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# Monetary Transmission in Money Markets: The Not-So-Elusive Missing Piece of the Puzzle

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## Abstract

We investigate the effects of U.S. monetary policy shocks from alternative policy indicators for a modern sample encompassing 1988-2020. The choice of the Wu and Xia (2016) shadow federal funds rate leads to persistent price puzzles. These puzzles arise despite inclusion of the *usual suspect* fixes such as commodity prices, federal funds futures and forward rate data. We find they occur at monthly and quarterly frequencies. We consider alternative indicators with the same broad monetary aggregates Keating et al. (2019) employed in their investigation of a historical sample. They provide a consistent resolution of the price puzzle and they do not require the *ad hoc* inclusion of commodity prices or futures data. This price puzzle correction is not a feature of our time-varying approach as it also obtains from constant parameter econometric estimation. Our analysis suggests monetary policy has transmitted substantial expansionary effects in money markets in the aftermath of the 2007 Financial Crisis and the decade that followed.

**Keywords:** Price puzzle, Divisia money, interest rate pass-through, time-varying-parameter vector autoregressions (TVP-VAR), time-varying-parameter factor-augmented vector autoregressions (TVP-FAVAR), unexpected monetary policy shocks.

**JEL classification codes:** E3, E4, E5

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## 1 Introduction

Important macroeconomic work in the 1960s by Brunner (1961), Brunner and Meltzer (1963), Friedman (1961), Friedman and Schwartz (1963), among others, changed economists' views regarding the efficacy of monetary policy and the importance of monetary aggregates (see Nelson (2003)).

In the years that followed, however, a New Keynesian “consensus” emerged that centered on de-emphasizing money in favor of a single nominal interest rate in order to link monetary policy and aggregate demand. While various candidate explanations date back to the Keynesian-Monetarist debates of the 1960s and early 1970s, two are particularly salient. First, standard textbook *IS* equations do not include a monetary aggregate but a single representative short-term real rate. Second, a once strong empirical relationship between the monetary aggregates, which the Federal Reserve produces, and economic activity began to break down in the 1980s. This erosion in the predictability of these monetary aggregates can be attributed primarily to an explosion of financial innovations and the mass adoption of new money markets, mutual funds, and other assets. Furthermore, changes in banking rules during the 1980s allowed banks to begin offering interest-earning demand deposits. Thus, in a data-rich monetary environment replete with a multitude of monetary instruments, a single relatively narrow measure of money balances, such as M2, loses its appeal.

Subsequently, identification of monetary policy shocks shifted attention to short-term interest rates. Even prior to the Taylor (1993) landmark paper, monetary economists had long recognized that central banks in practice treated the nominal interest rate—rather than the monetary aggregates—as their instrument of choice for the conduct of monetary policy. Interest-rate rules that responded to nominal variables in an appropriate manner could deliver low and stable inflation, even if these rules did not respond directly to movements in the stock of money.

There is extensive literature, some of which is outlined below, on how monetary policy shocks identified from innovations in the federal funds rate affect economic activity—with a number of candidate transmission mechanisms to explain the suggested effects. There has been comparatively less attention devoted to the effects on bank deposits and money markets from these shocks.

The 2007 Financial Crisis and the following protracted effective-lower-bound (ELB) period highlighted some shortcomings of the information content that the federal funds rate alone provides about monetary transmission. This opened the door to revisit the use of information from monetary aggregates in monetary models within the New Keynesian framework

(see examples in Belongia and Ireland (2015), Belongia and Ireland (2018), Keating et al. (2019), among others).

We estimate time-varying responses of economic activity, bank deposits, and various money markets to monetary policy shocks. We compare responses to policy shocks identified from innovations on a short-term rate to those identified from innovations in a monetary aggregate. As a preview of results, we outline three main findings. First, multiple VAR specifications with the (shadow) federal funds rate as an indicator of monetary policy yield unremitting price puzzles in a modern sample that begins in the late 1980s. These price puzzles persist even when including commodity prices, federal funds futures, or forward rate data. Second, every puzzle occurrence seems resolved when replacing the shadow rate with the broadest measure of a Divisia monetary aggregate (DM4) or the narrower Divisia measure (DM2). These Divisia specifications do not require the inclusion of commodity prices or futures/forward rate data for price puzzle resolution. Third, the transmission of these shocks onto money markets exhibits considerable time variation. Results show the transmission is magnified following the 2007 Financial Crisis with a larger magnitude response in money markets with lower liquidity properties such as time deposits, commercial paper, and treasuries.

The rest of the paper is organized as follows. Section 2 reviews the literature on policy identification from federal funds rate models. Section 3 provides background on monetary aggregates and Divisia money. Section 4 discusses our choice of data and our reasoning for considering a modern sample that begins in the late 1980s. Section 5 describes the econometric approach. Section 6 elaborates on the effects of expansionary policy shocks on the aggregate economy. Section 7 discusses the transmission into money markets from our identified shocks, and Section 8 concludes.

## **2 Background on Monetary Policy Identification from Short-Term Rate Indicators**

Ramey (2016) provides a comprehensive summary of the modern literature on the effects of monetary policy shocks. Most of that modern literature identifies these shocks from various instruments, innovations, or measures that generally exclude monetary aggregates. Her review begins with another foundational paper—also written in the *Handbook of Macroeconomics* nearly two decades prior—by Christiano et al. (1999). In a recursive specification that included GDP, price information, and monetary variables, Christiano et al. (1999) extracted monetary policy shocks as innovations in the federal funds rate. This paper was

transformational in that it yielded sensible responses and it seemed to resolve the *price puzzle* that was so common in the VAR literature at that time.<sup>1</sup> In a quarterly sample from 1965 to 1995, Christiano et al. (1999) reported some evidence of price puzzles in some of their specifications and concluded commodity prices were needed to resolve the puzzle.

A common explanation for specifications that yield counterintuitive responses to identified policy shocks is that the variables included in the VAR may not span the information set available to policymakers. The inclusion of commodity prices in a recursive VAR by Christiano et al. (1999) seemed to put to bed the issue of the price puzzle.<sup>2</sup> But in retrospect, commodity prices have been far from a panacea in price puzzle resolutions. Similar recursive (or block-recursive) approaches—before and since—have continued to report evidence of price puzzles (see Balke et al. (1994), Cushman and Zha (1997), Den Haan et al. (2007), and Den Haan et al. (2009), among others).

An alternative to augmenting the information set spanned in VARs with commodity prices has been to include the Federal Reserve’s Greenbook forecasts (see Romer and Romer (2004), Barth and Ramey (2002), and Coibion (2012), among others). Generally, the ability to resolve the price puzzle in these studies has been mixed. The inclusion of federal funds futures data has been another popular addition to the information set included in VARs (Kuttner (2001), Cochrane and Piazzesi (2002), Gürkaynak et al. (2005), Brissimis and Magginas (2006), Gertler and Karadi (2015), among others).

Yet another alternative to augmenting VAR specifications with prescribed variables is to add a broad number of factors in what Bernanke et al. (2005) called factor-augmented VARs (FAVARs). Two advantages of these models are (i) most applications remain proximate to Cholesky decompositions, which allow for direct comparability with benchmark recursive approaches (such as Christiano et al. (1999)), and (ii) these models are more likely to condition on pertinent information requisite for correct identification of the monetary policy shock.

Finally, there has been a relatively large literature (too numerous to fully reference) to address time variation in the transmission of monetary policy. Boivin et al. (2010) consider a benchmark recursive VAR, as well as a FAVAR, over a pre-1979Q3 period and a post-1984Q1 sample. They find the incidence of price puzzles are sensitive to changes in the VAR specification, and inclusion of commodity prices do not seem to ameliorate their puzzling responses. Barakchian and Crowe (2013) conduct a comprehensive investigation by replicating

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<sup>1</sup>The price puzzle—first coined by Eichenbaum (1992)—refers to the anomalous result in VAR models when the price level responds in the same direction to innovations in the short-term rate (the textbook response is that the price level should respond in the opposite direction to the short-term rate shock.)

<sup>2</sup>Christiano et al. (2010) show that this puzzle can in fact occur in DSGE models when businesses finance working capital by borrowing. A rise in the interest rate raises the cost of working capital and some firms adjust prices to higher costs.

multiple approaches advanced by earlier papers while splitting the U.S. sample in the late 1980s. In a sample spanning 1988-2008, they find a robust preponderance of price puzzles across several different specifications. We will be drawing from these latter approaches in considering various specifications of time-varying-parameter models.

### 3 Background on Monetary Aggregates

Even as central bankers moved to systematically expunge money out of monetary economics, Taylor clarified his own views on this issue at a conference in July 1992. While noting that “interest rates are likely to remain the preferred operating instrument of monetary policy,” Taylor (1992, p. 12) writes:

*“The evidence that the large swings in inflation are related to money growth indicates, however, that money should continue to play an important role in monetary policy formulation in the future.”* Taylor (1992)

In itself, the use of a Taylor rule for monetary policy analysis is neutral on the issue of the importance of monetary aggregates. Nelson (2003) points out that the fact that actual policy is well-characterized by a short-term interest rule (the federal funds rate) with no explicit money term does not preclude a role for monetary aggregates in the transmission of monetary policy.

A popular role for money in economic theories of the past was in the provision of a wealth effect. With exogenous increases in real money balances, the ensuing stimulative effect of raised real financial wealth should affect consumption or aggregate demand. However, work by Ireland (2001) shows empirically the role for money in the *IS* equation that arises from a non-separable utility is quantitatively negligible. Theory and evidence do not support the inclusion of a real balances term in the *IS* function. Nevertheless, a real balance effect is not the only operating mechanism at work. The importance of the money stock may not be through a direct real balance effect. Instead, money may act as an index of the gamut of (market and non-market) rates that are relevant for aggregate demand. “Real money balances capture the many channels of monetary transmission.” (Meltzer (2001, p. 125))

Friedman (1956) specified a money demand function, where a spectrum of yields enters the money demand function. This stands in contrast to the standard *LM* specification, in which the return on short-term nominal securities is the sole opportunity cost variable. A Friedman-style money demand function suggests that information content of money summarizes monetary conditions not contained in short-term interest rates. Friedman’s view

of money demand was comprehensive, including yields of financial instruments as well as returns on physical assets. The more direct observability of monetary aggregates presents an advantage.

Friedman’s was a disaggregated approach featuring the desirable property of heightened information content of money. The role for money arises from its ability to serve as an index of substitution effects, rather than wealth effects of monetary policy. In this paper, we take both of these notions seriously.

A complicating issue is that the standard monetary aggregates (e.g. M1 and M2) produced by the Federal Reserve—which are typically referred to in the literature as simple-sum aggregates—suffer from serious measurement error.<sup>3</sup> Instead, we take the following quote to heart and investigate other monetary aggregates known as Divisia created by William Barnett in the 1980s (see Barnett (1978) and Barnett (1980)).

*“Indeed, if pressed on this issue, virtually all monetary economists today would no doubt concede that the Divisia aggregates proposed by Barnett are both theoretically and empirically superior to their simple-sum counterparts.”* Belongia and Ireland (2014)

Friedman and Kuttner (1992) show evidence that the strong association between M2 and aggregate economic activity in the 1960s and 1970s all but disappeared in the 1980s. Many researchers have since concluded that money demand in the U.S. has been inherently unstable, thereby dooming any attempt to pin down money demand shocks.<sup>4</sup> However, Belongia (1996) and Hendrickson (2014) replicate portions of the Friedman and Kuttner (1992) model and conclude these allegations of a breakdown in the relationship are the consequence of measurement error in the monetary aggregate. In an investigation of the long-run relationship between nominal and real macroeconomic variables, Serletis and Gogas (2014) find evidence that Divisia monetary aggregates play an important role in money demand theory. Finally, in a recent paper, with a comprehensive investigation of Divisia aggregates, Belongia and Ireland (2019) show convincingly that money demand in the U.S. may be far more stable than previously thought.

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<sup>3</sup>This is because traditional measures of M1 and M2 simply add up the nominal value of all monetary assets in circulation while ignoring the fact that their components yield different flows of liquidity services and, in equilibrium, also differ in the opportunity (or user) costs that households and firms incur when they include them in their portfolios. Chrystal and MacDonald (1994) dubbed the essential message of Barnett’s work—that simply summing monetary assets imposes, unrealistically, that they are perfect substitutes for each other even when they render different yields—as the “Barnett Critique.” Belongia and Ireland (2014) emphasize the Barnett Critique is “...as relevant today as it was 30 years ago.”

<sup>4</sup>Many ascribe this as the last nail in the coffin for any consideration of monetary quantities in monetary models.

A theoretical construct consisting of a CES aggregate of currency and interest-bearing assets advanced by Belongia and Ireland (2012) provides an avenue for bringing back a broad measure of money into empirical monetary models. Their construct allows for a more direct comparison to the monetary aggregate used as the policy indicator in our VAR model.

Keating et al. (2019) show that a New Keynesian model can be closed with a specification of monetary policy that may be described by an interest rate feedback rule:

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

or by a money growth rule:

$$\mu_t = \bar{\rho} \mu_{t-1} + (1 - \bar{\rho})(\bar{\phi}_\pi \pi_t + \bar{\phi}_y (y_t - y_{t-1})) + \bar{\varepsilon}_t^{mp}, \quad (2)$$

where  $\mu_t = m_t - m_{t-1} + \pi_t$ ,  $m_t$  denotes the log of real money balances,  $\pi_t$  denotes inflation,  $\varepsilon_t^{mp}$  is an *i.i.d.* monetary policy shock,  $\rho$  denotes the degree of policy inertia, and the  $\phi$ 's are the standard stabilization coefficients in a Taylor-type rule.<sup>5</sup>

Keating et al. (2019) show that interest rate inertia is the most important determinant for whether monetary policy impulses under interest rate rules can be well approximated by money growth rules. Clarida et al. (1999) find evidence of inertia in monetary policy over the 1960-1979 sample (which we do not consider) as well as between 1979-1996 (which largely spans our own sample). Similarly, Orphanides (2001) finds substantial persistence in interest rate changes over the 1987-1994 period and Coibion et al. (2012) in the 1987-2006 sample.

The post-2008 period has also been marked by high inertia in the federal funds rate. Given that a range of evidence supports a high degree of persistence in estimated interest rate reaction functions in a modern sample, monetary aggregates hold promise as an alternative indicator of monetary policy in a VAR over the period we consider.

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<sup>5</sup>Our use of tildes on these parameters in 2 is to highlight these are analogous to (but distinct from) those in the interest rate rule 1.



## 4 Our Empirical Approach

We identify monetary policy shocks from innovations to two alternative indicators.<sup>6</sup> One is the traditional federal funds rate and the other is the broadest (M4) Divisia monetary aggregate available for the U.S.<sup>7</sup>

In what we consider the U.S. modern period, our monthly sample spans 1988:m10 to 2020:m2. We begin in the late 1980s for three reasons: (i) Perhaps as a result of the Monetary Control Act of 1980 and other banking deregulation efforts by Congress, financial markets experienced a boom in innovation, which led to a markedly different financial ecosystem. (ii) U.S. macroeconomic aggregates underwent a substantial shift in dynamics in the mid-1980s leading to the Great Moderation period. (iii) We follow a number of papers suggested earlier by augmenting our specifications with federal funds futures data. This data is only available since Oct. 1988.

We set out to estimate various time-varying specifications across a number of aggregate variables. For real output we consider: industrial production (IP), Chicago Fed national activity index (CFNAI), and the monthly measure of GDP from Macroeconomic Advisers (RGDP). For the price level we consider: the consumer price index (CPI), the personal consumption expenditure index (PCE) and their respective core counterparts (CPIcore and PCEcore); both indexes have received more attention than price deflators, particularly post 1985 (see Ramey (2016)). Two measures of commodity prices are considered: the Reuters Commodity Research Bureau (PCOM CRB) spot price and the International Monetary Fund global price index (PCOM IMF). We obtain these variables from HAVER and the Federal Reserve Bank of St. Louis database.

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<sup>6</sup>Our analysis is grounded on the nuanced, yet critical, difference between what constitutes an *indicator*—separate from what constitutes an *instrument*—of monetary policy. We eschew any characterization of any single variable to act as the instrument of monetary policy for our sample. Our analysis is more in line with Christiano et al. (1999), who consider competing specifications between the federal funds rate, simple-sum M2, or NBR, as possible indicators of monetary policy with samples that end in the mid 1990s. And it is more closely aligned with Keating et al. (2019) with a competition between Divisia M4 and the shadow federal funds rate for a sample that ends in 2017. An alternative would be to consider the joint usefulness of rates and money as indicators. For example, in a comprehensive treatment of the systematic component of monetary policy, Arias et al. (2019) interpret one of their restriction strategies as signifying that both the fed funds rate and the money supply respond to Fed actions, and that both indicators are important in describing the effects of monetary policy on the economy. In the post-2008 period their analysis would involve augmenting the federal funds rate with a shadow rate as we do in this paper. Of course, other indicators could prove useful for the ELB period. Smith and Valcarcel (2021) consider weekly movements in total reserves as a plausible indicator of policy for the 2017-2019 period.

<sup>7</sup>We also extend our consideration to the narrower Divisia M2 aggregate. Conclusions remain qualitatively consistent although there are quantitative differences in the price response to the broader and the narrower aggregate post 2008.

We employ the Wu and Xia (2016) shadow federal funds rate to substitute for the federal funds rate during the ELB period. We obtain that rate from the Federal Reserve Bank of Atlanta. Using the shadow rate allows us to extend our analysis through the aftermath of the U.S. financial crisis. However, the benefits of shadow rates are far from settled. For example, Keating et al. (2019) show that the incidence of the price puzzle is exacerbated in SVARS that include various shadow prices for a modern sample. And Krippner (2020) highlights that inflation outcomes post 2008 may be sensitive to shadow rate selection.

All monetary data is obtained from the Center for Financial Stability (CFS), which makes available the Divisia monetary aggregates as well as their components. Divisia M1 (DM1) includes currency (C), demand deposits (DD), other checkable deposits (OCDs) at commercial banks, and OCDs at thrift institutions. Divisia M2 (DM2) adds the following components to DM1: savings deposits (SDs) at commercial banks, SDs at thrift institutions, retail money-market funds (RMMFs), small time deposits (STDs) at commercial banks, and STDs at thrifts. At 15 components, Divisia M4 (DM4) is the broadest monetary aggregate currently available in the U.S. It adds the following five monetary instruments to DM2: institutional money-market funds (IMMFs), large time deposits (LTDs), repurchase agreements (REPOs), commercial paper (CP), and 3-month T-bills.<sup>8</sup>

## 5 Econometric Framework

Most of our analysis stems from time-varying-parameter vector autoregressions (TVP-VAR). We begin our investigation of various aggregate responses with a class of models outlined by Primiceri (2005). Consider the following VAR process:

$$\theta_t(L)x_t = e_t, \tag{3}$$

where  $x_t$  is an  $n$ -vector of endogenous time  $t$  variables;  $\theta_t = I_n - \theta_{1t}L - \dots - \theta_{pt}L^p$  is a  $p$ -th order lag polynomial<sup>9</sup> in which each  $\theta$  is a time-varying matrix of autoregressive coefficients and  $e_t$  is an  $n$ -vector of mean-zero VAR innovations. We allow for time variation in the variances of the shocks in the VAR model, all of which are summarized in the time-varying covariance matrix  $R_t$ . Let  $\Theta_t$  represent the stacked vector of all coefficients in  $\theta_t(L)$ , and assume it evolves according to:

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<sup>8</sup>All variables are log transformed except the interest rates and the CFNAI.

<sup>9</sup>We iterate over a relatively large number of variables within our time-varying investigation. For consistency across these we fix the lag length to three, even when in some cases the AIC criterion chose a different lag for a particular specification.

$$\Theta_t = \Theta_{t-1} + u_t, \quad (4)$$

where  $u_t$  is a Gaussian white noise process with zero mean and constant covariance  $Q$ , independent of  $e_t$  at all leads and lags. Potential methods to decompose the covariance matrix in this type of VAR include Kim et al. (1998), Jacquier et al. (2002), and Del Negro and Primiceri (2015) and are comprehensively cataloged in Cogley and Sargent (2005) and Primiceri (2005). We leave details on our chosen decomposition for the appendix.

We assume the underlying structural shocks ( $\epsilon_t$ ) are a time-varying transformation of the reduced-form innovations ( $e_t$ ) as follows:

$$e_t = P_t \epsilon_t \quad \forall t, \quad (5)$$

where  $P_t$  is a non-singular matrix that satisfies  $P_t P_t' = R_t$ . Given this mapping, changes in the contributions of different structural shocks to the volatility in innovations in the underlying variables of interest are captured by changes in  $P_t$ . We produce time-varying impulse responses contingent on the estimation of  $R_t$  and a recursive mapping structure for  $P_t$ .

Our TVP-VAR analysis covers a modern sample beginning in 1988 for the *usual suspect* macroeconomic variables typically included in investigations of monetary transmission, such as Christiano et al. (1999). Our investigation subsequently extends to the responses of non-aggregate money markets in a modern sample where diversification in these markets has likely become more prevalent. While we contend our TVP-VAR may serve us well for the lower-dimensional aggregate analysis, we look to a different approach for higher-dimension specifications for two reasons. First, the curse of dimensionality on the class of TVP-VARs we consider may be particularly virulent as we add more and more monetary assets into the mix.<sup>10</sup> Second, the class of TVP-VARs we employ for the aggregate investigation typically requires a relatively lengthy training sample where a standard VAR is estimated to initialize the Gibbs sampler. Therefore, the estimates that ensue from our TVP-VAR for a modern sample are contingent on data that predates 1988.<sup>11</sup>

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<sup>10</sup>Carriero et al. (2019) constitute an important improvement in this regard. Their recursive method naturally requires a full set of identification restrictions for the variables in the system. However, we do not follow their approach because we choose not to impose identifying restriction on the monetary assets. Instead, we want to consider them as free factors augmenting the structural VAR.

<sup>11</sup>We implement a 240-month training sample for some of our aggregate TVP-VAR analysis. Given that availability of some of our data begins in 1988, implementing a similar initialization for specifications that contain information available only since 1988 would yield results for too selective a sample, beginning in 2008—a period when a structural break in monetary transmission likely transpired.

As an alternative methodology, we opt for the time-varying-parameter factor-augmented approach (TVP-FAVAR) of Koop and Korobilis (2014). Initialization of their dual conditional linear filtering/smoothing algorithm requires no sample training. This provides the advantage that responses for a given period are not conditional on information from earlier samples. Thus, we are able to produce time-varying responses for our modern sample (1988 - 2020) without the need to condition on an information set from outside our sample of interest. Another advantage of this method is that it allows us to increase the dimension of the VAR, in a computationally inexpensive way (relative to the TVP-VAR), by augmenting it with (monetary) factors, which facilitates an investigation of the dynamic responses of non-aggregate money markets.

Let  $x_t$  be an  $n_1 \times 1$  vector of macroeconomic series and  $z_t$  be an  $n_2 \times 1$  vector of monetary variables of interest. The variables in  $z_t$  presumably provide information content about monetary flows that a central bank may find useful. Similar set-ups where monetary variables were included in the information block of a standard VAR were advanced by Christiano et al. (1999) for simple-sum and Keating et al. (2019) for Divisia. If variables in  $z_t$  share a common feature, then we assume it can be captured by a latent factor  $f_t$  that could then be used to augment the VAR of order  $p$  for  $x_t$  as follows:

$$\begin{bmatrix} x_t \\ f_t \end{bmatrix} = c_t + A_{t,1} \begin{bmatrix} x_{t-1} \\ f_{t-1} \end{bmatrix} + \dots + A_{t,p} \begin{bmatrix} x_{t-p} \\ f_{t-p} \end{bmatrix} + \omega_t \quad (6)$$

where  $c_t$  is an intercept,  $[A_{t,1}, \dots, A_{t,p}]$  are time-varying VAR coefficients, and  $\omega_t$  is a mean-zero Gaussian disturbance term with time-varying covariance  $Q_t^f$ . The vector  $f_t$  contains information common to monetary variables and relates  $x_t$  and  $z_t$  as follows:

$$z_t = \lambda_t^x x_t + \lambda_t^f f_t + u_t \quad (7)$$

where  $\lambda_t^x$  and  $\lambda_t^f$  are regression coefficients and  $u_t$  is a vector of idiosyncratic shocks with diagonal time-varying covariance matrix  $V_t^f$ . Equation (7) allows for the extraction of a latent factor in  $z_t$ , and equation (6) models the dynamic interactions of  $f_t$  with macroeconomic variables included in  $x_t$  as in Bernanke et al. (2005).<sup>12</sup>

Banerjee et al. (2006) show there is substantial time variation in the loadings and covariances of factor models that use both financial and macroeconomic data. This highlights the

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<sup>12</sup>One point worth highlighting is that Bernanke et al. (2005) show a price puzzle ensuing from a shock in the federal funds rate. Their specification across variables and factors is triangular with the indicator of monetary policy ordered last. Importantly, contrasting that approach, we order our monetary assets after the policy indicator (shadow rate or Divisia M) and we do not restrict the monetary assets not to respond to shocks in the indicator within the month. Therefore, ours is a block recursive approach along the lines of Keating et al. (2019).

importance of allowing for time variation in Bernanke et al. (2005)-type FAVARs. Thus, the specification given by (6) - (7) provides for a flexible model as it allows every parameter to take on a different value each period  $t$ .

However, this specification requires a stance on the evolution of the parameters over time. The loading vectors  $\lambda_t = ((\lambda_t^x)', (\lambda_t^f)')'$  and VAR coefficients  $\beta_t = (c_t', \text{vec}(A_{t,1})', \dots, \text{vec}(A_{t,p})')'$  evolve according to the following multivariate laws of motion:

$$\begin{aligned}\lambda_t &= \lambda_{t-1} + \nu_t \\ \beta_t &= \beta_{t-1} + \eta_t\end{aligned}\tag{8}$$

where  $\nu_t \sim N(0, W_t^\lambda)$  and  $\eta_t \sim N(0, W_t^\beta)$  and  $\omega_t \perp u_t \perp \nu_t \perp \eta_t$ . We leave details of the approach for the appendix.

Overall our identification strategy, both for the TVP-VAR and the TVP-FAVAR, allows for the policy indicator to react to a similar set of variables to—and it is thus comparable to the Cholesky decompositions in—Keating et al. (2019).

## 6 The Dynamic Effects of Shocks to Policy Indicators in a Modern Sample

We consider shocks consistent with an exogenous monetary policy expansion across all our specifications. Our time-varying structural model allows for three-dimensional point estimates—the response of a given variable to a given shock at each point in time and at each horizon.<sup>13</sup>

We begin by reporting responses from the TVP-VAR for a sample that spans Oct. 1988 to Feb. 2020. And, subsequently, we report responses from the TVP-FAVAR. We begin our investigation at the aggregate level with the most parsimonious specification in (3) where  $x_t = [GDP_t, P_t, R_t]'$ . We order the Macro Advisers monthly measure of real GDP first, the PCE index second, and the policy indicator third.

Figure 1 shows the (PCE) price level time-varying responses to an expansionary shock in the selected indicator. Each panel (a, b, c) in this figure contains four responses. The northwest and northeast charts in each panel correspond to the third-month and the 18th-month horizon responses, respectively, for the selected indicator over time. These constitute something of a short-to-medium run responses. The southwest and southeast responses show

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<sup>13</sup>Averaging our responses across all sample periods for each horizon would render responses reminiscent of a standard (constant parameter) approach. We conducted this analysis but we do not report results to save space. In addition, we estimated a counterpart constant parameter VAR to each of our time-varying parameter specifications. The results of both these pursuits were qualitatively robust to the time-varying responses we report. Our conclusions of overarching price puzzles in short-term rate specifications and resolution with Divisia specifications remain.

a longer run dynamic with the 30th- and 60th-month horizons, respectively. The top panel (a) shows that reductions in the Wu and Xia (2016) shadow federal funds rate yield (puzzling) reductions in the PCE level. This price puzzle seems to emanate quickly, already statistically apparent by the third month post shock. It is also quite persistent where the magnitude of the response seems to diminish slowly. In stark contrast, the middle panel (b) shows no statistical response of the price level to a shock in Divisia M4 in the third month post shock. Given that our zero restriction binds only on impact, on the first month, this response is evocative of the New Keynesian prediction of gradual price adjustment. Subsequently, the price dynamics at longer horizons all exhibit the correct qualitative response. Finally, the bottom panel (c) shows price responses to a shock in Divisia M2. Qualitatively, the responses are identical. There are some quantitative differences, however. The 68% confidence bounds are relatively tighter in the responses to the narrower aggregate. The point estimates suggest more muted price level responses to Divisa M2, particularly after the 2008 period. A possible explanation for these quantitative differences is that the broader aggregate (Divisia M4) captures a wider array of monetary shocks that eventually pass through to prices.

We now turn the three-variable specification onto the TVP-FAVAR approach. We make two changes. First, we cycle through a larger set of variables for output and prices. Second, we average the responses over the first 24-month horizon for each period in our sample. This gives us a general picture over the short and medium run. Finally, unlike the TVP-VAR responses of Figure 1, which were trained on data prior to 1988, the TVP-FAVAR responses need no similar conditioning. Figure 2 shows two sets of responses. Panel (a) shows a puzzlingly contractionary response of the PCE to an expansionary Wu and Xia (2016) shadow federal funds rate shock. Panel (b) shows a Divisia M4 specification is, again, void of the price puzzle.

As mentioned in Section 2, Christiano et al. (1999) showed that including commodity prices helped resolve the price puzzle in their federal funds rate specifications in a sample spanning 1965-1995. And commodity prices have been advocated by many as an appropriate proxy for the information content the Fed may have about expected inflation. We extend our specification  $x_t = [GDP_t, P_t, PCom_t, R_t]'$  to include the Reuters Commodity Research Bureau (PCOM CRB) spot price.<sup>14</sup> Our analysis shows commodity prices do not help resolve the price puzzle in a modern sample. This result is consistent with findings in Barakchian and Crowe (2013). Finally, Brissimis and Magginas (2006) suggest the inclusion of federal funds futures rates or forward rates in an otherwise recursive approach may also help attenuate or solve the price puzzle for historical samples that include the 1960s and 1970s. Thus,

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<sup>14</sup>Our conclusions are not sensitive to replacing this commodity price index with the IMF's global index. Figures from the 4-variable specification are omitted to save space but are available upon request.

we extend our analysis to a 5-variable specification  $x_t = [GDP_t, P_t, PCom_t, R_t, fut_t]'$ . We find the price puzzle remains even when adding the rate on the 30-day federal funds futures contract.<sup>15</sup>

Figures 3 —5 collate various price responses from our investigation. Figure 3 combines responses from 23 different iterations of the federal funds rate model ranging between the three-variable and the five-variable specifications. They comprise industrial production, CFNAI, or real GDP, for output; PCE, CPI, and their core measures for the price level; two measures of commodity prices, and data on federal funds rates futures. The confidence bounds are the upper and lower envelopes (the maximum and minimum at each point in time) of individual responses. This chart indicates some time variation in the incidence of the price puzzle but, overall, it is generally pervasive in a modern sample.

Conversely, Figure 4 shows the counterpart responses where, for each iteration, Divisia M4 replaces the Wu and Xia (2016) shadow federal funds as the policy indicator. It shows little evidence of price puzzles, even in specifications absent commodity prices or federal funds futures that have been suggested as “sine qua non” for resolutions in federal funds models. The magnitude of these 24-month-horizon average responses from the TVP-FAVAR are generally in the neighborhood of the 18th-month responses from the TVP-VAR reported in Figure 1—particularly in the post-2008 sample.<sup>16</sup>

Figure 5 repeats all the previous specifications while replacing Divisia M4 with the narrower Divisia M2. The responses, again, show sensible price level dynamics. The post-2008 price responses are generally more muted than those of the Divisia M4 specification. This is consistent with our findings from the TVP-VAR approach. Returning to our TVP-VAR specification we report responses for selected periods across the Wu and Xia (2016) shadow federal funds rate, the Divisia M4, and the Divisia M2 specifications. Figure 6 essentially *slices* the TVP-VAR responses (some of which are reported in Figure 1) for December 2008, November 2010, and September 2012. These months roughly correspond to the respective starts of the three quantitative easing periods (QE1, QE2, and QE3). Each of these charts shows the point estimates for the three selected periods. The confidence bounds are constructed from the lower and upper envelopes of the 68% confidence bounds from the

<sup>15</sup>Following Brissimis and Magginas (2006) we produced a forward rate from the daily spread between (two times) the overnight repo rate at  $t-1$  and the effective federal funds rate at  $t$ . Our results were largely unchanged from replacing the federal funds futures rate with this forward rate or the overnight repo rate. All these results are available upon request.

<sup>16</sup>However, the magnitudes of the estimated price responses early in the sample (late 1980s) tend to be somewhat larger for the TVP-FAVAR than for the TVP-VAR. This could be explained by the fact that those point estimates are conditioned on a relatively large training sample for TVP-VAR, whereas the TVP-FAVAR responses are constructed strictly from data that begins in 1988. The overall similarity in the responses from these ostensibly different approaches lends support for our conclusions.

respective responses. Here again, the Wu and Xia (2016) shadow federal funds rate yields a price puzzle for the three periods, which contrasts the Divisia M4 and Divisia M2 responses. The output responses across the three specifications are quite similar over the three periods. However, the magnitudes of the price level responses are substantially larger in the QE1 and QE2 periods than at the onset of the effective lower bound period.

Overall, our results show little evidence of a price puzzle from Divisia specifications, even when we remove commodity prices. They suggest that Divisia money does the heavy lifting in the resolution of the puzzle. A similar conclusion was reached by Keating et al. (2014) and Keating et al. (2019) for a historical sample (1960s to 2010s) and a Christiano et al. (1999)-type recursive identification. However, those papers found that commodity prices ameliorated the incidence of price puzzles until the onset of the Great Recession; whereas our results suggest that, for a modern sample, the federal funds rate specifications seem to be fraught with price puzzles. This is consistent with findings in Barakchian and Crowe (2013) and Ramey (2016).

## 7 Policy Transmission and Money Markets

As discussed in previous sections, a popular approach to establishing parsimonious monetary VAR specifications has typically involved appending some measure of money following a standard inclusion of a price level, output, and a short-term interest rate.

We take as an example a specification similar to Keating (1992) with  $x_t$  in equation (6) comprising the log level of the PCE index and industrial production as well as the Wu and Xia (2016) shadow rate. Three important distinctions in our specification are worth highlighting. First, we consider a monthly modern sample, whereas Keating (1992) investigated a historical quarterly sample. Second, ours is a time-varying parameter approach, while Keating (1992) was a standard VAR. Third, and most important, Keating (1992) includes a fourth (monetary) single variable—simple-sum aggregate M2—in the VAR.

In our view, including simple-sum aggregates is misguided. Therefore, rather than adding a monetary variable in fourth place in the VAR, we leave the main VAR component “as is” with price, output, and interest rates. And augment it with a factor ( $z_t$ ) component in equation (7) that includes various deposits and money markets represented in the monetary aggregates M1 and M2 produced by the Federal Reserve, along with various components of DM4 produced by the CFS. All responses of these money markets in ( $z_t$ ) are left completely unrestricted.<sup>17</sup>

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<sup>17</sup>We augment our three-variable VAR with a block ( $z_t$ ) that includes: currency (c), demand deposits (DD), other checkable deposits (OCDs) at commercial banks, and OCDs at thrift institutions—all of which



Figure 7 shows time-varying responses to an expansionary policy shock in an interest rate specification—PCE, industrial production and the (shadow) federal funds in the macroeconomic  $x_t$  block and all 14 money markets described above in the factor ( $z_t$ ) block. Given our comprehensive analysis of the aggregate responses in Section 6, and to save space, we omit the macroeconomic responses and focus on the responses of the money markets reflected in the ( $z_t$ ) block.

First, the responses exhibit considerable time variation. The magnitude response of the shadow federal funds rate to its own shock following 2008 (in panel a) is consistent with the massive expansionary policy stance of the Federal Reserve in the aftermath of the financial crisis and the decade that followed. This expansionary shock seems to counter-intuitively reduce balances of relatively liquid deposits in currency, demand deposits, and OCDs. Panel (b) shows that responses of savings, both at commercial banks and thrifts, are similarly puzzling—and of similar magnitudes to DDs—in the aftermath of the Financial Crisis. These contrast with the relatively muted RMMFs and STDs at banks. Beginning around 2011, STDs at thrifts respond positively to an expansionary MP.

Finally, Panel (c) shows that, while the LTD and CP responses are more muted, the magnitudes of responses in IMMFs and particular repos and T-bills, increased dramatically in the decade that followed the Financial Crisis of 2007. The magnitude of the responses to monetary policy action across these various assets has experienced some degree of time variation, with larger magnitude responses occurring after 2008. Notably, the direction of most of the money market responses to the shadow federal funds rate is puzzling—balances seem to contract in response to the expansionary shock. However, these conclusions should be tempered by a severe price puzzle, along with a more moderate output puzzle, that this specification yields.

Next, we replace the shadow federal funds rate with DM4 in the specification above—which otherwise remains identical in all other respects (variable/block ordering, number of lags, sample size). Figure 8 shows the time-varying responses to an expansionary monetary shock by way of an exogenous increase in Divisia money balances. Two features of these responses, relative to those of the rate specification, are particularly salient. First, the direction of the responses here seems to be more sensible in that many of these money/deposit markets increase following an expansionary shock. Second, in many cases, the magnitude of the re-

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are included in the headline M1 measure produced by the Federal Reserve. We extend ( $x_t$ ) with deposits included in M2 (but excluded from M1), namely: savings deposits (SDs) at commercial banks, SDs at thrift institutions, retail money-market funds (RMMFs), small time deposits (STDs) at commercial banks, and STDs at thrifts. Finally, we consider other money markets that are excluded from M2, but included in the broadest money measure produced by the CFS, namely: institutional money-market funds (IMMFs), large time deposits (LTDs), repurchase agreements (REPOs), commercial paper (CP), and 3-month T-bills (TB3).

sponses is substantially higher in the decade that follows the Financial Crisis of 2007. This is largely consistent with the massively expansionary stance of monetary policy at that time.

Panel (a) of Figure 8 shows the currency, DD, and OCDs responses are generally of similar magnitude. The direction of these responses seems sensible for all but OCDs at banks during most of the 1990s. Panel (b) shows that, after 2008, the savings response is large and of a higher magnitude than those of more liquid assets. The relatively lower magnitude of the currency response at the end of the sample is consistent with a reduction in the currency-to-deposit ratio of households following the 2008 Recession—which was more than offset by the substantial increase in the reserves-to-deposits ratio that resulted in a crash of the money multiplier over this period (see Hubbard et al. (2014)). The comparatively larger savings response is broadly consistent with an increase in the personal saving rate in the U.S. during the period. While in the 1990s, the RMMFs response is much lower—turning negative, perhaps as a function of a comparatively lower degree of participation in those markets then. RMMFs also exhibit a markedly increased response after 2008, lower than (but comparable with) the savings response. Conversely, substantially more moderate responses of STDs over the whole sample give way to a counter-intuitively negative response of STDs at thrifts.

Panel (c) in Figure 8 shows that responses in less liquid assets, such as IMMFs, LTDs, and T-bills, follow similar patterns to other assets reflected in M1 and M2 with larger magnitudes than currency and DDs and more comparable, in size, with savings. Comparing these responses to those of the shadow rate specification in Figure 7(c) suggests that IMMFs, LTDs, commercial paper—which has been typically used by firms for the near-term financing of operating expenses (e.g. payroll)—and repurchase agreements not only respond counter-intuitively to short-term rate shocks, but the magnitudes are substantially more muted, particularly in the period following 2007. Conversely, the magnitude of money market responses to DM4 shocks proves to be quite large in the aftermath of the Financial Crisis and the decade that followed. Consistent with the massive increase in holdings of Treasuries by the Fed during this period, the magnitude of the response of T-bills to the shadow rate or the DM4 specification is ample in both cases. However, the DM4 specification would suggest an expansionary response in this market, while the shadow rate specification shows a glaring and implausible contractionary effect in T-bills.

## 8 Concluding Remarks

There has been a long and established literature on the identification of monetary policy shocks from fluctuations in the federal funds rate. This focus on the nominal short-term rate has relied on two main pillars. First, a rich theoretical framework posits there is higher signal

power in the changing of an inter-banking rate—as opposed to the management of monetary balances. This is particularly relevant in a modern environment replete with a wealth of money and financial markets that were not generally available before 1980. Second, in an ecosystem characterized by scarcity in bank reserves, a neutral federal funds rate—with enough room for material movement in both directions—could exert meaningful effects on macroeconomic activity.<sup>18</sup>

However, as highlighted by a relatively large literature outlined in earlier sections, matching the theoretical predictions with the empirical evidence has been a difficult proposition. This is best illustrated by the repeated and endemic finding of price puzzles by many researchers over multiple periods, specifications, and empirical approaches.

Another strand of comparatively minute—but growing—literature investigates the relationship between monetary policy and properly measured monetary aggregates known as Divisia (DM) indices. Much of the recent empirical work in this area has focused on the effects of Divisia at various levels of aggregation, with DM2 receiving perhaps the most interest, and the broadest DM4 measure garnering increasing consideration of late. Most of this work has centered on understanding the macroeconomic effects of these shocks, the identification of money demand, or quantitative monetary effects in the aggregate. There has been far less attention devoted to understanding transmission to disaggregated monetary quantities. This paper constitutes a first attempt to compare and contrast the transmission effects of the shadow federal funds rates vs. Divisia aggregates on distinct money markets.

We document robust evidence of price puzzles in multiple variants of a shadow rate VAR specification. These price puzzles remain despite the inclusion of a commodity price variable; which was advocated by Christiano et al. (1999) and others as an *ad hoc* solution to the price puzzle. We also find federal funds future or forward rate data do not help resolve the puzzle. We observe considerable time variation in the transmission of shocks in the short-term rate onto deposits and money markets included in M1, M2, and broader aggregates. There too, the responses are puzzlingly contractionary to an expansionary shock.

In stark contrast are the responses to shocks in Divisia money. First, replacing the shadow federal funds rate with the log of DM4, or DM2, for every specification we considered elicits sensible responses of output and the price level. Second, these sensible macroeconomic responses remain even when excluding commodity prices or federal funds futures/forward rates information. This suggests that Divisia does the heavy lifting in the resolution of

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<sup>18</sup>The Volcker Disinflation of the early 1980s and the Bernanke Fed’s response to the Financial Crisis of 2007 are often brought up by market watchers as examples that short-term rate management can deliver a stabilizing influence on the economy. Although it could be argued that the stabilizing influence of the Volcker event was overt for inflation; whereas the stabilizing influence of the Bernanke response for the unemployment rate requires some counterfactual thinking.

the puzzle(s). Third, whereas the money market responses to short-term rate shocks look implausible, the responses to shocks in DM4 generally have the correct sign. Furthermore, the post-2008 period seems to exert a substantial change in the magnitude of the responses of many monetary assets. We find an increased magnitude of the response in savings that outstrips those of currency or demand deposits. This could be suggestive of a *flight-to-safety* effect for households. The post-2008 responses of less liquid assets such as IMMFS, LTDs, REPOS, CP, and T-bills are larger than currency and deposits—which typically yield transactional services—and more commensurate with the responses of savings. This suggests a similar flight-to-safety effect by firms accompanied the vast expansion of reserves through the large asset purchases (LSAPs) and quantitative easing (QE) episodes that occurred during this period.

Given we consider a post-1980 modern period, it is likely that higher degrees of fine-tuning and more gradual management of the short-term interest rate by the Federal Reserve has led to higher degrees of anticipation of the stance of monetary policy by financial markets. While the 2007 Financial Crisis brought out an aggressive Federal Reserve quantitative response—and our results imply it had important effects on money markets—a concerted effort on minimizing uncertainty associated with the policy response (e.g., forward guidance and large-scale asset purchases) would reduce the effect of unanticipated movements in the federal funds rate. This could explain the problematic results we obtain from our short-term rate specifications, both regarding the aggregate macroeconomic response and the implausible transmission to money markets. Various specifications of a Divisia monetary aggregate as a policy indicator (not necessarily an instrument) elicits responses that in every case seem more plausible.

Importantly, while we find a time-varying investigation sheds light on possible nonlinearities in monetary transmission, our results are not a feature of the estimation technique we employ. Constant-parameter counterparts to our various VAR specifications yield similar conclusions—where the Divisia specifications perform far better in the resolution of price or monetary transmission puzzles. Instead, our selection of a modern sample that begins in the late 1980s seems to be particularly virulent for any resolution of a price puzzle in various federal funds rate specifications.

There is wide agreement on a massively accommodative stance of U.S. monetary policy occurring in the decade following the 2007 Financial Crisis. We find a monetary policy indicator based on a short-term nominal interbank rate, at best, imperfectly captures this important dynamic. Our analysis suggests the federal funds rate might have lost some of its relevance in a modern sample. What has changed? The Federal Reserve is more forward-looking than it once was. Transparency about its fine tuning of lending rates in reserve

markets has made it more difficult to “shock” financial markets. Historically, the neutral federal funds rate had ample room for upward and downward movement, and it has likely become much lower in recent decades. The interbank system has transitioned from scarcity to an overabundance of reserves. Our results suggest that in an environment where a key short-term rate is quite persistent and very low, putting money back in monetary models offers a viable alternative. It might just be the missing piece of the puzzle.

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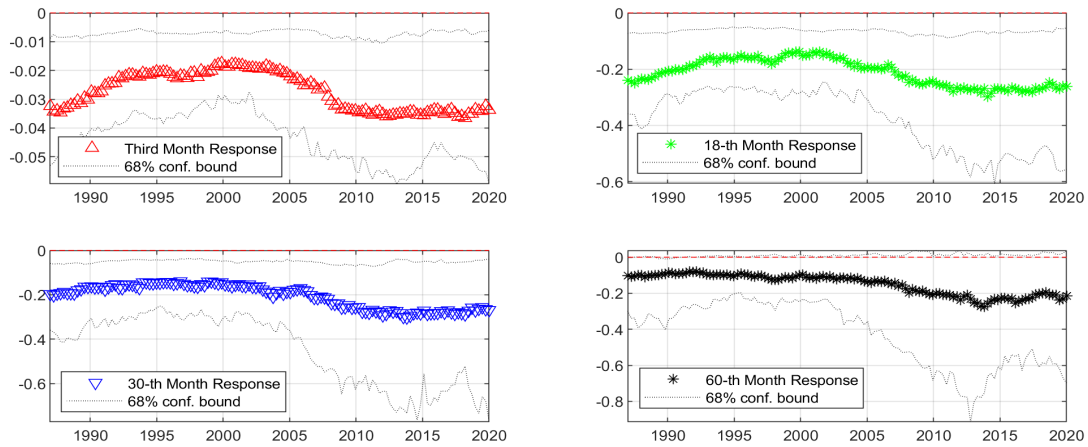


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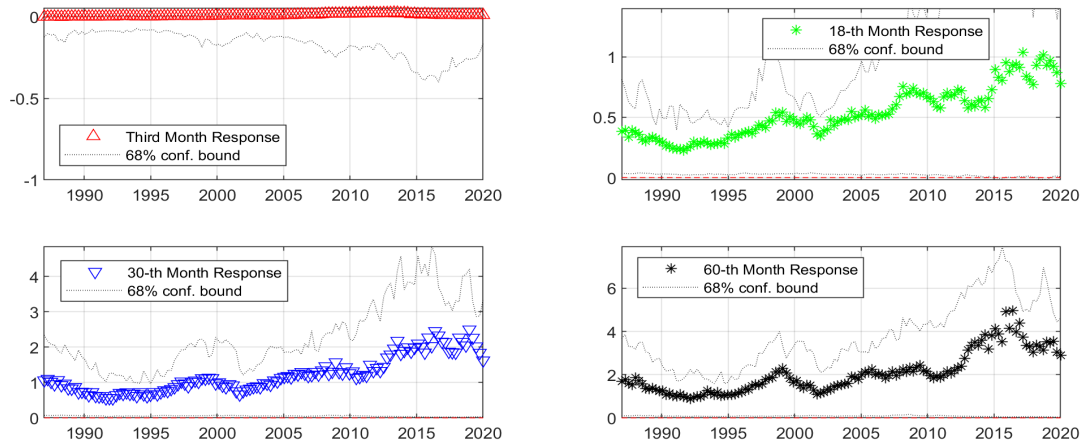
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(a) *One Standard Deviation Reduction in the Shadow Federal Funds Rate*



(b) *One Standard Deviation Increase in Divisia  $M_4$*



(c) *One Standard Deviation Increase in Divisia  $M_2$*

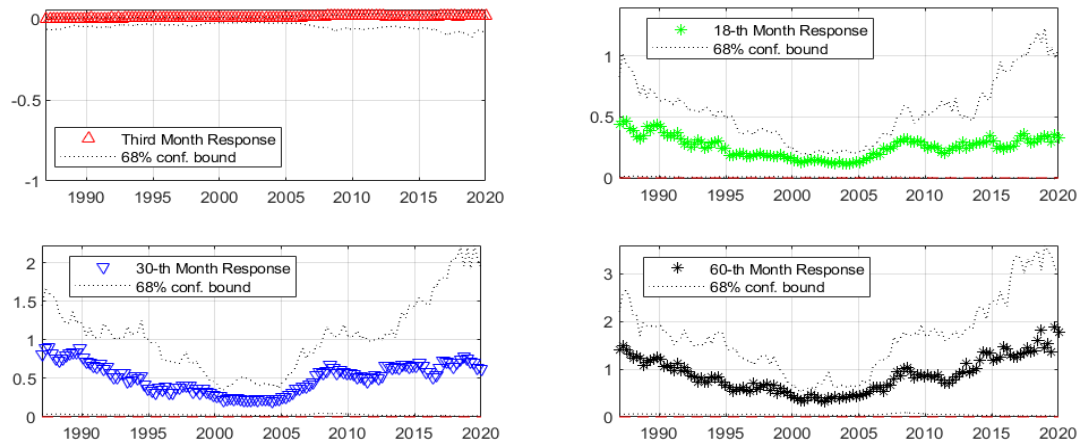


Figure 1: Price Level Responses to an Expansionary Shock (TVP-VAR)

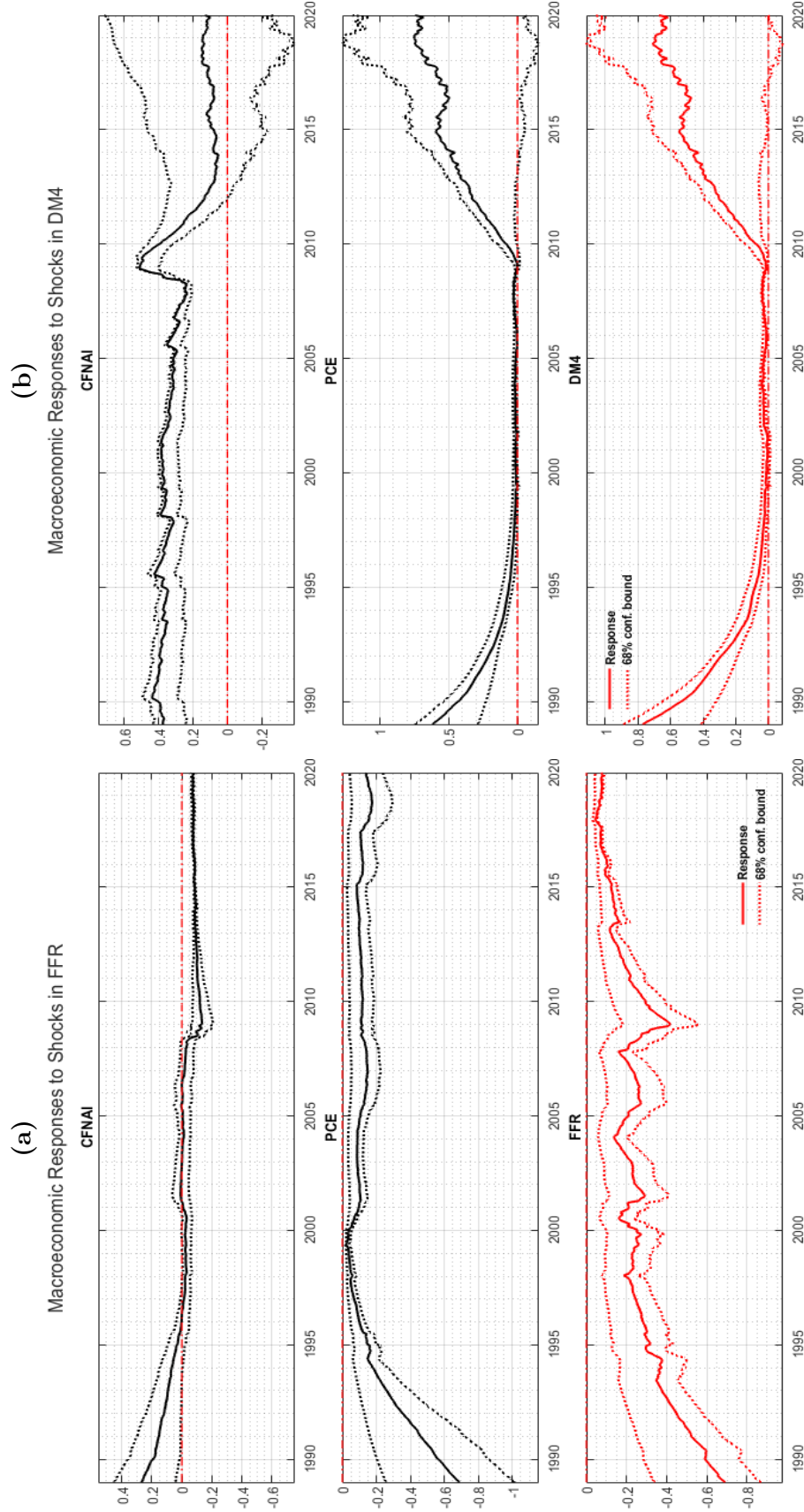
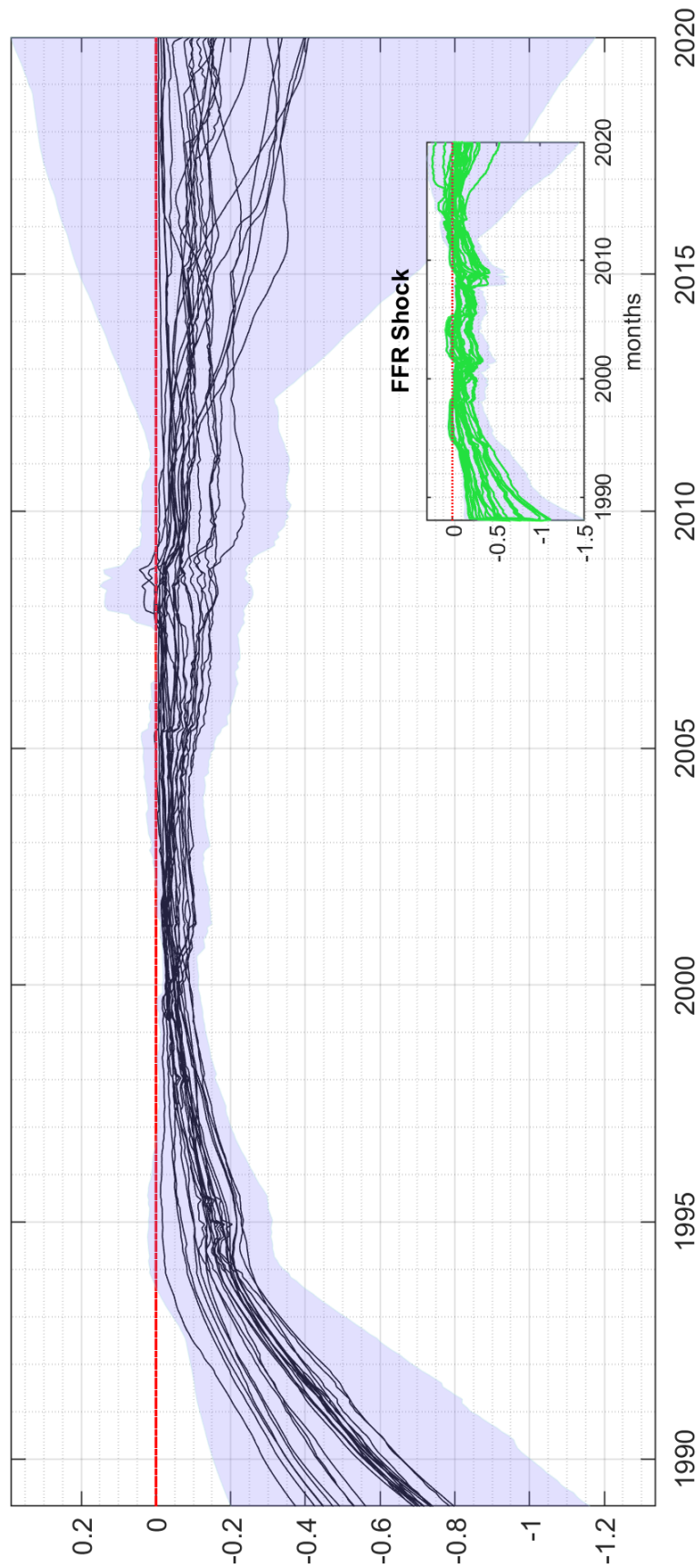
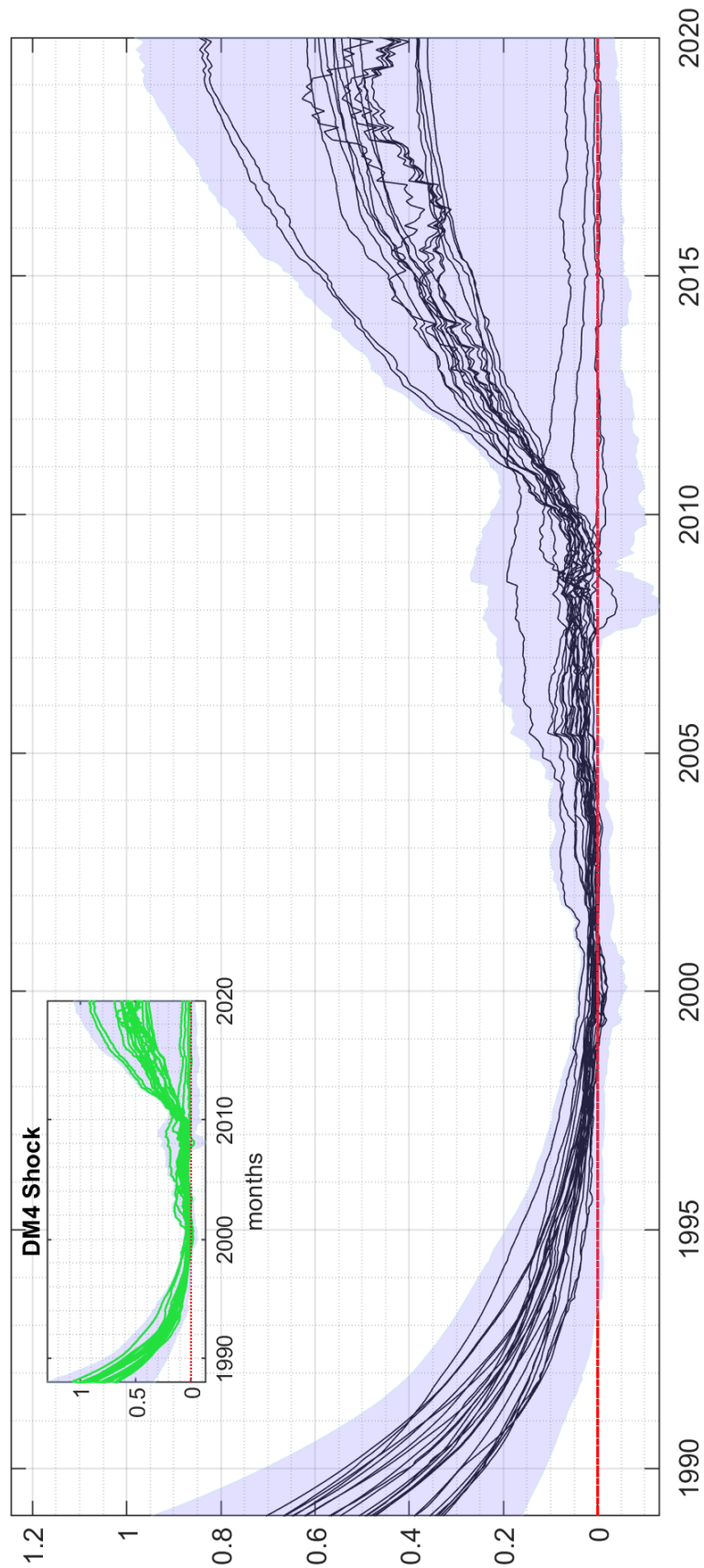


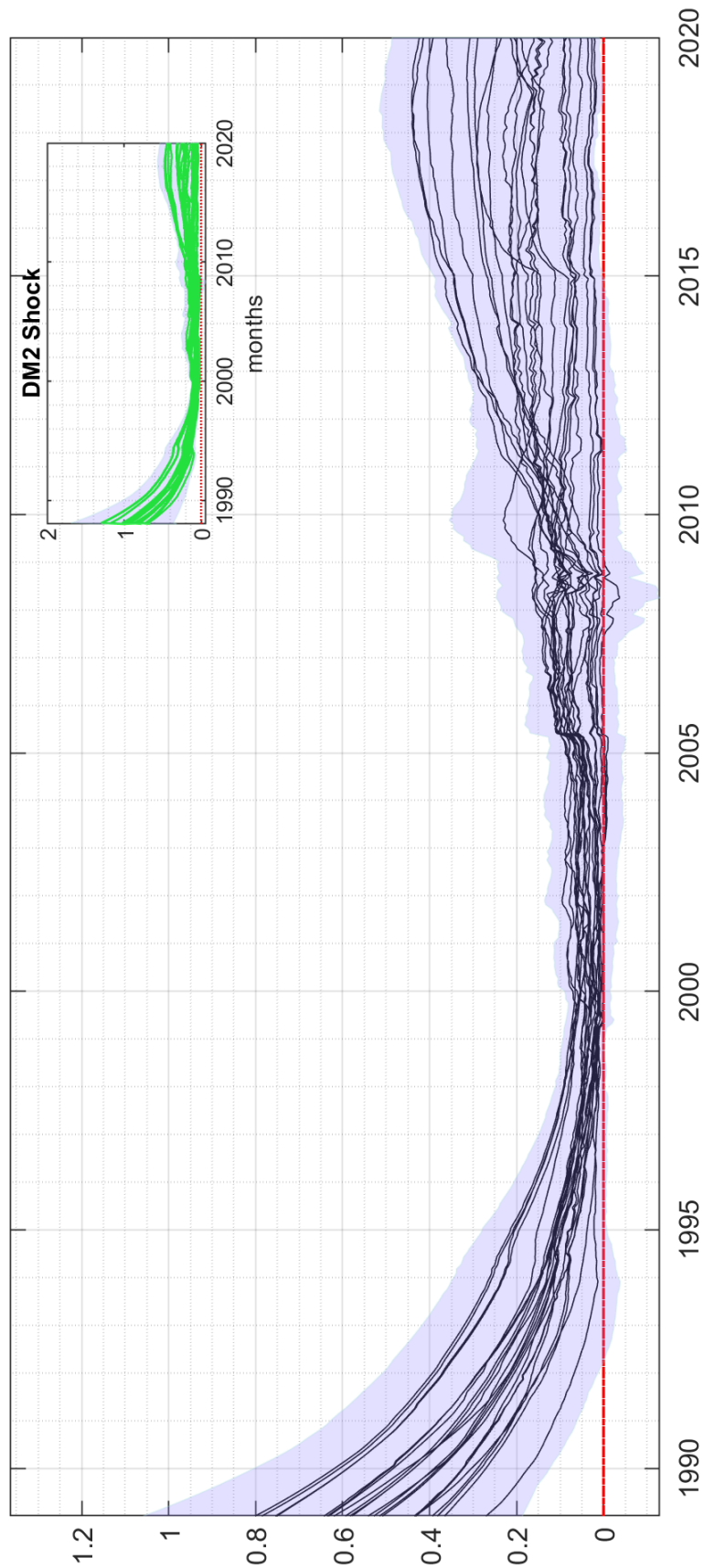
Figure 2: 24-Month-Average Responses to an Expansionary Shock (TVP-FAVAR)



**Figure 3: Price Puzzles to Expansionary Monetary Shocks  
Across Multiple Federal Funds Rate Specifications**



**Figure 4: Price Responses to Expansionary Monetary Shocks  
Across Multiple DM4 Specifications**



**Figure 5: Price Responses to Expansionary Monetary Shocks  
Across Multiple DM2 Specifications**



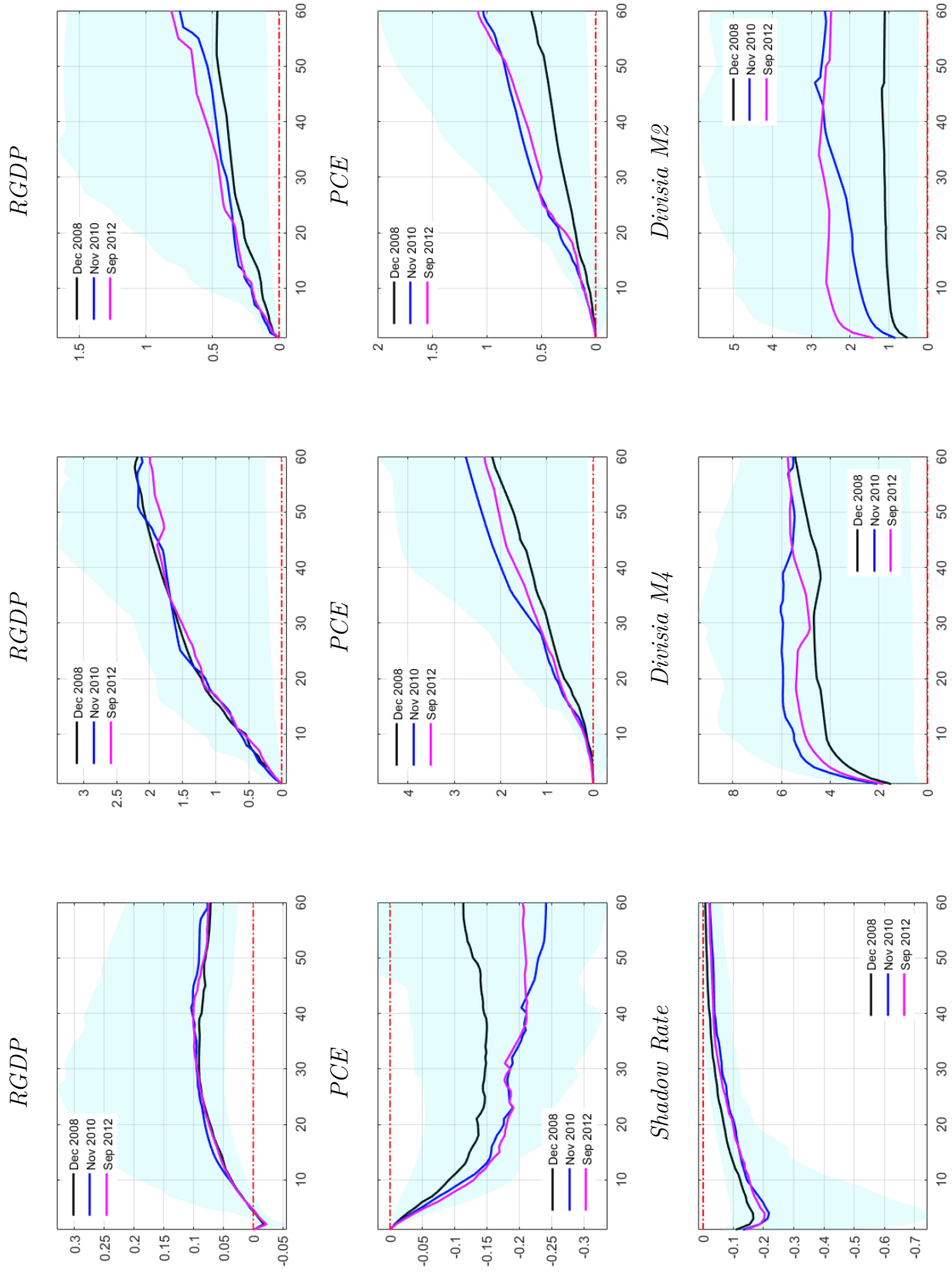
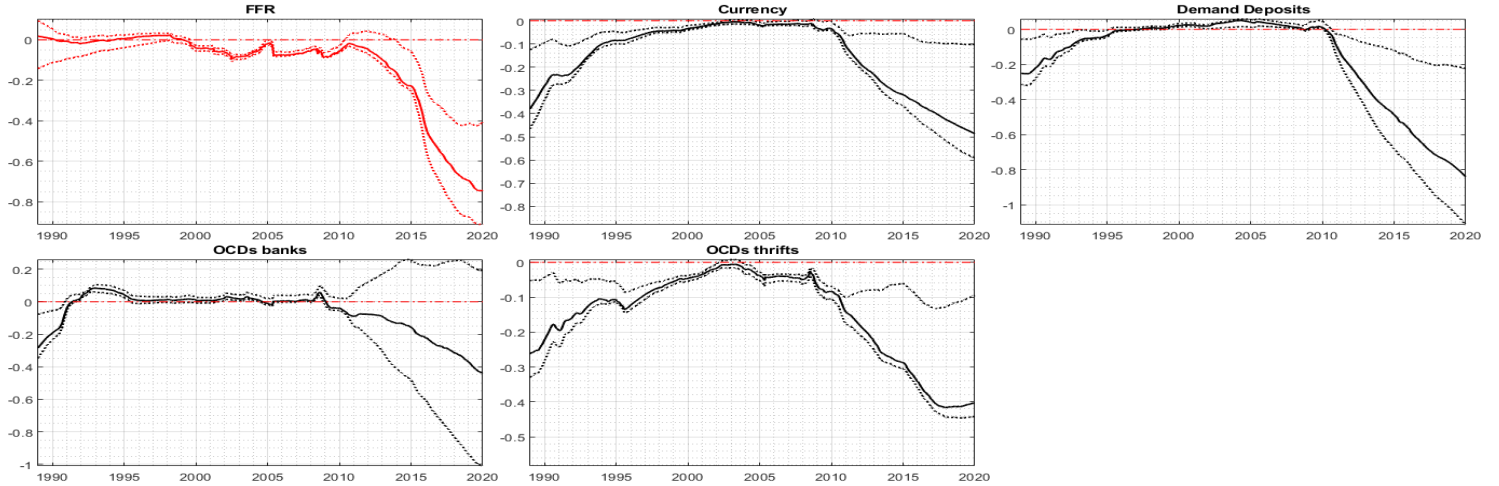


Figure 6: Post-ELB Responses to Expansionary Monetary Shocks for Selected Periods (TVP-VAR)

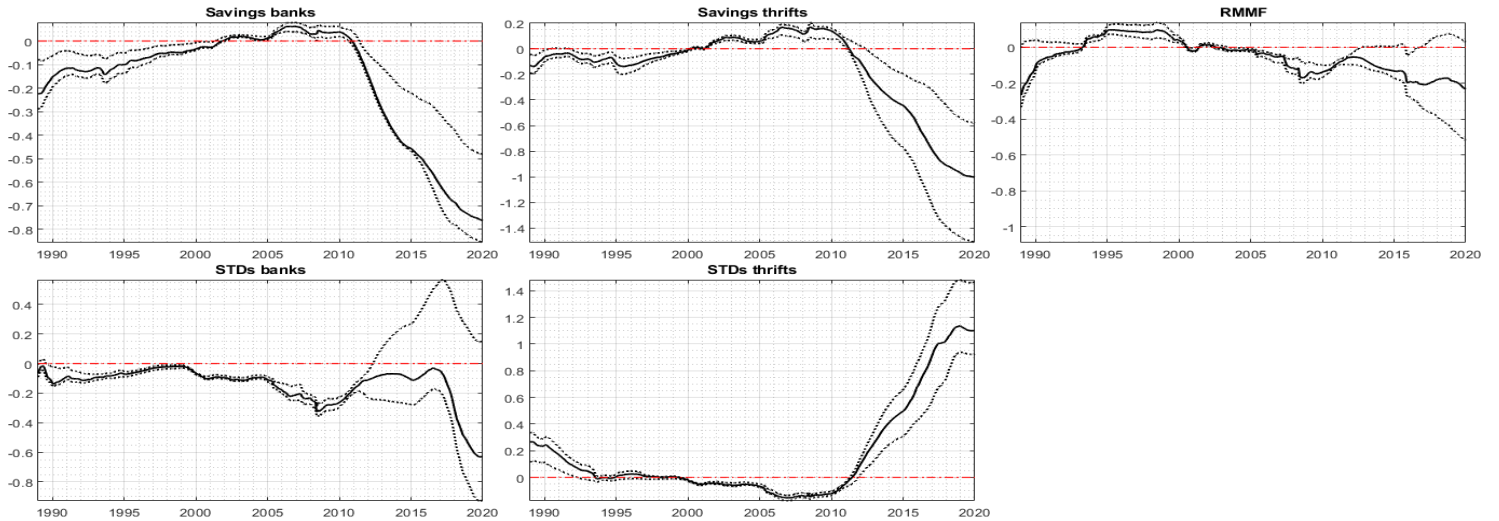
(a) *Money Markets Included in M1*

Monetary Responses to Shocks in FFR



(b) *Money Markets Included in M2*

Monetary Responses to Shocks in FFR



(c) *Money Markets Included in M4*

Monetary Responses to Shocks in FFR

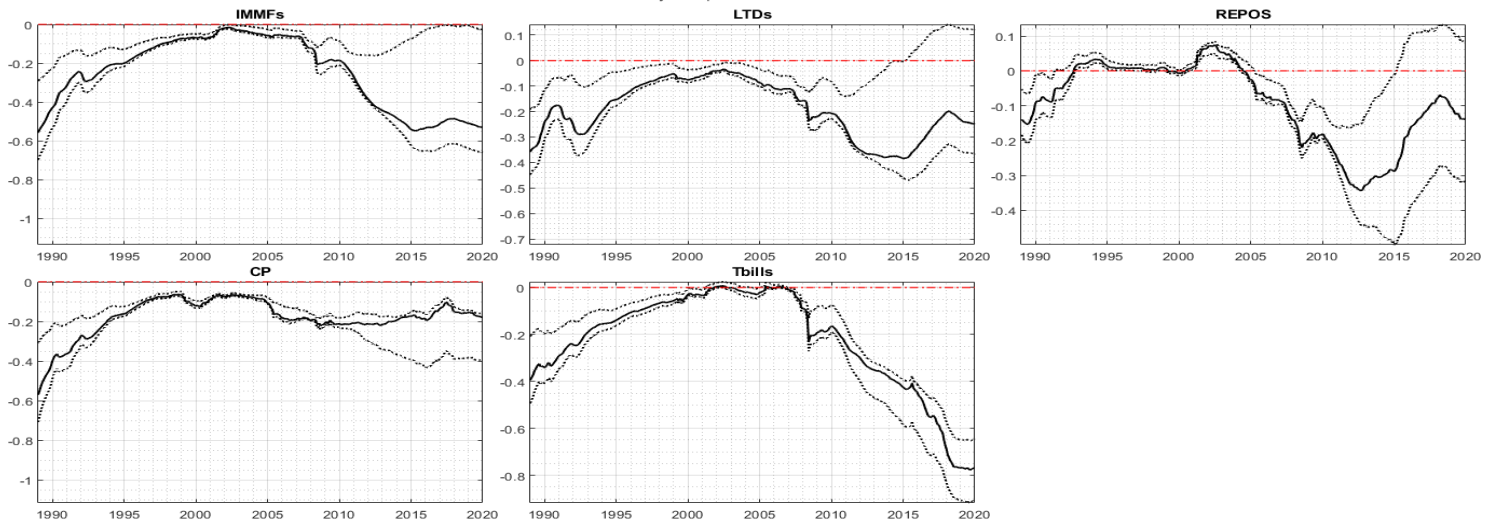
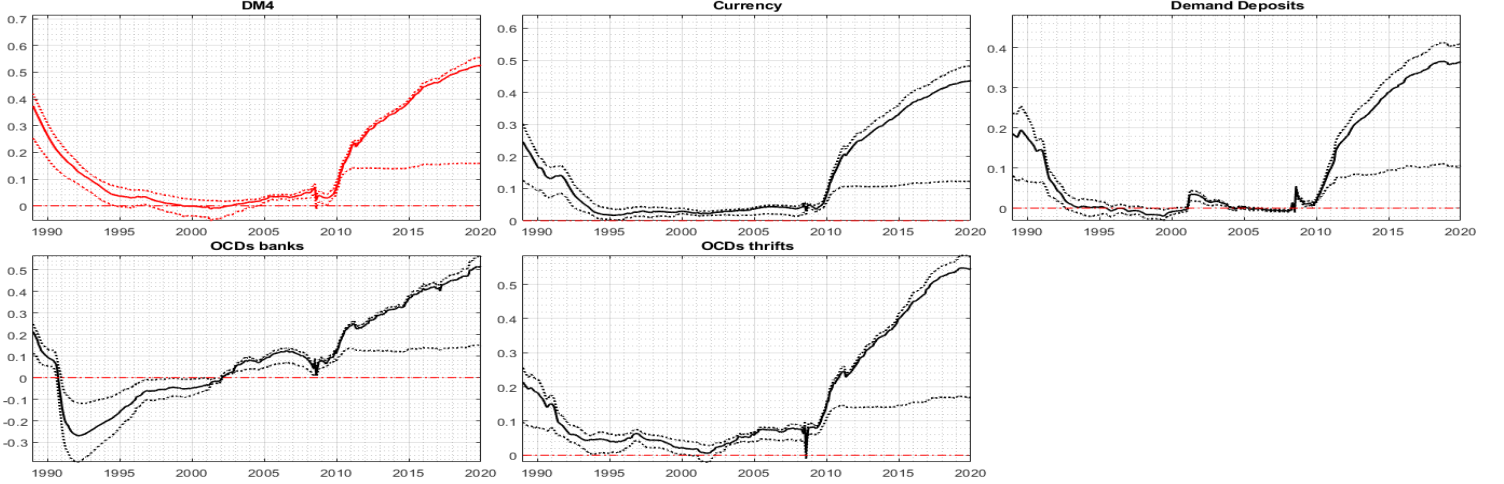


Figure 7: Avg. Money Market Responses to a 1 Std Reduction in the Federal Funds Rate

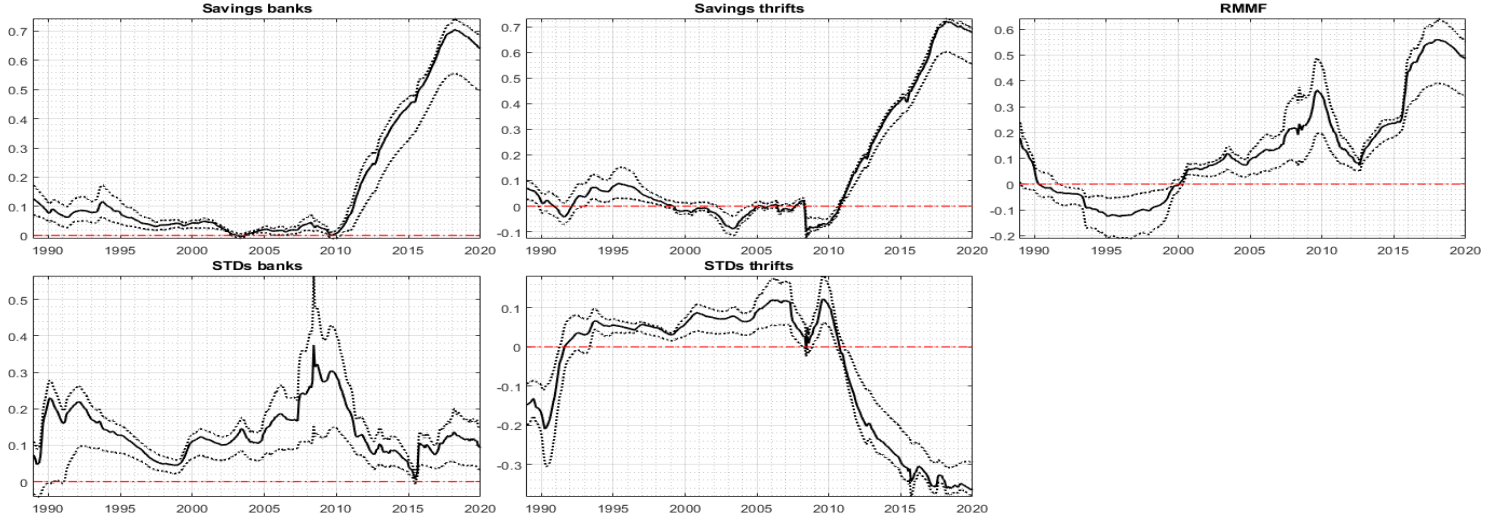
(a) *Money Markets Included in M1*

Monetary Responses to Shocks in DM4



(b) *Money Markets Included in M2*

Monetary Responses to Shocks in DM4



(c) *Money Markets Included in M4*

Monetary Responses to Shocks in DM4

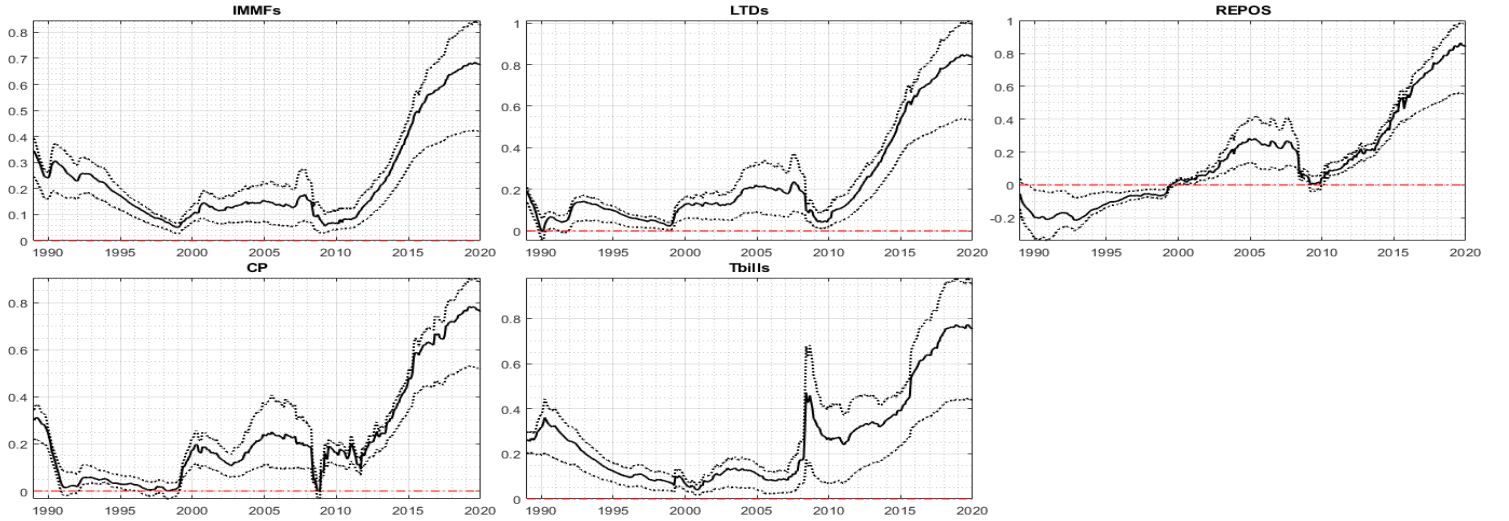


Figure 8: Avg. Money Market Responses to a 1 Std Increase in DM4