Monetary Regimes, Money Supply, and the US Business Cycle since 1959

Implications for Monetary Policy Today

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Abstract

The monetary authority's choice of operating procedure has significant implications for the role of monetary aggregates and interest rate policy on the business cycle. Using a dynamic general equilibrium model, we show that the type of endogenous monetary regime, together with the interaction between money supply and demand, captures well the actual behavior of a monetary economy—the United States. The results suggest that the evolution toward a stricter interest rate–targeting regime renders central bank balance-sheet expansions ineffective. In the context of the 2007–2009 Great Recession, a more flexible interest rate–targeting regime would have led to a significant monetary expansion and more rapid economic recovery in the United States.

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Monetary Regimes, Money Supply, and the US Business Cycle since 1959:

Implications for Monetary Policy Today

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> *If the structure of the economy through which policy effects are transmitted does vary with the goals of policy, and the means adopted to achieve them, then the notion of a unique "transmission mechanism" for monetary policy is a chimera and it is small wonder that we have had so little success in tracking it down.*
>
> —David Laidler, *Monetarist Perspectives* (1982, 150)

1. Introduction

To justify the operational procedures of central banks since the 2008 global financial crisis, reputable academics and practitioners have proclaimed the independence of interest rate policy from all things monetary—the so-called decoupling principle (e.g., Woodford 2000; Keister, Martin, and McAndrews 2008; Borio and Disyatat 2010; and Kashyap and Stein 2012).[1] This policy position can be traced back as far as Thornton (1802), Pigou (1917), Tinbergen (1939, 1951), and Poole (1970). The principal problem with this literature, Hetzel points out, is the especially great confusion "over *the effect* of the choice by the monetary authority between reserves and interest rate manipulation" (1986, 13, emphasis added). Furthermore, central banking operates in a continuously evolving system: its policy operations are difficult to define, and the transmission mechanisms of its instruments are nearly impossible to pinpoint. To

[1] Borio and Disyatat (2010, 57) state that "in setting the interest rate, no open market operations need be involved at all. . . . The interest rate is not controlled by moving up and down a well-behaved, traditional [money] demand schedule." This decoupling of the short-term nominal interest rate from "money" leaves the central bank's balance sheet "free" to pursue financial stability objectives. All too often, the consequential assumption is that conventional monetary policy objectives (of price stability and full employment) are achieved by the efficient allocation of resources conducted primarily through the interest rate transmission mechanism (see also Keister, Martin, and McAndrews 2008; Kashyap and Stein 2012; Thornton 2014; and Belongia and Ireland 2017).

understand the effect of monetary policy, we therefore require an endogenous monetary framework consistent with *both* theory and empirical regularity.

The purpose of this paper is twofold. First, we will show that the type of monetary policy regime—that is, the monetary policy rule chosen to determine the money stock, and hence the price level—has significant implications as to the role of monetary aggregates and interest rate policy in a standard New Keynesian (NK) framework.[2] Second, we will show that the US economy need not succumb to the low-inflation, low-interest-rate state it has been in since the onset of the Great Recession. On one hand, an interest rate–targeting regime (de facto or de jure) renders central bank balance sheet expansions superfluous. At the zero lower bound, this regime is also ineffective. On the other hand, an expansion of the central bank's balance sheet will be effective if the central bank relaxes its interest rate peg. This result obtains if we add a tractable micro-founded banking sector with an explicit monetary transmission mechanism for the money supply process.

To justify our approach, we highlight three bona fide arguments in favor of a traditional model of money stock determination that is based on the Fisher relation, price-level determination, and the behavior of money demand. Together, these three conditions form the core of the general equilibrium framework envisaged by McCallum (1981, 1986), McCallum and Hoehn (1983), and Hetzel (1986), which we incorporate into an NK dynamic stochastic general equilibrium (DSGE) model. The model is estimated by Bayesian methods over the period

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[2] Most central bank models base their conventional policy analysis on a strict interest rate reaction function, a Taylor-type policy rule, with little or no role for the money stock (Fernández-Villaverde, Guerrón-Quintana, and Rubio-Ramírez 2010; Lindé, Smets, and Wouters 2016). Kashyap and Stein (2012, 268n4) also liken this specification to a pegged interest rate (floor) regime, and, although acknowledged, this assumption is built into their analysis of a two instrument–two goal operational framework. We, instead, introduce an explicit monetary transmission mechanism for the money supply process.

1959Q1–2007Q3. This estimation period is chosen for two reasons. First, the long sample period serves to highlight the empirical and theoretical coherence of the model and to provide a detailed account of the US business cycle. (We also compare our results with an estimated version of the model over the period 1984Q1–2007Q3, which corresponds to the Great Moderation period.[3]) Second, we want to simulate the counterfactual scenario of a monetary expansion for the recovery period of the Great Recession (2009Q3–2012Q3) given the estimated structure of the model economy before the structural break in free reserves in 2007Q4 and the subsequent imposition of paying interest on bank reserves held at the central bank.[4]

The main findings show that monetary aggregates are important not only for monetary policy, but for capturing the actual behavior of a monetary economy. The interaction between money supply and demand and the type of monetary regime captures the dynamics of the US business cycle remarkably well over the observed 50 years. These results suggest that the evolution toward a stricter interest rate–targeting regime renders central bank balance sheet expansions ineffective. In the context of the 2007–2009 Great Recession, a more flexible interest rate–targeting regime would have led to a significant monetary expansion and a more rapid economic recovery in the United States. Specifically, a counterfactual simulation at the zero lower bound indicates that a one-off permanent increase in the stock of (broad) money would have reduced the 2009Q3 output gap from −6 percent to −2 percent, maintained the central bank's 2 percent inflation target, and seen the normalization of interest rates from the zero lower

[3] The Great Moderation was a period of relatively stable macroeconomic activity experienced in the United States and elsewhere after the Great Inflation of the 1970s.
[4] We take 2009Q2 to be the trough of the Great Recession. Free reserves represent funds available for interbank clearing and settlement, interbank loans, and the portion of excess reserves less borrowed reserves allocable to reserve requirements in the deposit creation process (see also Norman, Shaw, and Speight 2011). In December 2007, as the interbank market came under stress, borrowed reserves started to rise significantly (i.e., free reserves became negative), and once the Federal Reserve was authorized to pay interest on excess reserves (on October 6, 2008), the level of free reserves rose dramatically. By December 2008, with the federal funds rate pegged close to zero, a fundamental regime change had occurred.

bound. Model simulations also indicate that—on the basis of the postcrisis average free reserves held at the Federal Reserve—a $3.7 billion reduction in free reserves would have expanded the money supply by 3.65 percent and output by 3.84 percent. Although stylized, these results offer a clear alternative characterization of monetary policy that is often missing (or dismissed) from the contemporary narrative (see, e.g., Sims 2013, Thornton 2014, and Belongia and Ireland 2017).

Another principal contribution of this paper is to demonstrate that neither an interest rate–targeting regime nor a money-growth rule is desirable. At the same time, a two instrument–two goal operational framework (the "decoupling principle") overlooks money's essential role in economic activity and the determination of the general level of prices.[5] Rather than treating interest rates and reserves as unrelated, monetary authorities in a market economy should stabilize nominal income (or, equivalently, the product of the broad money supply and velocity) using both their monopoly over the monetary base and their interest rate policy. Under certain states of the world, at either the zero lower bound or highly elastic reserve demand, either interest rate policy or money base creation can be ineffective. Indeed, the superiority of an optimal combination policy was traced clearly in the seminal work of Poole (1970). But as McCallum and Hoehn (1983) point out, Poole's study, and similar studies thereafter, either lack optimizing behavior of individual agents in a general equilibrium setup (and are therefore not policy invariant)[6] or assume that the central bank adjusts the nominal stock of money to provide the *real* stock of money demanded (and that the price level is irrelevant for market clearing).

[5] That is, it inappropriately maps the implementation (or operating procedures) of monetary policy to the transmission mechanisms of monetary policy. We view this error as a misidentification of monetary canon (Poole 1970, 197): "Monetary authorities may operate through either interest rate changes or money stock changes, but not through both independently, and therefore must decide whether to use the interest rate or the money stock as the policy instrument [or, more correctly, the intermediate target]." See also Thornton (2014) for an accessible and related discussion.
[6] Arguably, even general equilibrium models may be subject to the Lucas (1976) critique under rational expectations (Farmer 1991) and reduced-form specifications (Fernández-Villaverde, Guerrón-Quintana, and Rubio-Ramírez 2010).

Indeed, recent literature on the optimal choice of monetary policy instruments highlights a similar lack of research on Poole's basic insights into modern dynamic general equilibrium models (e.g., Collard and Dellas 2005; Schabert 2006, 2009; Auray and Fève 2008; Berentsen and Monnet 2008; Chowdhury and Schabert 2008; and Hoffmann and Kempa 2009). To our knowledge, these models typically lack the dynamic interaction between the demand and supply of money that makes explicit the endogenous money supply process in monetary transmission mechanisms. This paper aims to fill that gap in the literature.[7]

The remainder of this paper is organized as follows. Section 2 discusses the three fundamental conditions in favor of a traditional model of money stock determination. Section 3 describes a model with money stock determination and a market for bank reserves. Sections 4 and 5 present the estimation results and main findings on the basis of that model. Section 6 discusses counterfactual simulations of alternative regimes for optimal policy, and section 7 concludes.

2. Revisiting Three Pillars of the Monetary Exchange Economy

2.1. The Fisher Relation

The "original" Fisher (1896) *effect* derives from a no-arbitrage condition on the expected terms of trade between money and commodities (Dimand and Betancourt 2012, 188).[8] In contrast, the well-known Fisher *relation* or *distinction* between nominal and real interest rates is a simplification (see Laidler 2013, 3). To be consistent with theory, we need a model that describes

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[7] As mentioned, this paper falls into the context of a long and rich literature. In the current economic state of low interest rates and "ineffective" monetary policy, however, the "liquidity trap" hypothesis and the fiscal theory of the price level have resurged. As these hypotheses directly apply to the arguments presented here, they require some attention. We provide such a discussion in the supplementary appendix; see also Sims 2013, Cochrane 2014, Belongia and Ireland 2017, and Buiter and Sibert 2017.

[8] See also Laidler 2013 for important clarifications on the use of the Fisher relation in the Great Depression and the Great Recession—especially with respect to monetary policy discussions of the times. Dimand (1999) also distinguishes the actual contributions of Fisher from those of the development of the relation attributed to his name.

(1) how price-level expectations are formed and (2) to what extent asset markets reflect inflation expectations in the difference between nominal (i) and real (r) rates of return.

First, under rational expectations, the expected value of fiat money $(1/P)$ equates as follows: $E(A) = E(1/P) \approx 1/E(P)$, and the "original" Fisher *effect*, $i = r - a - ra$, equates with the "conventional" Fisher *relation*, $i = r + \pi + r\pi$, where a is the expected appreciation of the value of money in terms of a basket of commodities and where π is expected inflation.[9] Notably, however, price-level determination with respect to *both* the money stock and the interest rate is crucial to satisfy the Fisher relationship.

Second, given this link between the money stock, commodity prices, and rates of return, the Fisher relation further implies—as shown in, for example, Ireland (2014) and Walsh (2010, 457)—that the monetary authority cannot independently determine the nominal interest rate and the expected rate of inflation (or, more correctly, the expected depreciation in the value of money). Instead, given an (intermediate) interest rate target, the money supply adjusts to a growth rate commensurate with the inflation rate, and vice versa.[10]

2.2. Money Stock and Price-Level Determination

The key result that Hetzel (1986, 7) brings to light is that for nominal money to play a causal role in determining the price level, "at least some of the determinants of nominal money supply must differ from the determinants of real money demand." And by implication of the quantity theory

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[9] It is straightforward to show, using Jensen's inequality and the Cauchy-Schwarz inequality, that $1 \leq E(P)E(1/P) \leq 1 + (b-a)^2/4ab$ for a bounded random variable P on the interval $[a, b] > 0$ with $Prob\ (a < P < b) = 1$. With negligible uncertainty about the expected price level ($a \approx b$), $E(P)E(1/P) \approx 1$.

[10] Fisher also used his hypothesis to investigate the term structure of interest rates (Dimand 1999). The hypothesis then naturally leads to questioning the central bank's control over short- and long-term interest rates and to understanding the transmission of expected policy rate changes across the term structure (see, e.g., Poole, Rasche, and Thornton 2002, 85; Thornton 2004, 2014; Coibion and Gorodnichenko 2012; and Hummel 2013).

of money approach, the price level adjusts to equate the real quantity of money supply with the real quantity of money demanded.[11] Put another way, changes in the supply of money are associated with the disequilibrium between the real (market) rate of interest and the natural rate of interest. Further, the ability of monetary policy to manipulate this disequilibrium (through, for example, the policy rate, bank reserves, or price expectations) generates temporary real effects.

Consequently, the problem of multiple equilibria arises if the equilibrium conditions of a model can determine neither the price level nor the nominal supply of money (McCallum 1986). In this case, alternative price-level sequences will be consistent with given paths for the nominal money stock.[12] In a regime of strict interest-rate targeting, however, the standard three-equation NK model does allow for the price level and real money balances to be determined by the money demand equation and the Fisher equation. Money is irrelevant only because the NK model lacks a deterministic path for the nominal money stock and hence for the price level. In fact, Walsh (2010, 460) shows that "there exists a path for the nominal money supply . . . that leads to the same real equilibrium under an interest rate peg as would occur with a flexible price regime." But again, this concept precludes the true specification of money stock determination. An interest rate–targeting regime is simply a special case in a continuum of endogenous monetary policy regimes.

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[11] In Hetzel's model, nominal shocks shift both demand and supply curves for money, whereas real shocks shift only the supply of money through changes in the natural rate of interest.

[12] In fact, Carlstrom and Fuerst (2001) show that because of multiple pricing equations for the nominal interest rate, "seemingly minor modifications in the trading environment result in dramatic differences in the policy restrictions needed to ensure real determinacy." They go on to caution that policymakers should be aware that a lot depends on basic assumptions about the modeling environment in monetary models. See Auray and Fève (2008) and Schabert (2009) for a similar analysis on the (non)equivalence of money supply and interest rate policy rules.

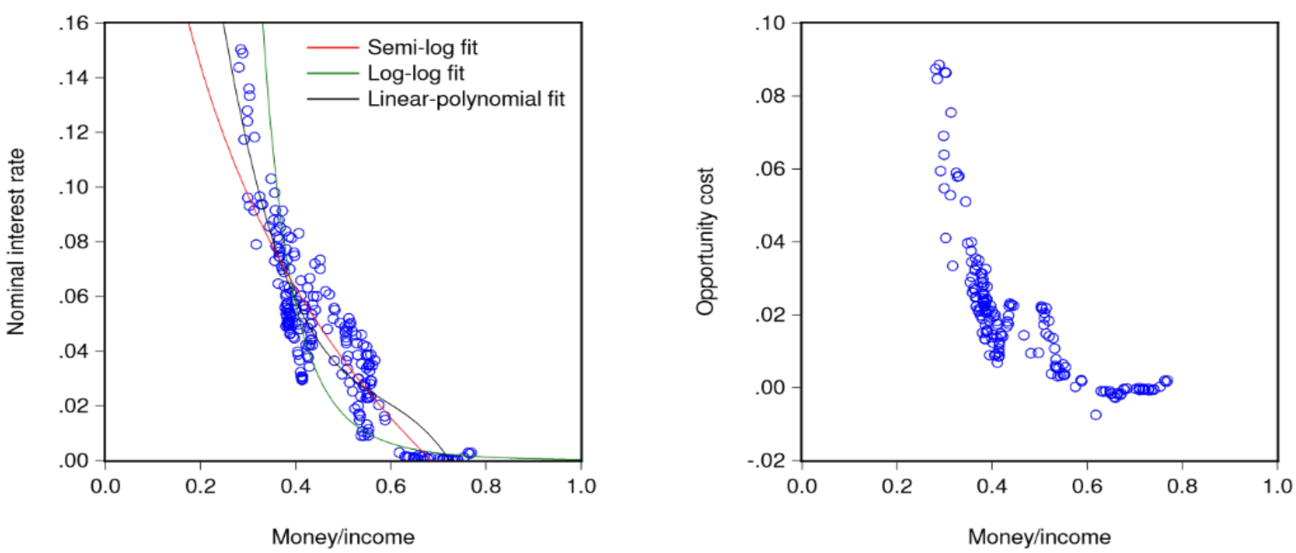
2.3. The Behavior of Money Demand Is Well Defined

Examining data from as far back as 1900, Benati et al. (2017), Ireland (2009), and Lucas (2000) illustrate a strikingly stable relationship between money demand and nominal interest rate. This relationship holds for more recent (post-1980) periods as well (Berentsen, Huber, and Marchesani 2015; Lucas and Nicolini 2015; Alvarez and Lippi 2009). Figure 1 highlights this negative relationship in the US data. The fundamental implication of this relationship within the context of a model of money stock determination relates to the relevance of bank reserves (Borio and Disyatat 2010, 73–80). The critique against the relevance of monetary aggregates is usually based on the empirical regularity that no clear and stable link exists between liquidity (reserves) and interest rates. Specifically, countries that do not employ a reserve regime can implement the so-called decoupling principle (Borio and Disyatat 2010, 55–57). As a result, various levels of reserves can exist for a given interest rate. This empirical regularity, however, is somewhat different from the decoupling hypothesis, which allows for a "two instrument–two goal" operational framework. Ireland (2014, 1301) sums up the difference as follows:

> Thus, although the extra degree of freedom does allow the central bank to target the short-term nominal interest rate and the real quantity of reserves simultaneously, the model shows that monetary policy actions intended to bring about long-run changes in the aggregate price level must still be accompanied by proportional changes in the nominal supply of reserves.

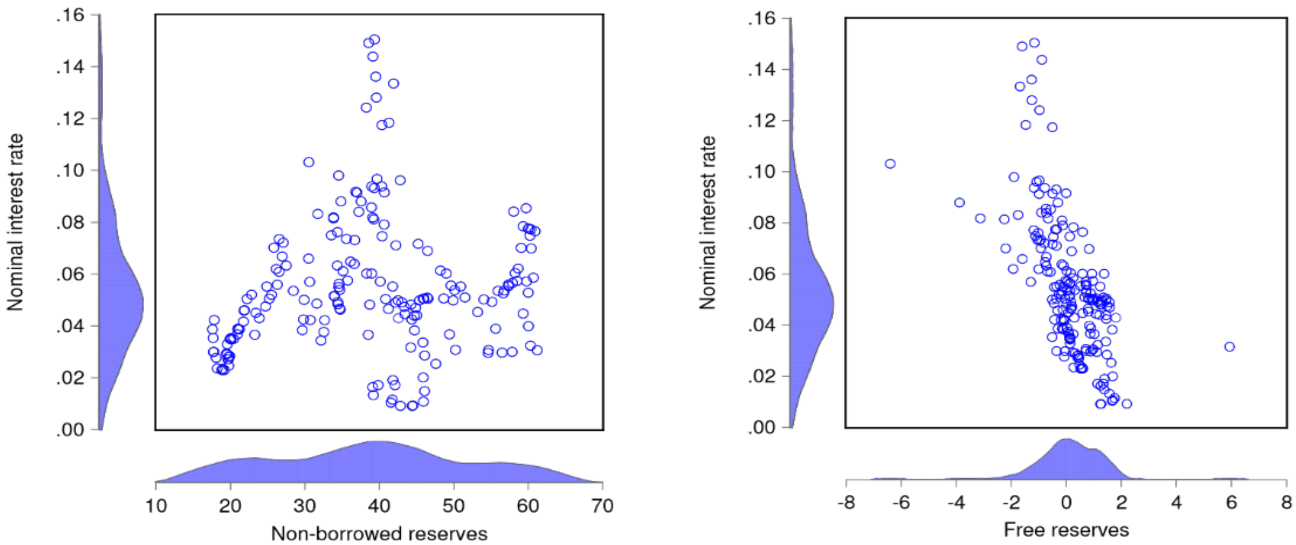
This relationship means that any monetary policy operation that fixes the price of short-term debt (e.g., by paying interest on reserves) can remove the liquidity effect altogether *in the market for reserves* (see, e.g., figure 2). In fact, Ireland (2014, 1301) finds that when a 25-basis-point increase in the short-term interest rate is brought about, both the *size* and the *sign* of reserves adjustment differ from the liquidity effect that would arise under a "traditional" reserve regime. A large *increase* in the balance sheet arises in the short run because of the simultaneous effect of the market rate on households' demand for deposits and banks' demand for reserves. And as Fama (2013, 180) points out, "There is no conclusive evidence (here or elsewhere) on the role of the Fed versus market forces in the long-term path of interest rates." Ireland (2014, 1303) goes on to show that although interest on reserves dramatically alters the endogenous response of reserves, in the long run, "a monetary policy action that decreases [increases] the price level always requires a proportional reduction [expansion] in the nominal supply of reserves. . . ." That is, the short-run versus long-run dichotomy in the literature raises some concern over the long-run efficacy of a decoupling policy framework. In short, the Fisher effect matters. (See also Hummel 2013 and Cochrane 2014).

Figure 1. US Money Demand



Notes: The left-hand panel shows the nominal interest rate from 1959Q1 through 2016Q3. The right-hand panel shows the opportunity cost with money zero maturity (MZM) own rate from 1975Q1 through 2016Q3.

Figure 2. US Reserve Demand



Notes: The left-hand panel shows nonborrowed reserves ($ billions) from 1959Q1 through 2007Q3. The right-hand panel shows free reserves ($ billions) from 1959Q1 through 2007Q3.

Figure 2 shows the relationship between reserves and the short-term nominal interest rate for quarterly US data from 1959Q1 to 2007Q3. Nonborrowed reserves (H) show no indication of a relationship with the interest rate. This result is unsurprising, given that for much of this period, the Fed followed a de facto (but not necessarily strict) interest rate–targeting regime (Hetzel 1981, 1982; Taylor 1993; Orphanides 2002, 2003; Sims and Zha 2006; Walsh 2010). In fact, the only extended period showing a clear negative log-linear relationship between H and the short-term nominal interest rate is that between 1982Q3 and 1987Q1—a period in which the Federal Reserve followed a borrowed-reserves operating procedure (see Cosimano and Jansen 1988).

Free reserves (FR), on the other hand, approximate a downward-sloping demand function for the entire period from 1959Q1 to 2007Q3.[13] The simple linear ordinary least squares (OLS) regression gives

$$FR = \underset{(0.15)}{1.60} - \underset{(2.40)}{27.05}i,$$

with $R^2 = 0.40$ and standard errors in parentheses. In comparison, the semi-log OLS regression for money demand from figure 1 gives

$$ln\left(\frac{M}{GDP}\right) = -\underset{(0.02)}{0.54} - \underset{(0.27)}{5.54}i,$$

with $R^2 = 0.69$ for the period from 1959Q1 to 2007Q3. Of course, these results serve a descriptive purpose only; for more comprehensive analyses and discussions on the demand for money, see, for example, Duca and VanHoose 2004, Ireland 2009, Walsh 2010, and Lucas and Nicolini 2015.

3. The Model Economy

McCallum's (1981, 1986) two-equation, full-employment IS-LM model with a money supply rule showed it was possible to peg the nominal interest to some target value with a money rule and obtain price determinacy. Hetzel (1986) extended McCallum (1986) to include a traditional banking sector for reserves. His model contains four key equations: a Fisher relation; a demand function for real money balances; a monetary rule; and a banking sector relationship between nominal money supply, the short-term market interest rate, and bank reserves. Equations (1) through (4) represent these four equations as first-order Taylor approximations around a deterministic steady state:

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[13] There are only two notable outliers over the 48.5-year period (−\$5.2 billion in 1984Q3 and \$5.9 billion in 2001Q3). Free Reserves = Excess Reserves − Borrowed Reserves.

$$\text{Fisher relation} \ : \ i_t = E_t \pi_{t+1} + r_t \tag{1}$$

$$\text{Money demand} \ : \ m_t^d - p_t = \phi_y y_t - \phi_i i_t \tag{2}$$

$$\text{Monetary policy} \ : \ h_t = p_h h_{t-1} - v_h (i_t - \bar{i}) \tag{3}$$

$$\text{Money supply} \ : \ m_t^s = \frac{1}{rr} \left(\phi_h h_t - \phi_{fr} fr_t \right), \tag{4}$$

where i_t, π_t, and r_t are the nominal interest rate, inflation rate, and real rate of interest, and p_t, y_t, h_t, and m_t denote the price level, output, bank reserves, and nominal money stock, respectively. The parameters φ_y and φ_i are the real income elasticity and the interest rate semi-elasticity of the demand for money, ρ_h is a persistence parameter, and ν_h measures the degree to which the monetary authority smooths the nominal interest rate. Finally, rr is the reserve requirement ratio, where φ_h and φ_{fr} are the steady-state ratios of nonborrowed reserves and free reserves to the money stock.[14]

In the spirit of Benchimol and Fourçans (2012), Belongia and Ireland (2014), and Ireland (2014), we use the above approach to money stock determination to deviate from the traditional NK model with a Taylor-type monetary rule to include a monetary rule, equation (3), and a money supply condition, equation (4), which allow for alternative operational instruments and intermediate targets. Specifically, ν_h captures the degree of interest rate smoothing enforced by the central bank. As $\nu_h \rightarrow \infty$, the money supply schedule becomes horizontal, and we enter a monetary regime of interest rate targeting—either a "pure" peg or a strict dynamic Taylor rule (e.g., by letting $\bar{i}$ follow some monetary policy reaction function that responds to inflation and output). Money and reserves become endogenous, and the reserve-money multiplier becomes

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[14] Note that equations (15) and (16) in Hetzel (1986, 10) imply a log-linear relationship between reserve demand schedule and reserve supply schedule.

irrelevant to the determination of the money stock (Hetzel 1986, 5–6, 13, 17–18, 20). Under this type of regime, the model reduces to the standard NK framework (Benchimol and Fourçans 2012). As $\nu_h \rightarrow 0$, we enter into a "pure" monetary aggregate targeting regime.[15]

The bank's decision problem for free reserves (fr_t) in an interest-rate corridor or channel system is based on Woodford (2001, 31) and Whitesell (2006); see also Walsh (2010, 544). In this framework, the net supply of settlement balances (free reserves) is zero in the steady state. As will be shown, this fact ensures that the effective federal funds rate hits the target policy rate in the steady state. In reality, as depicted in figure 3, the "target supply" of reserves may exceed required reserves in the steady state because of uncertainty or because the model applies to *average* reserve balances over a maintenance period (Keister, Martin, and McAndrews 2008, 43–45). In addition, we do not explicitly distinguish cash from reserve balances and deposits. Total bank reserves at the central bank therefore represent the monetary base, and household deposits therefore represent the broad monetary aggregate.[16]

3.1. Households

The representative infinitely lived household's utility is separable in consumption, money, and leisure. The household maximizes its expected lifetime utility function, given by

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[15] Note that the reserve-money multiplier only becomes irrelevant as a result of the modeling assumption. This assumption does not mean that the real demand for money (purchasing power) *determines* the quantity of nominal money (Tobin 1963, cited in Hetzel 1986, 19). Empirically, the relationship depends on the degree to which monetary aggregates (or reserve-money multipliers) become interest sensitive, that is, elastic (Inagaki 2009), or on how monetary aggregates are measured (Belongia and Ireland 2014, 2017; Tatom 2014): an insensitive or structurally stable monetary aggregate results in a relevant and predictable reserve-money multiplier. For historically relevant practical and technical expositions, see Brunner and Meltzer (1981) and Hetzel (1981).

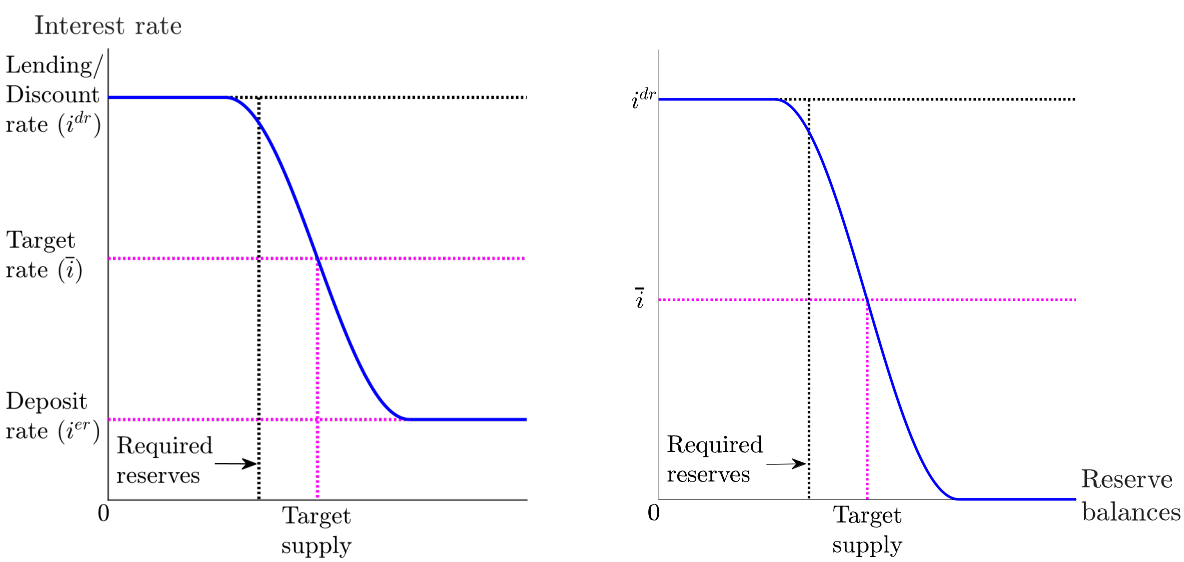
[16] This simplification follows the proposition that reserves are "the fundamental numeraire and means of final payment" (Cochrane 2014, 90–91). As of March 14, 2018, $100 notes account for 80 percent of the value of currency in circulation ($1.59 trillion), of which nearly 80 percent are held outside the United States (Haasl, Paulson, and Schulhofer-Wohl 2018). Currency accounts for 36 percent of the Federal Reserve's liabilities and under 8 percent of US GDP, of which typical transaction notes ($20s and below) account for under 1.5 percent of GDP (Judson 2017).

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{a}{1-\eta_c}(C_t)^{1-\eta_c} + \frac{(1-a)\xi_{m_d,t}}{1-\eta_m}(M_t^d/P_t)^{1-\eta_m} - \frac{\Psi}{1+\eta_l}(L_t)^{1+\eta_l}\right], \tag{5}$$

where β^t is the discount factor. Utility depends positively on the consumption of goods, C_t, and negatively on the supply of labor hours, L_t. Households' financial wealth is made up of risk-free bonds, B_t, and nominal money balances, M_t^d. Similar to Van den Heuvel (2008); Christiano, Motto, and Rostango (2010); Benchimol and Fourçans (2012); and Ireland (2014), we assume that households derive direct utility from the liquidity services of money. This utility drives a positive wedge in the spread between the return on bonds and the own return on money (the opportunity cost of holding money). The parameter η_l measures the inverse of the elasticity of hours worked to the real wage, η_c captures the inverse of the intertemporal elasticity of substitution in consumption, and η_m measures the inverse of the interest rate semi-elasticity of money. Last, the variable $\xi_{m_d,t} = \exp(\varepsilon_t^{m_d})$ is an exogenous shock to money demand.

Figure 3. Monetary Policy Implementation

Panel A. Corridor System ***Panel B. US Reserve Demand Pre-2008***

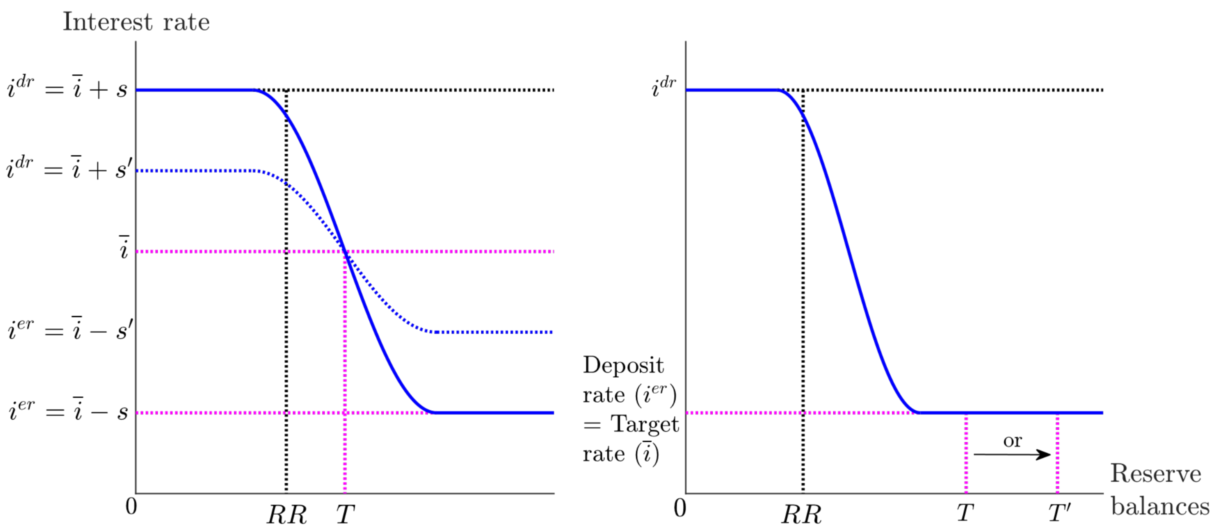


Sources: Adapted from Keister, Martin, and McAndrews (2008). See also Woodford (2001, 33, fig. 1); Whitesell (2006, 1181, fig. 1); and Walsh (2010, 546, fig. 11.2).

Figure 4. Monetary Policy Implementation

Panel A. Narrow Peg Regime

Panel B. US Reserve Demand Post-2008 under Floor Regime



Note: Left panel depicts narrowing of symmetrical spread $s' < s$. Right panel is equivalent to $\nu_h, \nu_f \to \infty$.
Source: Adapted from Keister, Martin, and McAndrews (2008).

Equation (6) gives the household budget constraint:

$$P_t C_t + M_t^d + Q_t B_t + P_t T_t \leq W_t L_t + B_{t-1} + M_{t-1}^d. \tag{6}$$

The household allocates periodic income from wages (W_t), risk-free bonds (B_{t-1}), and cash balances (M_{t-1}^d) to current consumption and new financial wealth holdings in the form of money and bonds. The variable Q_t is the discount on one-period bond purchases such that the payoff at maturity is the short-term nominal interest rate ($i_t = -log Q_t$). The variable T_t includes both lump-sum taxes net of transfers and rebated profits from firms.

The representative household's first-order conditions for bonds, money, and labor are the following:

$$U_{c,t} = \beta E_t \left[U_{c,t+1} \frac{(1+i_t)}{(1+\pi_{t+1})} \right], \tag{7}$$

$$U_{m,t} = U_{c,t} - \beta E_t\left[U_{c,t+1}\frac{1}{(1+\pi_{t+1})}\right], \tag{8}$$

$$\frac{W_t}{P_t} = \frac{U_{l,t}}{U_{c,t}}, \tag{9}$$

where π_t is the rate of inflation, $U_{c,t} = a(C_t)^{-\eta_c}$ is the marginal utility of consumption, $U_{m,t} = (1-a)\xi_{m_d,t}(M_t^d/P_t)^{-\eta_m}$ is the liquidity services from holding real money balances, and $U_{l,t} = \Psi(L_t)^{\eta_l}$ is the marginal disutility of labor. Equation (8) is the household's demand for real money balances. Equation (9) gives the standard real wage equation, which states that the real wage equals the marginal rate of substitution between consumption and labor. Equation (7) gives the consumption Euler equation, which is based on the standard asset-pricing equation for bonds.

Combining equation (7) and equation (8) illustrates the opportunity cost of holding money.

$$\frac{U_{m,t}}{U_{c,t}} = \frac{i_t}{1+i_t}. \tag{10}$$

Here, equation (10) states that the marginal utility of the liquidity services, expressed in units of consumption, equals the opportunity cost of not investing money holdings in risk-free nominal bonds.

3.2. Firms

Firms manage the goods-producing sector and are owned by households. Firms behave optimally in a monopolistically competitive environment in which their objective is to maximize profits. In each period, only a fraction of firms $(1-\theta)$ can reset their prices. The aggregate price level then evolves as

$$(P_t) = \left[\theta(P_{t-1})^{1-\varepsilon^p} + (1-\theta)(\tilde{P}_t)^{1-\varepsilon^p}\right]^{\frac{1}{1-\varepsilon^p}}. \tag{11}$$

Firms produce goods using identical technology in the form of a standard Cobb-Douglas production function:

$$Y_t = \xi_{z,t} L_t^{\alpha}, \tag{12}$$

where L_t is the demand of labor hours, $0 < \alpha < 1$ represents labor's decreasing returns to production, and $\xi_{z,t} = \exp(\varepsilon_t^z)$ represents the exogenous technology identical to all firms.

3.3. The Banking Sector

Our intention in constructing the stylized banking sector introduced below is to focus on the relationship between the demand for reserve balances and the effective (or target) policy rate. Although operational procedures in the United States before 2008 differed from the corridor (symmetric channel) systems used by several of the world's central banks (e.g., the European Central Bank and the central banks of Australia, Canada, and England), monetary policy in the United States was implemented in much the same way as in those regions (see figure 3).[17] Simply put, the central bank determines the quantity of reserves to achieve its target interest rate. At the same time, the aggregate stock of bank reserves (those necessary for interbank payments and required—or desired—reserves) is proportional to the broader stock of money.[18] Importantly, we take the pragmatic stance that the central bank accommodates shocks to the broader monetary aggregate (Goodhart 2017, 33–34, 38). In other words, the central bank provides the monetary base (bank reserves), consistent with both the stock of broad money in the economy and the desired free reserves, that aligns the short-term interbank (federal funds) rate with its target. That said, the Federal Reserve has in the past systematically adjusted (and still

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[17] See Gilbert (1985) and Keister, Martin, and McAndrews (2008) for an accessible discussion on central bank operating procedures in a stylized graphical framework as depicted here. A more detailed analysis can be found in Whitesell (2006).

[18] Although highly persistent, the effective reserve ratio has not been stable over the period 1959Q1–2016Q3 (see figure A1). In addition to the measurement and substitutability of monetary aggregates, regulatory changes and financial innovations can explain these structural changes over time. (See, e.g., Lucas and Nicolini 2015; Berentsen, Huber, and Marchesani 2015, 2018; Banerjee and Mio 2017; Bech and Keister 2017; and Li et al. 2017.)

can adjust) the monetary base to bring about changes to the stock of money used for transactional services in the broader economy (see, e.g., DeRosa and Stern 1977, Gilbert 1985, Chowdhury and Schabert 2008, Tatom 2014, and Schabert 2015). As such, our dynamic interaction between the supply of and demand for money, together with a stylized description of the banking sector, allows us to focus on the structural relationship between the market for money and macroeconomic aggregates in a conventional general equilibrium framework. (For a similar motivation, see also Chowdhury and Schabert 2008 and Ireland 2014.)

3.3.1. A traditional model of the reserve market. The central bank has autonomy over the quantity of reserves supplied (see equation [3]). However, the money supply function is derived from the banking sector's demand for free reserves (see equation [4]). Free reserves (FR) represent funds available for interbank clearing and settlement, interbank loans, and the portion of excess reserves (ER) less borrowed reserves (BR) allocable to reserve requirements (RR) in the deposit (D) creation process (see also Norman, Shaw, and Speight 2011). Assume that the central bank has a standing facility for borrowing at the discount window and that banks are required to hold reserves for a fixed reserve requirement ratio (rr). Required reserves ($RR = rrD$) and borrowed reserves (BR) are therefore not directly determined by the central bank, but the central bank directly determines nonborrowed reserves (H), the discount rate (i^{dr}), and interest on (excess) reserves (i^{er}). On the basis of this model from Tinbergen (1939, 1951), Hetzel (1986) defines the relationship between nominal money (supply), the short-term interest rate, and bank reserves as follows:

$$FR = H - RR = ER - BR \tag{13}$$

$$RR = H - FR \tag{14}$$

$$RR = rrD \tag{15}$$

$$FR = f(i|i^{dr}, i^{er}). \tag{16}$$

Equation (16) shows bank demand for free reserves as a function of the short-term nominal interest rate, given the spread between the discount rate on borrowed reserves and the interest on excess reserves. Deposits (D) equate with the nominal money supply (M^s). Substituting equation (15) into equation (14) gives the money supply function for period $= 1, 2, 3, \ldots$:

$$M_t^s = \frac{1}{rr}(H_t - FR_t). \tag{17}$$

Nonborrowed reserves evolve over time (t) according to their supply schedule:

$$H_t = (H_{t-1})^{\rho_h}(\overline{H})^{(1-\rho_h)}\left(\frac{1+i_t}{1+\bar{i}}\right)^{-\nu_h}, \tag{18}$$

where $\overline{H}$ is the trend rate of growth of nonborrowed reserves and ρ_h determines the degree of persistence in reserve accumulation. With the elasticity of bank reserves ν_h approaching 0, the reserve-deposit (money) multiplier $(1/rr)$ determines the quantity of money stock created. If $\rho_h = 1$, equation (18) follows a random walk, and independent changes to reserves are not offset. Furthermore, the market rate (i_t) equals the target rate ($\bar{i}$) in the steady state, which implies that any level of reserves is independent from the interest rate.

3.3.2. The banks' demand for free reserves in a corridor system. The representative bank is assumed to be risk neutral. In each period, the bank trades central bank deposit balances (free reserves) with other banks in a competitive interbank market at the market rate i. Free reserves are assumed to be subject to stochastic fluctuations ("margins of error") after the interbank market closes ($FR + \varepsilon$).

The demand for clearing balances in the interbank market follows directly from the models of Woodford (2001) and Whitesell (2006). Given the discount rate on borrowed reserves and any interest paid on excess reserves, equation (19) expresses bank j's optimal (period t) demand for free reserves as a function of (1) the opportunity cost of holding a positive end-of-period reserve balance relative to lending that balance out in the interbank market, $i_t - i_t^{er}$, and (2) the opportunity cost of holding a negative end-of-period reserve balance (overdraft) and having to borrow from the central bank rather than from the interbank market, $i_t^{dr} - i_t^{er}$:

$$F(-FR_t) = \left(\frac{i_t - i_t^{er}}{i_t^{dr} - i_t^{er}}\right), \tag{19}$$

where $F(\cdot)$ is the symmetric distribution of the reserve account shock. A symmetric distribution implies that $i^{er} = (\bar{i} - s)$ and $i^{dr} = (\bar{i} + s)$; they form a floor and a ceiling around the target interest rate $\bar{i}$ (see figure 4). With full information, the bank sets its desired level of period reserves $FR^* = -\varepsilon$, where $FR - E(FR) = \varepsilon$ is the end-of-day stochastic "margin of error" and where $E(\varepsilon) = 0$.[19] As a result, net settlement balances at the central bank are zero ($FR = 0$) and $i = \bar{i}$ (Whitesell 2006, 1180). Notice that this equation represents a strict interest rate–targeting regime in circumstances where ν_h, in equation (18), approaches ∞: the equilibrium point where reserves become irrelevant for the determination of the money stock.

Following Woodford (2001) and Whitesell (2006), it is further assumed that $F(\cdot)$ is a cumulative standard normal distribution function $N(\cdot)$ with variance σ^2. Summing over all banks, indexed by j, gives the aggregate demand for reserves (depicted in figure 4):

$$FR_t = \sum_j FR_t(j) = -N^{-1}\left(\frac{i_t - i_t^{er}}{i_t^{dr} - i_t^{er}}\right)\sum_j \sigma_j = H_t - RR_t, \tag{20}$$

[19] The bank's funding costs are therefore minimized at $-i\varepsilon$.

where $\sum \sigma_j$ captures the degree of uncertainty of (private) banks. Given the spread s, the function $N^{-1}(\cdot)$ can be rewritten as

$$N^{-1}\left(\frac{1}{2}+\frac{i_t-\bar{i}_t}{2s}\right),$$

such that if $i_t = \bar{i}_t$, then $FR_t = -N^{-1}(1/2) = 0$ under zero aggregate uncertainty and a symmetric distribution function.

Whitesell (2006, 1181) highlights two important characteristics of greater uncertainty in the market for reserves. First, on the demand side, interbank uncertainty leads to interest rate smoothing (i.e., to a flattening of the demand curve for reserves); second, on the supply side, central bank uncertainty in reserve supply raises the volatility of interest rates. The larger the ratio of central bank uncertainty to private bank uncertainty, the fatter the tails of the resulting distribution of overnight interest rates (Whitesell 2006, 1182). We can approximate the demand for free reserves over time *t* according to

$$FR_t = (FR_{t-1})^{\rho_{fr}}(\overline{FR})^{(1-\rho_{fr})}\left(\frac{i_t-i_t^{er}}{i_t^{dr}-i_t^{er}}\right)^{-\nu_{fr}}, \tag{21}$$

where ν_{fr} determines the interest elasticity of free reserves (or the degree of interest rate smoothing in the interbank market for reserves). Under a strict interest rate peg, the market rate (i_t) is the target rate ($\bar{i}$), and the central bank saturates the interbank market with reserves to narrow the width of the corridor until the elasticity of demand for reserves is infinite (ν_h and $\nu_{fr} \to \infty$). In this case, free reserves are irrelevant, as are nonborrowed reserves, to the determination of the money supply (see, e.g., figure 4).

A higher elasticity of reserve demand (a flatter demand curve at equilibrium—near the target interest rate) occurs not only with a narrower corridor, but also with greater reserve balance uncertainty. And, as originally indicated by Poole (1968), a higher elasticity of reserve demand essentially means a wider dispersion of reserve balances. It is important to note that ν_{fr} captures only the *sensitivity* of reserves to market rate changes. We therefore allow a degree of persistence, ρ_{fr}, to free reserve accumulation. Setting $\rho_{fr} = 0$ implies that independent changes to free reserves are offset around some constant level of free reserves or constant trend growth. If $\rho_{fr} = 1$, free reserves follow a random walk. A degree of persistence $0 < \rho_{fr} < 1$ therefore captures the speed of mean reversion of free reserves, which acts as a proxy for precautionary adjustments of free reserves to interest rate changes. The demand for free reserves thus need not respond immediately to aggregate uncertainty implied by σ_{fr}.

As noted by Hetzel (1986, 12), any changes in reserve demand typically derive from credit expansion in a fractional reserve system.[20] Equating money supply with money demand, we get the following expression for equilibrium in the market for reserves:[21]

$$\underbrace{H_t - FR_t}_{\substack{\text{reserve supply} \\ \text{schedule}}} = \underbrace{rr\left[\left(\frac{i_t}{1+i_t}\right)^{-\frac{1}{\eta_m}}(P_tC_t)^{\frac{\eta_c}{\eta_m}}\right]P_t^{\left(\frac{\eta_m-\eta_c}{\eta_m}\right)}}_{\text{reserve demand schedule}} \quad (22)$$

The money supply schedule slopes upward because a higher interest rate spread between i_t and i_t^{dr} produces a lower level of free reserves and a higher level of borrowed reserves (i.e., excess reserves fall). The rise in (borrowed) reserves accommodates monetary expansion. Conversely, reserve demand is downward sloping and relates to households' demand for *real* money balances.

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[20] This cause of changes in demand is accurate given equation (16) and the accounting link between assets and liabilities.

[21] $RR = rrD = rrM^s = rrM^d$.

3.4. DSGE Model

The usual market-clearing conditions ensure that $Y_t = C_t$, $M_t^s = M_t^d$, and $B_t = 0$. We now can derive the Hetzel (1986) framework presented in equations (1) through (4). For simplicity, all equations are expressed as first-order Taylor approximations around the steady state.

3.4.1. Real money demand and the velocity of money. The money demand equation (10) can be expressed in first-order Taylor approximation form as

$$m_t^d - p_t = \frac{\eta_c}{\eta_m} c_t - \frac{1}{\eta_m} i_t, \tag{23}$$

where, for now, we have ignored the exogenous money demand shock $\xi_{m_d,t}$. Notice that after we impose market-clearing conditions in equilibrium ($c_t = y_t$ and $m_t^d = m_t^s = m_t$), equation (23) gives equation (2), where $\phi_y = \eta_c/\eta_m$ and $\varphi_i = 1/\eta_m$. Given the equation of exchange for velocity, $v_t = p_t + y_t - m_t$, we can rewrite equation (2) as follows:

$$\underbrace{\phi_i i_t + (1 - \phi_y) y_t}_{\text{velocity: } v_t} = p_t + y_t - m_t. \tag{24}$$

We estimate the model for parameters φ_i and φ_y and determine the robustness of the estimates to the literature on interest and income semi-elasticities and to that of velocity of money dynamics over the business cycle.

3.4.2. The Fisher relation. The first-order condition for bonds (equation [7]) can be combined with the flexible price equilibrium to give

$$r_t = r_t^n + \eta_c (E_t[\tilde{y}_{t+1}] - \tilde{y}_t), \tag{25}$$

where $\tilde{y}_t = y_t - y_t^n$ is the output gap. Here, y_t^n is the natural level of output commensurate with flexible prices and wages. Importantly, this version of the output gap is not the efficient level of output—markets are still imperfect (Vetlov et al. 2011, 10).[22]

The Fisher relationship (equation [2]) can then be rewritten, using equation (25), as

$$i_t = E_t[\pi_{t+1}] + [r_t^n + \eta_c(E_t[\tilde{y}_{t+1}] - \tilde{y}_t)]. \tag{26}$$

In Hetzel (1986), $r_t^n = b_0 + v_t$ and $\eta_c(E_t[\tilde{y}_{t+1}] - \tilde{y}_t)] = b_1[p_t - E(p_t|I_{t-1})]$, the latter equation representing unanticipated price realizations (analogous to output gap changes), where $b_1 < 0$. The variable v_t represents an exogenous real shock that shifts the supply curve (i.e., both output and its flexible price equivalent (natural output) change in response to technology shocks). Furthermore, in Hetzel (1986), unanticipated price changes produce the necessary short-run tradeoff between inflation and unemployment. For our rational expectations model, the short-run NK Phillips curve derived from the firm's decision problem achieves the same end.

3.4.3. A monetary rule for money stock determination. The linearized nominal money supply from equation (17) follows as

$$m_t \quad = \quad h_t + \frac{1}{rr}\left[\frac{FR}{M}(h_t - fr_t)\right], \tag{27}$$

in which the monetary rule (equation [3]) is defined in terms of a reserve aggregate. Specifically, nonborrowed reserves (h_t) evolve according to their linearized supply schedule:

$$h_t = \rho_h h_{t-1} - \nu_h(i_t - \bar{i}_t), \tag{28}$$

in which $\nu_h > 0$ determines the degree of interest rate smoothing. If $\bar{i}_t$ is used as the monetary authority's operational instrument ($\nu_h \to \infty$), then the reserve-money multiplier is irrelevant to

[22] This fact means that although there is no price stickiness, the steady-state markup and markup shocks are still nonzero. (See also Hetzel 2015.)

the determination of the money stock. In this case, the monetary authority can peg the nominal short-term interest rate i to some constant rate $\bar{i}$ or follow a dynamic Taylor-type rule $\bar{i} = i_t^T = f(i_{t-1}^T, \tilde{y}_t, \pi_t, \varepsilon_{i,t})$. We will use this monetary rule to emulate the pre- and post-2008 global financial crisis regimes. That is, between 1984 and 2007, the effective federal funds rate closely followed a Taylor-type rule (Taylor 1993; Orphanides 2002, 2003; Walsh 2010), whereas after 2008, the effective federal funds rate was pegged in a floor system by paying interest on reserves and saturating the banking system with reserves. In this case, the zero lower bound accentuated the peg as s approached 0 in equation (29).

The demand for free reserves follows from equation (21), as

$$fr_t = \rho_{fr} fr_{t-1} - \frac{\nu_{fr}}{s}(i_t - \bar{i}_t). \tag{29}$$

Notice that the symmetric spread (s) serves as a "slackness" parameter in the corridor system. For example, if we assume that $\nu_h = \nu_{fr}$, a narrower (wider) spread raises (lowers) the effective elasticity of free reserves relative to nonborrowed reserves. That is, a narrower spread implies a stricter interest rate peg, a flatter demand curve for free reserves, and a wider dispersion of reserves. In 2003, $s = 0.01$ (Whitesell 2006, 1179); on August 17, 2007, $s = 0.005$; and on March 18, 2008, $s = 0.0025$ (Walsh 2010, 534).[23]

3.4.4. System of linearized equations. Equations (24) through (29), plus the NK Phillips curve, $\pi_t = \beta\pi_{t+1} + \tilde{\kappa}\tilde{y}_t$; the output gap, $\tilde{y}_t = y_t - y_t^n$; the natural (flexible price equilibrium) output, $y_t^n = (1 + \eta_n)/(\eta_c + \eta_n)\xi_{z,t}$; the natural rate of interest, $r_t^n = \eta_c(E_t[y_{t+1}^n] - y_t^n)$; and a definition for inflation, $\pi_t = p_t - p_{t-1}$, form the system of equilibrium conditions. We also

[23] The first-order Taylor approximation yields, after imposing the symmetrical spread, an additional constant term on the right-hand side of equation (29): $\nu_{fr} ln2$, which has no material effect on the results.

assume that the policy rate target follows a Taylor-type rule ($\bar{i}_t = i_t^T$), which therefore gives 12 equations and 12 endogenous variables, excluding exogenous shock processes:

$$\text{Fisher relation} : i_t = E_t[\pi_{t+1}] + [r_t^n + \eta_c(E_t[\tilde{y}_{t+1}] - \tilde{y}_t)] \tag{30}$$

$$\text{Money demand} : m_t - p_t = \frac{\eta_c}{\eta_m} y_t - \frac{1}{\eta_m} i_t + \xi_{m_d,t} \tag{31}$$

$$\text{Consumption Euler equation} : r_t = r_t^n + \eta_c(E_t[\tilde{y}_{t+1}] - \tilde{y}_t) \tag{32}$$

$$\text{Natural rate} : r_t^n = \eta_c(E_t[y_{t+1}^n] - y_t^n) \tag{33}$$

$$\text{Money supply} : m_t = h_t + \phi_{rr}(h_t - fr_t) + \xi_{m_s,t} \tag{34}$$

$$\text{Nonborrowed reserve supply} : h_t = \rho_h h_{t-1} - \nu_h(i_t - i_t^T) \tag{35}$$

$$\text{Free reserve demand} : fr_t = \rho_{fr} fr_{t-1} - \frac{\nu_{fr}}{s}(i_t - i_t^T) \tag{36}$$

$$\text{Policy target rate} : i_t^T = \rho_i i_{t-1}^T + (1 - \rho_i)\left(\kappa_\pi \pi_t + \kappa_y \tilde{y}_t\right) + \epsilon_t^i \tag{37}$$

$$\text{NK Phillips curve} : \pi_t = \beta E_t[\pi_{t+1}] + \tilde{\kappa}\tilde{y}_t \tag{38}$$

$$\text{Output gap} : \tilde{y}_t = y_t - y_t^n \tag{39}$$

$$\text{Natural output} : y_t^n = (1 + \eta_n)/(\eta_c + \eta_n)\xi_{z,t} \tag{40}$$

$$\text{Inflation definition} : \pi_t = p_t - p_{t-1}, \tag{41}$$

where $\phi_{rr} = \frac{FR}{rrM} = \frac{FR}{RR}$. Of course, the general equilibrium can be simplified further to a system of 7 equations and 7 observables. In this case, we would have Hetzel's (1986) 4-equation model with endogenous equations for free reserves and the target policy rate and a short-run NK Phillips curve instead of unanticipated price changes.[24] For the discussion of our results, we choose to expand the number of variables.

Corresponding to the 4-equation model in Hetzel (1986) (equations [1]–[4]), we capture four exogenous sources of shocks to the economy: a money demand shock, $\xi_{m_d,t}$; a money supply

[24] In Hetzel's model, the IS curve shifts with unanticipated price changes as reflected in the output gap (1986, 2).

shock, $\xi_{m_s,t}$; a technology shock, $\xi_{z,t}$; and an interest rate target shock, ϵ_t^i. Notice that we exclude the standard price-markup shock in the NK Phillips curve, which implies that firm price markups are constant. The idea here is to show that shifts in aggregate demand that arise from the interaction between money supply and demand and the policy rate target—that is, nominal shocks—are well able to account for business cycle fluctuations. As will be shown, the sticky price equation is still key to generating real effects in a rational expectations framework. A nonseparable utility function, as in Benchimol and Fourçans (2012), would ensure temporary real effects from monetary fluctuations without sticky pricing, but the point of this paper is to show that the standard NK framework—with separable utility, monetary neutrality, and sticky prices—assumes a special case in a continuum of monetary regimes. As such, we show that the type of monetary regime significantly alters the transmission mechanism of shocks through the economy.

4. Estimation

The model is estimated by Bayesian methods over the period 1959Q1–2007Q3. This estimation period is chosen for two reasons. First, we want to simulate the counterfactual scenario of a reduction in free reserves, given the estimated structure of the model economy before the onset of the Great Recession and the structural break in free reserves in 2007Q4. Second, the long sample period serves to highlight the empirical and theoretical coherence of the model. We also compare our results with an estimated version of the model over the period 1984Q1–2007Q3, corresponding to the Great Moderation. We set the prior parameter values and distributions of the model to fit the US economy following the example of Smets and Wouters 2007, Ireland 2009, and Walsh 2010. All persistence parameters are set to 0.8, with standard deviations of 0.10. We use US data obtained from St. Louis Federal Reserve Economic Data (FRED) over the period 1959Q1–2007Q3 to calibrate the relevant steady-state ratios for the banking sector and to estimate the model. The discount factor, $\beta = (1 + r)^{-1}$, is fixed at 0.98, corresponding to a steady-state quarterly real interest rate of 2 percent. The output gap, inflation, money, and the nominal interest rate are treated as observables, linearly detrended following Benchimol and Fourçans (2012):

π_t: log-difference of GDP implicit price deflator (year-on-year)

$\tilde{y}_t$: difference between the log of real GDP per capita and real potential GDP per capita

m_t: log-difference of MZM money stock per capita

i_t: short term (three-month) nominal interest rate.

Given that the three-month Treasury bill (market) rate tracks the effective funds rate over the sample period very closely and that the objective of the policymaker is to influence market interest rates, we use the three-month Treasury bill rate to represent the nominal interest rate (i). The equation $\bar{i} = i^T$ therefore represents the policy instrument (rule or target) that guides policy decisions.

Table 1 reports the prior distribution, means, and standard deviations, as well as the posterior means, medians, and confidence intervals, of the estimated parameters.[25] The estimated structural parameters for households and firms are stable across both estimation periods. The value $\eta_m = 5$ implies an interest elasticity of money demand of −0.2, which means that a 100-basis-point increase in the interest rate reduces the quantity of money demanded by 20 percent. The relative risk aversion parameter η_c is less than η_m in both estimation periods and falls in the range of 3–5, which implies an intertemporal elasticity of substitution of between 0.2 and 0.33. The elasticity of labor supply and labor's share in production are

[25] See the supplementary appendix for diagnostic statistics and estimation results.

approximately unity and two-thirds. A value of θ of approximately 0.875 implies that firms adjust their prices, on average, every eight quarters.

The parameters characterizing the monetary regime show that both free reserves and nonborrowed reserves are highly elastic over the Great Moderation period; however, nonborrowed reserves have a greater influence over the money stock in the full-sample estimate. This finding corresponds well with the evolution of the Federal Reserve's monetary operating procedures toward an interest rate–targeting regime (Walsh 2010, 547–53). Given this slant toward an (intermediate) interest rate target since 1959Q1, money demand shocks largely "determine" the price level, which is highly persistent.[26] Innovations to the target policy rate can best be described as a highly smoothed AR(1) process. As such, cyclical fluctuations to the short-term nominal interest rate are largely determined endogenously through money demand and supply.

[26] See, for example, table 2, columns 6 through 9, and the price-level historical decomposition (figure A5) in the supplementary appendix. By "determine," we mean that money supply accommodates demand at the given interest rate.

Table 1. Bayesian Estimation of Structural Parameters

	Parameter	Prior distribution			1959Q01–2007Q03 Posterior distribution			1984Q01–2007Q03 Posterior distribution		
		Type	Mean	Std. dev	Mean	90%	HPD int.	Mean	90%	HPD int.
Households										
η_c	Relative risk aversion	Normal	2	0.50	4.539	4.080	5.119	3.635	3.045	4.174
η_m	Inverse elasticity of money demand	Normal	5	0.20	5.024	4.675	5.349	4.920	4.619	5.237
η_l	Inverse elasticity of labor supply	Normal	1	0.10	0.983	0.674	1.311	0.980	0.610	1.296
β	Discount factor		0.98							
Firms										
α	Labor's share in production	Beta	0.67	0.05	0.672	0.594	0.750	0.675	0.590	0.750
ϑ	Price stickiness	Beta	0.75	0.05	0.881	0.867	0.895	0.873	0.852	0.895
Monetary regime										
ν_h	Elasticity of nonborrowed reserves	Inv. Gamma	1	10	2.427	0.272	5.750	11.374	5.935	17.977
ν_{fr}	Elasticity of free reserves	Inv. Gamma	10	10	55.108	35.742	76.365	12.239	8.156	17.861
ρ_h	Nonborrowed reserve persistence	Beta	0.8	0.10	0.638	0.505	0.770	0.437	0.366	0.522
ρ_{fr}	Free reserves persistence	Beta	0.8	0.10	0.175	0.111	0.234	0.201	0.130	0.269
κ_π	Weight on inflation	Gamma	1.5	0.20	1.428	1.115	1.726	1.500	1.208	1.814
κ_y	Weight on output gap	Beta	0.5	0.20	0.559	0.233	0.885	0.529	0.208	0.853
FR/RR	Ratio of free reserves to req. reserves				0.003			0.017		
AR(1) coefficients										
ρ_z	Technology	Beta	0.8	0.10	0.745	0.711	0.777	0.763	0.722	0.804
ρ_i	Interest rate target	Beta	0.8	0.10	0.998	0.996	1.000	0.996	0.992	0.999
ρ_{ms}	Money supply	Beta	0.8	0.10	0.835	0.804	0.868	0.770	0.723	0.818
ρ_{md}	Money demand	Beta	0.8	0.10	0.999	0.998	1.000	0.992	0.986	0.999
Standard deviations										
ϵ_z	Technology	Inv. Gamma	0.02	2.00	0.066	0.056	0.075	0.038	0.031	0.044
ϵ_i	Interest rate target	Inv. Gamma	0.02	2.00	0.003	0.003	0.004	0.005	0.004	0.005
ϵ_{ms}	Money supply	Inv. Gamma	0.02	2.00	0.172	0.130	0.213	0.079	0.059	0.101
ϵ_{md}	Money demand	Inv. Gamma	0.02	2.00	0.034	0.031	0.037	0.018	0.016	0.020
Log-data density		2200.48						1243.000		
Acceptance ratio range		[26%; 28%]						[22%; 25%]		
Observations		195						95		

Source: Authors' calculations.

5. Empirical Findings for the US Business Cycle

5.1. Impulse Response Functions

Figures 5 and 6 show the impulse responses to a technology shock, an interest rate target shock, a money supply shock, and a money demand shock for both the full sample period (1959Q1–2007Q3) and the Great Moderation period (1984Q1–2007Q3). Two overall observations are worth highlighting. First, for all four shocks, the dynamic responses of the variables are closely consistent across both sample periods. Second, nominal money balances and the degree of price stickiness consistently determine the dynamic adjustment of the price level. Therefore, to make our discussion concise, we will focus on the dynamics of the full sample.[27]

The nominal money supply shock (top panel, figure 5) highlights the effect of sticky prices on real variables. An initial 1.63 percent increase in the money supply results in a 0.95 percent increase in the price level, but only after 6 quarters. As a result, the monetary stimulus pushes the real interest rate down 1.3 percentage points and generates a cumulative positive output gap of 4 percent. A money demand shock (bottom panel, figure 5), on the other hand, affects the economy negatively, as households demand higher *real* money balances. Prices therefore fall below trend as households substitute away from consumption goods to money. This negative demand shock is somewhat offset by a rise in the nominal stock of money. In the flexible equilibrium, the price level would adjust downward to immediately satisfy the increase in demand for real money balances.

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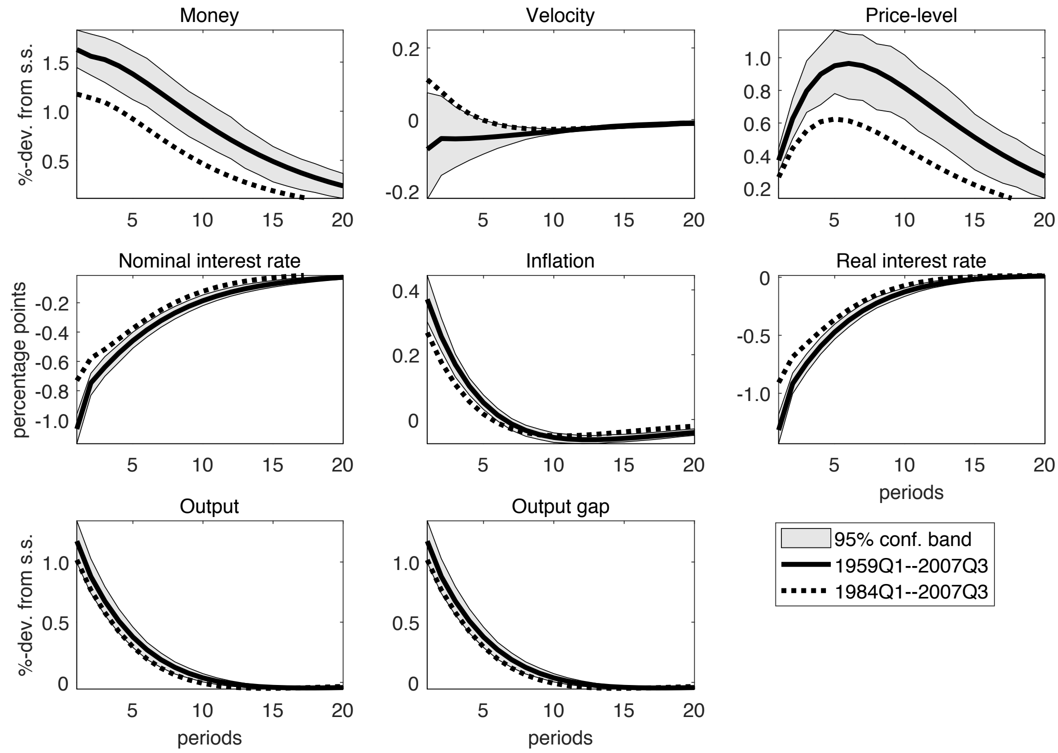
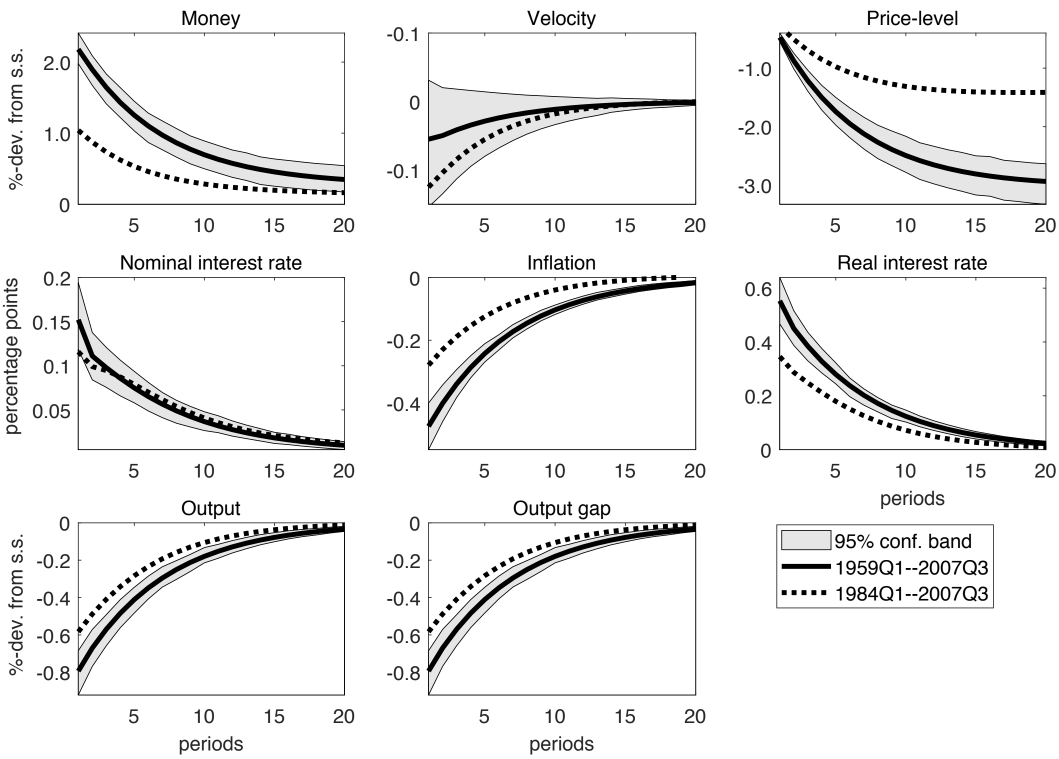
[27] Results for the Great Moderation period and for comparisons with alternative regimes represented in table 2 are available in the supplementary appendix.

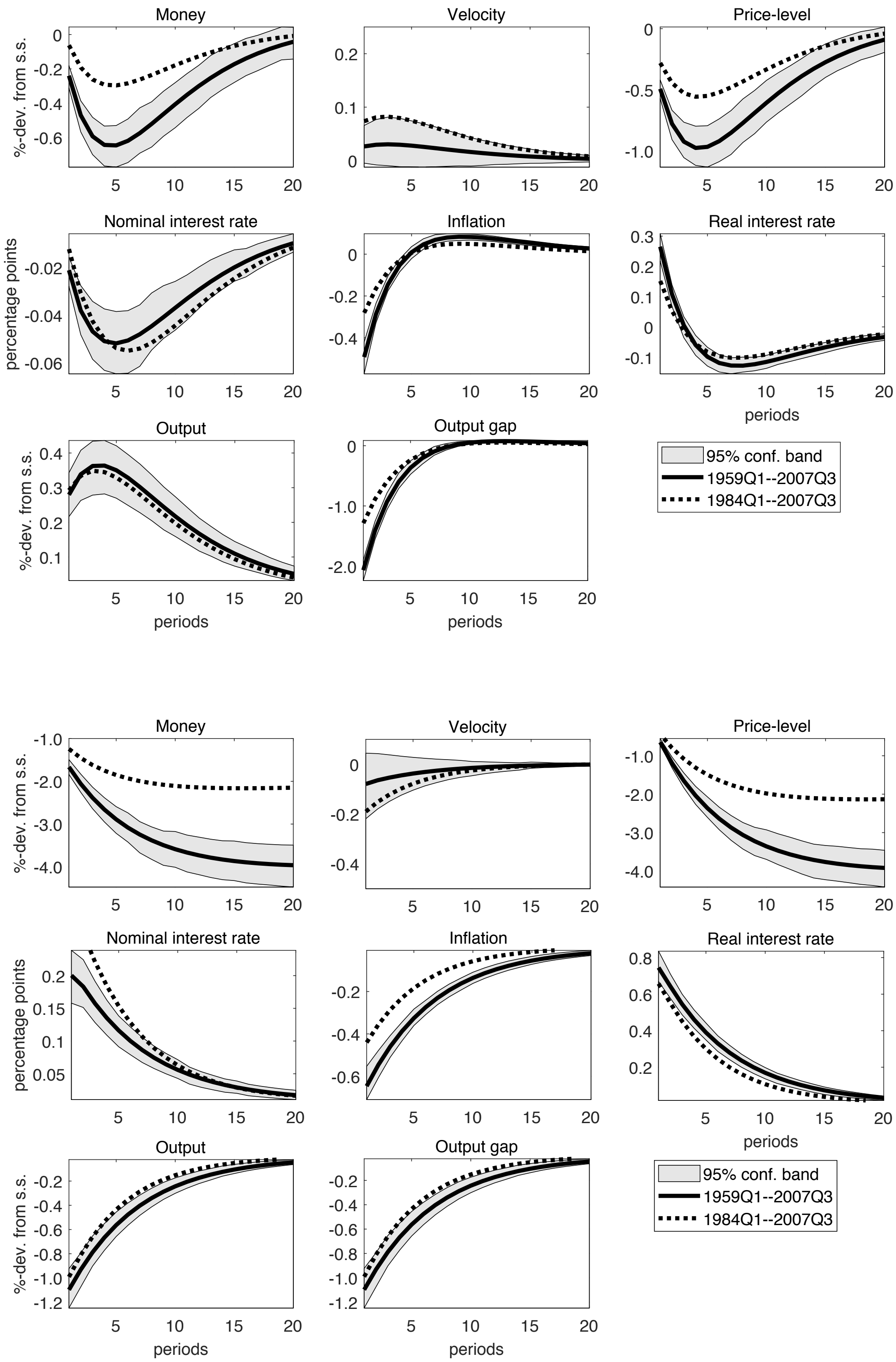
Figure 5. Impulse Response to Positive Money Supply Shock (Top) and Positive Money Demand Shock (Bottom)





Note: s.s. = steady state.

Figure 6. Impulse Response to Positive Technology Shock (Top) and Positive Interest Rate Target Shock (Bottom)



Note: s.s. = steady state.

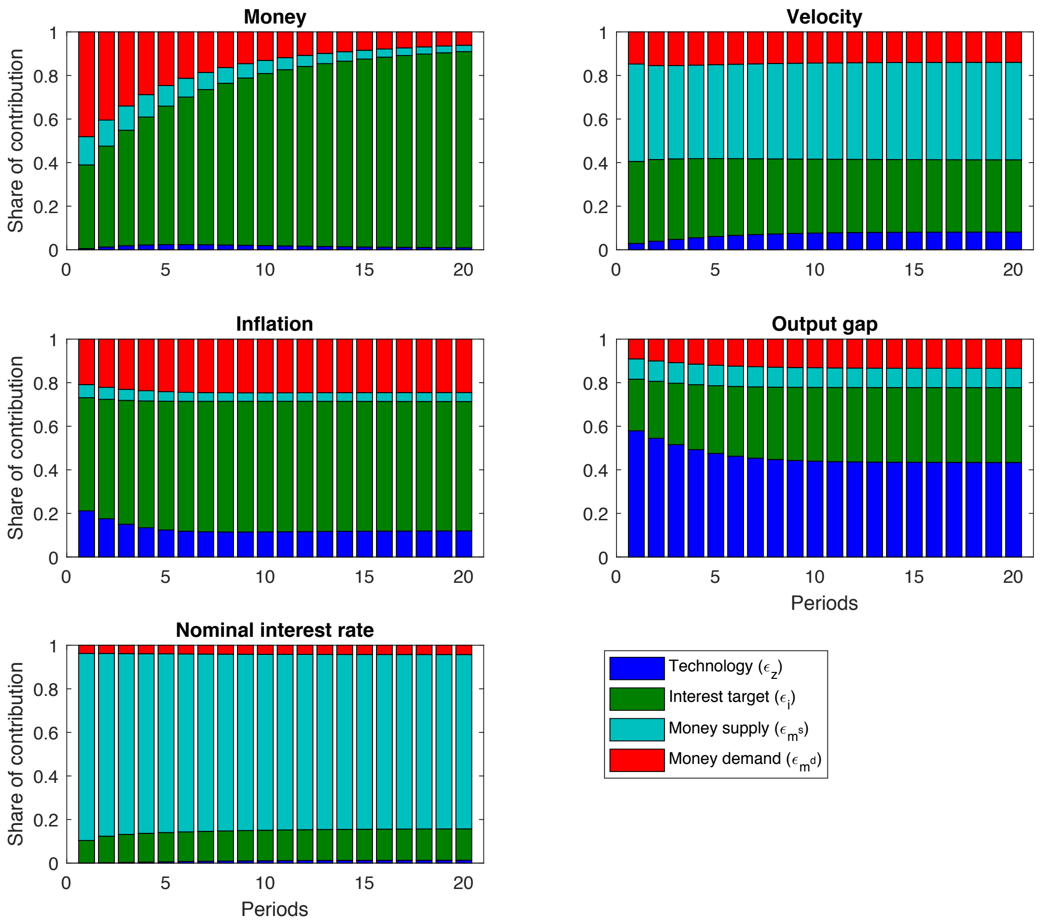
A positive technology shock (top panel, figure 6) generates greater output, lower inflation, and a negative output gap. The downward adjustment of the nominal interest rate is small, and the economy converges from an initial negative output gap of 2 percent to its flexible price equilibrium after 8 quarters. The net effect on real money balances is positive. A positive shock to the target interest rate (bottom panel, figure 6) follows a standard NK monetary policy shock. A 21-basis-point increase in the short-term nominal interest rate reduces output by 1.1 percent and inflation by 0.64 percentage points. The higher interest rate reduces real money balances (equation [23]) and generates a persistent decline in both nominal money supply and the price level.

5.2. Variance Decomposition

Figure 7 reports the contributions of the structural shocks to the forecast error variance of money, velocity, inflation, the output gap, and the nominal interest rate up to a 20-quarter horizon. Results are presented for the full sample period: 1959Q1–2007Q3. As such, the results represent a monetary regime with some degree of interest elasticity to nonborrowed reserves ($\nu_h = 2.43$).

The contributions of the shocks to velocity are remarkably stable across the forecast horizon, with the money supply shock and the interest rate shock contributing 44 percent and 34 percent of the forecast error variance, respectively. The effect of technology (supply-side) shocks on the output gap is large but declines steadily for 8 quarters after the shock. More than half of output deviations from the flexible price equilibrium are attributable to nominal shocks (54 percent). As will be shown in section 6.3, monetary authorities can easily eliminate any nominal shock to inflation ($\pi_t = p_t - p_{t-1}$), the output gap ($\tilde{y}_t = y_t - y_t^n$), and nominal income ($p + y$), whereas supply-side (technology) shocks present a nontrivial tradeoff between nominal income stability and inflation-output gap stability. Exogenous shocks to the policy rule contribute the most to inflation variance (59 percent), with about a quarter of this variance originating from nominal money demand shocks. Finally, there is a clear strong liquidity effect between nominal interest rates and the nominal money stock. On one hand, money supply shocks contribute the bulk of the forecast error variance of nominal interest rates (81 percent). On the other hand, interest rate shocks contribute the bulk of variation in the money stock over the forecast horizon (75 percent). That said, the interaction between money supply and money demand is still important: the on-impact contribution of money demand and money supply to money stock variance is 61 percent, which declines steadily over the forecast horizon.

Figure 7. Variance Decomposition (1959Q1–2007Q3)



Source: Authors' calculations.

Overall, the prevalence of exogenous interest rate target shocks corroborates the consistency of the Taylor rule in approximating interest rate responses to output and inflation over the US business cycle. Moreover, corresponding to the estimated structural parameters, there is evidence of a strong liquidity effect over the entire forecast horizon. In addition, the interaction between money supply and demand does matter over the short run to the money stock.

5.3. Historical Decomposition

Figures 8 through 10 provide the historical shock decomposition of the main macroeconomic variables. Here, we focus on how the structural shocks predict the US business cycle over the sample period 1959Q1–2007Q3. To assist our discussion, each figure has been subdivided into Federal Reserve governor tenures: William McChesney Martin (1951Q2–1970Q1), Arthur Burns and William Miller (1970Q1–1979Q2), Paul Volcker (1979Q3–1987Q2), Alan Greenspan (1987Q3–2006Q1), and Ben Bernanke (2006Q1–2014Q1).[28]

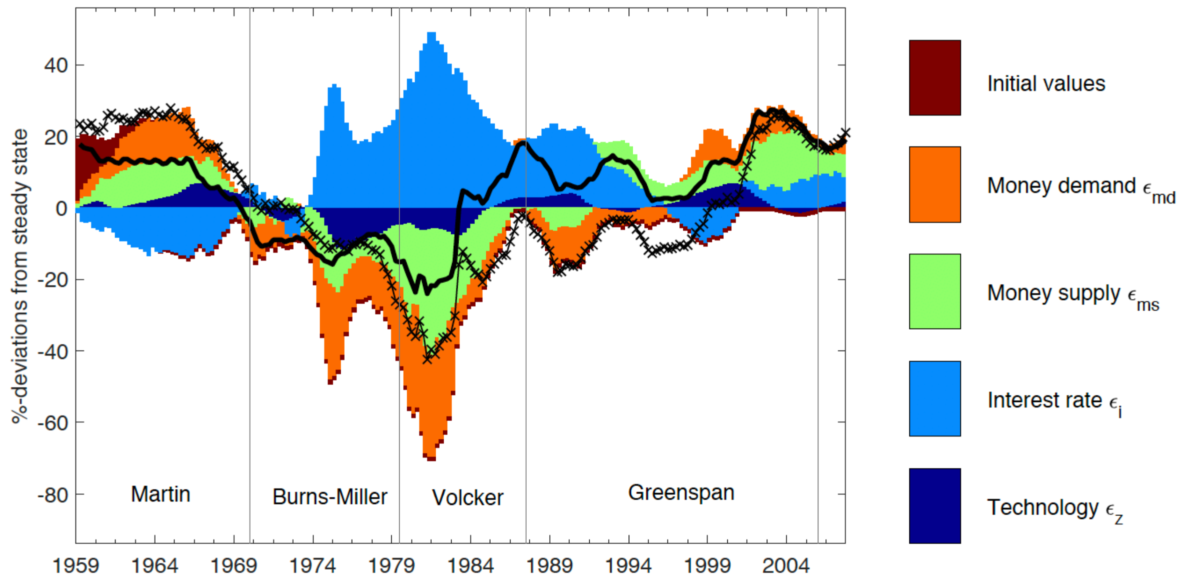
The dawn of the Great Inflation period came toward the end of Martin's tenure (Bremner 2004). In fact, from as early as 1963, Martin expressed his deep concern that the United States was heading for "an incipient expansion at an unsustainable rate" and an "inflationary mess" (Bremner 2004, 184, 191). The US output gap began to rise rapidly in 1964 and stayed positive until the end of Martin's tenure in 1969 (see figure 9). Over the same period, inflation rose from a low and stable average of 1.25 percent to 5 percent. First an adverse technology shock and then a negative money demand shock contributed to the overheating economy. Figure 8 shows how velocity rose sharply from 1966 in three consecutive bouts over the Martin, Burns-Miller, and Volcker tenures. Throughout these

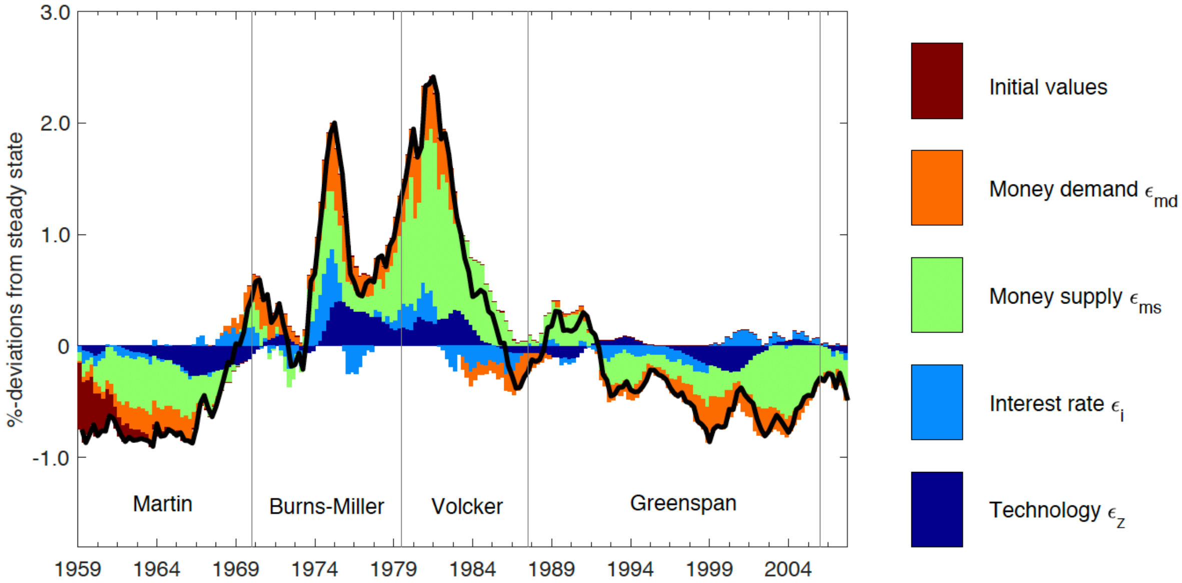
[28] See Fernández-Villaverde, Guerrón-Quintana, and Rubio-Ramírez (2010) for a similar, and more detailed, reading of recent US monetary history.

periods, the interaction between money supply and demand reinforced spending (velocity) and nominal growth so that the money stock (MZM) fell steadily as a share of nominal GDP (cross-marker line). Throughout the sample period up to 2000, we can observe a clear liquidity effect between interest rate shocks and shocks to money supply and demand (top panel, figure 8).

It is a common fallacy to associate high (low) interest rates with excessively tight (loose) monetary policy. As the Fisher relation (equation [30]) suggests, high levels of inflation are associated with high nominal interest rates. The impulse responses from figure 6 (section 5.1) show, however, that expansionary monetary policy (i.e., negative shocks to the policy target rate) should *raise* the money stock, inflation, and the output gap (as shown in figures 8 and 9). How, then, can we reconcile the Great Inflation period of *high* nominal interest rates with upward pressure on the money stock, inflation, and the output gap?

Figure 8. Historical Decomposition (1959Q1–2007Q3): Money (MZM, Top) and Velocity (Bottom)





Notes: Solid lines represent the percentage deviation of the latent variable from its long-run trend (the steady state). The cross-marker line represents actual data for the log of the money-to-output ratio. The *growth rate* of money is the observable variable for estimation.

Figure 9. Historical Decomposition (1959Q1–2007Q3): Inflation (Top) and Output Gap (Bottom)

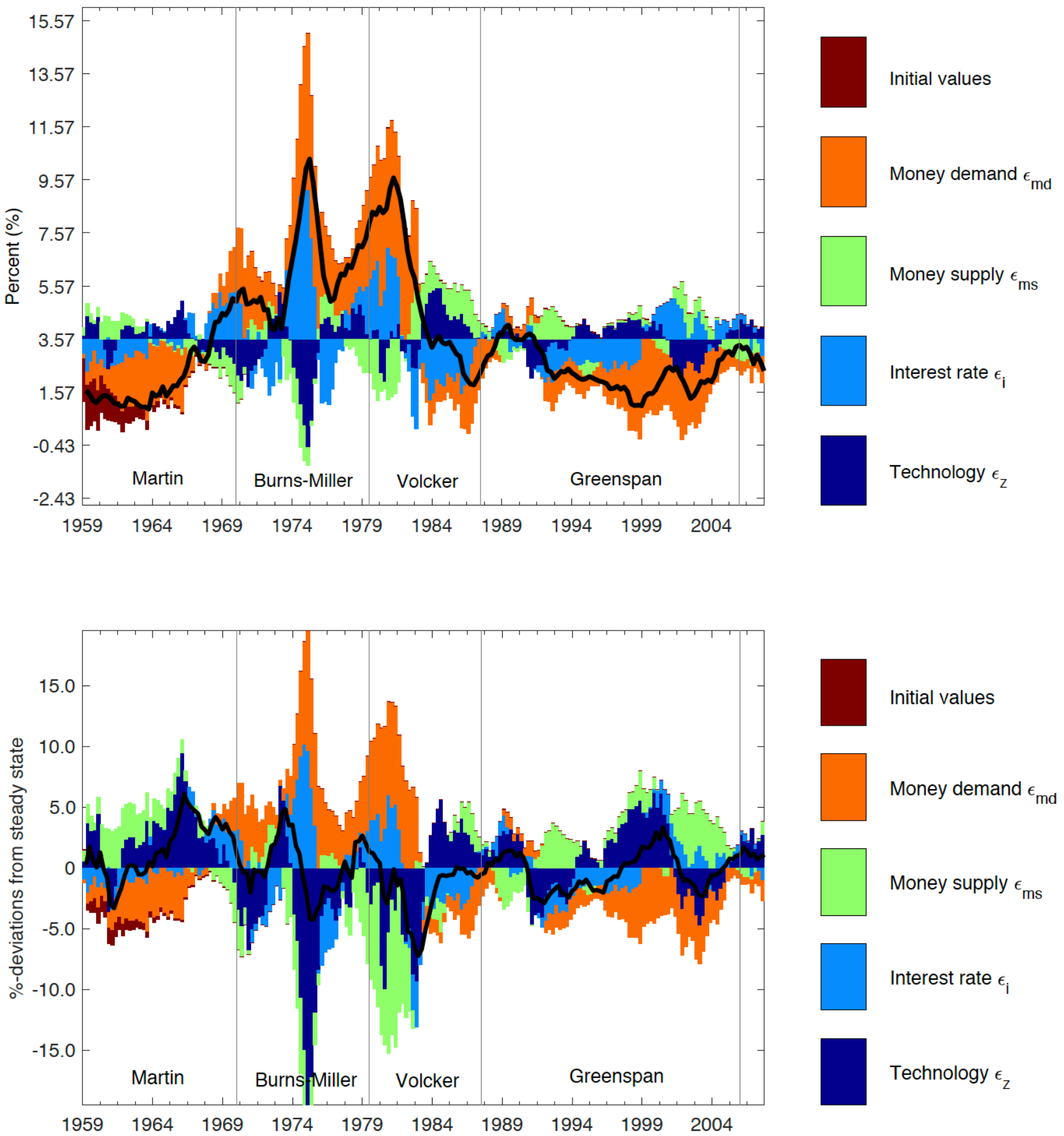
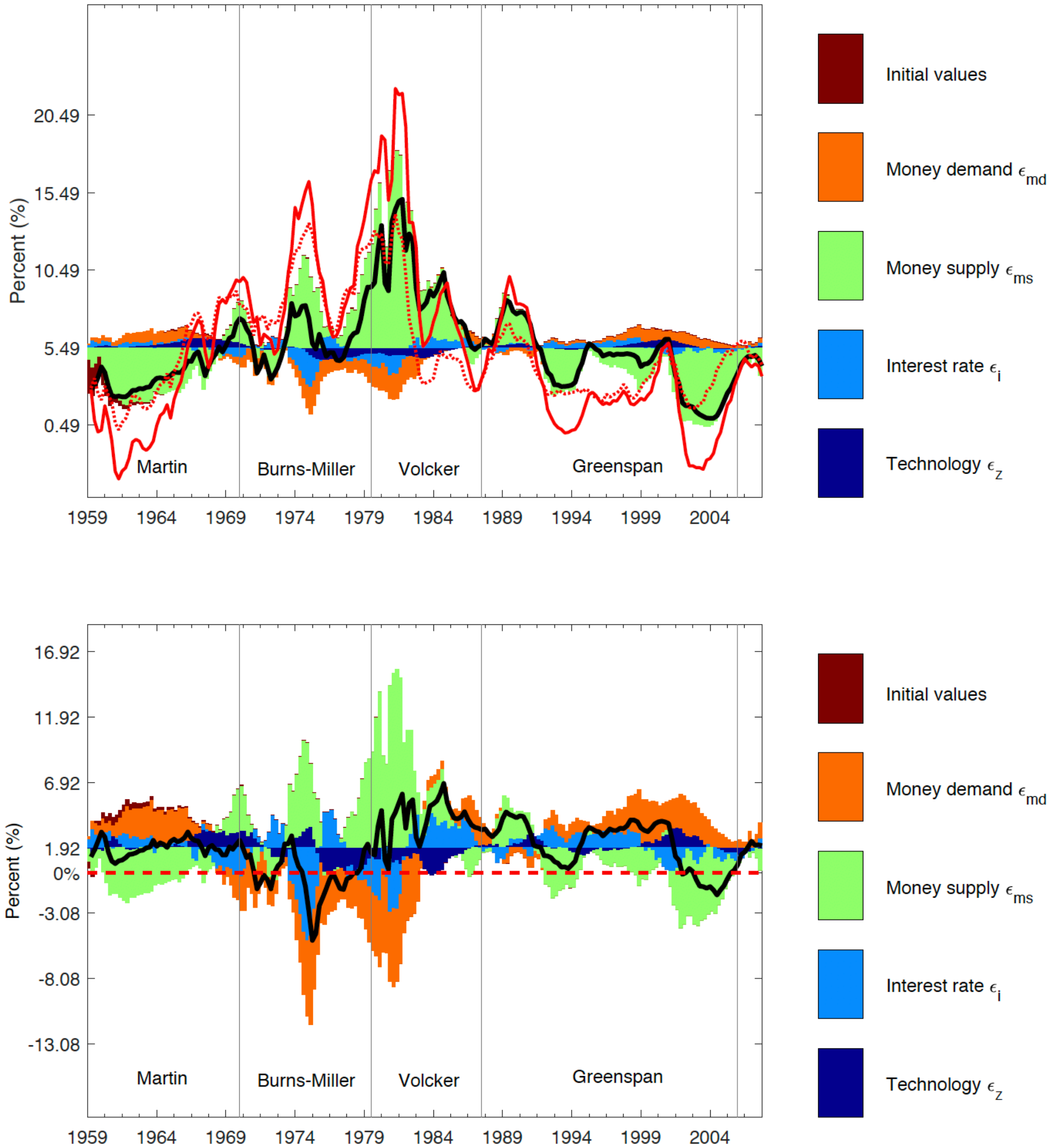


Figure 10 plots the implied deterministic Taylor rule (DTR) fit from the estimated monetary policy rule (equation [37]) using the data for the output gap and inflation. Here, we can clearly see that for the entire Burns-Miller tenure, the observed short-term nominal interest rate was below the estimated model's implied policy rate level—indicating an accommodative policy stance (i.e., successive negative shocks to the target interest rate, i^T).[29] The well-established findings of Clarida, Gali, and Gertler (2000) and Collard and Dellas (2008) suggest that this "violation" of the Taylor principle in the 1970s triggered self-fulfilling inflation expectations. Significant endogenous velocity fluctuations (bottom panel, figure 8) and exogenous money demand shocks (top panel, figure 9) confirm this narrative. This expansionary policy narrative is further corroborated by the real interest rate in the bottom panel of figure 10—which fell below zero for much of the 1970s (−4.6 percent by 1975Q1). In fact, Fernández-Villaverde, Guerrón-Quintana, and Rubio-Ramírez (2010, 13) find, by using time-varying parameter estimates on inflation in the Taylor rule, that the Federal Reserve under Burns and Miller put significantly less weight on inflation (less than 1) than it did under Martin and Volcker (± 2).

A few years after Volcker's appointment, we see a marked decline in velocity (spending), inflation, and nominal interest rates. But, as suggested in table 1, a relatively high responsiveness between nonborrowed reserves and the policy rate ($\nu_h = 2.43$) corresponds to the dominance of money supply shocks on the sustained high interest rate levels going into the Volcker period. The output gap closed by 1985, and the ratio of money to nominal income rose steadily into the Great Moderation period.

[29] Comparing the solid red line with the dotted red line in figure 10 indicates that interest rate smoothing (i.e., persistence in the policy rate) was an important factor in the spillover of expansionary policy into the Volcker period.

Figure 10. Historical Decomposition (1959Q1–2007Q3): Nominal Interest Rate (Top) and Real Interest Rate (Bottom)



Notes: The solid red line represents deterministic Taylor rule (DTR) fit. The dotted red line represents DTR fit without interest rate smoothing. The dashed red line represents the zero real interest rate level.

From the mid-1980s until 2007, the successful reining-in of inflation led to successive bouts of benign macroeconomic shocks and stable business cycle fluctuations (see also Sims and Zha 2006). Although it is clear that the Great Inflation can be attributed largely to a lack of policy responsiveness to inflation—and, in particular, to *expected* inflation—this was not the case in the later days of the Great Moderation. Signs that the US economy was on an unsustainable trajectory began after 2001. Figure 10 shows the well-known example that the Fed kept rates too low for too long from 2002 to 2005: the nominal interest rate was lower than what the Taylor rule prescribed (top panel: dotted red line versus solid black line),[30] and the real interest rate fell below zero (bottom panel). During this period, the Fed accommodated a positive technology shock (figure 9) by raising the money supply. As inflation picked up, the negative output gap closed and turned positive leading into Bernanke's tenure—a mere year and a half before the first signs of the global financial crisis (St. Louis Fed 2016).

Without going into too much more detail, figures 8 to 10 suggest that the model does well to explain stylized business cycle facts for the US economy. Section 6 presents counterfactual simulations of alternative monetary policy regimes to assess the effectiveness of the current strict interest rate–targeting regime and whether a more flexible monetary regime is preferable: that is, whether there is a more preferable optimal combination policy.

6. Counterfactual Simulations

6.1. The Behavior of Alternative Monetary Regimes

To illustrate how the choice of monetary regime changes the behavior of the economy, table 2 shows the variance decomposition of all the macroeconomic variables for two types of endogenous monetary regimes. The four shocks are a technology shock, an interest rate target shock, a money supply shock, and a money demand shock. The structural parameters and sizes of the shocks are calibrated to the posterior estimates of the Great Moderation period (see

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[30] It is interesting to note here that the Fed's historical preference to smooth the interest rate *target* (solid red line) was not at odds with the decision to keep rates low during the 2002–2005 period. Of course, data come with lag and can often be revised. It is likely that both of these factors contributed to the Fed's policy stance.

table 1). For the interest rate–targeting regime, the elasticity of reserves is high: $\{\nu_h, \nu_{fr}\} = \{11, 12\}$. The monetary authorities therefore prefer to minimize (smooth) interest rate variations by allowing the money supply curve to flatten, which leaves money and reserves endogenous and thus weakly relevant for price determination. For the interest-sensitive monetary regime, $\nu_h = 1$ and $\nu_{fr} = 1$. Here, an exogenous shock to money supply directly influences the interest rate and generates real effects in the short-run. The following result goes to show that the choice of monetary regime has a significant influence on the role of monetary aggregates and that money may be neutral in the long run, but sticky prices generate the distortion necessary for it to have a significant influence over real economic variables.

First, to illustrate price level determination, we show the variance decomposition of the nominal and real variables under a strict interest rate–targeting regime, as observed over the actual Great Moderation period ($\nu_h = 11; \nu_{fr} = 12$) and in a counterfactual flexible (interest-sensitive) monetary regime ($\nu_h = \nu_{fr} = 1$). It is immediately clear that long-run variations in money, velocity, prices, and output are mainly determined by shocks to the target interest rate under the Great Moderation monetary rule. But given that money supply shocks still have a strong effect on the interest rate, exogenous innovations in money supply still have a significant impact on real variables because of sticky price adjustment. The final two columns clearly show that nominal (monetary) shocks in an NK model are neutral under flexible prices. A flexible (interest-sensitive) monetary rule, in contrast, highlights the importance of exogenous innovations in money supply and demand to business cycle fluctuations. Here, money supply and demand interact to determine variation in inflation and the price level over the entire forecast horizon. And, as shown analytically by McCallum (1986), we see that the type of monetary regime can influence the transmission mechanism of monetary policy dramatically *without changing the dynamic adjustment path of the* *economy*.[31] A strict interest rate–targeting regime becomes problematic, however, if the operational instrument—the policy rate—cannot lower the real interest rate enough. It is the monetary regime, not the zero lower bound, that renders monetary policy ineffective.

6.2. An Alternative Economic Recovery?

This section provides two counterfactual scenarios for the economic recovery of the United States from the Great Recession. For the entire post–Great Recession period, we assume that the de facto monetary regime follows a strict interest rate (floor) regime such that the stock of money is not driven by changes in bank reserves.

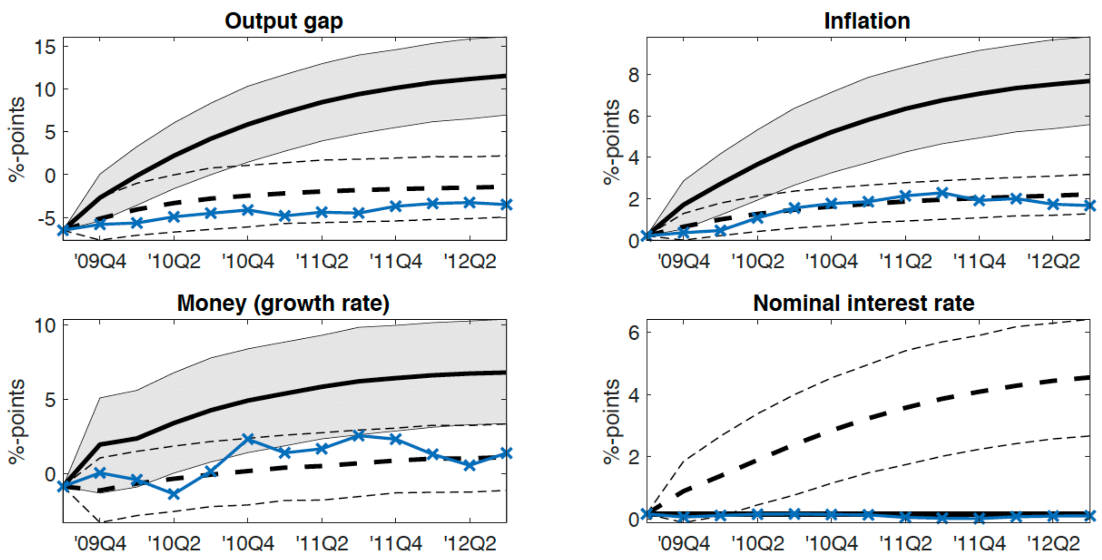
For our first counterfactual exercise, figures 11 and 12 compare conditional and unconditional forecasts of the output gap, inflation, money growth, and nominal interest rate to the actual data for the recovery period 2009Q3–2012Q3. Here we reestimate the model for the Great Moderation period, up to the trough of the Great Recession and the imposition of the effective zero lower bound on nominal interest rates (1984Q1–2009Q2). For both forecasts, we assume the Fed controls the policy rate to obtain the given constrained path of the nominal interest rate target (figure 11) and the inflation rate target (figure 12). Overall, the unconditional forecasts of the model do well to capture the paths of inflation and money growth. Although the trajectory of the actual output gap is captured, the model predicts a more speedy economic recovery: a −2 percent output gap instead of the observed −4 percent output gap by 2012Q3. In stark contrast to actual developments, the model predicts the normalization of nominal interest rates to slightly above 4 percent by 2012Q3.

[31] See figures A2, A3, and A4 in the supplementary appendix.

Table 2. Variance Decomposition of Business Cycle under Two Monetary Regimes (in Percent)

	Great Moderation monetary rule (v_h = 11; v_{fr} = 12)				Interest-sensitive monetary rule ($v_h = v_{fr}$ = 1)				Flexible prices ($v_h = v_{fr}$ = 1)			
Shock	ϵ_z	ϵ_i	$\epsilon_m s$	$\epsilon_m d$	ϵ_z	ϵ_i	$\epsilon_m s$	$\epsilon_m d$	ϵ_z	ϵ_i	$\epsilon_m s$	$\epsilon_m d$
money (m)	0.09	98.23	1.06	0.62	0.02	3.6	96.07	0.31	0.59	2.56	96.85	0
velocity (v)	19.3	48.42	12.5	19.78	21.58	0.09	56.3	22.03	49.85	0.05	49.99	0.12
prices (p)	0.26	83.36	0.38	16	0.52	1.44	10.84	87.19	3.6	1	35.03	60.37
output (y)	12.1	43.29	30.41	14.21	3.83	0.17	87.5	8.5	100	0	0	0
real rate (r)	2.72	37.62	50.03	9.63	0.46	0.17	95.06	4.31	100	0	0	0
nominal rate (i)	1.23	18.09	77.24	3.43	0.26	0.14	97.27	2.32	35.73	0.06	64.05	0.16
nominal target rate (i^T)	0.02	99.92	0.02	0.05	0.01	99.73	0.18	0.08	0.01	99.97	0.01	0.02
inflation (π)	11.79	55.26	12.64	20.31	4.33	0.25	73.95	21.47	11.35	0.16	83.12	5.37
output gap ($\tilde{y}$)	31.66	33.65	23.64	11.04	6.19	0.17	85.35	8.29	100	0	0	0
natural output (y^n)	100	0	0	0	100	0	0	0	100	0	0	0
natural rate (r^n)	100	0	0	0	100	0	0	0	100	0	0	0
nonborrowed reserves (h)	0.07	93.78	5.69	0.45	0.14	45.84	52.53	1.49	6.11	81.99	11.82	0.08
free reserves (fr)	0.07	93.23	6.23	0.46	0.14	42.37	55.97	1.52	6.77	80.08	13.07	0.08

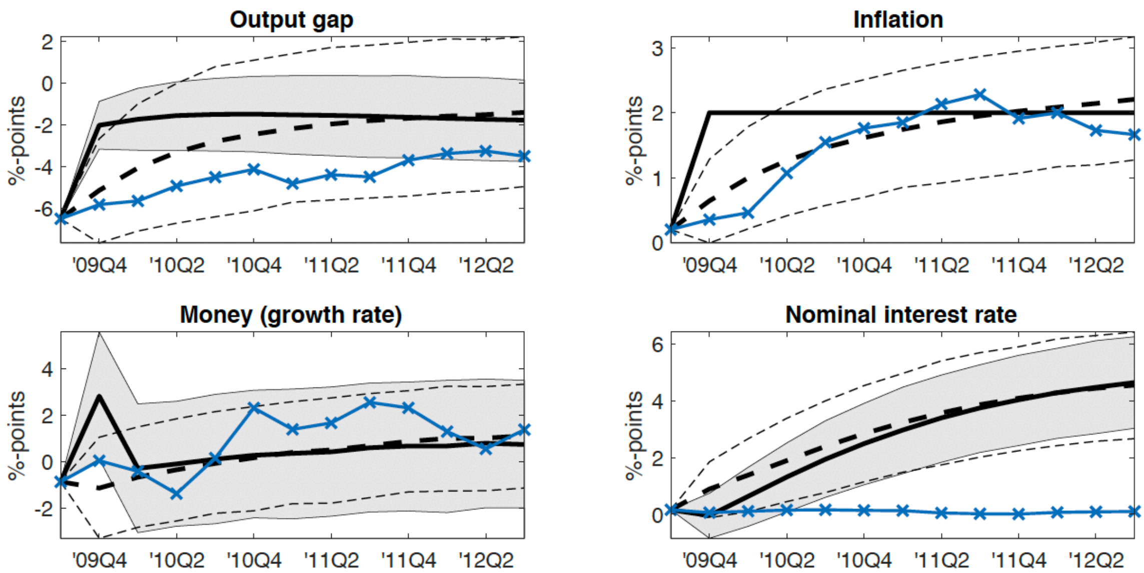
Figure 11. The Recovery Period 2009Q3–2012Q3 Conditional on Actual Fed Interest Rate Path near ZLB



Note: Forecast conditional on actual Federal Reserve interest rate path near the zero lower bound (solid line). Unconditional forecast (dashed line). Actual data (cross-marker line). Plotted with 90 percent confidence intervals.

Figure 11 provides the counterfactual paths of the output gap, inflation, and money growth for the Great Moderation monetary regime under the scenario that the Federal Reserve maintained interest rates at the zero lower bound. The results highlight the far greater responsiveness of the variables when the growth rate of the money stock is not constrained by a floor regime associated with a satiated market for bank reserves. Turning to figure 12, we observe that both the actual data and the unconstrained forecast show the Federal Reserve achieving its 2 percent inflation target after 7 quarters (2011Q2). In contrast, a one-off permanent increase in the stock of (broad) money reduces the 2009Q3 output gap from −6 percent to −2 percent, maintains the central bank's 2 percent inflation target after 1 quarter, and sees the normalization of interest rates from the zero lower bound. One explanation for this observed stagnant recovery is that the Federal Reserve was unable to make a credible commitment to permanently expand the monetary base (Beckworth 2017). In the context of the 2007–2009 Great Recession, the results confirm that a strict interest rate–targeting regime renders the monetary expansion ineffective. A more flexible interest rate regime would have, in contrast, led to a significant monetary expansion and to more rapid economic recovery in the United States.

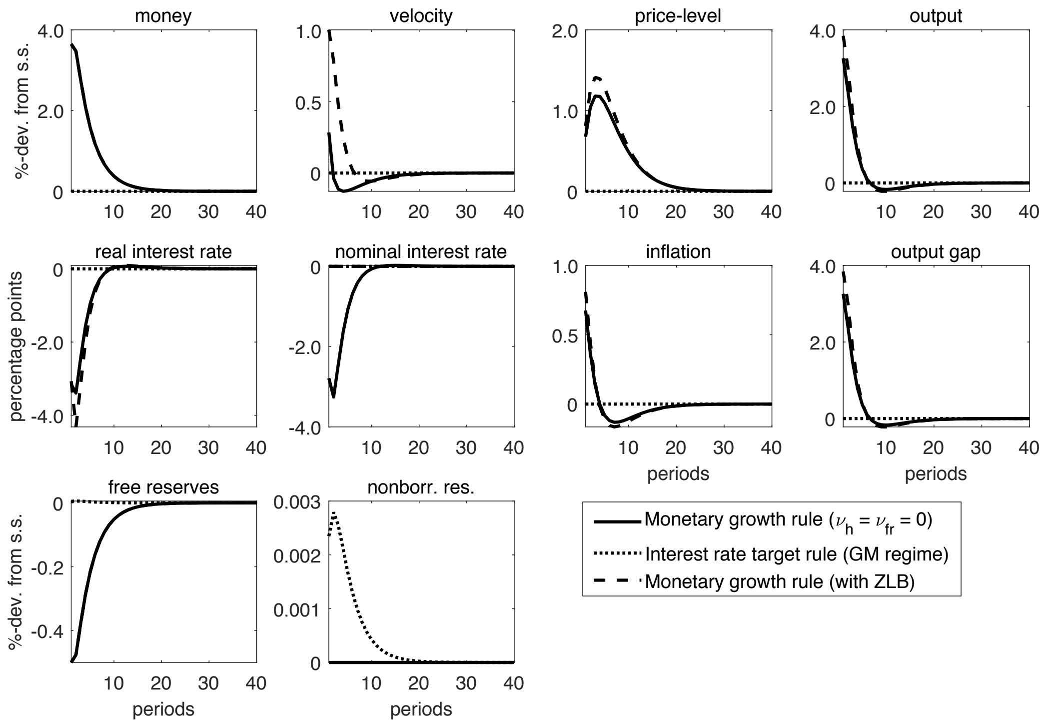
Figure 12. The Recovery Period 2009Q3–2012Q3 Conditional on Maintaining 2 Percent Inflation Target



Note: Forecast conditional on maintaining 2 percent inflation target (solid line). Unconditional forecast (dashed line). Actual data (cross-marker line). Plotted with 90 percent confidence intervals.

For our second counterfactual exercise, figure 13 presents simulated results for alternative scenarios of a reduction in free reserves. Here, we assume that (inside) money creation will likely be observed as a decline in ER and a rise in RR, holding TR (total reserves) constant. The results are analogous when the Federal Reserve increases H (nonborrowed reserves). For the period 2007Q4–2016Q3, the banking sector held, on average, approximately \$1.570 billion in excess reserves (\$1.483 billion in free reserves) at the Federal Reserve.

Figure 13. Impulse Responses to a Negative Free Reserves Shock



Note: GM = Great Moderation, ZLB = zero lower bound.

On the basis of the postcrisis average free reserves held at the Federal Reserve, the counterfactual simulation—with the zero lower bound constraint on nominal interest rates imposed—indicates that a \$3.7 billion (0.25 percent) reduction in free reserves expands the money supply by 3.65 percent and output by 3.84 percent. Of course, this stylized example fails to capture post-2008 uncertainty and regulatory constraints in the banking sector that constrain the (inside) money creation process.[32] Moreover, the Fed's "unconventional" policy responses in the postcrisis period largely targeted long-term government securities and alternative private asset classes—that is, quasi–debt management policies and credit policies (Borio and Disyatat 2010, 62). In other words, a constant short-term nominal interest rate

[32] For example, paying interest on reserves, raising capital requirements, and implementing liquidity coverage ratios all raise bank demand for free reserves ($FR = -RR$) and constrain credit and deposit creation (M^s). In equation (17), this result would imply that the reserve-deposit (money) multiplier ($1/rr$) is not constant (i.e., it is an *effective* reserve ratio for the determination of the money stock). See section 3.3 and figure A1.

does not generate any intertemporal substitution of consumption in a standard NK model. The result is therefore more indicative of the constraint on the type of monetary regime (operational framework) adopted by the Federal Reserve going into the crisis—which ignores the income (and wealth) effect that arises from changes in, for example, asset portfolio reallocations or long-term yields (see, e.g., Kaplan, Moll, and Violante 2018). Here, we direct the reader to Brunnermeier and Sannikov (2016), who develop a model in which monetary policy redistributes wealth and risk to stimulate (inside) money creation and counteract disinflationary pressures.

6.3. Optimal Policy

Distortions caused by price stickiness lead to short-run nonoptimal fluctuations in relative prices. This price dispersion in the intermediate goods sector generates a welfare loss. The central bank therefore dislikes output gaps and inflation, and setting $\pi_t = \tilde{y}_t = 0$ will eliminate price distortions from the Phillips curve (equation [38]). We assume that the central bank seeks to minimize the following quadratic loss function,[33]

$$\min_{\pi_t \tilde{y}_t} \frac{1}{2} E_0 (\textstyle\sum_{t=0}^{\infty} \beta^t (\pi_t^2 + \omega \tilde{y}_t^2)), \tag{42}$$

such that $\pi_t = \beta E_t[\pi_{t+1}]\ \tilde{\kappa}\tilde{y}_t$, where $\omega = \tilde{\kappa}/\epsilon$ and ϵ is the price elasticity of demand. The optimal policy rules under discretion and commitment follow as

$$\tilde{y}_t = -\frac{\tilde{\kappa}}{\omega}\pi_t, \tilde{y}_t = -\frac{\tilde{\kappa}}{\omega}p_t. \tag{43}$$

For all shocks considered so far, optimal discretion and commitment policy deliver the same global minimum of the above objective function in the standard NK framework. That is, there is no gain from commitment to a price level target over period-by-period policy discretion.

[33] This standard loss function representation can be derived from a quadratic approximation of household welfare. This representation also requires a sufficiently small utility weight $(a \to 1)$ on real money balances. Collard and Dellas (2005) show that welfare rankings are robust to a relative risk aversion coefficient greater than one (η_C>1) and that the assumption of a separable utility function makes a negligible difference.

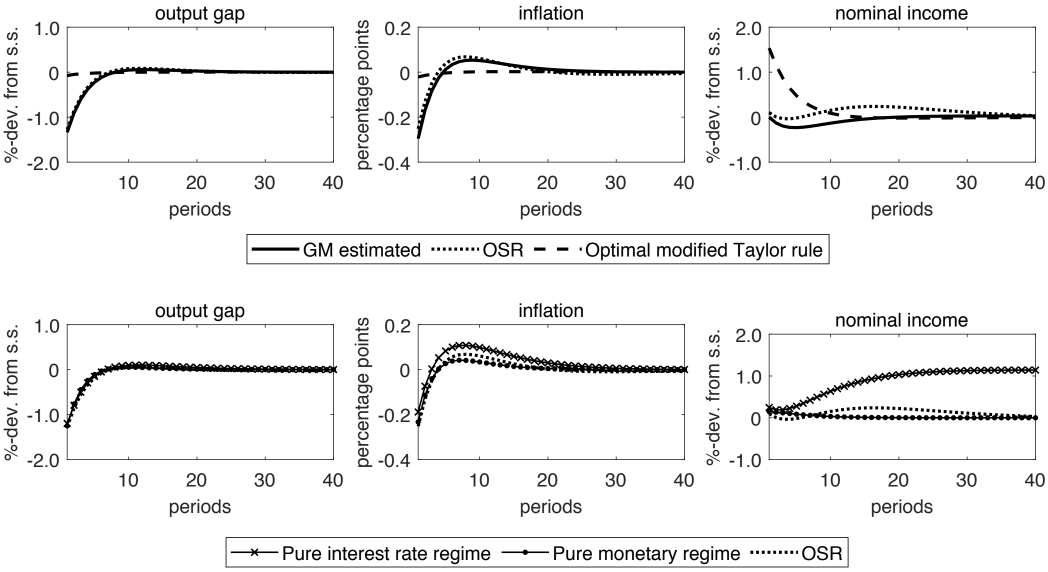
In what follows, we discuss possible optimal rules for the central bank under alternative regimes. Indeed, it is always possible for the central bank to eliminate output gaps and inflation under any nominal or technology shock. We take the pragmatic position that the estimated model for the Great Moderation period represents the best abilities of the monetary authorities under the imposed structural regime, whereas the following modified optimal Taylor rule represents the efficient benchmark:

$$i_t = r_t^n + \kappa_\pi \pi_t + \kappa_y \tilde{y}_t. \tag{44}$$

Notice that when $\pi_t = \tilde{y}_t = 0$, equation (44) accomplishes the optimal policy goal of the central bank. We compare these results with our extreme cases of a pure interest rate policy ($\nu_h = \nu_{fr} \to \infty$) and a pure monetary growth rule ($\nu_h = \nu_{fr} \to 0$). In each case, we allow the monetary authority to calibrate its rule to minimize the welfare loss function.

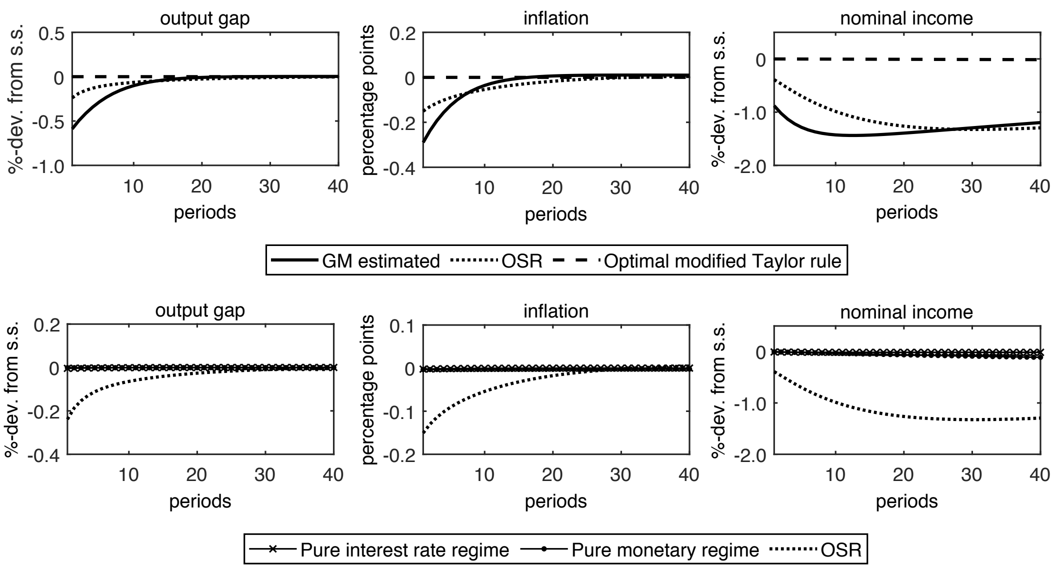
Figures 14 and 15 show the impulse responses of the output gap, inflation, and nominal income to a positive technology shock and a positive money demand shock. As expected, the optimal modified Taylor rule (OMTR) produces flat responses for the output gap and inflation. The OSR (optimal simple rule) shows the optimized policy instrument parameters ($\rho_h, \nu_h, \rho_i, \kappa_\pi, \kappa_y$) of the Great Moderation estimated model. Although we see little improvement from the benchmark estimate, nominal income stability improves significantly. In contrast, the OMTR *accommodates* the positive technology shock to close the negative output gap and lower inflation, which leads to *more rapid* nominal income growth. The bottom panel shows that moving from the strict interest regime of the Great Moderation toward a pure monetary regime would improve nominal income stability further. In fact, a pure monetary regime improves welfare by 28 percent (OSR) to 39 percent (pure interest regime). For the money demand shock, however, either of the extreme regimes eliminates the nominal shock.

Figure 14. Impulse Response to a Positive Technology Shock



Note: GM = Great Moderation, OSR = optimal simple rule.

Figure 15. Impulse Response to a Negative Money Demand Shock

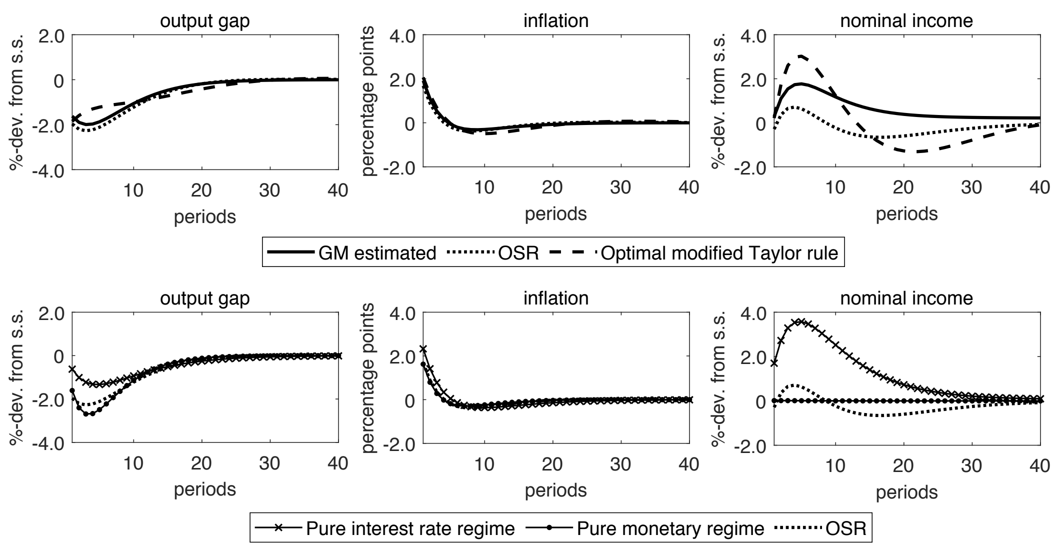


Note: GM = Great Moderation, OSR = optimal simple rule.

One way to force an output-inflation tradeoff is to introduce a cost-push shock to equation (38). The structural interpretation implies that price markups are possibly time-varying over the business cycle. This AR(1) shock process essentially shifts the Phillips curve, and persistent shifts in $E_t\pi_{t+1}$ require either the output gap or inflation (or both) to shift. This wedge in the output-inflation tradeoff reduces welfare.

Figure 16 shows how possible exogenous shifts to the Phillips curve considerably weaken the OMTR. In fact, the OSR regime for the GM estimation improves welfare by 41 percent (objective function: 0.000864 to 0.000507). As with the technology shock, this supply-side shock engenders a OMTR policy response which generates significantly more nominal income instability. Notably, in comparing the "pure" regimes in the bottom panel, we can see that moving toward a pure monetary regime (i.e., a less-strict interest rate regime) can lead to far greater nominal income stability by not responding as aggressively to supply-side shocks. Acknowledging the price level (in a nominal income target) still provides "a free lunch" (Svensson 1999).

Figure 16. Impulse Response to a Positive Price Markup Shock



Note: GM = Great Moderation, OSR = optimal simple rule.

7. Concluding Remarks

Most models base their conventional central bank policy analysis on a strict interest rate reaction function, a Taylor-type policy rule with little or no role for the money stock. In this paper, we present arguments in favor of a traditional model of money stock determination to show that the type of monetary policy regime has significant implications for the role of monetary aggregates and interest rate policy in a standard NK framework. We draw three main conclusions. First, the interaction between money supply and demand and the type of monetary regime in our model captures the dynamics of the US business cycle remarkably well. Second, the model's results suggest that the evolution toward a stricter interest rate–targeting regime renders central bank balance sheet expansions ineffective. Third, neither an interest rate–targeting regime nor a money growth rule is desirable. Instead, monetary authorities should adopt an optimal combination policy to stabilize nominal income. In this regime, the central bank would adhere to its goal of price stability, not to a rule for the intermediate (interest rate or money growth) target, because under certain states of the world, either interest-rate policy or money-base creation can be ineffective. As a result, the stance of monetary policy is measured by the deviation of nominal income growth from its target (see, e.g., Sumner 2016).

We identify two immediate shortcomings to be addressed in future research. First, nonlinearities and structural breaks across Federal Reserve governor tenures could be partly addressed using parameter drift and stochastic volatility or regime switching (Sims and Zha 2006; Fernández-Villaverde, Guerrón-Quintana, and Rubio-Ramírez 2010).[34] The effect of regulatory changes (such as interest on reserves) and financial innovations on the reserve-deposit

[34] Notably, some studies, such as Eggertsson and Singh (2016), find only a modest difference between the accuracy of a log-linear approximation and that of an exact nonlinear solution of an NK model at the zero lower bound. The aforementioned suggestion is therefore question specific or a robustness check on the simplified linearized model.

(money) multiplier should also be considered (Brunner and Meltzer 1981; Banerjee and Mio 2017; Bech and Keister 2017; Berentsen, Huber, and Marchesani 2015, 2018; and Li et al. 2017). Second, the operational framework of a monetary authority without an intermediate target is problematic if its goal comes with significant data lags and revisions. For now, it is unclear how a combination policy would affect private-sector decisions and expectations in the short run. Two policies worth consideration are a medium-term price level target or a market for nominal GDP futures (Sumner 2013, 2015, 2016, 2017; Beckworth and Hendrickson 2016; Sumner and Beckworth 2017).

Supplementary Appendix

A. Implications of the "Liquidity Trap" Hypothesis and the Fiscal Theory of the Price Level

In the current economic state of low interest rates and ineffective monetary policy, some notable hypotheses have gained traction. One strand of literature, in particular, posits a theory of price level determination based on the interaction between fiscal policy and monetary policy. Cochrane (2014) and Leeper (2016) form the argument by identifying three basic approaches to monetary policy and price level determination: money supply and demand in the spirit of the monetarist MV≡PY tradition; interest-rate controlling NK models; and the fiscal theory of the price level (FTPL). Their important critique, as previously raised by Sargent and Wallace (1985), is that the economy is satiated with money when the return on money (or reserves) equals the return on risk-free assets (e.g., Treasury bills). That is, any amount of money will be held at this point, and exchanging Treasuries for money has no effect on the economy—the price level is therefore indeterminate. In response to this state of the world, Cochrane (2014) and Leeper (2016) show that a determinant equilibrium necessitates an "active" fiscal policy.[35] Indeed, Cochrane (2014) correctly emphasizes that this holds *only* in the current international monetary system of fiat money and central banks. But if the price level is the price of goods in terms of nominal (government) liabilities (money plus bonds), the question then becomes: what determines the price level in a world of free banking with unbacked, decentralized fiat money? Is there a more fundamental theory of price-level determination that precludes fiscal debt management and present discounted government deficits and surpluses?

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[35] "The aggregate price level is a relative price: it measures how much a basket of goods is worth in terms of nominal government liabilities—money plus bonds. This relative price must be determined by the interaction of supply and demand for these government liabilities." (Leeper, 2016, p. 2)

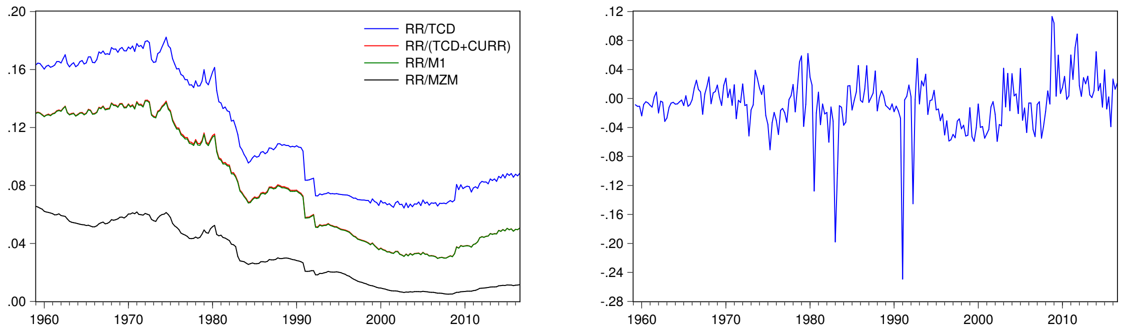
Understanding the interaction between fiscal and monetary policy certainly needs more attention. Cochrane (2014, 78) emphasizes the fiscal theory of the price level as follows: "In this way, the Treasury and the Fed acting together do, in fact, institute a system in which the government as a whole sets the interest rate i_{t-1} and then sells whatever facevalue of the debt B_{t-1} that [is demanded] . . . even though the Fed does not directly change the overall quantity of debt, and even though the Treasury seems to sell a fixed quantity, not at a fixed price." The model developed here could easily be extended to incorporate fiscal policy and the government budget (see, e.g., Schmitt-Grohé and Uribe 2007), but under the assumption that fiscal policy is "passive" it is not necessary: in Leeper's (1991; 2016) "Regime M," monetary policy controls inflation and fiscal policy ensures government solvency (see also Cochrane 2014, 91). That said, Leeper's framework falls into the same trap identified by McCallum (1986, 156) in relation to Sargent and Wallace (1982), namely that the model "neglects the medium-of-exchange role of money, thereby negating the possibility of distinguishing between monetary and non-monetary assets."

In contrast, the model developed in Belongia and Ireland (2014) and Ireland (2014), based on Barnett's (1978; 1980) "user cost of money and monetary aggregation" theory, emphasizes the role of the true aggregate of monetary (liquidity) services demanded. Their shopping time model maintains the core NK (IS-LM) framework and ensures that the opportunity cost on this true monetary aggregate is always positive—provided the risk-free rate is not zero. With regard to the zero lower bound, it is not immediately evident that money demand has no satiation point. While the threshold appears to be currently rather high in the market for reserves, Ireland (2009) shows evidence of a finite satiation point for broader monetary aggregates (also illustrated in figure 1). As this is likely true, then even at zero nominal interest rates, the true monetary aggregate—whether currency or highly liquid, risk-free assets—commands some positive finite transactions value (Yeager 1986). In effect, all perfectly substitutable, perfectly liquid assets will inherit this valuable attribute. In the context of macroeconomic models, the demand for fiat money depends on whether we expect it will hold its *exchange value* in the future: its discounted present value. By backward induction, money would be valueless today if we knew with certainty that money would be valueless at some given date in the future. But if money has positive value in all future periods, we can proceed.

This is basically illustrated by assuming that all wealth assets are in the household's utility function and that their corresponding rate of return has some implicit transactions value, no matter the illiquidity or riskiness—someone, somewhere is willing to trade for that asset. This is effectively Say's Law: the supply of any good, including fiat money and specie, generates a demand for all other goods (see, e.g., Yeager 1986). Further, we are essentially proposing some measure of "moneyness" attached to any item of value, to which, as it approaches perfect substitutability with money, it will approach the finite value of liquidity (transactions) services.

B. Figures

Figure A1. Effective Reserve Ratio (Left Panel) and Log-Difference Effective Reserve Ratio (Right Panel)



Note: The left panel shows the effective reserve ratio, $RR_t/M_t = rr_t$. The right panel shows the log-difference effective reserve ratio, $RR_t/MZM_t = rr_t$. The sample period is 1959Q1–2016Q3.

Figure A2. Simulation IRF: Positive Money Supply Shock

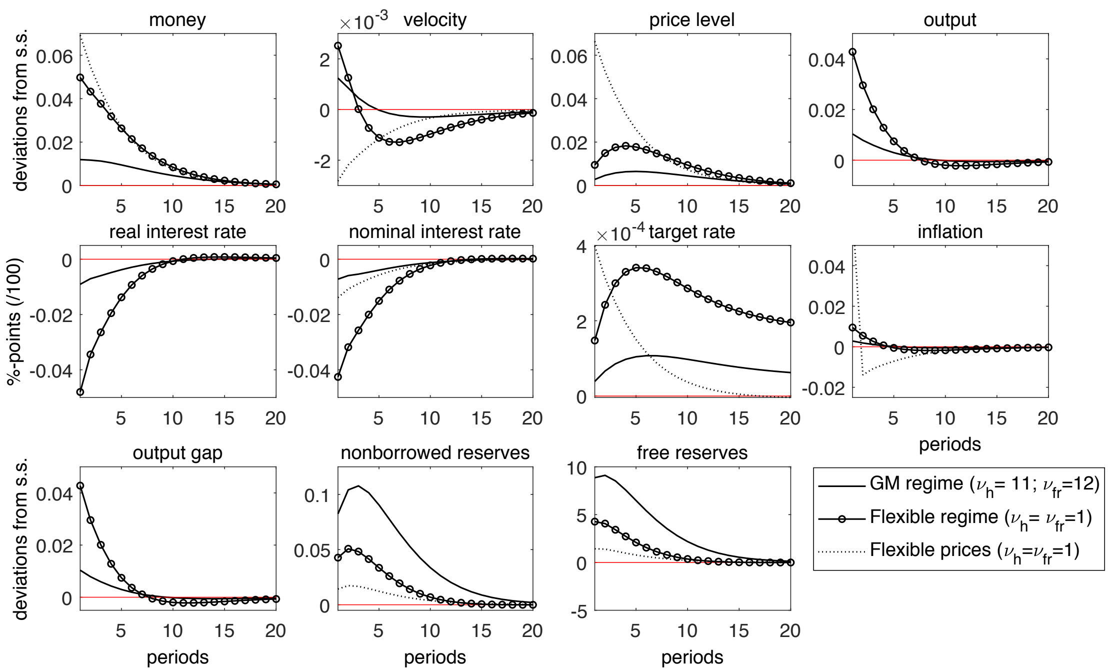


Figure A3. Simulation IRF: Positive Money Demand Shock

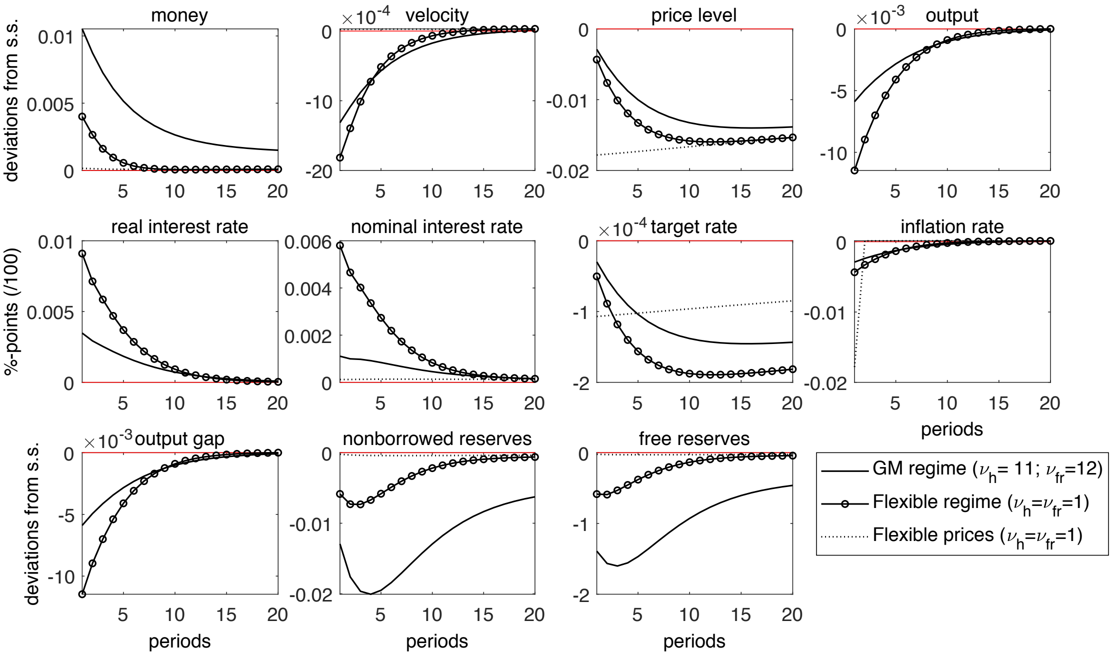


Figure A4. Simulation IRF: Negative Technology Shock

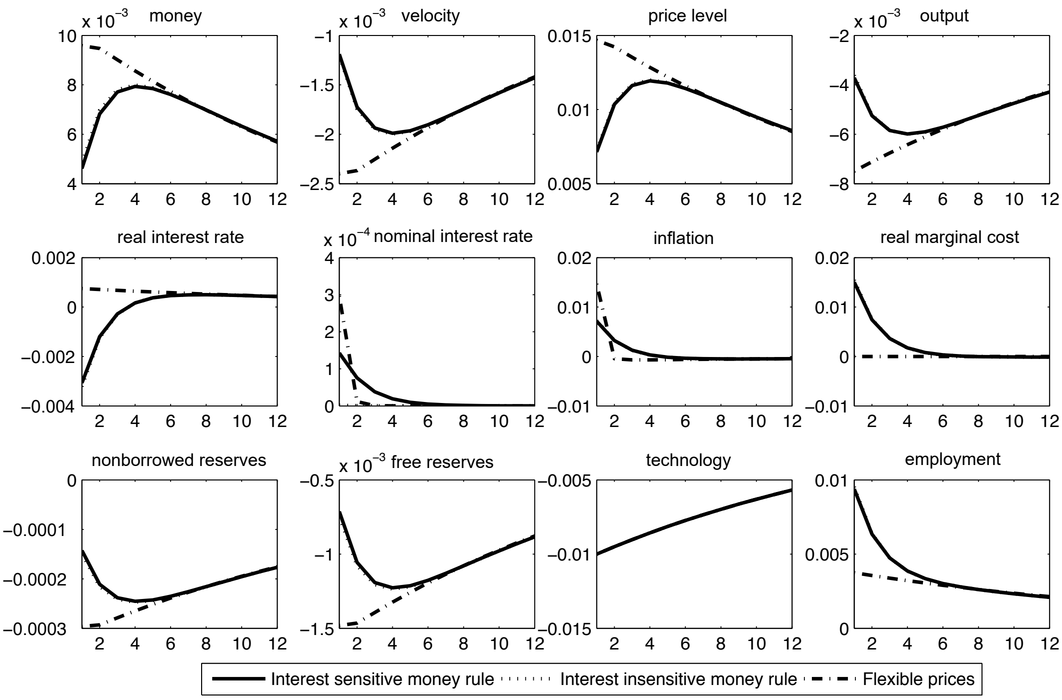
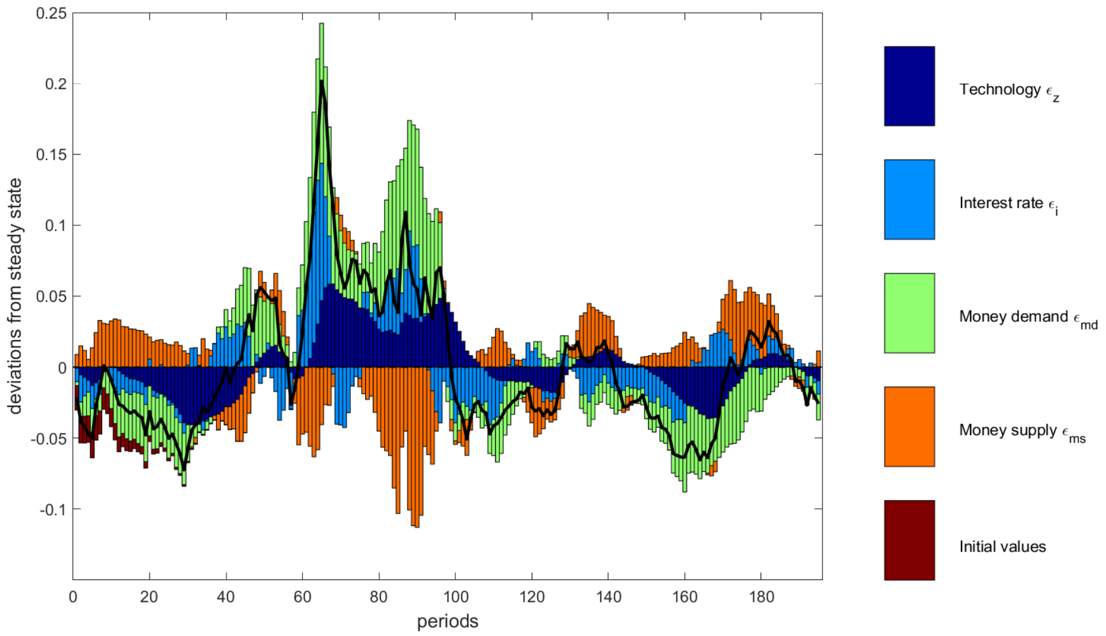


Figure A5. Historical Decomposition (1959Q1–2007Q3): Output (Top Panel) and Price Level (Bottom Panel)



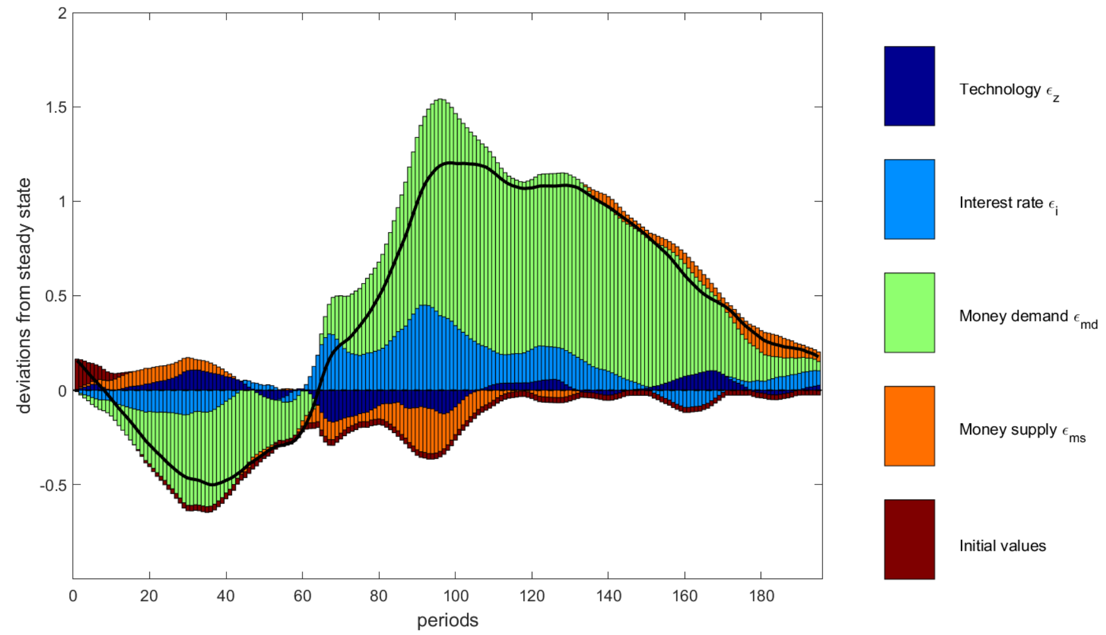
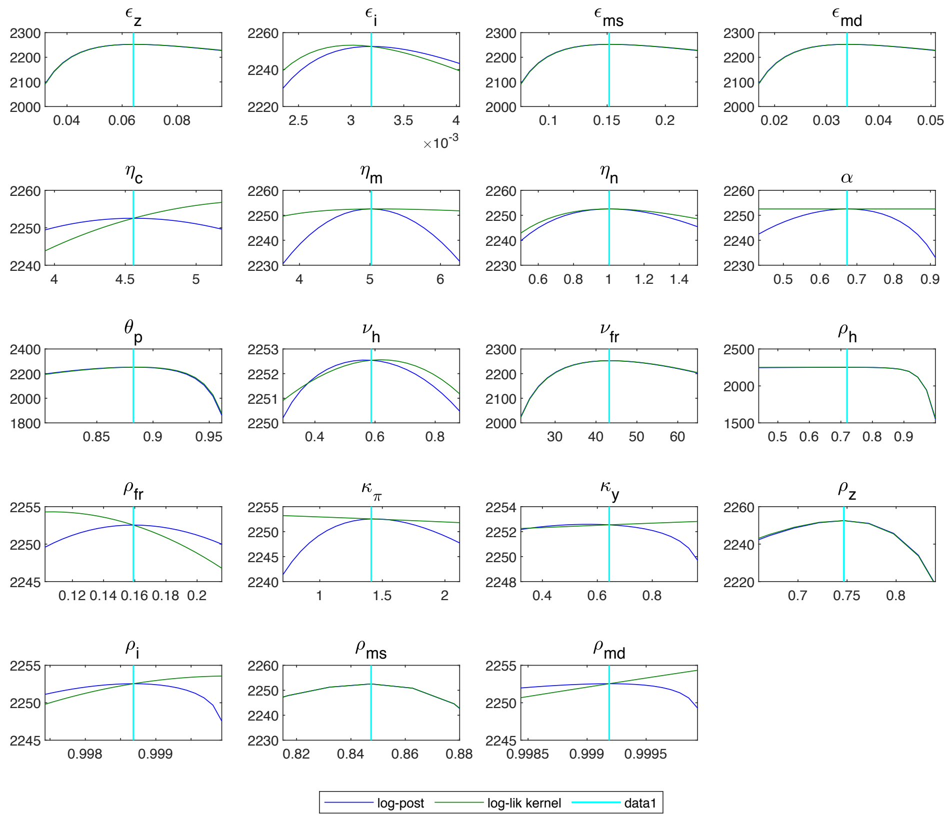


Figure A6. Estimation Diagnostic Statistics: Log-Data Density (Top Panel) and Prior and Posterior Distributions (Bottom Panel)



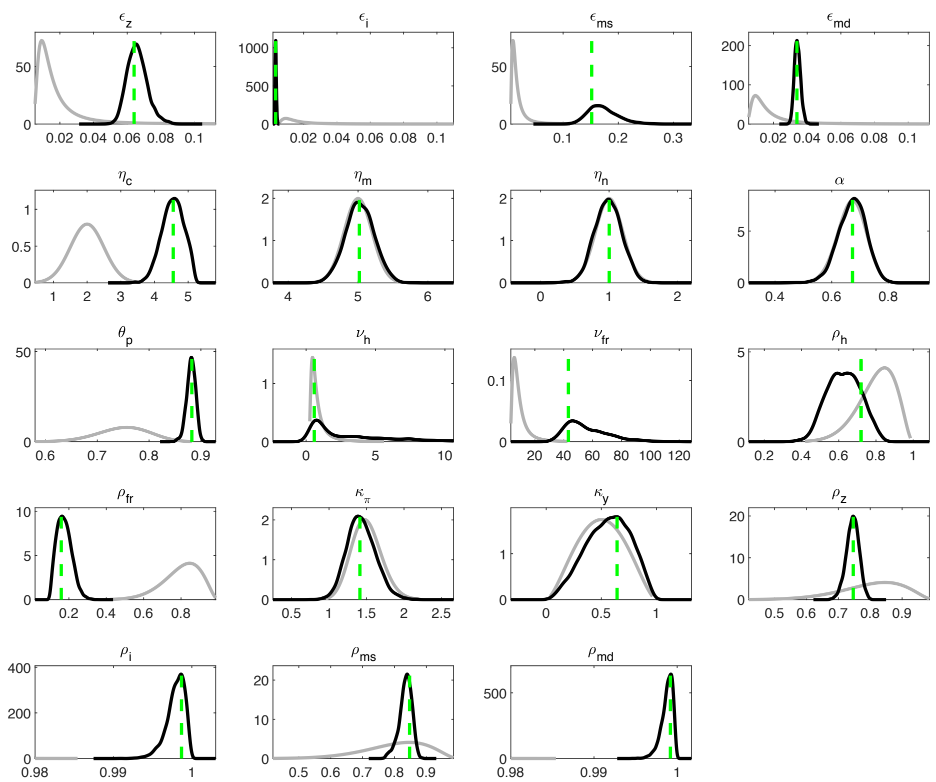


Figure A7. Smoothed Shocks

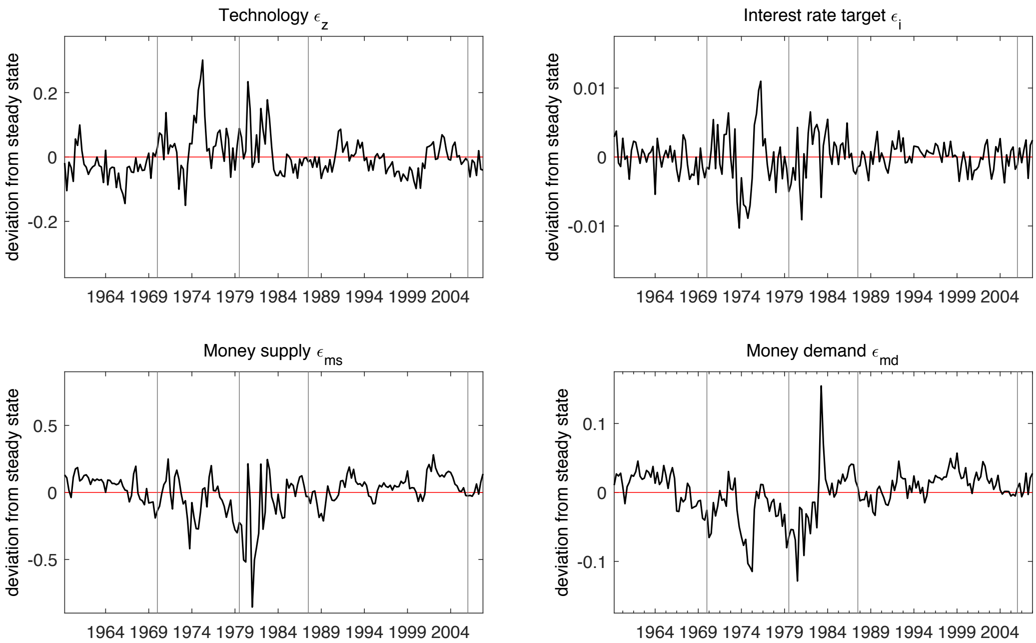
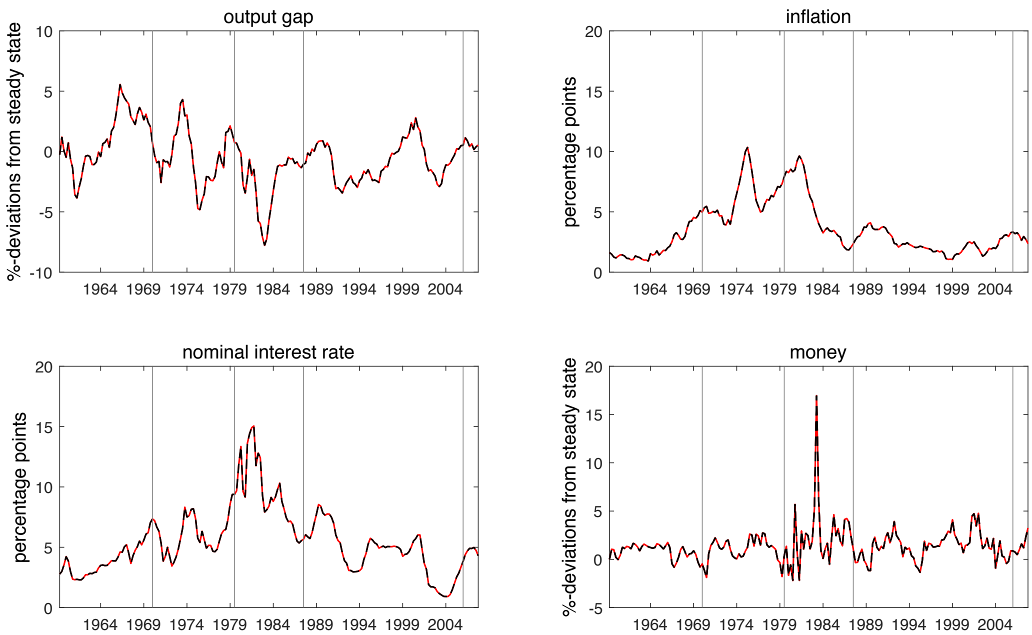


Figure A8. Historical Variables



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