-run interest semi-elasticity is considerably smaller than the longer-run elasticity specified by Lucas (2000). The parameters governing the CES aggregate of monetary assets are calibrated as in Ireland (2014). Given a calibration of η , these parameters simply govern the way households allocate their portfolio between currency and interest

bearing bank deposits, enabling us to define the monetary base and alternative monetary aggregates in the model economy.

We consider three alternative interest rules for our model experiment. The first rule is calibrated by estimating equation (2.4) over the 1967-2007 sample on quarterly data via nonlinear GMM. We measure the short-term interest rate with the effective federal funds rate, inflation with the quarterly change in logarithm of the GDP deflator, and output growth as the log difference in real GDP.³ The resulting estimates imply that $\rho = 0.94$, $\phi_\pi = 2.20$, and $\phi_y = 2.69$ and all coefficient are found to be statistically significant. Relative to Clarida et al. (2000), who estimate $\rho = 0.79$, $\phi_\pi = 2.15$, and $\phi_y = 0.93$ using the output gap in place of output growth over the post-Volcker period, we find a bit more inertia in the policy rule and a larger reaction to real activity. However, the coefficient on inflation is in line with their estimates. While we prefer our specification which excludes the output gap – because it is absent from our VAR model – we also consider two rules which include a reaction to the output-gap as opposed to output growth. One is the aforementioned rule estimated by Clarida et al. (2000) (adjusted to represent a contemporaneous reaction function) while the other is the rule calibrated by Taylor (1993) which sets $\rho = 0$.

We seek parameters $\bar{\rho}$, $\bar{\phi}_\pi$, and $\bar{\phi}_y$ of the the money growth rule to minimize the distance between the impulse response functions following a monetary policy shock under a given interest rate rule. The responses we seek to match are those of output, the price level, the monetary aggregate, the monetary base, and the short-term interest rate.⁴ Following Christiano et al. (2005), we assume that households learn about the monetary policy shock after making their consumption plans and similarly firms learn about the monetary policy shock after setting their prices. This implies that output and prices don't move until the period after the monetary policy, as is the case in a recursive VAR with output and prices ordered ahead of the policy indicator.

The resulting impulse responses are illustrated in Figure 1. Under our estimated rule (column 1), output features a hump-shaped response and prices fall gradually suggesting a fair amount of inflation inertia. Monetary quantities fall immediately reflecting a clear liquidity effect. As the initial effects of the shock fade and money growth stabilizes, a long run price effect takes hold leading to permanent declines in the nominal level of broad and narrow money. A nominal money growth

³We use as instruments 1 to 4 lags of output growth, inflation, the federal funds rate, commodity price inflation, Divisia M4 growth, and the 10 year-2 year term spread. This selection of instruments follows closely from Clarida, Gali, and Gertler (2000).

⁴The responses of individual variables are scaled when entered into the loss function so that each variable is of a similar order of magnitude. We restrict the parameters as follows: $-1 < \bar{\rho} < 1$, $-10 < \bar{\phi}_\pi < 10$, and $-10 < \bar{\phi}_y < 10$. For our estimated rule and the Clarida et al. (2000) rule these parameter constraints do not bind.

rule is able to essentially replicate these impulse responses. Similarly, if we simulate a monetary policy shock under the policy rule estimated by Clarida et al. (2000) we find a near observational equivalence. The fit deteriorates marginally relative to our estimated rule, but the differences are not obvious (see the second column of Figure 1), in this rule which effectively replaces output growth with output but maintains a large degree of policy inertia. Meanwhile, when we attempt to fit impulse responses to a Taylor rule featuring no policy inertia, shown in the third column of Figure 1, the fit deteriorates more significantly. The money growth rule struggles to generate as large of an initial decline in output, and hence, by way of the Phillips Curve, fails to initially generate a large enough decline in prices as generated under the Taylor (1993) rule.

To understand why monetary policy shocks under a money growth rule are a better fit to the model's dynamics under some interest rate rules than others, suppose for simplicity that $h = 0$, $\rho = 0$ and $\bar{\rho} = 0$. Then the interest rate rule is given by:

$$r_t = \phi_\pi \pi_t + \phi_y y_t + \varepsilon_t^{mp},$$

while the implied interest rate rule, under the money growth instrument regime is given by:

$$r_t = r_{t-1} + (1/\eta)[(y_t - y_{t-1}) + (1 + \bar{\phi}_\pi)\pi_t + \bar{\phi}_y y_t - \bar{\varepsilon}_t^{mp}],$$

where the last equality combines the money growth rule with the money demand curve. This equation suggests two potential explanations for the inability to quantitatively fit a nominal money growth rule's monetary policy impulses to those under the Taylor (1993) rule. The first is the large amount of inertia in the implied interest rate rule under a money growth instrument rule that is absent from the Taylor (1993) rule. The second discrepancy could come from the lack of an output growth response in the Taylor (1993) rule. However, the results in the second column of Figure 1 indicate that the lack of an output growth response is not all that detrimental to fitting the impulse responses. In particular, we are able to closely approximate the dynamics under the Clarida et al. (2000) rule which also lacks any reaction to output growth but features a large degree of interest-rate smoothing.

Thus we conclude that interest rate inertia is the primary factor determining whether monetary policy impulses under interest rate rule can be well approximated by money growth rules. Given

that a variety of sources of evidence support a high degree of persistence in estimated interest rate reaction functions over the 1967-2007 period, money growth holds promise as an alternative indicator of monetary policy in a VAR over this period. In addition to our policy rule estimates, Clarida et al. (2000) find evidence of inertia in monetary policy over the 1960-1979 sample as well as the 1979-1996 sample. Similarly, using Greenbook data, Orphanides (2001) finds substantial persistence in interest rate changes over the 1987-1994 period. Coibion and Gorodnichenko (2012) also present evidence that target interest rate changes are persistent because of an explicit desire to gradually adjust rates over the 1987-2006 sample. Widespread evidence of interest-rate smoothing from the late 1980's onwards is most reassuring to our empirical strategy since the monetary aggregates played a less prominent role in Federal Reserve policy over this period (Sims and Zha, 2006).

3 A Robust Model of Monetary Policy Shocks

The theoretical model laid out above is used to help formulate our new strategy for identifying monetary policy shocks based on the reduced-form vector autoregression (VAR):

$$z_t = B_1 z_{t-1} + \dots + B_q z_{t-q} + u_t \quad (3.1)$$

where q is the number of lags and $E u_t u_t' = V$ is the covariance matrix for residuals.⁵ Correspondingly, a linear structural model may be written as:

$$A_0 z_t = A_1 z_{t-1} + \dots + A_q z_{t-q} + \varepsilon_t \quad (3.2)$$

where $E \varepsilon_t \varepsilon_t' = D$ is the diagonal covariance matrix for structural shocks.⁶ The variables in the model are sub-divided into three groups:

$$z_t = (X'_{1t}, X'_{2t}, X'_{3t})'. \quad (3.3)$$

Each group might consist of multiple variables; however in this work X_{2t} is a single policy indicator.

The structure is assumed to take on the following form:

⁵In all of our VAR models, $q=5$ except in our monthly VAR in which case $q=13$.

⁶For our purposes X_{2t} is a single variable and so we only require that D take on a *block-diagonal* form. This condition is sufficient to make the policy shock uncorrelated with the other structural shocks.

$$A_0 = \begin{bmatrix} A_{11} & 0_{12} & 0_{13} \\ A_{21} & A_{22} & 0_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \quad (3.4)$$

where A_{ij} is an $n_i \times n_j$ matrix of parameters and 0_{ij} is an $n_i \times n_j$ zero matrix. The vector of structural shocks is given by: $\varepsilon_t = (\varepsilon_{1t}', \varepsilon_{2t}', \varepsilon_{3t}')'$. Christiano et al. (1999) prove that under these assumptions the Cholesky factor of V will identify the effects of shocks to the structural equation for X_{2t} .⁷

This identification assumes that the policy variable, X_{2t} , responds contemporaneously to X_{1t} a set of important macroeconomic variables that slowly adjust to policy and a variety of other nominal shocks. Throughout our analysis we follow Christiano et al. (1999) and identify monetary policy shocks using a block-recursive formulation in which X_{1t} consists of real GDP, the GDP deflator, and a commodity price index. The first two variables are included because of the assumption that central banks consider real output and prices when determining the stance of monetary policy. If the policy variable is the fed funds rate, a reaction to these two variables is consistent with a Taylor Rule formulation which is often assumed to describe the central bank's policy rule. The commodity price index has been included in previous work because it was thought to encapsulate current information about future price movements that forward-looking central banks tend to monitor. A key identifying assumption is that monetary policy has no contemporaneous effect on X_{1t} .

The third set of variables, X_{3t} , consists of money market variables that respond immediately to X_{1t} or X_{2t} but only affect these variables with a lag. In the benchmark specifications of Christiano et al. (1999), X_{3t} includes nonborrowed reserves, total reserves, along with M1 or M2. When Christiano et al. (1999) use money as the policy indicator then this lower block includes interest rates in its place. We follow their approach and include interest rates, or more precisely the user cost of DM4, in this block. Our use of the user cost is based on the fact that macroeconomic models typically include at least one interest rate. The user cost is a function of all interest rates relevant to the monetary aggregate and in the data has not been subject to a lower bound constraint. An added advantage is that the user cost and the Fed Funds rate are highly correlated during the period

⁷Keating (1996) generalizes Christiano et al. (1999), showing that if $n_2 > 1$ and A_{22} is a lower triangular matrix, the Cholesky factor of V will identify the effects of structural shocks for all n_2 shocks in ε_{2t} . Structures that take on this form are defined as partially recursive.

when Fed Funds were well above the effective lower bound.⁸ But, in contrast to the Christiano et al. (1999) specification, we exclude nonborrowed reserves (which takes on negative values beginning in 2008) and replace total reserves with the monetary base. We choose to work with the monetary base instead of total reserves since an open market operation that changes the amount of inside money has the same effect on the monetary base irrespective of how the composition between currency and reserves is affected. However, in practice, we find little difference in our responses when we replace the monetary base with total reserves.

3.1 Baseline VAR Model

We propose using DM4 as the policy indicator variable to identify monetary policy shocks. Although the Federal Reserve has never formally targeted such a broad monetary aggregate, the theoretical analysis in our DSGE model suggests this doesn't preclude its use as a policy indicator for measuring the effects of monetary policy shocks.⁹ Indeed, in this section we show this approach is capable of producing impulse responses which: are free from empirical puzzles, are robust across samples that include or exclude the recent zero lower bound period, and have significant effects on output and prices. Figure 2 reports results based on the sample period used in Christiano et al. (1999), the pre-crisis period ending in 2007, and the full sample ending in 2015, respectively.

We first analyze impulse responses to a monetary policy shock over the pre-crisis period our Baseline Model which uses DM4 as the policy indicator. The results are shown in the second column of Figure 2 along with 90% bootstrapped confidence intervals.¹⁰ The impact response of output is restricted to be zero by assumption. But in subsequent periods output falls with a trough response after about two years before gradually increasing towards zero. This generates a hump-shaped dynamic for real GDP which has been a hallmark feature of monetary VARs. The negative output response is significant for three years after the initial shock. Prices display considerable inertia, not moving until 6 quarters after the shock. Importantly, we find no evidence of a price puzzle as the price level eventually falls a statistically significant amount two years later and the point estimate is never positive. Commodity prices fall even faster than the overall price level.

⁸Using quarterly data from 1967 to the end of 2007, the correlation is 0.96 for the series in levels and 0.74 when both are differenced.

⁹We note that as in Bernanke and Blinder (1992) (see their footnote 4), there are no Lucas critique concerns raised by our approach since we are not analyzing the effects of a proposed change in the policy rule but instead analyzing the response of the economy over particular historical periods.

¹⁰All impulse response functions in the paper are accompanied by 90% posterior credible sets calculated using the approach in Sims and Zha (1999).

We orient the impulse response of DM4 so that it is negative whereas the reaction of the monetary base and the user cost of DM4 are left unconstrained following the shock. The monetary base falls on impact by a statistically significant amount and is consistently negative thereafter. Furthermore, we identify a statistically significant liquidity effect on impact as the DM4 user cost rises on impact. However, this weighted average of rate spreads returns to its pre-shock value fairly quickly, with the short-run liquidity effect being the only significant response. In all, the decline in output and prices along with the rise in user cost reveals the ability of our DM4 model to produce impulse responses which are consistent with theoretical predictions about the effects of contractionary monetary policy shocks and free from the output, price, and liquidity puzzles that plague many monetary VARs.

We now extend the sample period over which we estimate our VAR to include the recent financial crisis and ensuing zero lower bound period. The impulse responses are shown in the second column of Figure 2. Qualitatively the effects are similar to the pre-crisis sample responses. Output falls with a hump-shaped pattern, prices display significant inertia beginning to fall after about 4 quarters, but significantly falling more than two years after the shock, while interest rates, measured by the user cost of money, rises on impact before returning towards zero after about one year. This shows that in samples which include the recent crises our DM4 model continues to produce plausible impulse responses free from output, price, and liquidity puzzles.

Although the impulse responses are qualitatively unchanged across samples, there are two quantitative differences when we extend our model through the end of 2015. First, prices fall by less than they did in the pre-crisis sample. The dampening of the price response becomes even more apparent when comparing the responses in the sample ending in 1995:Q2 and the full sample.¹¹ This is consistent with the widespread belief that the Phillips curve has flattened over time (Blanchard, 2016). We also find significant quantitative differences in the behavior of the monetary base in the full sample. Including the crisis period causes the base response to become very large compared to the pre-crisis sample. This large increase in the response of the monetary base is likely due to the notable expansion in the Federal Reserve's balance sheet. Assets acquired through various rounds of quantitative easing (QE), as a by-product, resulted in a large expansion in total reserves.

The change in the response of the monetary base in the post crisis sample indicates a shift in monetary policy towards balance-sheet oriented policies. While this matches the narrative description of U.S. monetary policy post 2008, we now examine if our time series of identified shocks is

¹¹1995:Q2 is the sample end date in Christiano et al. (1999).

consistent with this narrative. Figure 3 recovers the structural shocks from our VAR model to verify this interpretation. The series of policy shocks aligns with changes in the Federal Reserve’s QE policies, cresting at the initiation of each of the three rounds of QE. Our identification strategy is even able to isolate the taper tantrum that occurred in the second quarter of 2013 as a large negative monetary policy shock.¹² The ability of our VAR model to isolate policy surprises which broadly align with the narrative description of monetary policy reinforces the interpretation of our identified shocks as changes in the stance of monetary policy.

3.2 Comparison to the Christiano, Eichenbaum, and Evans (1999) Model

In this section we show that our DM4 model of monetary policy shocks doesn’t deliver fundamentally different conclusions regarding the effects of monetary policy when compared to the benchmark model of Christiano et al. (1999). Christiano et al. (1999) convincingly argue that using the federal funds rate as the indicator of monetary policy delivers the most sensible dynamics of all the models they consider. When we compare impulse responses using our preferred DM4 indicator in place of the federal funds rate in their benchmark model over admissible sample periods we find remarkably similar impulse responses from both a qualitative and quantitative standpoint. We view this as further evidence in favor of our approach since the primary issue with the workhorse model of Christiano et al. (1999) is the sample limitations following the global financial crisis and ensuing ZLB period.

We first compare our approach to identifying monetary policy shocks with the Fed Funds Benchmark specification of policy shocks estimated through the second quarter of 1995 which is the end of the sample analyzed in Christiano et al. (1999). Figure 4 reports our estimated impulse responses. The first column is their Fed Funds Benchmark model which uses the federal funds rate as the policy indicator and the second column is the DM4 Benchmark model which replaces the federal funds rate with DM4.

The output and price responses generally share the same dynamics and statistical significance in both the Fed Funds and the DM4 Benchmark models. Across these two benchmark specifications output falls with some delay and has a U-shaped response to a monetary contraction. The negative output response is significant after three quarters in the Fed Funds Benchmark and significant after

¹²In May then Chairman Bernanke suggested that the pace of asset purchases may be tapered if the U.S. economy continues to improve during congressional testimony and then reiterated this view in a press conference after the June FOMC meeting. Financial markets tightened considerably with the yield on the 10-year treasury note jumping nearly 50 basis points over this span, indicating that financial markets weren’t expecting this shift in policy.

just one quarter in the DM4 Benchmark. The price level response is eventually negative across both Benchmark models, although the Fed Funds benchmark has a small price puzzle that is never statistically significant. This leads to a longer delay before prices decline in the Fed Funds model relative to the DM4 Benchmark model. The price response in the DM4 Benchmark is always non-positive and becomes significantly negative after 8 quarters. The commodity price response is initially zero, by assumption, but afterwards is consistently negative in both Benchmark specifications.¹³

The responses of the variables across the lower block of the Fed Funds and DM4 Benchmark models are also similar. The responses of nonborrowed and total reserves in the DM4 Benchmark model are always negative and sometimes statistically significant while the declines in the Fed Funds Benchmark model are not significant. The response of M2 is always negative and frequently significant. In all we find that, consistent with our DSGE model, DM4 can serve as the policy indicator and has similar effects on variables when the federal funds rate is used in this capacity.

We now estimate these two Benchmark models (Fed Funds and DM4) with more recent data to examine the extent to which the impulse responses are similar over an extended sample period. How far we are able to extend the sample is limited by the problems nonborrowed reserves and the fed funds rate incurred during the financial crisis. Nonborrowed reserves began taking on negative values in the first quarter of 2008.¹⁴ Since this variable enters the VAR in log levels, our sample period goes from 1967:Q1 to 2007:Q4. We report the estimated impulse responses in Figure 5.

Once again the Fed Funds and DM4 Benchmark models yield many responses to a policy shock that are qualitatively similar, consistent with the prediction from our DSGE model. The largest change in the impulse responses when we extend the sample is the response of prices. The Fed Funds Benchmark model obtains a price puzzle that is large and statistically significant for the first year. On the other hand, the DM4 Benchmark model has a negative price level response that eventually becomes statistically significant. However, given the uncertainty surrounding each impulse response, these differences don't appear to be statistically significant. Therefore, our conclusion remains that prior to 2008 it is largely a matter of choice whether DM4 or the federal funds rate is used as the policy indicator when analyzing the dynamic responses to monetary policy shocks in the Benchmark

¹³Comparing impulse responses in our Fed Funds Benchmark Model to that which is reported in Christiano et al. (1999) one finds only a few very modest differences which can be attributed to using a different commodity price index, using a more recent vintage of data, and using different lag lengths. A fourth difference is that our sample begins at a slightly later date than the benchmark models estimated in Christiano et al. (1999) due to the availability of the DM4 series.

¹⁴This economic impossibility seems to have resulted from peculiar accounting. Since nonborrowed reserves equals total reserves minus borrowed reserves some items were included in borrowed reserves that were not included in total reserves.

model of Christiano et al. (1999). However, VAR models which use DM4 as the policy indicator instead of the federal funds rate can be successfully extended beyond 2008.

3.3 Shadow Rate Approaches to Circumventing the ZLB

Shadow federal funds rate models provide an alternative means of dealing with the zero lower bound constraint. This approach replaces the effective federal funds rate with a hypothetical short-term rate that is not subject to a lower bound. Shadow rate VAR models seek to extend the success of federal funds rate based VAR model of monetary policy pre-2008 to analyze the effects of monetary policy afterwards. In this section, we explore the relative merits of this approach compared to our money-based VAR model.

Figure 6 shows impulse responses to an identified monetary policy shock in VAR models which use the effective federal funds rate as the policy indicator until 2008:Q3 and then uses one of three shadow federal funds rates thereafter. Other than the policy indicator, we use the same variables in each VAR that we include in the Baseline Model. The first column uses the Lombardi and Zhu (2014) rate, the second column uses the Krippner (2013) rate, and the third column employs the Wu and Xia (2016) shadow rate. All three shadow rate VAR models display a persistent, and statistically significant, price puzzle. With aggregate prices rising persistently for the first year following a monetary policy shock, prices fail to significantly fall within the impulse response horizon across all three shadow rate models. Furthermore, the Krippner (2013) and Wu and Xia (2016) shadow rate VAR models also display a liquidity puzzle, with the monetary base initially rising following an unexpected increase in the shadow federal funds rate. The rise in the monetary base in the Krippner (2013) model is statistically significant for 2 quarters.

The price puzzles emanating from the shadow rate VAR models lead to uncomfortable implications when considering counterfactual monetary policy regimes. For example, Wu and Xia (2016) present a factor-augmented VAR in their paper which also displays a price puzzle to an identified monetary policy shock using their shadow federal funds rate as the policy indicator. In turn, their counterfactual exercise which considers the effects of leaving their shadow rate at the zero lower bound after 2008 suggests that this less accommodative stance of monetary would have led to lower levels of economic activity but *higher* aggregate prices. This interpretation of the effects of monetary policy after 2008 is problematic since unexpected shifts in unconventional monetary policy are pre-

dicted to lead to higher levels of economic activity and prices in standard models of unconventional policy (Eggertsson and Woodford, 2003; Gertler and Karadi, 2011).

3.4 Quantitatively Assessing the Effects of Monetary Policy

We now turn to our Baseline VAR model to quantitatively assess the effect of monetary policy shocks, focusing especially on the post 2008 period. We use historical decompositions to show that monetary policy shocks themselves have had positive, but negligible effects on output and prices since 2008. Hence, our Baseline VAR model interprets the sequence of policy actions taken after 2008 as the Federal Reserve’s endogenous response to declines in output and a slowing rate of price growth. Furthermore, we find that were the Federal Reserve to have allowed large deviations from its historical rule in light of the binding zero lower bound on the federal funds rate and thereby let the money supply collapse as it did in the Great Depression the U.S. economy would have experienced years of deflation and a much larger decline in output.

The first column of Figure 7 shows the historical decomposition of monetary policy shocks beginning in 2008:Q4. In particular, we find that cumulatively since the zero lower bound became binding policy shocks have on net been slightly positive (expansionary), leading to marginally higher levels of output and prices than otherwise would have been realized. However, the economic significance of these cumulative policy shocks is rather small with real GDP and the GDP deflator a mere 0.48% and 0.50% higher respectively than they would have been without monetary policy shocks. The evidence from these historical decompositions is echoed in the variance decompositions shown in Table 2. At its peak of about 8 quarters, the share of the forecast error explained by monetary policy shocks is only 8.4%, and similarly, monetary policy shocks explain only 6.47% of the forecast error in prices even 5 years out. As is common in the monetary VAR literature, we find that monetary policy shocks are not a major force driving business cycles even when the post 2008 period is included in our estimation.

The negligible effects of monetary policy shocks on the real economy and inflation doesn’t imply that monetary policy more generally hasn’t shaped macroeconomic outcomes in recent years. Instead, the small contribution of policy shocks to the real economy and prices suggests that the policy actions taken after 2008 were a systematic policy response to the unfolding macroeconomic conditions. To make this point clear, we now conduct a second counterfactual where we assume that the Federal Reserve allows the broad money supply to collapse, as it did in the Great Depression.

According to Friedman and Schwartz (1963), a sequence of monetary policy contractions turned a financially induced recession into the Great Depression. And more recently, Bernanke (2012) argued that the actions taken by the Federal Reserve following the global financial crisis prevented a repeat of this mistake during the Federal Reserve's second encounter with the zero lower bound on nominal interest rates.

The second column of Figure 7 seems to support the view that the actions taken by the Federal Reserve may have prevented something akin to a Great Depression 2.0 from being realized. If DM4 grew at the same rate from 2007:Q4 to 2015:Q4 as did M2 from 1929:Q3 to 1937:Q3, then Real GDP would have fallen by 12.65% (actual -4.35%) from peak to trough and prices would have fallen with the rate of *deflation* reaching 4.1% (actual +0.26% inflation).¹⁵ These estimates are likely conservative given that Romer and Romer (2013) showed inflation expectations were also falling in the Great Depression, whereas our estimates are over a period of largely anchored inflation expectations. With this, and all other caveats associated with comparing two different historical episodes, in mind our Baseline VAR suggests that the Federal Reserve's actions after 2008 were largely taken in response to the state of the economy, were not large deviations from their historical policy rule, prevented a much larger economic contraction, and fought off deflation.

3.5 Robustness to Using Monthly Data

The key identifying assumption in the recursive VAR models estimated to this point is that monetary policy makers adjust the stance of policy based on the evolution of output and prices. Given the recursive ordering, this assumption also implies that output and prices do not respond upon impact following monetary policy shock. This assumption may be more palatable at a monthly frequency than quarterly. Therefore, an important question is whether we find any evidence that output and prices respond within the quarter when we allow for such movements by only imposing the zero impact restriction on monthly data. Of course, the monthly model also implies that the FOMC makes incremental adjustments to the stance of monetary policy 12 times per year when, in reality, the FOMC has only 8 regularly scheduled meetings each year.¹⁶

¹⁵We find slightly larger differences between the realized data and counterfactual outcomes if we use M2 in the VAR and slightly smaller differences if we feed in a predicted path of DM4 from 1929:Q3 to 1937:Q3 using a linear projection onto DM2.

¹⁶Although the Fed has also at times conducted conference calls between its scheduled meeting dates to make additional changes to monetary policy.

Figure 8 shows the impulse responses from our Baseline model estimated at a monthly frequency.¹⁷ For the purpose of comparing the impulse responses from this monthly VAR with the Baseline quarterly model, we aggregate the monthly impulse responses to quarterly by averaging the impulse responses across three consecutive months.

The impact responses of output and prices in the monthly model are not statistically different from the impact responses in the quarterly model. Therefore, even if we relax the assumption that output and prices are pre-determined within the quarter to simply assuming they are pre-determined within the month, we find no evidence of a significant quarterly adjustment to output and prices. Even beyond the impact responses, the time paths of output and prices are remarkably similar in our monthly model. The same is true for commodity prices, DM4, and the monetary base. Only the impact response for the user cost of M4 from the quarterly model falls outside of the confidence band from the estimated monthly model which contains zero. But finding only 1 out of 102 quarterly model responses that falls outside the 90 percent confidence bounds seems rather remarkable. We interpret our findings as strong evidence of robustness to different data frequencies. And while the monthly model does lack a statistically significant liquidity effect, overall the qualitative inference from the monthly VAR aligns with the conclusions from the quarterly model and the quantitative inference are also quite similar.

3.6 Why is DM4 Useful for Identifying Monetary Policy Shocks?

Our money-based VAR model has been shown to identify monetary policy shocks which result in impulse responses that are free from output, price, and liquidity puzzles across several samples. These results are at odds with the findings of most of the previous research on monetary VAR models which use money as the policy indicator. Eichenbaum (1992), Gordon and Leeper (1994) and Christiano et al. (1999) consider VAR models that use a monetary aggregate as the policy indicator, and each of these papers finds a puzzling rise in output, prices, or reserves in response to a contractionary monetary policy shock. However, these previous studies have used narrower aggregates than we consider here. Additionally, the DM4 aggregate we use is expenditure weighted

¹⁷Real GDP and the GDP deflator were acquired from Haver Analytics. From 1967:01-1992:04 the monthly nominal and real GDP series are from Stock and Watson (2010) and after 1992:04 are from Macroeconomic Advisers. Both sources use a similar approach of informing their monthly estimates with source data used by BEA to construct the official quarterly data.

which we show in this section using our DSGE model, may explain another source of divergence between our results and the previous literature.

In practice, Christiano et al. (1999) find that broader aggregates have more success at identifying monetary policy shocks than do the narrower aggregates. One reason for this may be that a broad measure of money provides for a wide scope of transmission mechanisms, some of which may be difficult to capture with a narrower aggregate. For example, textbook models of money and banking suggests that monetary policy transmits through a money multiplier and multiple deposit creation. If this is a primary channel through which monetary policy operates, then M1 should be a sufficiently broad measure of liquidity to capture the monetary transmission mechanism. However, VAR models using M1 as the policy indicator often lead to output puzzles suggesting other transmission mechanisms may be at play.

While M2 has considerably more success than M1 in avoiding output puzzles, a model with M2 still finds that after following a contractionary shock to M2 the price level rises and, in some samples, the monetary base also rises.¹⁸ This casts doubt on the interpretation of shocks to M2 as monetary policy shocks and led us to work with an M4 aggregate which contains: institutional money market funds, overnight and term repurchase agreements, commercial paper, and treasury bills. In addition to capturing the basic transmission mechanism described above, this aggregate is also capable of capturing non-bank transmission mechanisms. For example, Adrian and Shin (2010) show that traditional monetary policy has considerable effects on the repo holdings, and ultimately the “risk-taking,” of large broker-dealers suggesting monetary policy may transmit through money markets and various short-term credit markets not captured by M2 but better tracked by DM4. Hence, the DM4 aggregate is better suited to capture potential shifts in the transmission mechanism of monetary policy over time from one operating primarily through a fractional reserve banking system to one operating through non-bank financial firms.

In addition to plausibly capturing multiple transmission mechanisms of conventional monetary policy, DM4 is better suited than M2 to capture the multiple dimensions of monetary policy used in response to the Global Financial Crisis. In its capacity as lender of last resort, the Federal Reserve created the Primary Dealer Credit Facility which targeted repo markets and the Term Securities Lending Facility which auctioned treasuries in exchange for eligible collateral to accommodate de-

¹⁸The size of the rise in prices varies with what variables are included in the money market block, but in all cases we find a persistent rise in prices.

mand for high quality collateral. The Federal Reserve also provided liquidity directly to investors and borrowers to ensure credit would flow to the financial sector despite the impairment of bank-based lending in following Lehman’s bankruptcy. These facilities targeted commercial paper markets (the Commercial Paper Funding Facility) and money market mutual funds (Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility and the Money Market Investor Funding Facility) which had come under pressure due to increased demand for redemption. Since M4 contains these asset classes specifically targeted by the Federal Reserve’s liquidity facilities it is better able to capture shifts in monetary policy after 2008 than would be a narrower aggregate.

Another important difference between our money-based VAR model and previous papers is that DM4 is an expenditure weighted monetary aggregate of the Divisia variety proposed by Barnett (1980). Nearly all macroeconomic aggregates are expenditure weighted, but surprisingly the most well-known monetary aggregates are not. While the difference may seem innocuous, our DSGE model suggests that non-expenditure weighted aggregates (e.g. M1 and M2) have an unstable response to a monetary policy shock, even if the money demand relationship is perfectly stable.

In our DSGE model, the monetary aggregate M is defined by the CES function:

$$M_t = \left[\nu^{\frac{1}{\omega}} N_t^{\frac{\omega-1}{\omega}} + (1-\nu)^{\frac{1}{\omega}} D_t^{\frac{\omega-1}{\omega}} \right]^{\frac{\omega}{\omega-1}}, \quad (3.5)$$

where N denotes currency, D denotes interest bearing deposits, $0 \leq \nu \leq 1$ governs the weight placed on each asset in the CES aggregate, and $\omega \geq 0$ is the elasticity of substitution between each asset. While an expenditure weighted aggregate in our (log-linear) model will be equal to M , an unweighted aggregate will fail to properly internalize substitution effects when these are imperfectly substitutable assets.¹⁹ This will result in an endogenous, time-varying gap between the unweighted aggregate and M .

Figure 9 illustrates the implications of this aggregation error by showing in the DSGE model how the impact response of the unweighted monetary aggregate following a contractionary monetary policy shock varies for different values of ν and ω . All the while, the interest semi-elasticity is held fixed by adjusting the value of χ .²⁰ Two implications emerge from this exercise as it pertains to the empirical literature on monetary policy shocks. First, the liquidity effect, as estimated by response

¹⁹When the assets are perfect substitutes (i.e. ω goes to infinity) then an unweighted aggregate will be equal to M .

²⁰When $h = 0$ the response of M is stable across the simulations whereas with $h > 0$ the response changes slightly as χ adjusts to keep η constant which affects the coefficients on y_t and y_{t-1} in the money-demand curve.

of an unweighted aggregate following a monetary policy shock, is likely to be biased upwards and the degree of this bias will vary over time if the importance of, or substitutability between, some assets shift over time. This is one possible explanation for the seeming difficulty in uncovering a stable response of M2 in monetary VARs (Gordon and Leeper, 1994; Bernanke and Mihov, 1998b). The second implication is that using unweighted aggregates as the policy indicator could easily result in empirical puzzles. The graph indicates that there is a substantial range of values for ν and ω for which the correlation between the unweighted aggregate and other macroeconomic time series has a different sign than the correlation between M and those same time series. This suggests that one possible explanation as to why we find no output, price, nor liquidity puzzles in our money-based VAR model, unlike previous recursive VAR models which have used money as the policy indicator, is because DM4 is expenditure weighted.²¹

4 Conclusion

Much emphasis in the field of monetary economics has centered on understanding what effects monetary policy may typically have on the aggregate economy. One goal of this paper is to characterize the effects of monetary policy under a wide variety of conditions. A good deal of recent work has focused exclusively on explaining, or accounting for, the aftermath of the recent US financial crisis with methodological departures from what was overwhelmingly orthodox just a few years ago. Thus, one might conclude that a consensus model might work under normal conditions, and a different rule book should be used to characterize large financial crises. While there may be certain advantages to studying different periods separately, we do not set out to analyze these sub-periods in a vacuum. Instead, we develop a new method for identifying monetary policy shocks that is suitable in both financial crises and normal conditions.

We extend the identifying assumption that central banks react to real economics activity and prices, but only affect these variables with a lag, to a framework that remains valid whether the federal funds rate is stuck at zero or not. Drawing heavily from the implications of a relatively standard New-Keynesian model of monetary policy, we propose using DM4 money as the policy indicator variable. Abandoning the fed funds rate as the policy indicator might have raised concerns that we reach fundamentally different conclusions about the effects of monetary policy. Our theoretical and

²¹For more information on the construction of the DM4 aggregate by the Center for Financial Stability see: http://www.centerforfinancialstability.org/amfm_data.php.

empirical findings, however, show that when the federal funds rate is above its zero lower bound, the dynamic responses are very similar whether DM4 or the fed funds rate is used. Importantly, the money-based model is able to measure the effects of monetary policy whether or not the fed funds rate is at its effective lower bound.

Aside from our work, there has been a concerted effort to discover other options for gaging the effects of monetary policy during the recent zero lower bound period. In particular, Krippner (2013), Lombardi and Zhu (2014), and Wu and Xia (2016) use factor models to estimate “shadow” measures of the fed funds rate that extend beyond 2008. These shadow rates allow economists, in principle, to continue to use macroeconomic models that assign important roles to the fed funds rate. However, we show that the use of these shadow rates result in price and, in some cases, liquidity puzzles that our money-based model avoids. In addition to the reemergence of these puzzles when using these shadow rates, there is some question about which shadow rate to use. For example, Christensen and Rudebusch (2014) find that estimated shadow rates are sensitive to the number of factors used to estimate the term structure model and, therefore, warn against using the shadow rate to measure the stance of monetary policy.

Due to multiple changes in stewardship and operating procedures of the Fed during our sample of study, an obvious direction for future research is to estimate, rather than impose, dates of potential structural breaks. The efficacy of the monetary response to a financial crisis may be subject to structural change (see, e.g., Boivin, Kiley, and Mishkin (2010) among many others). In fact, there is a long tradition of characterizing the effects of monetary policy as time dependent. In a well-known contribution that excludes the most recent US financial crisis, Sims and Zha (2006) find that even if one assumes that US monetary policy has undergone changes in regime, the differences among them are not large enough to explain the US Great Inflation or its subsequent Great Moderation.

Qualitatively, our results show a substantial robustness in the responses to monetary policy in various periods we consider. We expect qualitative conclusions to remain unchanged if we allow for time-varying parameters, although some difference in the magnitudes are expected. Indeed our empirical analysis of impulse responses shows that during the financial crisis the Fed had to inject a much larger amount of money into the banking system to achieve a given amount of liquidity. We also find considerable evidence that the Phillips curve has flattened over time. However, we don't find a fundamental change in the qualitative effects monetary policy has on output and prices.

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A DSGE Model

This section describes the DSGE model used in the paper in detail. Our approach to modeling the household's portfolio of monetary assets follows closely from Belongia and Ireland (2014). The production side of the economy is a standard New-Keynesian model.

A.1 The household

The representative household enters any period $t = 0, 1, 2, \dots$ with a portfolio consisting of maturing bonds B_{t-1} and monetary assets totaling A_{t-1} . The household faces a sequence of budget constraints in any given period. In the first sub-period the household allocates their monetary assets A_{t-1}/P_t net of central bank transfers τ_t between currency N_t and deposits D_t . Any loans L_t needed to finance these transactions are made at this time. This is summarized in the constraint below:

$$N_t + D_t = \frac{A_{t-1}}{\Pi_t} + L_t + \tau_t, \quad (\text{A.1})$$

where $\Pi_t = P_t/P_{t-1}$. In the second sub-period, the household receives income from hours worked H_t during the period at wage rate W_t , dividends F_t from intermediate goods firms, any residual assets of the bank F_t^b , and receives interest on deposits $R_t^D D_t$ and the par value of nominal bonds purchased last period B_{t-1}/Π_t . The household then allocates this income between consumption goods C_t , loan payments $R_t^L L_t$, and lump-sum taxes T_t . Any remaining funds are carried over into the next period in the form of monetary assets A_t or bonds B_t purchased at a price of $1/R_t$.

$$A_t = N_t + F_t + F_t^b + R_t^D D_t - R_t^L L_t + W_t H_t - C_t - \frac{B_t}{R_t} + \frac{B_{t-1}}{\Pi_t} - T_t. \quad (\text{A.2})$$

The household seeks to maximize their lifetime utility, discounted at rate β , subject to these constraints. The period flow utility of the household takes the following form.

$$U_t = [\ln(C_t - hY_{t-1}) - \xi H_t - H_t^s]$$

The household receives utility from consumption relative to last periods aggregate demand (i.e. the household has external habits) and dis-utility from working and shopping. Time spent shopping increases with aggregate demand Y_t (i.e. long lines) but is reduced with higher liquidity services.

Therefore the time spent shopping takes the following form:

$$H_t^s = \frac{1}{\chi} \left(\frac{Y_t}{M_t} \right)^\chi. \quad (\text{A.3})$$

The monetary aggregate, M_t , which enters the shopping-time function takes a rather general CES form,

$$M_t = \left[\nu^{\frac{1}{\omega}} (N_t)^{\frac{\omega-1}{\omega}} + (1-\nu)^{\frac{1}{\omega}} (D_t)^{\frac{\omega-1}{\omega}} \right]^{\frac{\omega}{\omega-1}} \quad (\text{A.4})$$

where ν calibrates the relative expenditure shares on currency and deposits and ω calibrates the elasticity of substitution between the two monetary assets. Given these parameters, χ is left free to calibrate the interest semi-elasticity of money demand.

The representative household faces the problem of maximizing its lifetime utility subject to its budget constraints. Letting $\mathcal{C}_t = [C_t, H_t, M_t, N_t, D_t, L_t, B_t, A_t]$ denote the vector of choice variables, the household's problem can be recursively defined using Bellman's method:

$$\begin{aligned} V_t(B_{t-1}, A_{t-1}) = \max_{\mathcal{C}_t} & \left\{ \left[\ln(C_t - hY_{t-1}) - \xi H_t - \frac{1}{\chi} \left(\frac{Y_t}{M_t} \right)^\chi \right] \right. \\ & - \lambda_t^1 \left(N_t + D_t - A_{t-1}/\Pi_t - L_t - \tau_t \right) - \lambda_t^2 \left(M_t - \left[\nu^{\frac{1}{\omega}} (N_t)^{\frac{\omega-1}{\omega}} + (1-\nu)^{\frac{1}{\omega}} (D_t)^{\frac{\omega-1}{\omega}} \right]^{\frac{\omega}{\omega-1}} \right) \\ & - \lambda_t^3 \left(A_t - N_t - F_t - F_t^b - R_t^D D_t + R_t^L L_t - W_t H_t + C_t + B_t/R_t - B_{t-1}/\Pi_t + T_t \right) \\ & \left. + \beta \mathbb{E}_t [V_{t+1}(B_t, A_t)] \right\}. \end{aligned}$$

The first order necessary conditions are given by the following equations:

$$\frac{1}{(C_t - hY_{t-1})} = \beta \mathbb{E}_t \left[\frac{1}{(C_{t+1} - hY_t)} \frac{R_t}{\Pi_{t+1}} \right] \quad (\text{A.5})$$

$$W_t = \xi(C_t - hY_{t-1}) \quad (\text{A.6})$$

$$\frac{C_t - hY_{t-1}}{M_t} = \frac{\lambda_t^2}{\lambda_t^3} \left(\frac{Y_t}{M_t} \right)^{-\chi} \quad (\text{A.7})$$

$$N_t = \nu M_t \left[\frac{\lambda_t^2/\lambda_t^3}{(R_t - 1)} \right]^\omega \quad (\text{A.8})$$

$$D_t = (1-\nu) M_t \left[\frac{\lambda_t^2/\lambda_t^3}{(R_t - R_t^D)} \right]^\omega \quad (\text{A.9})$$

$$M_t = \left[\nu^{\frac{1}{\omega}} (N_t)^{\frac{\omega-1}{\omega}} + (1-\nu)^{\frac{1}{\omega}} (D_t)^{\frac{\omega-1}{\omega}} \right]^{\frac{\omega}{\omega-1}}. \quad (\text{A.10})$$

A.2 The goods producing sector

The goods producing sector features a final goods firm and an intermediate goods firm. There are a unit measure of intermediate goods producing firms indexed by $i \in [0, 1]$ who produce a differentiated product. The final goods firm produces Y_t combining inputs $Y_{i,t}$ using the production technology,

$$Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}$$

in which $\theta > 1$ governs the elasticity of substitution between inputs. The final goods producing firm sells its product in a perfectly competitive market, hence solving the profit maximization problem:

$$\max_{Y_{i,t} \in [0,1]} P_t Y_t - \int_0^1 P_{i,t} Y_{i,t} di,$$

subject to the above constant returns to scale technology. The resulting first order condition defines the demand curve for each intermediate goods producing firm's product:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\theta} Y_t. \tag{A.11}$$

Given the downward sloping demand for its product in (A.11), the intermediate goods producing firm has the ability to set the price of its product above marginal cost. To permit aggregation and allow for the consideration of a representative firm, I assume all such firms have the same constant returns to scale technology:

$$Y_{i,t} = H_{i,t}. \tag{A.12}$$

The term $H_{i,t}$ in the production function denotes the level of employment chosen by the intermediate goods firm. Given the linear production function, the intermediate goods producing firm's real marginal cost takes the same functional form:

$$MC_t = (1 - \mathcal{S})W_t,$$

A production subsidy, \mathcal{S} , is introduced to make the steady state price of goods equal to the marginal cost of production.

The price setting ability of each firm is constrained as in Calvo (1983). In this staggered price-setting framework, the price level P_t is determined in each period as a weighted average of a fraction of firms $1 - \alpha$ are able to re-optimize their price and a fraction α must leave their prices unchanged. Therefore, each firm maximizes the present value of its current and future discounted profits, taking into account the possibility that the firm may not be able to re-optimize for sometime:

$$\max_{P_{i,t}^*} \mathbb{E}_t \sum_{j=0}^{\infty} (\beta\alpha)^j \frac{\lambda_{t+j}^3}{\lambda_t^1} [\Pi_{t-1,t+j-1} P_{i,t}^* Y_{i,t+j} - MC_{t+j} P_{t+j} Y_{i,t+j}]$$

subject to

$$Y_{i,t+j} = \left(\Pi_{t-1,t+j-1} \frac{P_{i,t}^*}{P_{t+j}} \right)^{-\theta} Y_{t+j},$$

where $\Pi_{t-1,t+j-1} \equiv P_{t+j-1}/P_{t-1}$ which captures the indexation of prices to lagged inflation. The firm's first order condition is given by:

$$\mathbb{E}_t \sum_{j=0}^{\infty} (\beta\alpha)^j \frac{\lambda_{t+j}^3}{\lambda_t^3} Y_{i,t+j} \left(\Pi_{t-1,t+j-1} \frac{P_{i,t}^*}{P_{t-1}} - \Pi_{t-1,t+j} \frac{\theta}{\theta-1} MC_{t+j} \right) = 0. \quad (\text{A.13})$$

Finally, in equilibrium, the aggregate price dynamics are determined by the following price aggregate:

$$\Pi_t^{1-\theta} = \alpha \Pi_{t-1}^{1-\theta} + (1-\alpha) (\Pi_t^*)^{1-\theta} \quad (\text{A.14})$$

where $\Pi_t^* = P_t^*/P_{t-1}$ and P_t^* is the optimal price firms choose who re-optimize in period t .

A.3 The Financial Firm

The financial firm performs the intermediation process of accepting household's deposits and making loans. The financial firm must satisfy the accounting identity which specifies assets (loans to firms plus reserves) equal liabilities (deposits),

$$L_t + rrD_t = D_t. \quad (\text{A.15})$$

Although changes in banking regulation have effectively eliminated reserve requirements, banks may often choose to hold reserves in lieu of making loans. Therefore, instead of assuming the central

bank controls the reserve ratio rr , we assume it is exogenously fixed and represents the average ratio of deposits banks hold for regulatory and liquidity purposes.

The financial firm chooses L_t and D_t in order to maximize period profits

$$\max_{L_t, D_t} R_t^L L_t - R_t^D D_t - L_t + D_t - xL_t$$

subject to the balance sheet constraint (A.15). The term xL_t denotes the real resource costs banks bear in making loans. We assume for simplicity that these resources are not destroyed in the loan production process, but instead are rented and remitted back to the household as dividends F_t^b . Since the loan and deposits markets are perfectly competitive, substituting the balance-sheet constraint into the profit function and imposing zero profits results in the loan-deposit spread,

$$R_t^L - R_t^D = (R_t^L - 1)rr + x(1 - rr). \quad (\text{A.16})$$

This expression describes the loan deposit spread as a weighted average of the (opportunity) cost of accepting one unit of deposits. The fraction rr are held as reserves which bears the foregone revenue of making loans while the remaining fraction $(1 - rr)$ are loaned out which bears the real resource cost of making a new loan.

A.4 Equilibrium and the Output Gap

Here we define the equilibrium conditions which close the model. Equilibrium in the final goods market requires that the accounting identity

$$Y_t = C_t \quad (\text{A.17})$$

holds. Equilibrium in the money market and bond market requires that at all times: $A_t = A_{t-1}/\Pi_t + \tau_t$ and $B_t = B_{t-1} = 0$ respectively. Market clearing in the labor market requires that labor supply equals labor demand:

$$H_t = \int_0^1 H_{i,t} di = \int_0^1 Y_{i,t} di = \int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{-\theta} di Y_t$$

where the second equality uses the firm's production function (A.12) and the third equality uses the demand for the intermediate goods product (A.11). Therefore, aggregate output is related to price

dispersion, aggregate labor supply, and technology by:

$$Y_t = \left[\int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{-\theta} di \right]^{-1} H_t. \quad (\text{A.18})$$

The production subsidy $(1 - \mathcal{S})$ to the intermediate goods producers is set so that in steady state the subsidy offsets the steady state markup of the monopolistically competitive firm implying $1 - \mathcal{S} = (\theta - 1)/\theta$. Finally, the government funds this subsidy with lump-sum taxes from the household implying the following government budget constraint:

$$T_t = SW_t H_t. \quad (\text{A.19})$$

A.5 Monetary Aggregates

Three monetary aggregates are defined in the DSGE model. The first is the monetary base which, given the equilibrium conditions in the money and bond markets together with equations (A.1) and (A.15) reveals that:

$$A_t = N_t + rrD_t \quad (\text{A.20})$$

so that A_t is equal to the monetary base, currency plus reserves, in this model.

The second aggregate is a weighted non-parametric Divisia aggregate $M_t^{\mathcal{W}}$ used to approximate the parametric aggregate M_t as defined by Barnett (1980):

$$\ln \left(\frac{M_t^{\mathcal{W}}}{M_{t-1}^{\mathcal{W}}} \right) = \frac{S_t^N + S_{t-1}^N}{2} \ln \left(\frac{N_t}{N_{t-1}} \right) + \frac{S_t^D + S_{t-1}^D}{2} \ln \left(\frac{D_t}{D_{t-1}} \right), \quad (\text{A.21})$$

where $S_t^N = (R_t - 1)N_t / ((R_t - 1)N_t + (R_t - R_t^D)D_t)$ is the share of total implicit spending on monetary assets allocated to currency and $S_t^D = 1 - S_t^N$ is the complimentary share spent on deposits.

The third aggregate is an unweighted aggregate $M_t^{\mathcal{U}}$ used to approximate the parametric aggregate M_t :

$$\ln \left(\frac{M_t^{\mathcal{U}}}{M_{t-1}^{\mathcal{U}}} \right) = \ln \left(\frac{N_t + D_t}{N_{t-1} + D_{t-1}} \right). \quad (\text{A.22})$$

A.6 The Non-Linear Model

$$\frac{1}{C_t - hY_{t-1}} = \beta \mathbb{E}_t \left[\frac{1}{C_{t+1} - hY_t} \frac{R_t}{\Pi_{t+1}} \right] \quad (\text{A.23})$$

$$W_t = \xi(C_t - hY_{t-1}) \quad (\text{A.24})$$

$$\frac{Y_t}{M_t} = \left(\frac{\lambda_t^2}{\lambda_t^1} \right)^{\frac{1}{\chi+1}} \quad (\text{A.25})$$

$$N_t = \nu M_t \left[\frac{\lambda_t^2/\lambda_t^3}{(R_t - 1)} \right]^\omega \quad (\text{A.26})$$

$$D_t = (1 - \nu) M_t \left[\frac{\lambda_t^2/\lambda_t^3}{(R_t - R_t^D)} \right]^\omega \quad (\text{A.27})$$

$$M_t = \left[\nu^{\frac{1}{\omega}} (N_t)^{\frac{\omega-1}{\omega}} + (1 - \nu)^{\frac{1}{\omega}} (D_t)^{\frac{\omega-1}{\omega}} \right]^{\frac{\omega}{\omega-1}} \quad (\text{A.28})$$

$$Y_t = \left[\int_0^1 \left(\frac{P_{i,t}}{P_t} \right)^{-\theta} di \right]^{-1} H_t \quad (\text{A.29})$$

$$0 = \mathbb{E}_t \sum_{j=0}^{\infty} (\beta\alpha)^j \frac{\lambda_{t+j}^3}{\lambda_t^3} Y_{i,t+j} \left(\Pi_{t-1,t+j-1} \Pi_t^* - \Pi_{t-1,t+j} \frac{\theta}{\theta-1} M C_{t+j} \right) \quad (\text{A.30})$$

$$\Pi_t^{1-\theta} = \alpha \Pi_{t-1}^{1-\theta} + (1 - \alpha) (\Pi_t^*)^{1-\theta} \quad (\text{A.31})$$

$$M C_t = \frac{\theta - 1}{\theta} W_t \quad (\text{A.32})$$

$$R_t - R_t^D = (R_t - 1) r r + x(1 - r r) \quad (\text{A.33})$$

$$Y_t = C_t \quad (\text{A.34})$$

$$A_t = N_t + \tau D_t \quad (\text{A.35})$$

$$\ln \left(\frac{M_t^W}{M_{t-1}^W} \right) = \frac{S_t^N + S_{t-1}^N}{2} \ln \left(\frac{N_t}{N_{t-1}} \right) + \frac{S_t^D + S_{t-1}^D}{2} \ln \left(\frac{D_t}{D_{t-1}} \right) + \ln(\Pi_t) \quad (\text{A.36})$$

$$S_t^N = \frac{(R_t - 1) N_t}{(R_t - 1) N_t + (R_t - R_t^D) D_t} \quad (\text{A.37})$$

$$S_t^D = \frac{(R_t - R_t^D) D_t}{(R_t - 1) N_t + (R_t - R_t^D) D_t} \quad (\text{A.38})$$

$$\ln \left(\frac{M_t^U}{M_{t-1}^U} \right) = \ln \left(\frac{N_t + D_t}{N_{t-1} + D_{t-1}} \right) + \ln(\Pi_t) \quad (\text{A.39})$$

A.7 The Log-Linear Model

In this section we provide a linear representation of the model by taking a first order Taylor expansion of the relevant equations around the steady state. Lower case variables denote log deviations from the steady-state: $g_t = \ln(G_t) - \ln(G)$, where G is the steady state value of G_t .

The log-linear Euler equation can be derived from combining (A.23) and (A.34):

$$y_t = \frac{1}{1+h} \mathbb{E}_t y_{t+1} + \frac{h}{1+h} y_{t-1} - (r_t - \mathbb{E}_t \pi_{t+1}). \quad (\text{A.40})$$

The log-linear money demand equation can be derived in two steps. First, combine equations (A.27), (A.28) and (A.29) to show that:

$$\lambda_t^2 / \lambda_t^3 = [\nu(R_t - 1)^{1-\omega} + (1-\nu)(R_t - R_t^D)^{1-\omega}]^{\frac{1}{1-\omega}}$$

Then we use this expression for $\lambda_t^2 / \lambda_t^3$ in (A.25) along with equations (A.33) and (A.34) to arrive at the following log-linear expression for real money balances:

$$m_t = \frac{1 + \chi(1-h)}{(1+\chi)(1-h)} y_t - \frac{h}{(1+\chi)(1-h)} y_{t-1} - \eta r_t, \quad (\text{A.41})$$

so that in equation (2.2) $\eta = \left(\frac{\nu(R-1)^{-\omega} R + (1-\nu)(R-R^D)^{-\omega} R r r}{\nu(R-1)^{1-\omega} + (1-\nu)(R-R^D)^{1-\omega}} \right) \frac{1}{1+\chi}$.

The Phillips Curve can be derived in two steps. First, log-linearizing (A.30):

$$\begin{aligned} \pi_t^* - \pi_{t-1} &= (1 - \beta\alpha) \mathbb{E}_t \sum_{j=0}^{\infty} (\beta\alpha)^j (m c_{t+j} + \pi_{t+j,t-1} - \pi_{t+j-1,t-1}) - \pi_{t-1} \\ &= (1 - \beta\alpha) \mathbb{E}_t \sum_{j=0}^{\infty} (\beta\alpha)^j (m c_{t+j} + \sum_{k=0}^j \pi_{t+k} - \sum_{k=0}^j \pi_{t+k-1}) \\ &= \beta\alpha \mathbb{E}_t (\pi_{t+1}^* - \pi_t) + (1 - \beta\alpha) m c_t + (\pi_t - \pi_{t-1}). \end{aligned}$$

The first relationship follows from linearizing the firms pricing decision. The second equality follows after some algebra, particularly noting that $\pi_{t-1} = (1 - \beta\alpha) \sum_{j=0}^{\infty} (\beta\alpha)^j \pi_{t-1}$ and the third equality rewrites the infinite sum as a recursive formula. Next, we linearize equations (A.31) and use the

resulting expression $\pi_t - \pi_{t-1} = (1 - \alpha)(\pi_t^* - \pi_{t-1})$ to eliminate $\pi_t^* - \pi_{t-1}$ above:

$$\pi_t = \pi_{t-1} + \frac{(1 - \alpha)(1 - \beta\alpha)}{\alpha} \left(\frac{1}{1 - h} y_t - \frac{h}{1 - h} y_{t-1} \right) + \beta \mathbb{E}_t(\pi_{t+1} - \pi_t). \quad (\text{A.42})$$

where we have also written real marginal cost in terms of output by combining equations (A.32), (A.24), and (A.34) and log-linearizing.

A linear expression for the monetary base is obtained by log-linearizing equation (A.35):

$$a_t = \gamma^a n_t + (1 - \gamma^a) d_t \quad (\text{A.43})$$

where $\gamma^a = \nu(R - 1)^{-\omega} / [\nu(R - 1)^{-\omega} + rr(1 - \nu)(R - R^D)^{-\omega}]$. Log-linear expressions for N_t and D_t are obtained from equations (A.26) and (A.27) as follows:

$$n_t = m_t + \omega \left[(1 + \chi)\eta - \frac{R}{R - 1} \right] r_t \quad (\text{A.44})$$

$$d_t = m_t + \omega \left[(1 + \chi)\eta - rr \frac{R}{R - R^D} \right] r_t \quad (\text{A.45})$$

Log-linearizing (A.36) reveals that: $m_t^{\mathcal{W}} = m_{t-1}^{\mathcal{W}} + m_t - m_{t-1}$ and therefore $m_t^{\mathcal{W}} = m_t$. Log-linearizing (A.39) provides a log-linear expression for the unweighted monetary aggregate:

$$m_t^{\mathcal{U}} = m_{t-1}^{\mathcal{U}} + \gamma^{\mathcal{U}}(n_t - n_{t-1}) + (1 - \gamma^{\mathcal{U}})(d_t - d_{t-1}) + \pi_t \quad (\text{A.46})$$

where

$$\gamma^{\mathcal{U}} = \frac{\nu(R - 1)^{-\omega}}{\nu(R - 1)^{-\omega} + (1 - \nu)(R - R^D)^{-\omega}}.$$

A.8 Baseline Calibration

The model is calibrated so that each period represents one quarter. We set $\beta = 0.99$ which implies an annualized nominal bond rate equal to 4%. We set $\alpha = 0.75$ so the average duration of a price is about 1 year, as found by Nakamura and Steinsson (2008). The degree of habit persistence $h = 0.65$ as estimated in Christiano et al. (2005). The interest semi-elasticity of money demand is set to $\eta = 1.9$ as estimated in Ireland (2009). The parameters governing the CES aggregate of monetary assets are calibrated as in Ireland (2014) who uses component level data on N_t and M_t to estimate

equation (A.26). so that $\omega = 0.5$ and $\nu = 0.2$. We set $rr = 0.02$ which is the average ratio of reserve to non-currency components of M2 from 1967 to 2007 using data from the Federal Reserve Bank of St. Louis. Using data from the Center for Financial Stability we find that after setting $rr = 0.02$, setting $x = 0.0067$ implies the annualized steady state spread between R^L and R^D of 2.7% which is the average interest rate differential between the benchmark interest rate used to measure R_t^L and the own-rate on the non-currency components of M2.

Table 1: Baseline Model Calibration

Parameter		U.S
Discount Rate	β	0.99
Habit Adjustment	h	0.65
Calvo Probability	α	0.75
Interest Semi-Elasticity of Money Demand	η	1.9
CES Elasticity for Monetary Portfolio	ω	0.5
CES Weight for Monetary Portfolio	ν	0.2
Reserves Ratio	rr	0.02
Loan Origination Cost	x	0.0067

Table 2: **Baseline VAR Model (1967:Q1-2015:Q4)**

Percentage of Forecast Error Variance Due to Monetary Policy Shocks			
	4 Quarters Ahead	8 Quarters Ahead	20 Quarters Ahead
Real GDP	5.55 (1.13, 12.59)	8.44 (1.36, 19.68)	6.25 (1.23, 17.56)
GDP Deflator	0.25 (0.03, 1.83)	0.35 (0.06, 4.25)	6.47 (0.52, 18.18)
Commodity Prices	3.43 (0.50, 9.54)	9.50 (1.71, 20.87)	18.18 (5.76, 29.03)
Divisia M4	70.68 (54.87, 79.59)	43.73 (25.39, 58.44)	30.94 (11.65, 46.82)
Monetary Base	0.61 (0.24, 5.36)	1.90 (0.39, 10.12)	8.58 (0.84, 22.52)
User Cost (M4)	3.40 (0.71, 10.62)	2.41 (1.00, 9.64)	3.02 (1.49, 11.04)

Numbers in parentheses are the boundaries of the associated 90% confidence interval.

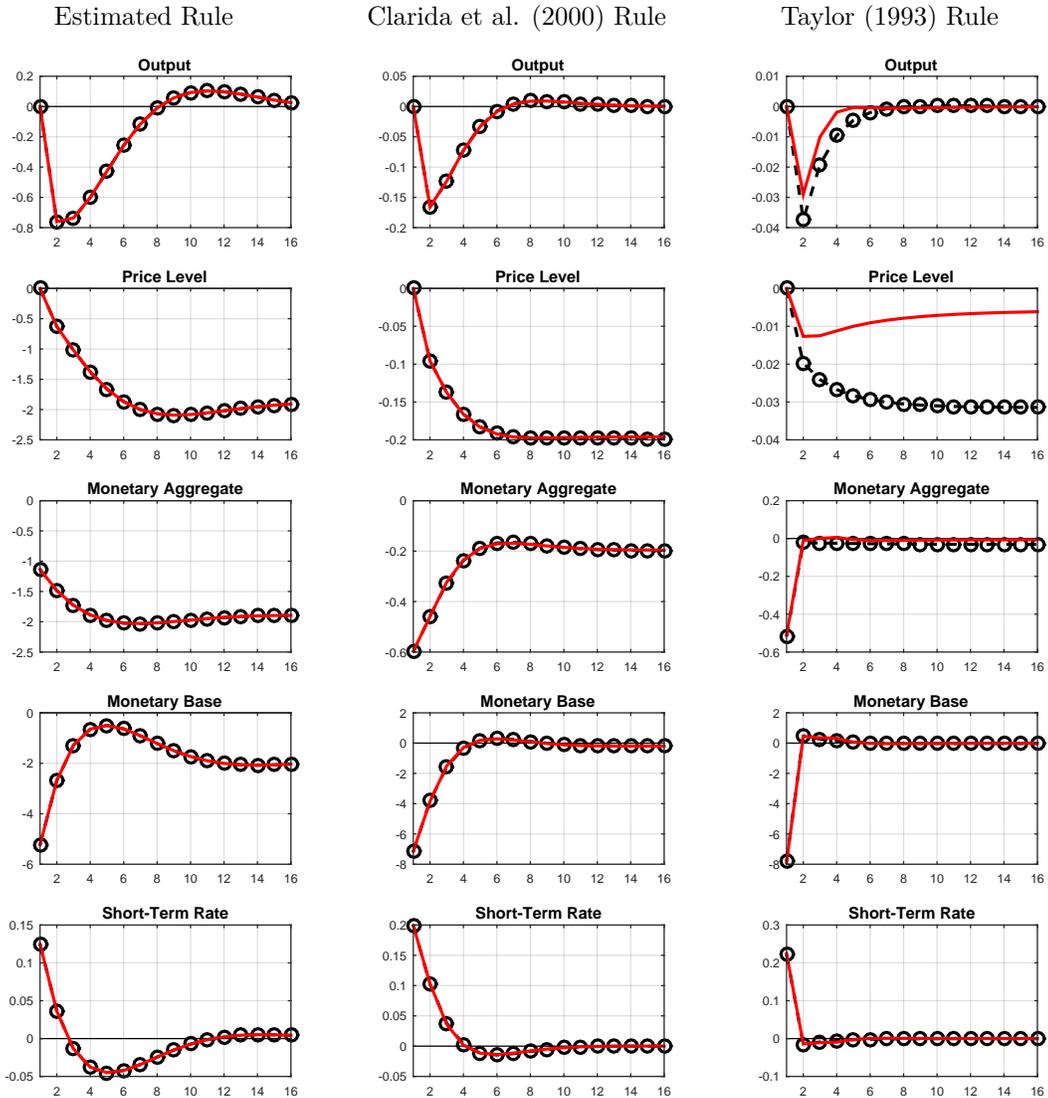


Figure 1: **DSGE Model Impulse Responses**

Contractionary monetary policy shocks under alternative monetary policy regimes. Dynamics following a monetary policy shock under an interest rate rule are denoted by black dashed line with circles and the dynamics following a monetary policy shock under the money growth rule are shown by the red solid lines. The parameters governing the money growth rules are found by minimizing the distance between the impulse response functions under the interest rate rule and the money growth rule.

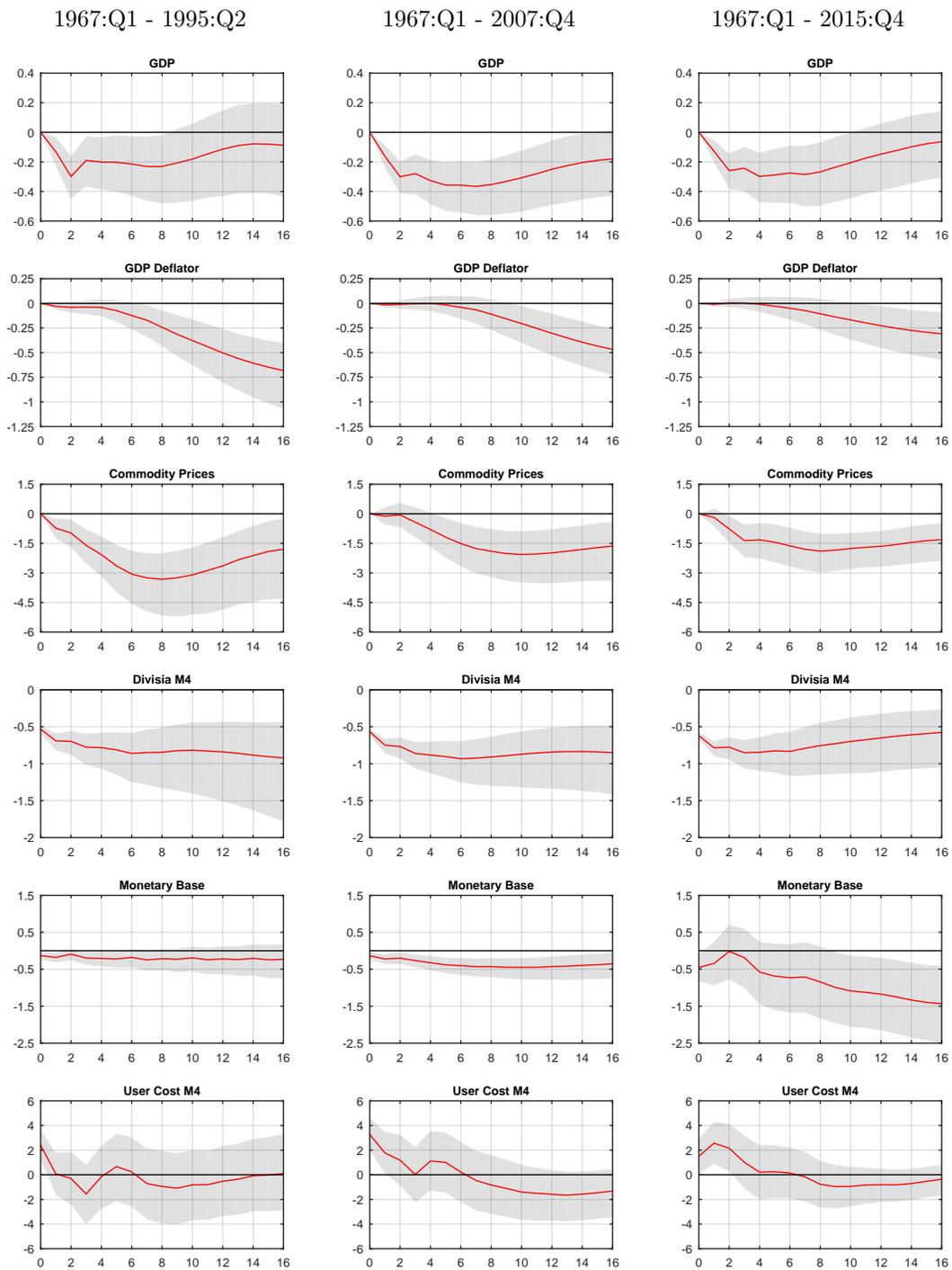


Figure 2: Baseline VAR Model (Various Sample Periods)
 The Baseline VAR model uses DM4 as the policy indicator and includes the monetary base and the user cost of DM4 in the money market block.

Cumulative Monetary Policy Shocks

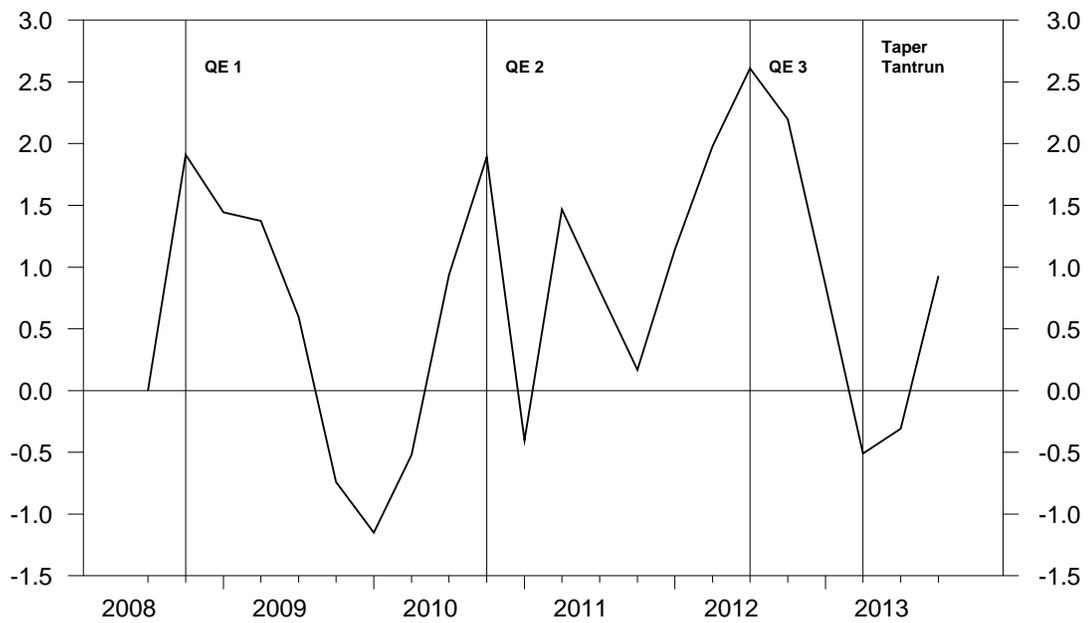


Figure 3: **Structural Monetary Policy Shocks**

This Figure plots the cumulative sum of the structural monetary policy shocks from our Baseline VAR model.

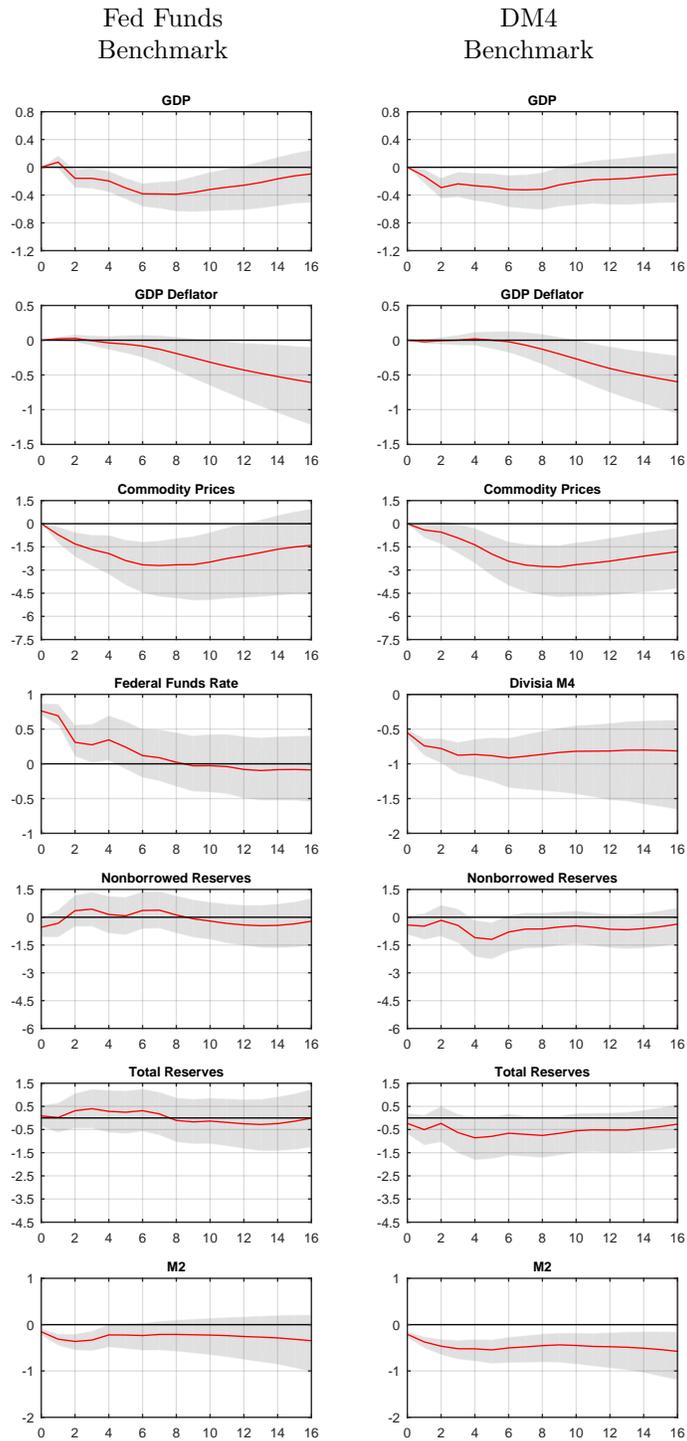


Figure 4: **Benchmark Specifications (1967:Q1 - 1995:Q2)**

The Fed Funds Benchmark model of Christiano et al. (1999) uses the fed funds rate as the policy indicator variable. The DM4 Benchmark model replaces the federal funds rate in the Fed Funds Benchmark model with DM4.

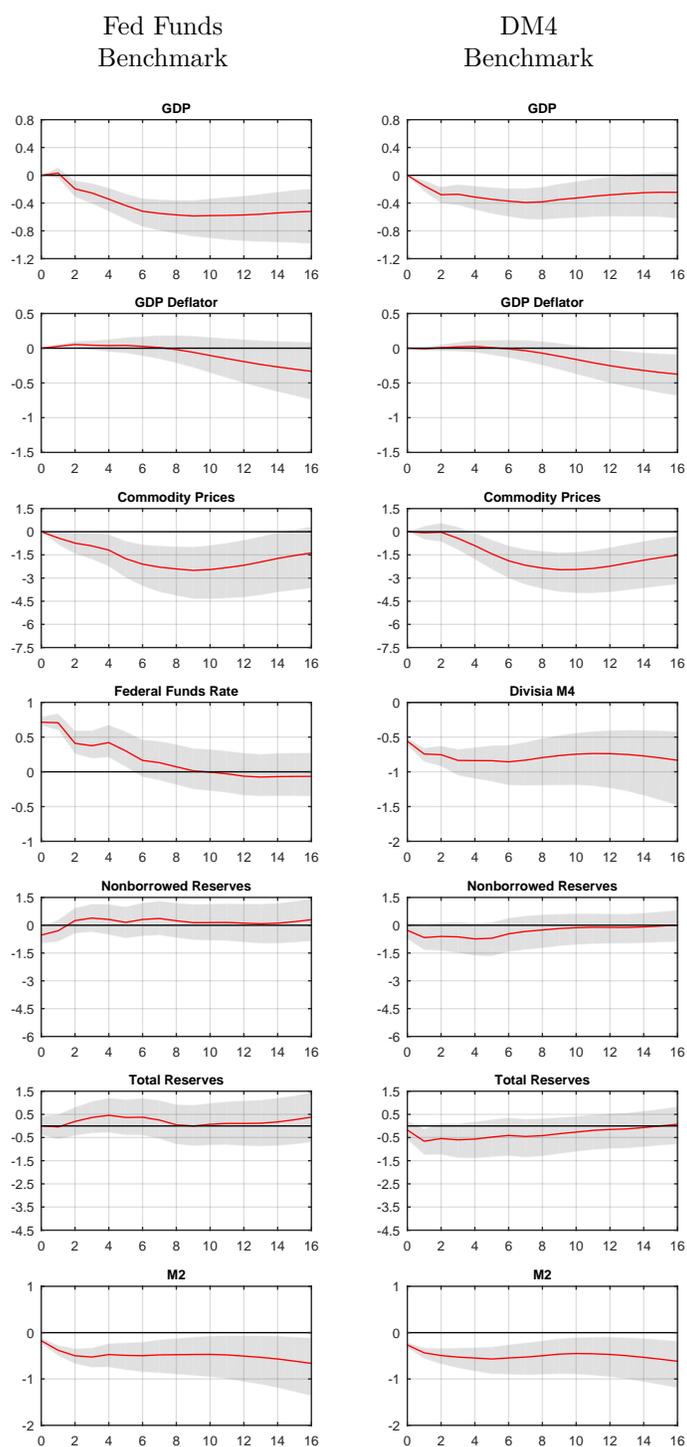


Figure 5: **Benchmark Specifications (1967:Q1 - 2007:Q4)**

The Fed Funds Benchmark model of Christiano et al. (1999) uses the fed funds rate as the policy indicator variable. The DM4 Benchmark model replaces the federal funds rate in the Fed Funds Benchmark model with DM4.

Lombardi and Zhu (2014)
Shadow Rate

Krippner (2013)
Shadow Rate

Wu and Xia (2016)
Shadow Rate

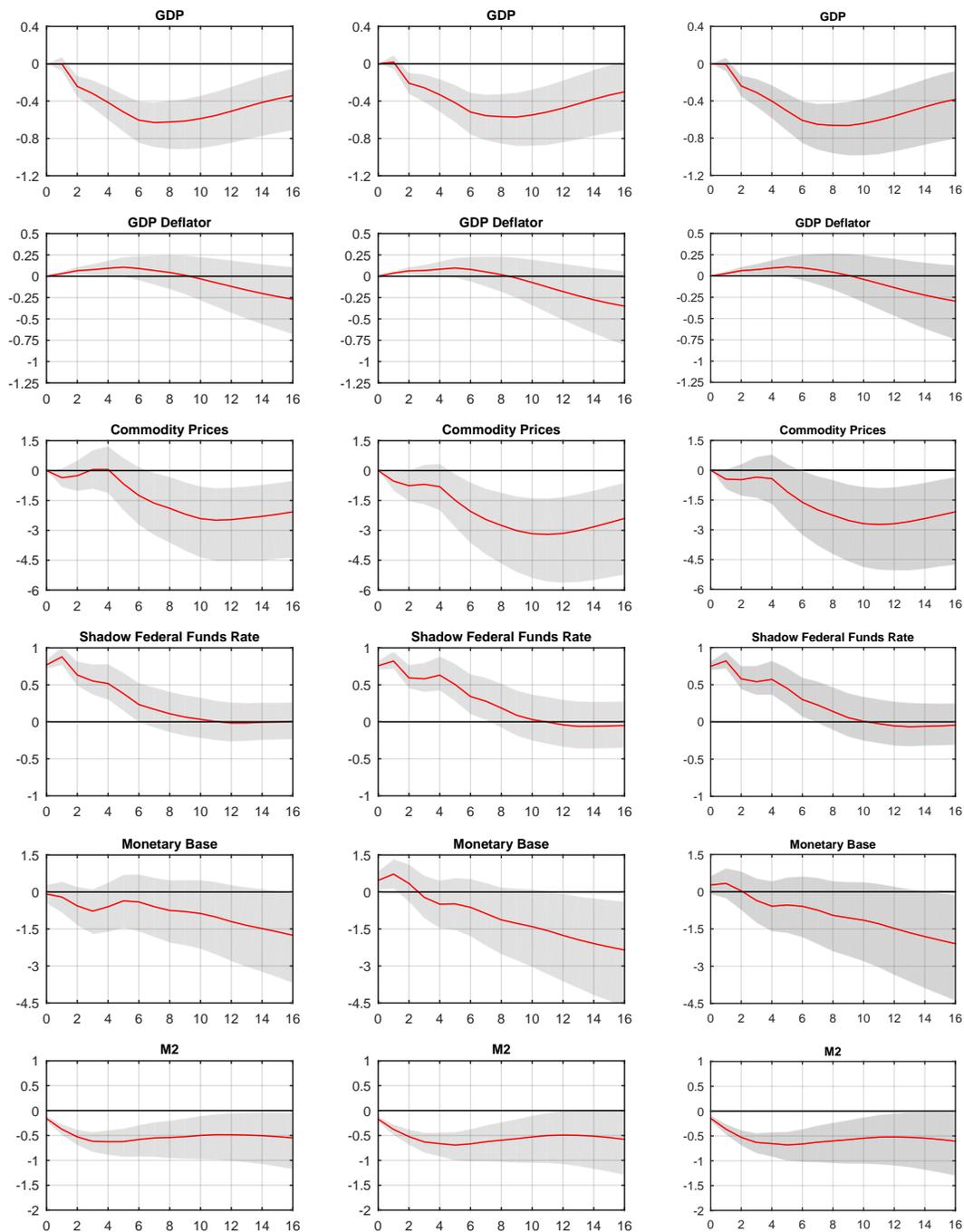


Figure 6: **Shadow Rate VAR Models**

Shadow rate VAR models replace DM4 with various shadow federal funds rates as the policy indicator variable in our Baseline VAR model.

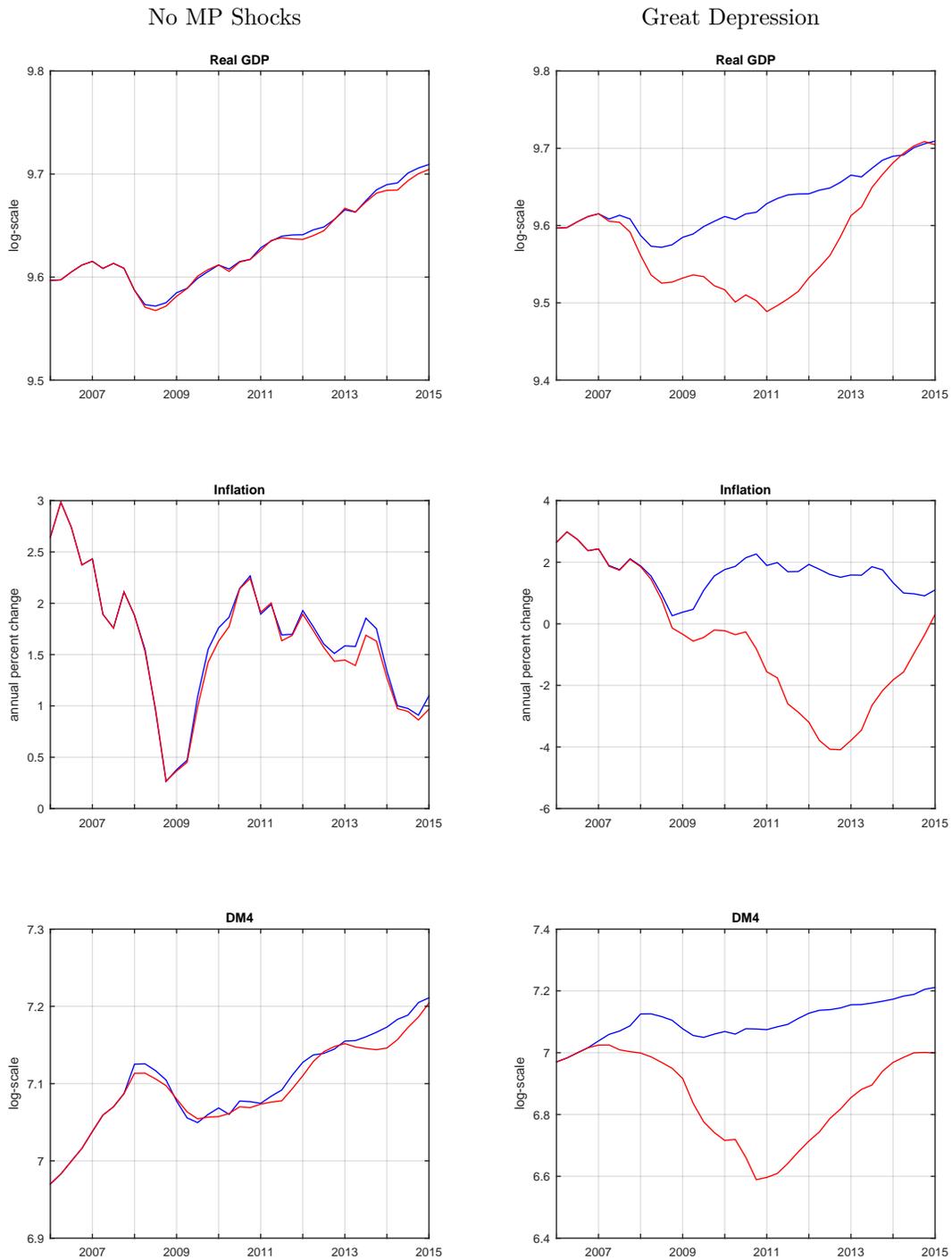


Figure 7: Counterfactual Monetary Policy Shocks

The blue lines are realized data and the red lines are counterfactual data generated from our Baseline VAR model. The no MP shocks scenario generates alternative paths for real GDP, inflation, and DM4 by setting all monetary policy shocks after 2008:Q4 to zero. The Great Depression scenario generates alternative paths for real GDP, inflation, and DM4 by generating a sequence of monetary policy shocks that causes DM4 to grow from 2007:Q4 to 2015:Q4 at the same rate that M2 grew from 1929:Q3 to 1937:Q3.

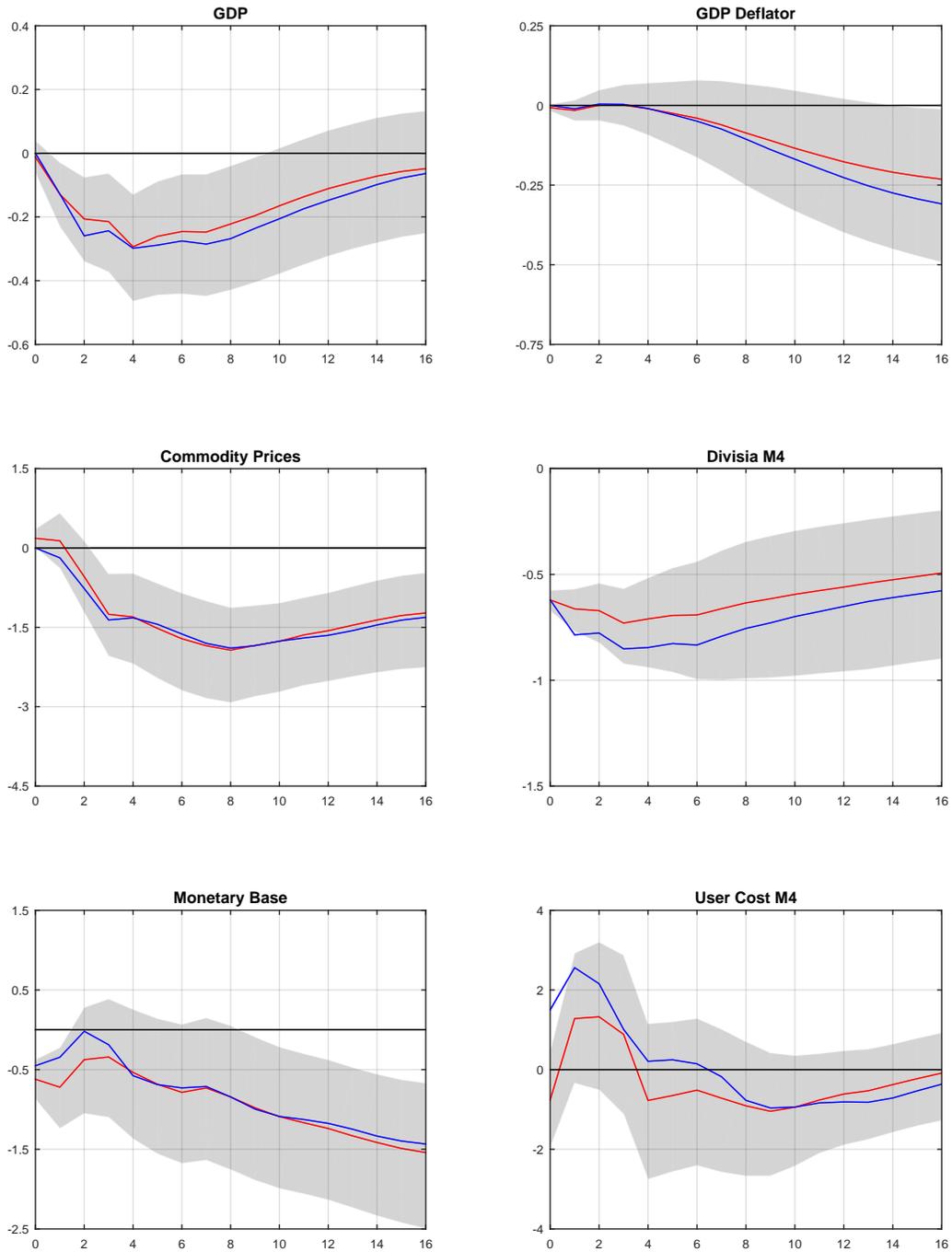


Figure 8: **Monthly VAR**

This Figure plots the impulse responses to an identified monetary policy shock in our Baseline VAR model using both monthly data (red line is the point estimate and shaded areas are confidence bands) and quarterly data (blue line is the point estimate). The monthly impulse responses are averaged across three months to generate quarterly impulse responses. The resulting quarterly impulse responses are scaled so that the impact response of DM4 is identical in both sets of impulse responses.

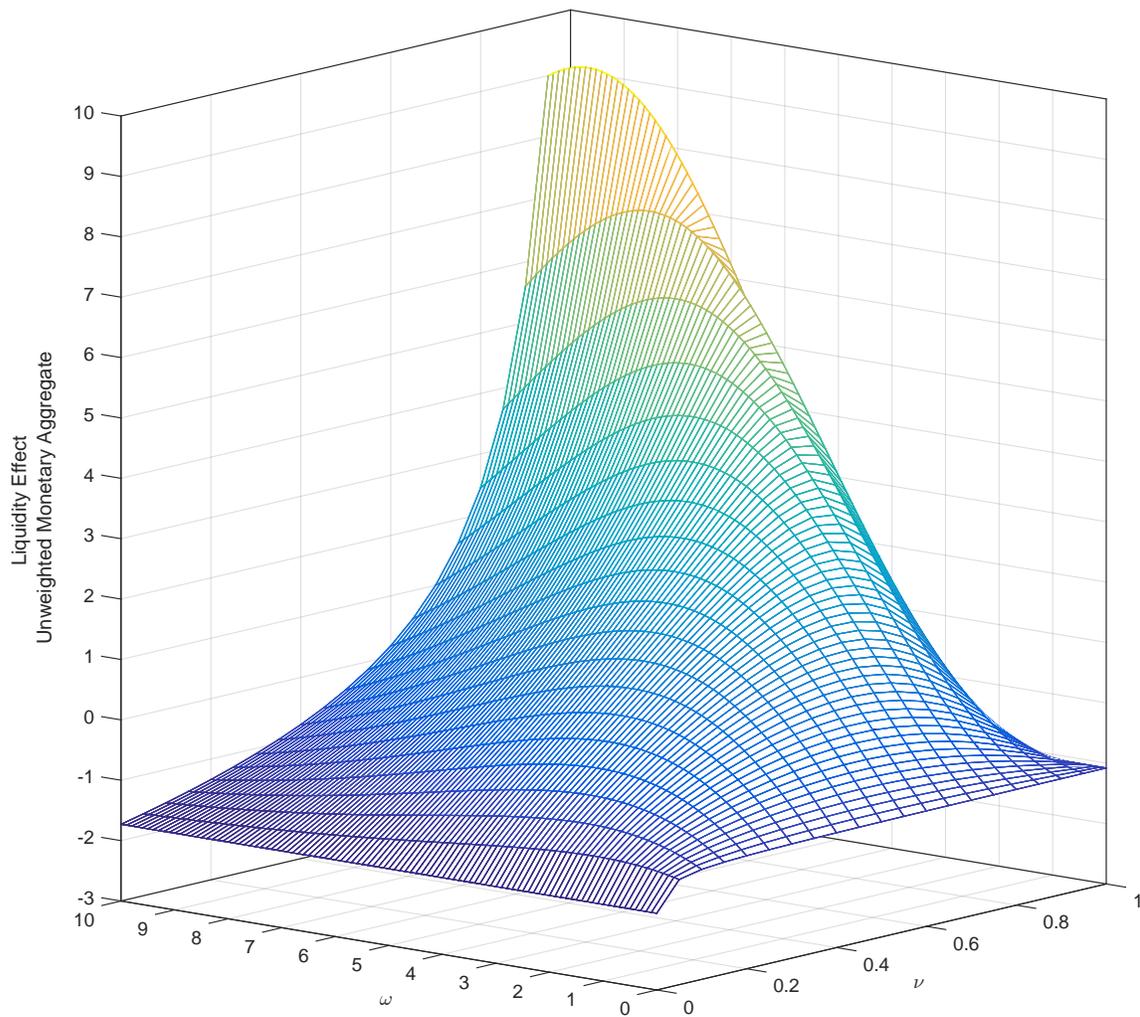


Figure 9: Unstable Liquidity Effects with an Unweighted Monetary Aggregate

This graph shows how the initial period response of an unweighted monetary aggregate (such as M2) to a contractionary monetary policy shock varies as a function of ν , which governs the weight placed on each asset in the CES aggregate, and ω , which is the elasticity of substitution between each asset. For all values of ν and ω , the interest-semi-elasticity of money demand is held fixed at $\eta = 1.9$.