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Reserves, Liquidity and Money: An Assessment of Balance Sheet Policies*

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Abstract

The financial crisis and its aftermath has stimulated a vigorous debate on the use of macro-prudential instruments for both regulating the banking system and for providing additional tools for monetary policy makers. The widespread adoption of non-conventional monetary policies has provided some evidence on the efficacy of liquidity and asset purchases for offsetting the lower zero bound. Central banks have thus been reminded as to the effectiveness of extended open market operations as a supplementary tool of monetary policy. These tools are essentially fiscal instruments, as they issue central bank liabilities backed by fiscal transfers. And so having written these tools into the fiscal budget constraint, we can examine the consequences of these operations within the context of a micro-founded macroeconomic model of banking and money. We can mimic the responses of the Federal Reserve balance sheet to the crisis. Specifically, we examine the role of reserves for bond and capital swaps in stabilising the economy and also the impact of changing the composition of the central bank balance sheet. We find that such policies can significantly enhance the ability of the central bank to stabilise the economy. This is because balance sheet operations supply (remove) liquidity to a financial market that is otherwise short (long) of liquidity and hence allows other financial spreads to move less violently over the cycle to compensate.

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1 Introduction

The ongoing financial and credit crisis has pushed existing monetary policy practices to their limit and created considerable interest in the appropriate post-crisis operating framework for monetary policy, particularly as there has been an active parallel debate about the regulatory framework for commercial banking. What might ultimately be termed the first generation of micro-founded monetary policy models had little to say on new monetary policy frameworks, as the short term policy rate was sufficient to stabilise the economy. But during this crisis many types of extended open market operations have been used to try and affect longer term interest rates and asset prices, as a substitute for the short term rate which was constrained at its lower zero bound. In this paper, we thus seek to address the question of post-crisis monetary policy by considering the role of balance sheet operations in a model in which commercial banks, lending and external finance premia all impact on the optimal formulation of monetary policy.

The Goodfriend-McCallum (2007) model is a Calvo-Yun monopolistically competitive production economy with sticky prices where households respect their budget constraint in formulating consumption plans, but one in which households must hold bank deposits to effect transactions. And so the loans technology for the banking sector takes centre stage in this model,[1] which meets the requirements of the private sector subject to monitoring and quality of collateral constraints. Households can work either in the goods producing sector or in the banking sector monitoring loan quality. But in order to consider the implications of reserves, in the version of the model developed by Chadha and Corrado (2012), banks also have to make a choice on their asset mix between reserves with the central bank or as loans with the private sector. The central bank in this model holds commercial bank reserves and sets the interest rate paid on those reserves. In this model the government budget constraint is modified to include claims from reserves, as well as standard issuance of public debt to meet excess of expenditures over taxes. Reserves in this model are outside money and respond to the demand for liquidity from financial institutions.

A banking sector based model can both amplify and add persistence to a standard macroeconomic set-up. This is because decision rules for output are shown to incorporate the equilibrium level of commercial bank assets and the price (or spread) at which those assets are provided. The recent boom and bust in advanced country debtor economies would seem to confirm the continuing relevance of this insight. First, we consider the non-standard monetary, or balance sheet, policies carried out by the Federal Reserve in response to the financial crisis and examine how they can be modelled. Specifically, we model the injection of bank reserves in our model economy in three ways, either as perfectly elastic supply of bank reserves meeting commercial bank demand or as a swap for bonds or capital. Furthermore we consider the role of a policy rule for the supply of reserves to supplement or replace existing interest rate rules. These one-off responses are shown to be able to stabilise the economy following a negative

[1] See Goodfriend and McCallum (2007) and Chadha, Corrado and Holly (2008) for an outline of this modelling device and its implications.

downward shock to asset prices.

The motivation for providing reserves is to meet the liquidity preference for commercial banks. Gale (2011) shows that under risk aversion the market cannot supply sufficient liquidity to the financial system. This is because there is an incentive for savers to swap illiquid assets for liquid assets and this will leave the market as a whole short of liquid assets and long illiquid assets. This problem will tend to be exacerbated if there is a collapse in confidence in the interbank market, when distributional shocks to banks no longer get re-cycled around the system. The monetary authorities can offset this liquidity shortage by issuing short-term liabilities backed by fiscal transfers i.e. interest bearing reserves or T-Bills. This operation reduces the holding of illiquid assets by the private sector and increases the reserve-deposit ratio of the banking sector. From a fiscal or debt management perspective if we take the structure of debt as given, the swap of illiquid for liquid debt instruments hedges the private sector against liquidity risk and allows the fiscal policy maker to collect liquidity premia as their return. The danger of this operation is that it is conducted at a time of fiscal deficits and so may be viewed as a change in the preferences of the monetary and fiscal policy maker and thus leads to an expectation of lower interest rates and higher fiscal deficits (see Nordhaus, 1994).

Under co-ordination of monetary and fiscal policy, we can examine the case for the systematic use of balance sheet or reserve policies. Because compared to a model that does not explicitly model bank balance sheets, this model can deliver an endogenous dynamic response for various risk premia and for the supply of loans and deposits. Using standard methods, we can also compare the responses of our artificial economy with and without reserve injections. We derive the approximate welfare criterion of the representative household and find that the economy where commercial banks have an endogenous choice over reserve holdings (*qua* liquidity) performs better in welfare terms than when commercial banks do not have such an incentive. The holding of reserves over the business cycle acts as a substitute for more costly provision of commercial bank assets and thus reduces the volatility of interest spreads to shocks, and varying the availability of reserves over expansions and contractions, acts to help stabilize the impulse from the monetary sector.[2]

The structure of this paper is as follows. Section 2 outlines the unconventional monetary policies carried out by the Federal Reserve, as an example, and uses a simple framework for understanding a stylized flow of funds and the role of commercial banks in the monetary system. We also set-up the government's budget constraint in this section, showing that the payment of the policy rate on bank reserves will mean that there will be a direct impact on the equation of motion for government debt. Section 3 outlines the implications of the loans production function approach for key macroeconomic decision rules and outlines the determination of key market interest rates. Section 4 considers the implications of commercial banks asset management in terms of reserve holdings to account for the relative returns from holding reserves or producing loans and liquidity concerns. Section 5 explains the standard calibration techniques used. Section 6 outlines the results of the impulse response analysis of various balance sheet operations and Section 7 undertakes welfare analysis of some key results. Section

[2]Paying interest on reserves is thus a way to meet the Friedmanite maximum without having a deflation.

8 then concludes and offers some final observations.

2 Unconventional Monetary Policy in the U.S

The outbreak of the financial crisis in the U.S housing market in early 2007 and how it spread to a full-blown, global financial meltdown by 2008 is well documented. In response to immense contractionary pressure the Federal Reserve, as many other central banks the world over, cut its policy rate quickly and dramatically. The target Federal Funds rate fell from 5.25% in September 2007 to between 0 and 0.25% by January 2009, effectively reaching the zero lower bound (ZLB). With short-term nominal interest rates constrained, what was previously a largely theoretical discussion of how to gain traction for monetary policy at the ZLB became a real and practical problem. The Federal Reserve embarked on a number of unconventional policy initiatives to try and provide a monetary stimulus to the U.S economy and re-awaken frozen credit markets. Many of these measures were concerned directly with the Fed's balance sheet, reserves and asset holdings. These policies at the ZLB are effectively fiscal policies, as they involve the issuance of short term fiscal instruments and so we wish to integrate these monetary-fiscal instruments into our model.

2.1 Paying Interest on Reserves

An initial, yet important, policy development was the payment of interest on reserves held by commercial banks with the central bank. The Federal Reserve had applied to Congress for the authority to pay interest on bank reserves on various occasions (Meyer,2001; Kohn, 2004) and was granted permission in 2006 under the Financial Services Regulatory Relief Act. Originally, the policy was not due to become effective until 2011 as Congress had worries about its fiscal costs,[3] but as the economic conditions in the U.S worsened its implementation was brought forward to 2008. There is strong theoretical backing for such a policy. Hall (2002) outlines a model by which the payment of interest on reserves can become a policy tool capable of controlling the price level in a world without money, whilst Chadha and Corrado (2012) show that paying interest on reserves equal to the policy rate can provide an incentive for financial intermediaries to vary their holdings of reserves cyclically which in turn attenuates fluctuations in the external finance premium and helps stabilise a monetary economy. The issuance of such reserves are very close substitutes to short-term T-bills and because interest is payable, they are in effect a swap of liquid assets for illiquid assets.

Kashyap and Stein (2012) show that if interest is paid on reserves the monetary authority has two tools, the quantity and price of reserves, by which they can implement policy and thus can pursue two

[3]Estimates of the cost of paying interest made by the Congressional Budget Office suggest the cost in the first year would be $253 million, rising to $308 million by the fifth year, with a total over 5 years of $1.4 billion over five years. This is based on the assumption that the federal funds rate would average 4.5% from 2008 to 2016 and the Fed would pay interest at a rate 0.1 to 0.15 percentage points below that. It projected required reserves of about $8.3 billion. If the Fed only paid interest on excess reserves held then the cost would be considerably smaller. Though that would rise if commercial banks took up more use of the facility. See Goodfriend (2002) for a recent survey.

objectives; both price stability and more macroprudential regulation.

2.2 Large Scale Asset Purchases

Large Scale Asset Purchases (LSAPs) can be thought of as traditional open market operations, in which the central bank changes the monetary base by buying and selling assets in exchange for reserves, but on a much larger scale and over a longer duration. Traditionally the central bank would use OMOs to meet the demand for reserves at its target interest rate, requiring relatively small, short-lived fluctuations in the level of reserves. In November 2008 the Fed announced it would begin purchasing housing agency debt and mortgage-backed agency securities to the value of $600bn in response to the housing crisis and in order to promote the health of mortgage lending. In March 2009 this was increased to $1.25 trillion. These purchases were largely of maturities between 3 months and 5 years. As they have reached maturity, the principal has been reinvested to fund the purchase of Treasury securities and maintain the value of the agency debt and agency backed securities section of the LSAP.

Accompanying this extension was the announcement that the Fed would begin to buy $300bn of Treasury securities, over 60% of which were of between 3 and 10 year maturities. The purchase of Treasuries was designed to support falling asset prices by acting as a large buyer and through the portfolio balance channel this should spread to other assets in the economy. It was also a direct injection of liquid reserves into the economy aimed at improving confidence and conditions in impaired credit markets. These large scale asset purchases were predominantly funded by the creation of over a trillion dollars of new reserves, making them the largest quantitative easing programme enacted since the crisis. In November 2010, in light of a continuing weakness in economic forecasts, the purchase of longer-term Treasuries was extended further by $600bn under a second round of quantitative easing (QE2) which took the total LSAP to over $2 trillion. In September 2011, the FOMC announced a maturity extension programme under which it will buy an additional $400bn of longer-dated treasuries but simultaneous sterilise these by selling short-term Treasuries to the same value. The goal is to lower longer-term yields without increasing the size of the central bank's balance sheet by "twisting" the yield curve and increasing the average maturity of the Fed's Treasuries portfolio by 25 months. More may follow.

2.3 Credit Versus Quantitative Easing

The term quantitative easing first arrived in the lexicon to describe the Bank of Japan's policy of central bank reserve creation in response to finding themselves constrained by the zero lower bound to the policy rate in the early 2000s. In a speech at the London School of Economics in January 2009, Federal Reserve Chairman Ben Bernanke tried to distance the unconventional policy of the Fed in 2007 from this largely unsuccessful policy by saying:

> In a pure QE regime, the focus of policy is the quantity of bank reserves, which are liabilities of the central bank; the composition of loans and securities on the asset side of the central

bank's balance sheet is incidental.... In contrast, the Federal Reserve's credit easing approach focuses on the mix of loans and securities that it holds and on how this composition of assets affects credit conditions for households and businesses.

In theory QE is a policy which seeks to change the size of the central bank's balance sheet, increasing liabilities through the creation of new reserves, or other liquid fiscal liabilities. Often these reserves are then used to purchases assets from the financial or private sector. Credit easing (CE) differs in that it targets the asset side of the balance sheet, specifically the compositional mix of assets held by the central bank. In pure CE, the level of reserves and subsequently the size of the central bank's balance sheet, does not change. In practice, most central banks' reactions to the crisis, including the Fed's, have elements of both quantitative and credit easing. In early 2008, the Fed began purchasing illiquid assets from private markets via liquidity swaps and the Term Auction Credit (TAC) programme, which it sterilised by selling its holdings of more liquid Treasury securities. Figure 1 shows that Fed holdings of U.S. Treasury securities fell from around \$780bn in December 2007 to just \$479bn by June 2008. This can be thought of as pure credit easing as the sales of T-bills almost exactly offset the purchases of assets and the size of the balance sheet remained unaffected around \$900bn, whilst reserves continued to be a tiny 0.01% of GDP. When the crisis worsened following the collapse of Lehman Brothers in September 2008, the Fed increased the provision of liquidity swaps and TAC as well as introducing the CPFF and providing direct support to a number of systematically important institutions. Figure 1 shows that the Fed's holdings of Treasury securities remained relatively constant over this period. Figure 2 shows how these increased purchases were funded in two ways. One was the introduction of the Supplementary Treasury Financing Account (STFA) where the Treasury brought forward its borrowing to exceed its current need and deposited the excess funds with the Federal Reserve. The second, and ultimately much larger source of funds came from the creation of new reserves. These now unsterilised purchases caused the Fed's balance sheet to grow rapidly. The Fed had now moved into QE, though it continued to assert that it was solely focussed on providing liquidity through its mix of assets and the increase in the size of the balance sheet was an incidental by-product of its credit easing policy.

However, with the LSAPs funded almost entirely through the creation of new reserves[4], reserve holdings have increased 158 times their previous level from around just \$11bn in 2007 to \$1.66tn, making them 13% of GDP. Table 1 shows the consolidated balance sheet of all Federal Reserve Banks pre- and post-crisis to demonstrate the scale of the change. The central bank balance sheet is now three times the size it was in 2007. Of the approximately \$2tn increase in the balance sheet, Treasury securities made up around £1tn to Jully 2011 on the asset side, with MBS making up most of the remainder. On the liabilities side reserves, which originally accounted for around 1.5% of the Fed's liabilities, now make up almost two-thirds, increasing by just over \$1.5tn.

[4]In November 2009 the Fed began reinvesting the returns it made on agency debt and other short term assets it had bought to part-fund its further purchases of longer term Treasury securities.

2.4 The Balance Sheet of Unconventional Policies

We introduce a simple framework for analyzing the effect of unconventional policies on the monetary balance sheet. For simplicity, since we abstract from other forms of central bank money and concentrate on bank reserves alone in our model, high powered money is identical to reserves. More traditionally the central bank controls the stock of fiat money (outside money) and financial intermediaries create other forms of money, which are claims on the private sector. As financial intermediation allows alternative assets to serve as money, it offers a close substitute to (outside) fiat money and the ability of the central bank to determine the overall nominal level of expenditure depends on the relationship between outside and inside money. The central bank has a powerful tool to regulate financial intermediaries and to affect the quantity of money in circulation: reserves, which may be either or both of fractional and or voluntary.[5]

Private Sector		Government	
Assets	Liabilities	Assets	Liabilities
Deposits D	Loans $(D-r)$	Tax $\sum_{i=0}^{\infty}\beta^i t_i$	Bonds B
Bonds γB	Tax $\sum_{i=0}^{\infty}\beta^i t_i$		
Capital $\gamma_k K$	K		

Commercial Banks		Central Bank	
Assets	Liabilities	Assets	Liabilities
Reserves r	Deposits D	Bonds $(1-\gamma)B$	Reserves r
Loans $(D-r)$		Capital $(1-\gamma_k)K$	

We first look at the private sector's balance sheet. The private sector has three forms of assets: deposits, D, held at banks and some fraction of bonds, γB, issued by the government and a fraction of total capital.[6] Their liabilities are loans, $D-r$, provided by banks. The government sector has liabilities in the form of outstanding public debt, B and assets given by the present discounted value of future taxation. The commercial banks' balance sheet liabilities are deposits, D. Some fraction of liabilities, r, is held as reserves and the rest, $D-r$, is available to be lent to the private sector. The central bank holds assets in the form of some fraction of government bonds, $(1-\gamma)B$, and a fraction of capital, $(1-\gamma_k)K$, with liabilities determined by central bank money, which are reserves in this model.[7] The net assets of commercial banks and of the central bank are both zero. The private sector has net assets given by $D+\gamma B+\ \gamma_k K-\left(D-r+\sum_{i=0}^{\infty}\beta^i t_i\right)$ and so because $r=(1-\gamma)B+\gamma_k K$ and $\sum_{i=0}^{\infty}\beta^i t_i=B$, we can note that the net private sector assets are also zero.

[5] See Freeman and Haslag (1996) and Sargent and Wallace (1985).

[6] In this example we assume that the private sector is represented by households.

[7] If we operate in an open economy, central bank assets would also include foreign exchange reserves r^f.

We can see from this flow of funds the mechanism by which unconventional policies occur. The central bank can perform quantitative easing by increasing the size of its balance sheet. It does this by extending an increased level of reserves to commercial banks which must be backed by an increased holding of either bonds or capital, which in turn must be bought from the private sector. Alternatively, credit easing is conducted through the composition of the balance sheet. With their liabilities unchanged, the central bank can buy capital from the private sector, increasing its own holdings. It funds these purchases by selling bonds back to the private sector, leaving the net effect on the size of both the central bank and private sector's assets at zero. Due to the differing properties of bonds and capital as collateral in our model's loan production function, this exchange has implications for levels of deposit demand which we will discuss later.

2.4.1 Reserves and the fiscal position

How might paying interest on reserves change the fiscal position? Because, ultimately paying interest rates on reserves will rely on public sector's budget constraint. The per period government budget constraint means that any excess of government expenditure, G_t, over tax receipts, T_t, and payment of interest on debt, $R^B_{t+1}\gamma B_{t+1}$, and/or reserves, $R^{IB}_t r_t$, will be financed by the issuance of bonds or central bank money given the consumption good price index, P^A_t. Note that the interest paid to the private sector is R^B and to commercial banks is R^{IB}, which is the policy rate in our model. Hence if we look at the consolidated budget identity for the government sector we note that:[8]

$$g_t - tax = \frac{r_t}{P^A_t(1+R^{IB}_t)} - \frac{r_{t-1}}{P^A_t} + \frac{\gamma B_{t+1}}{P^A_t(1+R^B_{t+1})} - \frac{\gamma B_t}{P^A_t} \tag{1}$$

so the government can finance its net expenditure by issuing government debt, γB, or by issuing reserves, r_t. However if interest rates are paid on reserves they will become interest bearing and therefore comparable to government debt. Clearly any excess government expenditure can be financed by issuing bonds to the private sector or by supplying reserves to commercial banks at a differentiated interest. We leave the determination of the relative interest rates to section 3.1. As we assume a stationary level of debt in this model there are not implications for fiscal solvency in this set-up as all deviations from steady state debt to GDP are strictly temporary. In effect, we are conditioning the issuance of reserves on a given path of public debt, which we simply assume to be optimal save for liquidity considerations.

3 The General Equilibrium Monetary Model

As pointed out by Kiyotaki and Moore (2001) money aggregates should be reconnected to general equilibrium models as they affect consumption decisions of liquidity constrained households and the

[8]In this setting the government sector includes both the government and the Bank of England. We also assume that high powered money comprises only reserves not coins.

spreads across several financial instruments and assets. Similarly open market operations, or balance sheet policies, will affect loans and therefore consumption. A simple way to incorporate money and spreads into a general equilibrium setting is to study the banking sector proposed by Goodfriend and McCallum (2007) which we extend to mimic the responses of the Federal Reserve balance sheet to the crisis. Specifically, we examine the role of reserves for bond and capital swaps in stabilising the economy and also the impact of changing the composition of the central bank balance sheet.

The model by GM complements the traditional accelerator effect (Bernanke *et al.*, 1999) with an attenuator effect, which is present in the model because monitoring effort is drawn into the banking sector in response to the expansion of consumption, which is accompanied by an expansion of bank lending that raises the marginal cost of loans and the external finance premium (EFP). The main feature of the model is the inclusion of a banking sector alongside households, production and the monetary authority, which leads subject to monitoring costs, quality of capital and the availability of reserves.

3.1 Households and the Production Sector

Households are liquidity constrained and decide the amount of consumption and the amount of labour they wish to supply to the production sector and to the banking sector according to the following utility function:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t [\phi \log(c_t) + (1-\phi) \log(1 - n_t^s - m_t^s)], \tag{2}$$

where c_t denotes real consumption, n_t^s is supply of labour in goods sector, m_t^s is the supply of monitoring work in the banking sector and ϕ denotes the weight of consumption in the utility function. They are subject to the budget constraint:

$$\begin{aligned} & q_t(1-\delta)K_t + \frac{\gamma B_t}{P_t^A} + \frac{D_{t-1}}{P_t^A} + w_t(n_t^s + m_t^s) + c_t^A (\frac{P_t}{P_t^A})^{1-\theta} + \Pi_t \\ & -w_t(n_t + m_t) - \frac{D_t}{P_t^A} - tax_t - q_t K_{t+1} - \frac{\gamma B_{t+1}}{P_t^A(1+R_t^B)} - c_t = 0 \end{aligned} \tag{3}$$

where q_t is the price of capital, K_t is the quantity of capital, P_t is the price of household's produced good, P_t^A is the consumption good price index, n_t is the labour demanded by household as producer, m_t, is the labour demanded by household's banking operation, w_t is the real wage, D_t is the nominal holding of broad money, tax_t is the real lump-sum tax payment, R_t^B is the nominal interest rate on government bonds purchased in $t+1$, B_{t+1}. We also assume that any profit from the banking sector, Π_t, goes to the households' sector. The Lagrange multiplier of this constraint is denoted as λ_t and θ is the elasticity of household demand. Household choose the level of monitoring work, m_t, and the level of employment work, n_t, they wish to offer to the production and the banking sector.

At the same time households' consumption, given the cash-in-advance constraint, is affected by the amount of loanable funds they can obtain:

$$c_t = v_t D_t / P_t^A \tag{4}$$

where v_t denotes velocity and D_t are deposits.

The production sector, characterized by monopolistic competition and Calvo pricing, adopts a standard Cobb-Douglas production function with capital, K_t, and labour, n_t, subject to productivity shocks. Firms decide the amount of production they wish to supply and the demand for labour by equalizing sales to net production:

$$K_t^\eta (A1_t n_t)^{1-\eta} - c_t^A (P_t/P_t^A)^{-\theta} = 0, \tag{5}$$

where η denotes the capital share in the firm production function, $A1_t$ is a productivity shock in the goods production sector whose mean increases over time at a rate ϱ and θ denotes the elasticity of aggregate demand, c_t^A. The Lagrange multiplier of this constraint is denoted as, ξ_t. By clearing the household and production sectors,[9] we can define the equilibrium in the labour market and in the goods market. Specifically, the demand for monitoring work:

$$m_t = \left(\frac{\phi}{\lambda_t c_t} - 1 \right) \frac{1-\alpha}{w_t} c_t \tag{6}$$

depends negatively on wages, w_t, and positively on consumption, c_t, and where $1-\alpha$ is the share of monitoring in the loan production function. These two sectors also provide the standard relationship for the riskless interest rate and the bond rate.

3.2 Banking Sector

We now turn to the analysis of how the banking sector affects the economy. The production function for the quantity of loans is given by:

$$L_t/P_t^A = F(\gamma b_{t+1} + A3_t k q_t K_{t+1})^\alpha (A2_t m_t)^{1-\alpha} \quad 0 < \alpha < 1, \tag{7}$$

where $A2_t$ denotes a shock to monitoring work, $A3_t$ is a shock on capital as collateral and $b_{t+1} = B_{t+1}/P_t^A(1 + R_{t+1}^B)$. The parameter k denotes the inferiority of capital as collateral in the banking production function, while α is the share of collateral in the loan production function. Increasing monitoring effort is achieved by increasing the number of people employed in the banking sector and therefore reducing the employment in the goods production sector.

While in standard Calvo-Yun models nominal consumption plans pin down the demand for money, in this model with banking, money is produced by banks, so any shift in the supply of loanable funds generated by shocks to monitoring effort or collateral also affect consumption. Specifically the banking sector matches deposit demand from liquidity constrained consumers with a technology to produce

[9] For details on the model set-up, derivation and notation see the technical appendix, available on request.

loans by substituting monitoring work for collateral in supplying loans. Also, we assume that loans are affected by the reserve/deposit ratio, rr_t:

$$L_t = (1 - rr_t)D_t. \tag{8}$$

Note that while Goodfriend and McCallum (2007) assume a fractional reserve requirement where the reserve-deposit ratio is given, we analyse the implications of varying reserve holdings and outline this mechanism in Section 4. Loan demand comes through the cash in advance constraint as consumption requires deposits and this must be financed above the level of reserves, by loans (8). Loan demand and supply come together with a simple substitution of the bank's loan production function in to (8) and the resultant equation in to the household's cash in advance constraint (4) leading to:

$$c_t = v_t \frac{F(\gamma b_{t+1} + A3_t k q_t K_{t+1})^{\alpha}(A2_t m_t)^{1-\alpha}}{P_t^A(1 - rr_t)}. \tag{9}$$

In this way financial shocks have real effects.

The differentiation of (9) with respect to K_{t+1} gives an expression $\Omega_t A3_t k q_t$ which is a function of the marginal value of collateralized lending:

$$\Omega_t = \frac{c_t \alpha}{\gamma b_{t+1} + A3_t k q_t K_{t+1}}, \tag{10}$$

which depends on consumption, c_t, and on the value of the collateral, q_t and b_t. This expression also enters in the asset price equation:

$$q_t = \frac{\left(E_t \frac{\lambda_{t+1}}{\lambda_t} q_{t+1}(1-\delta)\beta + E_t \beta \eta \left[\frac{\lambda_{t+1}}{\lambda_t}\frac{\xi_{t+1}}{\lambda_{t+1}}(\frac{A1_t n_t}{K_t})^{1-\eta}\right]\right)}{(1 - (\frac{\phi}{c_t \lambda_t} - 1)\Omega A3_t k)} \tag{11}$$

Finally the Central Bank sets the policy rate which affects the incentives of banks to hold reserves.

3.3 Consumption, monitoring work and asset prices

We now describe in more detail the main log-linear relationships which characterize the model. In our notation variables without time subscript denote steady-state values whereas those with a time subscript denote log-deviation from steady-state. A log-linear formulation of (9) shows how loanable funds affect the consumption of liquidity constrained consumers:

$$c_t = \left\{ \begin{array}{c} v_t c + rr_t c + (1-\alpha)(m_t + a2_t) + \\ \alpha \left[\frac{b}{b+k_1} b_t + \frac{k_1}{b+k_1}(q_t + a3_t)\right] \end{array} \right\} \left(\frac{b + k_1}{b(1-\alpha) + k_1}\right). \tag{12}$$

With the presence of a cash in advance constraint, a shock to velocity, v_t, will increase consumption. Consumption, c_t, is also positively affected by the amount of monitoring work, m_t, where α is the share of collateral in the loans production function and $(1-\alpha)$ represents the share of monitoring costs. It is also affected by the amount of collateral represented by bonds, b_t, and capital whose value is given by

q_t. A positive shock to monitoring, $a2_t$, by increasing the efficiency with which banks produce loans, increases the supply of loans and therefore consumption. Similarly a negative shock to collateral, $a3_t$, by reducing the price of capital, q_t, will negatively affect consumption. The parameters c, b and k_1 represent the steady-state fraction of consumption in output, the holding of bonds and a composite parameter reflecting the inferiority of capital compared to bonds as liquidity.[10]

The demand for monitoring work, which derives from (6), is given by:

$$m_t = -w_t - \frac{(1-\alpha)c}{mw}(c_t + \frac{\phi}{\lambda}\lambda_t). \tag{13}$$

A higher wage, w_t, will reduce the resources devoted to monitoring. Similarly monitoring will be affected by the marginal utility of consumption and the marginal value of households' funds, λ_t. The steady state parameters, m, w, and $\frac{\phi}{\lambda}$ represent the steady-state proportions of employment in the banking sector, the level of the real wage, and the ratio of the weight of consumption in the utility function relative to the steady-state shadow value of consumption. A key term here is the marginal value of collateralized lending, Ω_t, from (10), which increases as consumption rises and falls as collateral becomes more widely available:

$$\Omega_t = \frac{k_2}{b+k_2}(c_t - q_t - a3_t) - \frac{b}{b+k_2}b_t. \tag{14}$$

Ω_t depends on the value of the collateral, q_t and b_t, on a collateral shock, $a3_t$, and on consumption, c_t. Higher levels of consumption increase the marginal value of capital and hence the collateral value, q_t. The increase in collateral value leads to more borrowing and more consumption. The parameter k_2 is again a composite coefficient similar to k_1.[11]

The marginal value of collateralized lending also feeds back into the capital asset price equation, q_t, derived from (11):

$$\begin{aligned} q_t \quad = \quad & (\delta_1 + \gamma_1)(E_t\lambda_{t+1} - \lambda_t) + \delta_1 E_t q_{t+1} - \frac{k\Omega\phi}{c\lambda}(c_t + \lambda_t) + \\ & k\Omega(\frac{\phi}{c\lambda} - 1)(\Omega_t + a3_t) + \gamma_1 E_t\left[mc_{t+1} + (1-\eta)(n_{t+1} + a1_{t+1})\right]. \end{aligned} \tag{15}$$

In (15) the marginal value of collateralized lending, Ω_t, potentially can amplify asset price volatility and magnify the response of the economy to both real and financial shocks. Both real, $a1$, and financial shocks, $a3$, directly feed back into asset prices alongside the expected marginal productivity of capital $[mc_{t+1} + (1-\eta)(n_{t+1} + a1_{t+1})]$ where mc_{t+1} denotes marginal cost in period $t+1$, η is the share of capital in the goods production function and n is employment in the goods production sector. Similarly expected asset prices, $E_t q_{t+1}$, the change in the shadow value of households' funds $(E_t\lambda_{t+1} - \lambda_t)$ alongside the wedge between the marginal utility of consumption and the shadow value of funds also

[10] The parameter $k_1 = \frac{(1+\gamma)kK}{c}$ is a function of the ratio of consumption to output, c, of the parameter reflecting the inferiority of capital as collateral, k, of steady-state capital, K, and of the trend growth rate, γ.

[11] The parameter $k_2 = \frac{k_1 K}{c}$ is a function of k_1, of steady-state capital, K, and of the steady-state ratio of consumption, c.

affect the value of capital, q_t. The parameter δ_1 is a composite function of the depreciation rate of capital while the parameter γ_1 is a composite function of steady-state marginal costs, of steady-state employment in the goods sector and of the capital share in the production of goods.[12]

3.4 Market Interest Rates

The decision of the banking sector is articulated in two stages. In the first one interest rates are determined and then, given the constellation of spreads, banks decide the optimal level of reserves and assets in order to maximize expected returns. The benchmark theoretical interest rate R^T is simply a standard intertemporal nominal pricing kernel, priced off real consumption and inflation. Basically it boils down to a one-period Fisher equation:

$$R_t^T = E_t(\lambda_t - \lambda_{t+1}) + E_t\pi_{t+1}. \tag{16}$$

The interbank rate or policy rate is set by a standard feedback rule responding to inflation, π_t, and output, y_t, with parameters, ϕ_π and ϕ_y, respectively. Policy rates are smoothed by $1 > \rho > 0$.

$$R_t^{IB} = \rho R_{t-1}^{IB} + (1-\rho)(\phi_\pi \pi_t + \phi_y y_t) \tag{17}$$

To find the loan rate R^L we must equate the marginal product of loans per unit of labour $(1-\alpha)\frac{L_t}{m_t}$ to their marginal cost $\frac{w_t}{P_t^A}$ with loans defined by the following relationship $L_t = D_t(1-rr_t) = \frac{c_t P_t^A}{v_t}(1-rr_t)$. Therefore in log-linear form the interest rate on loans, R_t^L, is greater than the policy rate by the extent of the external finance premium.

$$R_t^L = R_t^{IB} + \underbrace{[v_t + w_t + m_t + rr_t - c_t]}_{EFP_t}. \tag{18}$$

The external finance premium, EFP_t, is the real marginal cost of loan management, and it is increasing in velocity, v_t, real wages, w_t, monitoring work in the banking sector, m_t, and reserve requirements, rr_t, and decreasing in consumption, c_t. The yield on government bonds is derived by maximizing households' utility with respect to bond holdings, $R_t^T - R_t^B = \left[\frac{\phi}{c_t\lambda_t} - 1\right]\Omega_t$. In its log-linear form it is the riskless rate, R_t^T, minus the liquidity service on bonds, which can be interpreted as a liquidity premium (LP):

$$R^B R_t^B = R^T R_t^T - \underbrace{\left[\left(\frac{\phi}{c\lambda} - 1\right)\Omega\Omega_t - \frac{\phi\Omega}{c\lambda}(c_t + \lambda_t)\right]}_{LP_t}, \tag{19}$$

where $(c_t + \lambda_t)$ measures the household marginal utility relative to households shadow value of funds while Ω_t is the marginal value of the collateral. It is in fact these key margins - the real marginal cost

[12] The parameter $\delta_1 = \frac{\beta(1-\delta)}{1+\gamma}$ is a function of the discount factor, β, of the depreciation rate of capital, δ, and of the trend growth rate, γ. The parameter $\gamma_1 = \frac{\beta\eta mc}{1+\gamma}(\frac{n}{K})^{1-\eta}$ is function of steady-state employment in goods sector, n, of steady-state marginal costs, mc, of steady-state capital, K, and of the parameter reflecting the capital share in the production function of the goods sector, η. Details of the derivation are reported in the technical appendix, available on request.

of loan management versus the liquidity service yield - that determine the behavior of spreads. In the above expression, ϕ denotes the consumption weight in the utility function whereas λ_t is the shadow value of consumption, c_t. The interest rate on deposits is the policy rate, R_t^{IB}, minus a term in the reserve deposit ratio:

$$R_t^D = R_t^{IB} - \frac{rr}{1-rr} rr_t. \tag{20}$$

These spreads will be effected by the supply of reserves or liquidity in this model and so will impact on the resulting path of consumption.

4 Central Bank Reserves and Commercial Banks

Monetary policy operates through the manipulation of short-term interest rates as the policy instrument, which affects the market clearing level of high powered money, or reserves. The previous section shows that this short term rate also impacts on other interest rates spreads via the external finance premium and/or the liquidity premium by changing the path of aggregate private or public demand. In this section, we outline the approach of Chadha and Corrado (2012) for considering the implications of introducing an incentive for commercial banks to hold reserves to account for the relative returns from holding reserves or producing loans and to deal with liquidity concerns.

Commercial banks may decide to vary the mix of their assets and central banks, through balance sheet operations may allow them to do so. Unlike Curdia and Woodford (2011) where reserves are provided up to the banks' satiation point, in our framework banks optimise their reserve holdings subject to a profit maximising condition under a liquidity constraint.

We adopt a simple expression for the commercial bank's within period bank expected returns. Given the constellation of interest rates as defined in the previous section, the bank's problem (see Baltensperger, 1980) is to maximize total returns within period subject to the returns from loans, L_t, which are lent out at the collateralized interest rate of R_t^L, reserves held at the central bank, r_t, which are assumed to pay the interbank (policy) interest rate, R_t^{IB}, and the payment of deposit interest, R_t^D, to deposits:

$$\max_{r_t} \Pi_t = R_t^L L_t + R_t^{IB} r_t - R_t^D D_t, \tag{21}$$

$$\text{s.t. } C_t = \frac{1}{2} R_t^T (\bar{r} - r_t)^2 + \tau_t(\bar{r} - r_t). \tag{22}$$

Here commercial banks' profits are subject to a side-constraint motivated by concerns about the management of liquid reserves. Note that reserves are returned at the end of the period but loans at the beginning of the next period. We assume that there is an exogenous target for the level of reserves, $\bar{r}$, perhaps set by custom and practice or by legislation.[13] The costs of reserve management, C_t, are then modelled in two parts: banks wish to smooth reserves and face a penalty rate of an uncollateralized external finance premium, R_t^T, in deviations of reserves from target and are also subject to a liquidity preference term, τ_t, which we can think of as an *ex ante* probability of a liquidity shortfall. The first term will imply that reserves are likely to be smoothed over time because banks may not wish to implement large-scale changes in their asset allocation from period to period, as these may signal mismanagement of previous asset allocations or run reputational risks. The cost of deviation from target is the penalty interest rate, which is symmetric in this set-up. This is because if $r_t < \bar{r}$, the commercial banks will fund its shortfall at the penalty rate, and if $r_t > \bar{r}$ the commercial banks will not be paid interest on excess reserves and pays the opportunity cost of lending its assets out at R_t^T. The liquidity preference term represents shifts in the commercial banks' chosen level of reserves and reflects an exogenous probability of a liquidity shortfall and so an increase in τ_t corresponds to a fall in bank liquidity below the minimum required level $\bar{r}$.

Note that by choosing the reserve level, the asset side of the commercial banks balance sheet , $L_t + r_t$, is now fully determined and so by construction are liabilities, that is deposits, D_t. From the balance sheet of the banking sector, discussed in the previous section, $L_t = D_t - r_t$ so we can substitute and write the Lagrangian as:

$$\Pi_t = R_t^L(D_t - r_t) + R_t^{IB} r_t - R_t^D D_t + \lambda_t^r \left(C_t - \frac{1}{2} R_t^T (\bar{r} - r_t)^2 - \tau_t(\bar{r} - r_t) \right). \tag{23}$$

For which the first order conditions are:

$$\frac{\partial \Pi_t}{\partial r_t} = -R_t^L + R_t^{IB} + \lambda_t^r \left(R_t^T(\bar{r} - r_t) + \tau_t \right) = 0. \tag{24}$$

The Lagrange multiplier is the shadow value of reserve management and is given by the ratio of profits on reserves to the 'precautionary' motives for holding reserves:

$$\lambda_t^r = \frac{R_t^L - R_t^{IB}}{R_t^T(\bar{r} - r_t) + \tau_t}, \tag{25}$$

If λ_t^r is set to one as to reflect the equal relative importance of the two arguments, we can solve for the optimal level of bank reserves:

$$\hat{r}_t - \bar{r} = \frac{\hat{\tau}_t}{\hat{R}_t^T} + \frac{\hat{R}_t^{IB} - \hat{R}_t^L}{\hat{R}_t^T}. \tag{26}$$

[13] In the Eurozone, for example, 2% of commercial bank reserves are lodged with central banks. In the UK, up to 2% of eligible reserves can be lodged with the Bank of England as interest bearing accounts. Basel III's liquidity coverage ratio will seek to increase the holdings of liquid assets.

Hence at the optimal profit rate the reserve ratio, $\hat{r}_t$, is determined by the interbank loan rate (the return on reserves) minus the returns on collateralized loans, $\hat{R}_t^{IB} - \hat{R}_t^L$, scaled by the penalty uncollateralized loan rate, $\hat{R}_t^T$, if reserves are different from target, $\bar{r}$, and a term reflecting a preference for reserves or liquidity, τ_t. With a sufficiently high preference for liquidity, τ_t, then increasing quantities of reserves will be held. Another way to think about this expression is that the deviation of reserve requirements from steady-state is the ratio of the cost of a liquidity shortfall to the opportunity cost of holding further deposits. Now let us examine the reserves in terms of market interest rates. Given (18) we can re-write (21) as:

$$\begin{aligned} \hat{r}_t &= \frac{\hat{\tau}_t}{\hat{R}_t^L} + \frac{\hat{R}_t^{IB} - \hat{R}_t^L}{\hat{R}_t^L} + \bar{r} \\ &= \frac{\hat{\tau}_t}{\hat{R}_t^{IB} + EFP_t} - \frac{EFP_t}{\hat{R}_t^{IB} + EFP_t} + \bar{r}, \end{aligned} \tag{27}$$

which introduces the trade-off between reserves being driven down (up) by higher (lower) external finance premium, and the need to offset changes in the probability of a liquidity shortfall. We will return to the policy implications of this result in the conclusion.

Figure 3 shows the implication of liquidity preference for reserves on the bank asset allocation across reserves and loans. Having produced a quantity of loans, D_t, as a function of collateral and monitoring inputs, the banks lies on the line tangential between the production function and the allocation line. If there is a preference for liquidity over illiquidity, as necessitated by a financial intermediary that transforms maturity, which reflects *inter alia* the liquidity preference term, $\hat{\tau}_t$, the bank will be better off if excess reserves can be supplied and this will be accomplished by swapping loans for reserves at some rate of transformation which reflects the relative interest rates on the two activities. Now let us consider a simple thought experiment in which the rate of return on reserves increases and that on loans stays constant - the allocation towards reserves per unit of loans will increase and reserves relative to loans will rise and hence so will the reserve-deposit ratio. Similarly if the rate of return on reserves falls, the rate of allocation to reserves will fall and accordingly the reserve-deposit ratio will fall. For comparison, Figure 4 plots the ratio of the behaviour of reserves relative to loans for a fixed reserve-deposit ratio (black dotted) and for changes induced by changes in the return on reserves alone (red line). The basic mechanism is illustrated here but what we find in the model will result from the interaction of both loan rates, policy rates (which are paid on reserves) and the movement in the loans production function and so we turn to the calibrated model.

5 Calibration

Table 2 provides a complete list of the endogenous and exogenous variables of the model and their meaning while Table 3 reports the values for the parameters and Table 4 the steady-state values of relevant variables.[14] Following Goodfriend and McCallum (2007) we choose the consumption weight in utility, ϕ, to yield 1/3 of available time in either goods or banking services production. We also set the relative share of capital and labour in goods production η to be 0.36. We choose the elasticity of substitution of differentiated goods, θ, to be equal to 11. The discount factor, β, is set to 0.99 which is close to the canonical quarterly value while the mark-up coefficient in the Phillips curve, κ, is set to 0.1. The depreciation rate, δ, is set to be equal to 0.025 while the trend growth rate, ϱ, is set to 0.015 which corresponds to 6% per year. The steady-state value of bond holding level relative to GDP, b, is set to 0.56 as of the third quarter of 2005. The steady state of private sector bond holdings relative to GDP is set at 0.50, consistent with holdings of U.S. Treasury securities as of end of year 2006.[15]

The parameters linked to money and banking are defined as follows. Velocity at its steady state level is set at 0.276 which is close to the ratio between US GDP and M3 at fourth quarter 2005, yielding 0.31. The fractional reserve requirement, rr , is set at 0.1. This is consistant with the reserve ratio set by the Federal Reserve on all liabilities above the low reserve tranche and approximately equal to the average tier one capital ratio in the US since the mid 2000s. The fraction of collateral, α, in loan production is set to 0.65, the coefficient reflecting the inferiority of capital as collateral, k, is set to 0.2 while the production coefficient of loan, F, is set to 9.14. The low value of capital productivity reflects the facts that usually banks use higher fraction of monitoring services and rely less on capital as collateral.

With these parameters values we see that the steady state of labour input, n, is 0.31 which is close to 1/3 as required. The ratio of time working in the banking service sector, $\frac{m}{m+n}$, is 1.9% under the benchmark calibration, not far the 1.6% share of total US employment in depository credit intermediation as of August 2005. As the steady-states are computed at zero inflation we can interpret all the rates as real rates. The riskless rate, R^T, is 6% per annum. The interbank rate, R^{IB}, is 0.84% per annum which is close to the 1% per year average short-term real rate. The government bond rate, R^B, is 2.1% per annum. Finally the collateralized external finance premium is 2% per annum which is in line with the average spread of the prime rate over the federal funds rate in the US.[16] The model is solved using the solution methods of King and Watson (1998) who also provide routines to derive the impulse responses of the endogenous variables to different shocks, to obtain asymptotic variance and covariances of the variables and to simulate the data.[17] For the impulse response analysis and simulation exercise we consider the real and financial shocks described in Table 5, which reports the volatility and persistence parameters chosen for the calibration and simulation exercise. These are standard parameters in the literature and simulate a fall in output consistent with the crisis.

[14] The equations for the steady-state equations are listed in Section A.4 of the technical appendix, available on request.

[15] The steady state of the transfer level, the Lagrangian of the production constraint and base money depend on the above parameters. The steady state of the marginal cost is $mc = \frac{\theta-1}{\theta}$.

[16] The equations for the steady-states are listed in the Technical Appendix.

[17] The log-linearized equations for the model are listed in section C of the Technical Appendix. King and Watson's MATLAB code is generalized in that for any model, we adapt three MATLAB files. King and Watson's package includes standardized auxiliary programs impkw.m to generate the impulse responses to different shocks to the endogenous variables and the program fdfkw.m to obtain the filtered autocovariances and the filtered second moments from the model solution. The program impkwsimu.m simulates the artificial series and allows to generate HP filtered data.

6 Impulse Responses From Balance Sheet Policies

To understand the dynamics of this model, in this section we outline the impact of a negative shock to the value of collateral in the context of various adaptations of the original framework. Our financial sector shock operates through the asset price and can be thought of as a primitive representation of the shock which hit the U.S. housing market towards the end of 2007. This had a negative impact on the value of assets that households were able to post as collateral in exchange for loans in the form of housing. The securitisation of these mortgage loans, and their subsequent trade by financial intermediaries, meant that this also affected the value of collateral banks themselves held, damaging their ability to raise funds.

We also analyse a case in which we negatively shock productivity in the manufacturing sector before briefly discussing the response of the system to a change in the composition of assets held on the central bank's balance sheet to provide a simplistic insight into credit easing policies. Figures 5-9 plot the log-deviation from steady state responses of real consumption, inflation, the external finance premium, the liquidity premium, the policy rate, real deposits, real reserves, real loans, the reserve-deposit ratio, private sector bond holdings, the level of monitoring work employed, employment in the goods sector, asset prices, the bond rate and the loan rate.

6.1 The Role of Reserves

We first show the mechanism through which reserve decisions can affect the real economy in our framework. Figure 5 shows the effects of our negative collateral shock under a regime of a fixed reserve-deposit ratio compared to one in which reserves are decided endogenously by profit maximising banks. In the first instance, when the shock hits there is an initial fall in asset prices which reduces the efficiency of producing loans as households have less collateral to post. As bonds are fixed, to produce the same amount of loans would require an increase in monitoring effort on the part of the banks and thus loan production becomes more expensive. This causes the external finance premium to increase and through the cash-in-advance constraint we see a fall in consumption and deposits which increases the EFP yet further. As the reserve/deposit ratio is fixed, the fall in deposits leads to an equally proportioned fall in loans and reserves. In response to the fall in output and inflation the central bank cuts the policy rate and the economy returns to equilibrium.

Alternatively, by endogenising the reserve decision and allowing the reserve-deposit ratio to fluctuate, as the cost of providing loans increases banks demand more reserves and the central bank supplies them perfectly elastically. This allows banks to shed the now more costly loans, pushing up the reserve/deposit ratio. This means the EFP rises by less with monitoring effort actually falling and a smaller contraction in consumption. The smaller fall in consumption is mirrored by a smaller fall in deposits and the policy rate now follows a much smoother path as reserve policy takes some of the burden of stabilising the economy. Thus we can see that reserves have a significant role to play in our economy due to their financial attenuation effects.

In the recent crisis policymakers were faced with having to respond to a contractionary shock whilst their default policy tool, the short-term nominal interest rate, was constrained by the zero lower bound. To investigate this in the context of our model we de-activate the Taylor rule, holding the policy rate constant and subject the model to the same negative collateral shock. What we see in Figure 5 is that because the policy rate does not fall in response to the downturn in consumption and inflation, the return from holding reserves is even higher, increasing the level of demand from financial intermediaries. This creates an even larger response in reserves than we saw under an active interest rate policy which attenuates the rise in the external finance premium to such an extent that it temporarily falls before returning to equilibrium. The strength of this attenuation is enough to bring consumption and inflation back to equilibrium along more or less the same path as when interest rate policy was unconstrained. This suggests that altering the level of reserves on commercial banks' balance sheets can stabilise the economy, even in the absence of interest rate policy.

6.2 Open Market Operations

In practice, changes in the level of reserves are effected via open market operations. The central bank buys (sells) assets from the private sector in exchange for an increased (decreased) level of reserves. Recent quantitative easing policies are theoretically just extensions of these operations, differing only in their unprecedented magnitude.

In order to realistically model OMOs we must augment the original endogenous reserves framework to take account of this swap of reserves for assets. Reserves, which are the central bank's only liability, must be backed by an equally valued holding of asset holdings. Initially we assume the central bank holds only government bonds, the total supply of which is fixed unless exogenously shocked. This means that in order to increase the level of reserves the central bank must buy bonds from the private sector, increasing the fraction of total bonds it holds and decreasing the amount held by the private sector.

To model this we define total bond holdings as the sum of private sector and central bank bond holdings

$$b_t = b_t^{CB} + b_t^P \tag{28}$$

and as central bank bond holdings must equal reserves, we can substitute and re-arrange to give the log linear relationship

$$b_t^p \hat{b}_t^p = b_t \hat{b}_t - r_t \hat{r}_t \tag{29}$$

which we add to our system of equations. It is this newly defined variable b^p which determines the amount of collateral households have available so we substitute it for b in the loan supply and marginal value of collateralised lending equations[18].

[18] As we deal with a consolidated government budget constraint, the net effect of interest payments on bonds held by the central bank is zero. Therefore, it is appropriate to also change the terms in b to terms in b^p in this equation as well.

An alternative is to swap the other type of asset in our economy, capital. This is less liquid and less efficient as collateral, but could equally be bought by the central bank in exchange for new reserves in the same way that bonds are. To do this we introduce an equation defining total capital holdings as a function of an exogenous shock in the same way we did for bond holdings. The central bank can now hold two assets on its balance sheet, so we hold the level of bonds fixed as before and set the steady state value of capital held by the central bank at zero. By defining private sector capital holdings in a log linear form as

$$k^p \hat{k}_t^p = b\hat{b}_t - r\hat{r}_t \tag{30}$$

what we model is a situation where the central bank buys and sells illiquid assets/capital in exchange for reserves.

In Figure 6 we can see how a negative collateral shock propagates in the presence of each type of OMO when the short-term nominal interest rate is constrained. It appears that the type of asset exchanged has very little impact on the path taken by key variables or the mechanism through which the policy works. This poses no deep problem in itself as one of the core motivations for making these adaptations to the model is to ensure the policy we model can be related as closely to the practical conduct of real world policies. However during our welfare analysis in the following section we see that there are differences between the implications of differing styles of OMOs. This suggests a channel by which OMOs, such as those carried out by central banks post crisis, can be an effective and practical means by which to stabilise the economy, even in the absence of an active interest rate policy.

6.3 The Role of Policymakers

Having demonstrated a clear role for reserves in this model, the next question is one of how to control this policy tool. If the central bank chooses to supply reserves perfectly elastically to meet the demand of the banking sector then banks will set that demand at the level which is optimal for them in terms of profits. This can be thought of as a financially optimal path for reserves. This may not, however, be consistent with the macroeconomic optimum desirable to policymakers. To test this we compare the model where reserves are determined by the banking sector's demand to one where the central bank determines reserve levels in response to a simple policy rule dependent on inflation.

$$\widehat{r}_t = (\rho_r - 1)\phi_\pi \widehat{\pi}_t + \rho_r \widehat{r}_{t-1} \tag{31}$$

Figure 7 shows that in response to a negative collateral shock, even an incredibly simple policy rule can outperform banks setting the level of reserves in terms of stabilisation of key macroeconomic variables. This is because the central bank is at first more aggressive, forcing the financial intermediaries to take on more reserves than would be profit maximising for them and this provides a greater attenuation of the EFP via the same mechanisms an increase in reserves works through when chosen by banks. This brings the economy back to equilibrium quicker and the level of reserves returns quicker to its steady state.

The key point to be taken from Figure 7 is that the financially optimum path for reserves and the macro-optimal path are not always the same suggesting an important role for policymakers in monitoring and setting the reserve levels of financial institutions, who have an incentive to try and keep reserve levels away from the macro optimal level.

This result holds true when we constrain the policy rate and also when we vary which of the exogenous shocks we put through the system with one exception: a productivity shock. Figure 8 shows that if our contraction is caused by an exogenous fall in productivity in the manufacturing sector then our policy rule causes a deeper and more prolonged fall in real consumption/output. This is due to the fact that under a productivity shock inflation and output move in opposite directions causing a conflict of objectives for the central bank. As the central bank follows its policy rule and cuts reserves to curb the higher inflation, this simultaneously induces a fall in consumption, worsening the contraction already experienced.

6.4 The Implications of Balance Sheet Composition

So far we have considered policies which can be loosely termed as quantitative easing, where the level of reserves, and thus the size of the central bank's balance sheet is allowed to fluctuate. However, in practise many central banks carried out at least a degree of credit easing (CE) alongside their quantitative easing programmes, especially the U.S. CE differs from QE in that the overall level of reserves doesn't need to change, but the central bank changes the mix of assets on its balance sheet, buying less liquid assets up and selling off more liquid ones to increase liquidity to the private sector. Eggerston and Woodford (2003), among others suggest this should have no impact on the wider economy as there is no motive for it to change agents' long term expectations of monetary policy.

In the context of our model in which reserves are determined by commercial banks' demand we can outline a very basic credit easing policy by simulating a swap, exogenously increasing the level of liquid bonds held by the private sector and simultaneously reducing the level of less liquid capital. When we run this credit easing swap (Figure 9), what we find is that the marginal value of collateralised lending decreases as there are more liquid assets available to be put up as collateral by the private sector, increasing the efficiency of loan production. This causes consumption to rise and the level of monitoring effort needed by banks to fall, both of which decrease the EFP. The liquidity premium drops as consumption rises and the marginal value of collateralised lending falls, whilst the central bank raises the policy rate in response to the increase in inflation and output. The improved economic conditions subsequently lead to an increase in reserves, but this is less than the increase in lending. This result implies that if credit easing was employed countercyclically then it would be a useful tool in limiting rises in the EFP and liquidity premium, such as those much of the world has experienced recently, even when the policy rate is constrained by increasing the quantity of more liquid assets available to be used by banks as collateral for loans thus increasing their loan production efficiency.

7 Welfare analysis

Table 6a shows the asymptotic standard deviation and the contemporaneous cross-correlation with consumption from a simulation of the model allowing us to compare a fixed reserve-deposit ratio regime with one in which reserves are determined by commercial banks and one in which they are set by a central bank policy rule. We also show the results for each type of reserve setting policy with the policy rate constrained so as to highlight the efficacy of policies should the policymaker find themselves unable to use interest rate policy.

What we find is that endogenising reserves can dramatically lower the standard deviation of inflation, asset prices and the policy rate but with a cost of increased standard deviation in output and monitoring work. There is also an increased deviation in the external finance and liquidity premia. Perhaps counterintuitively the standard deviation of reserves falls. This is caused by the fact that under a 'fixed' regime reserves have to constantly move in order to maintain a constant reserve deposit ratio, whilst in an endogenous reserve setting scenario this is smoothed. By introducing a reserve policy rule we manage to reduce the standard deviation in inflation and asset prices even further but manage to negate some of the trade-off with monitoring work, the EFP and liquidity premium and especially consumption which has a lower standard deviation under a reserves rule than under fixed reserve-deposits. It is worth noting that when the nominal interest rate is constrained, there is an increase in the standard deviation of output, inflation asset prices and other variables, but in an almost equal amount between the two policy rules.

Table 6b shows the same information for models in which open market operations are present, responding to endogenous, bank-determined reserve levels. We see here that conducting OMOs by swapping reserves for bonds results in much lower standard deviations, in all but one variable, than conducting them through swaps for capital, even when the interest rate is constrained. The standard deviation of private sector bond holdings logically increases since bonds are now part of an active policy tool. Figure 10 shows the middle segment, as an illustration, from a simulation of 10,000 data points, discarding the first 500 observations, of key macroeconomic variables under each policy regime. The simulated data are HP filtered ($\lambda = 1600$). Plotting the reserve-deposit ratio we see that endogenising reserves causes the reserve-deposit ratio to fluctuate as it responds to commercial bank demand. These fluctuations can be smoothed, and a degree of volatility removed by the central bank taking control of reserve policy with an active reserves rule.

7.1 Approximating the welfare function

The welfare approximation derived from the canonical New Keynesian model finds that welfare of the representative household only depends on the variance of output and inflation (Galí (2008)). We wish to investigate whether this result continues to hold when applied to our richer class of model. The use of the approximation allows us to quantify precisely the welfare rankings arising from each of our policy rules, possibly allowing some normative statements. Thus, we derive a quadratic loss function using a second-order Taylor approximation to utility by using the labour demand function, marginal cost function and sales-production constraint to substitute for household consumption.[19] Once re-ordered and simplified we are left with a loss function with relevant terms in the variances of consumption, inflation, wages, employment in the goods sector and the marginal cost.[20]

$$\begin{aligned} U_t - U &= -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t L_t + O3 \qquad (32) \\ \text{with } L_t &= \frac{1}{2} \left[\begin{array}{c} \sigma_c^2 + \left[\frac{\theta}{\chi(1-\eta)} \left(\frac{w}{c} \left(1+\eta^2\right) - \frac{n}{c} \right) \right] \sigma_\pi^2 + \\ \frac{w}{c}\sigma_w^2 - \frac{n}{c}\sigma_n^2 + \frac{mc}{c}\sigma_{mc}^2 \end{array} \right] \end{aligned}$$

where $\chi = \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1-\eta}{1+\eta(\theta-1)}$.

Remark The welfare of the representative household in this model, as in the original New Keynesian framework, is approximated by standard variables on the supply side rather than those specifically attributable to financial factors. This means that changes in financial conditions do not directly impact on utility, only in so far as they impact on the variance of consumption, inflation, wages, labour supply hours and marginal costs.

Having obtained the welfare approximations we can calculate the loss under each policy rule at the benchmark calibration and then rank them using the metric laid out by Gilchrist and Saito (2006), defined as the ratio between the loss obtained from implementing a given policy rule x versus a benchmark policy rule and the loss obtained under the most stabilising policy rule versus the same benchmark.

$$Gain(x) = \frac{L(\text{Benchmark Policy}) - L(\text{Policy } x)}{L(\text{Benchmark Policy}) - L(\text{Most Stabilising})} \qquad (33)$$

If this relative gain criteria is less (more) than one then the given policy can be said to be worse (better) than the most stabilising policy. If it is negative than the given policy actually performs worse than the benchmark. This metric allows us to explicitly rank our policies. For our calculations we chose an active interest rate policy rule under a fixed reserves system as our benchmark and our most stabilising reference policy is an active interest rate policy alongside a central bank reserve rule responding to inflation. Table 7 confirms that, whilst all endogenous reserve policies outperform a fixed reserve system our best welfare outcome is reached by allowing the central bank to control both the

[19]The additive nature of our household's utility function allows us to take a Taylor expansion of each term and substitute it back into the original function. The labour demand function is then rearranged for monitoring work, a second order expansion taken and substitution made. This process is then repeated for the marginal cost equation. Following Galí (2008) we substitute the resulting linear term in goods sector employment for a second order term in inflation using the sales equal net production constraint.

[20]The welfare approximation is derived in Section F of the the Technical Appendix.

policy rate and the reserve level in response to macroeconomic factors. Within this framework OMOs conducted by swapping reserves for bonds have better welfare implications than OMOs carried out via a swap for capital, but only marginally outperform our benchmark endogenous reserves model. An interesting aspect of this analysis is that we can see the relative loss in welfare caused by the short-term nominal interest rate becoming constrained (CIR) by comparing an endogenous reserves system with interest rate policy and one of just endogenous reserves. The size of the loss suggests that when confronted with the ZLB, policymakers operating an active reserve strategy may be able to have only limited welfare losses despite not being able to make use of their major policy tool.

The supply of liquidity through the issuance of reserves alongside an active interest rate would appear to reduce the welfare losses faced by the representative household over the business cycle. Reserves attenuate the fluctuations in the external finance premium in response to demand (consumption) and supply (loans) responses to shocks. A banking sector with a liquidity preference is better off when liquidity is supplied over the business cycle and because the requirement for loans from the private sector can in part be met by increasing reserves rather than increasing costly monitoring. Reserves as a monetary-fiscal instrument allow the banks to hedge liquidity risk and also improve macroeconomic outcomes so there is not necessarily a trade-off between financial and monetary stability.

7.2 Balance Sheet Policy and the Business Cycle

Table 8 shows the asymptotic standard deviation and contemporaneous cross-correlation with real consumption (output) of the reserve-deposit ratio and nominal spending under each policy regime. What we see is that as with consumption, inflation and asset prices, we can lower the standard deviation on nominal spending by endogenising our reserve decision, and still further if we allow reserves to be set by a policy rule. The fixed nature of the reserve-deposit ratio in the first regime means that by design we have zero standard deviation, but as we allow it to fluctuate and take on an active role as a policy tool, our reserves rule, which gives the best welfare option actually has the lowest standard deviation.

To contextualize these movements in terms of the business cycle we can analyse how the movements of these variables are correlated with real GDP, or in the case of our model, consumption. Endogenizing the reserves decision creates a deal of procyclicality in the reserve-deposit ratio suggesting in a boom period commercial banks build up their stock of reserves relative to loans and then run these down in an economic downturn. This is a key part of the mechanism by which the financial attenuator works as a systematic policy tool. Under a reserve rule this procyclicality is mostly removed as reserves react to inflation, not output. Nominal spending also becomes more procyclical as we endogenize reserves as we dampen fluctuations in the price level, bringing real consumption and nominal spending much closer together.

8 Conclusions

This paper uses a micro-founded macroeconomic model to consider the implications of balance sheet, or non-conventional monetary polices in which bank lending, interest rate spreads and the variance of the central bank balance sheet is shown to matter. To the model of Goodfriend and McCallum (2007), we append velocity shocks in the demand for money function (see Chadha, Corrado and Holly, 2008) and a process for commercial bank reserve accumulation (see Chadha and Corrado, 2012) and now show that these policies can map into central bank balance sheet policies. The issuance of reserves swaps short term debt obligations for long term obligations and thus improve the liquidity of the banking sector. The converse is also true. We then find that varying the central bank balance sheet attenuates the excessive volatility in the external finance premium that would otherwise ensue. We also solve for commercial banks' optimal levels of illiquid (loans) and liquid asset (reserves) holdings and for the government's budget position by allowing two forms of debt liabilities to be issued: one-period debt to finance any excess in government expenditures over tax receipts and debt to finance the issuance of reserves. We are then able to consider the implication of both one-off balance sheet operations and also systematic adoption of balance sheet policies.

We find that balance sheet policies can also contribute to the stabilisation of the economy when the interest rate rule is constrained. Our impulse responses show that policies that expand the central bank balance sheet can be shown to stabilise the economy. Rules that swap reserves for assets perform well compared to a straight injection of reserves. We also examine the welfare implications of balance sheet policies and find that when reserves are set countercyclically - i.e. they expand when the economy contracts - then the welfare of the representative household is in general burnished compared to an active interest rate rule alone. This is because by setting both the quantity and price of central bank money, the central bank can amplify the control of a monetary economy. Rather than just setting interest rates and letting money supply be supplied elastically on demand, some extra incentives are placed on financial activity to that act to prevent the exacerbation of the cycle (Walsh, 2009). Encouraging the central bank to alter the size of its balance sheet will not only increase the efficacy of standard interest rate policy but also help prevent the excesses of financial intermediation. But ultimately these operations are fiscal and require the debt authority to accept the responsibility in hedging liquidity shortages or gluts in the financial sector.

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Table 1: Consolidated Federal Reserve Balance Sheet Pre- and Post-Crisis

Assets	Value (Millions of Dollars)	
	December 2007	July 2011
Gold Certificate Account	11,037	11,037
Special Drawing Rights Certificates Account	2,200	5,200
Coin	1,017	2,096
Securities, Repurchase Agreements and Loans	815,979	2,660,990
Securities Held Outright	779,640	2,648,438
U.S. Treasury Securities	779,640	1,624,515
Bills	267,019	18,423
Notes & Bonds[21]	512,621	1,606,092
Federal Agency Debt Securities	-	115,070
Mortgage Backed Securities	-	908,853
Repurchase Agreements	35,000	0
Loans	1,338	12,552
Net Portfolio Holdings Maiden Lane I, II & III	-	59,637
Net Portfolio Holdings TALF LLC	-	757
Items in Process of Collection	7,235	419
Bank Premises	2,079	2,199
Other	37,244	131,714
Total[22]	876,791	2,874,049
Liabilities		
FR Notes (Net of FR Bank Holdings)	778,611	990,861
Reverse Repo Agreements	35,098	67,527
Deposits	16,112	1,741,336
Held by Deposit Institutions	11,286	1,663,022
U.S. Treasury Account, General	4,489	67,270
U.S. Treasury Supplementary Financing Account	-	5,000
Foreign Official	97	127
Other	241	5,918
Deferred Availability Cash Items	6,509	2,074
Other Liabilities and Accrued Dividends	6,066	20,584
Capital Accounts	34,345	51,667
Total	876,791	2,874,049

[21] Includes nominal, inflation indexed and inflation compensation.

[22] Preferred interests in AIA Aurora LLC and ALICO Holdings LLC do not appear as they were repaid as of January 2011. Likewise CPFF has been fully repaid and no longer appears.

Table 2: List of Variables

Variable	Description
c	Real Consumption
n	Labour Input
m	Labour Input for Loan Monitoring, or 'Banking Employment'
w	Real wage
q	Price of Capital Goods
P	Price Level
π	Inflation
mc	Marginal Cost
r	Reserves
rr	Reserves/Deposit Ratio
D	Deposits
L	Loans
P^A	Aggregate Prices
b	Real Bond Holding
b^p	Real Private Sector Bond Holdings
Ω	Marginal Value of Collateral
EFP	Uncollateralized External Finance Premium (R^T - R^{IB})
LSY^B	Liquidity Service on Bonds
LSY^{KB}	Liquidity Service on Capital ($kLSY^B$)
R^T	Benchmark Risk Free Rate
R^B	Interest Rate for Bond
R^{IB}	Interbank Rate
R^L	Loan Rate
R^D	Deposit Rate
λ	Lagrangian for Budget Constraint (shadow value of consumption)
ξ	Lagrangian for Production Constraint
T	Real transfer (%)

Table 3: Parameterisation

Parameter	Description	Value
β	Discount factor	0.99
κ	Coefficient in Phillips curve	0.1
α	Collateral share of loan production	0.65
ϕ	Consumption weight in utility	0.4
η	Capital share of firm production	0.36
δ	Depreciation rate of capital	0.025
ϱ	Trend growth rate of shocks	0.015
ρ	Interest rate smoothing	0.8
ϕ_π	Coefficient on Inflation in Policy	1.5
ϕ_y	Coefficient on Output in Policy	0.5
F	Production coefficient of loan	9.14
k	Inferiority coefficient of capital as collateral	0.2
θ	Elasticity of substitution of differentiated goods	11

Table 4: Steady State Parameters

Steady State	Description	Value
m	Banking Employment	0.0063
n	Labour Input	0.3195
R^T	Risk Free Rate	0.015
R^{IB}	Interbank Rate	0.0021
R^L	Loan Rate	0.0066
R^B	Bond Rate	0.0052
b/c	Bond to Consumption Ratio	0.56
b^p/c	Private Sector Bond Holdings to Consumption Ratio	0.50
γ (b^p/b)	Fraction of Bonds Held By Private Sector	0.893
c	Consumption	0.8409
T/c	Transfers Over Consumption	0.126
w	Real Wage	1.9494
λ	Shadow Value of Consumption	0.457
ν	Velocity	0.31
Ω	Marginal Value of Collateral	0.237
K	Capital	9.19
K^P	Private Sector Capital Holdings	9.19
rr	Reserve ratio	0.1
r/c	Reserves to Consumption	0.36

Table 5: Properties of Exogenous Shocks

Shock Name	Standard Deviation	Persistence
Productivity	0.35%	0.95
Monitoring	1.00%	0.95
Collateral	0.35%	0.9
Monetary Policy	0.82%	0.3
Mark Up	0.11%	0.74
Bond Holdings	1.00%	0.9
Velocity	1.00%	0.33
Liquidity	1.00%	0.33

Table 6a: Impact on the Economy of Endogenising Reserves

Policy	Fixed[23]		Endogenous[24]		Endogenous CIR[25]		Reserve Rule[26]		Reserve Rule CIR[27]	
	St.Dv[28]	Corr[29]	St.Dv	Corr	St.Dv	Corr	St.Dv	Corr	St.Dv	Corr
Real Consumption/Output	1.03	1	1.14	1	1.17	1	0.75	1	0.78	1
Inflation	0.89	0.79	0.40	0.65	0.42	0.67	0.33	0.51	0.35	0.55
Employment in Monitoring	2.01	-0.46	4.27	-0.81	3.58	-0.85	2.61	-0.56	2.25	-0.66
Employment in Goods Sector	1.63	0.95	1.72	0.96	1.77	0.96	1.13	0.90	1.19	0.91
Real Wage	1.77	0.99	1.80	0.99	1.87	0.99	1.20	0.98	1.26	0.98
Private Sector Bond Holdings	1.30	0.21	1.30	0.07	1.30	0.07	1.30	0.1	1.30	0.11
Asset Prices	0.93	0.98	0.92	0.98	0.97	0.98	0.63	0.97	0.66	0.97
Loans	2.81	0.24	1.00	0.29	1.08	0.33	0.91	-0.08	0.90	-0.07
Reserves	2.81	0.24	2.00	0.76	1.79	0.07	0.20	-0.13	0.20	-0.15
Policy Rate	1.30	-0.04	1.28	0.17	0.80	-0.1	1.13	-0.13	0.80	-0.22
Loan Rate	0.68	0.30	0.80	-0.89	0.80	-0.88	0.47	-0.77	0.51	-0.78
Bond Rate	0.68	0.30	5.19	0.60	3.78	0.60	3.72	0.23	2.99	0.27
Deposit Rate	1.30	-0.04	1.19	0.07	0.78	-0.23	1.10	-0.14	0.78	-0.22
External Finance Premium	1.25	0.20	1.66	-0.56	1.04	-0.60	1.26	-0.18	0.79	-0.28
Liquidity Premium	0.02	-0.14	5.77	-0.66	4.31	-0.69	3.97	-0.30	3.15	-0.38

[23] Model with a fixed reserve-deposit ratio and an unconstrained interest rate policy.

[24] Model with an endogenous reserve-deposit ratio set by demand from profit maximising banks with an unconstrained interest rate policy.

[25] Model with an endogenous reserve-deposit ratio set by demand from profit maximising banks with a constrained interest rate policy

[26] Model with endogenous reserves set by the central bank according to a reserves policy rule alongside unconstrained interest rate policy.

[27] Model with endogenous reserves set by the central bank according to a reserves policy rule with constrained interest rate policy.

[28] St.Dv denotes the asymptotic standard deviation of the relevant variable derived from the filtered second moments of the solution obtained from the given model.

[29] Corr denotes the contemporaneous cross-correlation with consumption derived from the filtered autocovariance of the solution obtained from the given model.

Table 6b: The Impact on the Economy of Different Methods of Conducting Open Market Operations

Policy	Bond OMO[30]		Bond OMO CIR[31]		Capital OMO[32]		Capital OMO CIR[33]	
	St.Dv	Corr	St.Dv	Corr	St.Dv	Corr	St.Dv	Corr
Real Consumption/Output	1.03	1	1.07	1	1.21	1	1.24	1
Inflation	0.39	0.61	0.41	0.64	0.50	0.70	0.54	0.72
Employment in Monitoring	4.08	-0.77	3.44	-0.82	4.25	-0.73	3.69	-0.68
Employment in Goods Sector	1.56	0.95	1.62	0.95	1.83	0.96	1.89	0.96
Real Wage	1.62	0.99	1.70	0.99	1.94	0.99	2.03	0.99
Private Sector Bond Holdings	1.83	-0.35	1.79	-0.32	1.30	0.33	1.30	0.33
Private Sector Capital Holdings	-	-	-	-	1.30	0.30	1.31	0.30
Asset Prices	0.84	0.98	0.88	0.98	1.00	0.98	1.05	0.99
Loans	0.96	0.16	1.03	0.21	1.52	0.34	1.66	0.36
Reserves	1.83	0.70	1.64	0.71	1.97	0.68	1.78	0.65
Policy Rate	1.24	0.11	0.80	-0.12	1.35	0.22	0.80	-0.09
Loan Rate	0.71	-0.87	0.71	-0.86	0.78	-0.76	0.79	-0.73
Bond Rate	4.90	0.54	3.63	0.54	5.38	0.62	3.80	0.59
Deposit Rate	1.16	0.03	0.78	-0.25	1.30	0.16	0.80	-0.16
External Finance Premium	1.55	-0.49	0.96	-0.53	1.68	-0.53	1.03	-0.49
Liquidity Premium	5.39	-0.61	4.07	-0.63	5.89	-0.67	4.28	-0.65

[30] Model in which OMOs involve an exchange of reserves for bonds to meet endogenous reserve demand of banks alongside unconstrained interest rate policy.
[31] Model in which OMOs involve an exchange of reserves for bonds to meet endogenous reserve demand of banks with constrained interest rate policy.
[32] Model in which OMOs involve an exchange of reserves for capital to meet endogenous reserve demand of banks alongside unconstrained interest rate policy.
[33] Model in which OMOs involve an exchange of reserves for capital to meet endogenous reserve demand of banks with constrained interest rate policy.

Table 7: Relative Welfare Analysis

Policy Regime	Welfare Loss[34]	Gain Criterion[35]
Fixed	24.21	0
Endogenous	10.48	0.73
Endogenous CIR	11.38	0.69
Reserve Rule	5.53	1
Reserve Rule CIR	6.14	0.97
Bond OMO	9.01	0.81
Bond OMO CIR	9.94	0.76
Capital OMO	13.57	0.57
Capital OMO CIR	15.24	0.48

[34] Loss determined by a quadratic loss function derived using a second-order Taylor approximation to utility. See Section 7.1

[35] Uses Gilchrist and Saito (2006) criteria to show welfare gain between a given policy and a benchmark relative to the most stable policy. See Section 7.1.

Table 8: The Implication of Balance Sheet Policies for Reserve Ratios and Nominal Expenditure[36]

Policy Regime

		Reserve-Deposit Ratio	Nominal Spending
Fixed			
	St.Dv	0	2.84
	Corr	0	0.40
Endogenous			
	St.Dv	1.70	1.51
	Corr	0.65	0.82
Endogenous CIR			
	St.Dv	1.52	1.58
	Corr	0.61	0.81
Reserves Rule			
	St.Dv	0.93	1.03
	Corr	0.05	0.68
Reserves Rule CIR			
	St.Dv	0.94	1.08
	Corr	0.03	0.67
Bond OMO			
	St.Dv	1.72	1.39
	Corr	0.59	0.78
Bond OMO CIR			
	St.Dv	1.54	1.47
	Corr	0.56	0.78
Capital OMO			
	St.Dv	1.94	1.82
	Corr	0.38	0.75
Capital OMO CIR			
	St.Dv	1.96	1.92
	Corr	0.25	0.73

[36] Corr denotes the contemporaneous cross-correlation of the given variable with real consumption/output

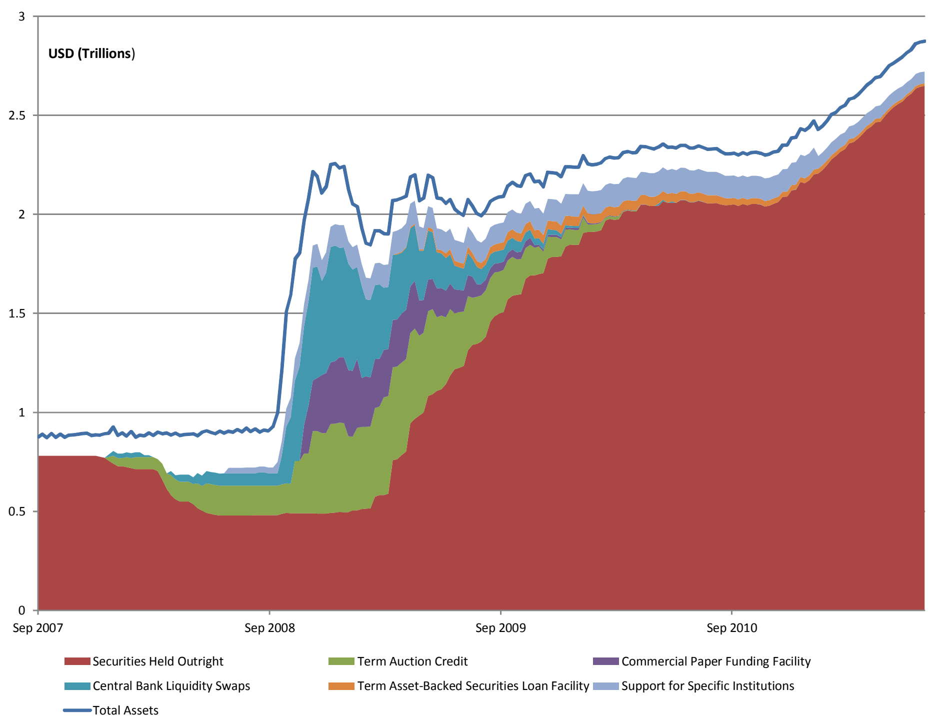

Figure 1: Federal Reserve Assets[37]

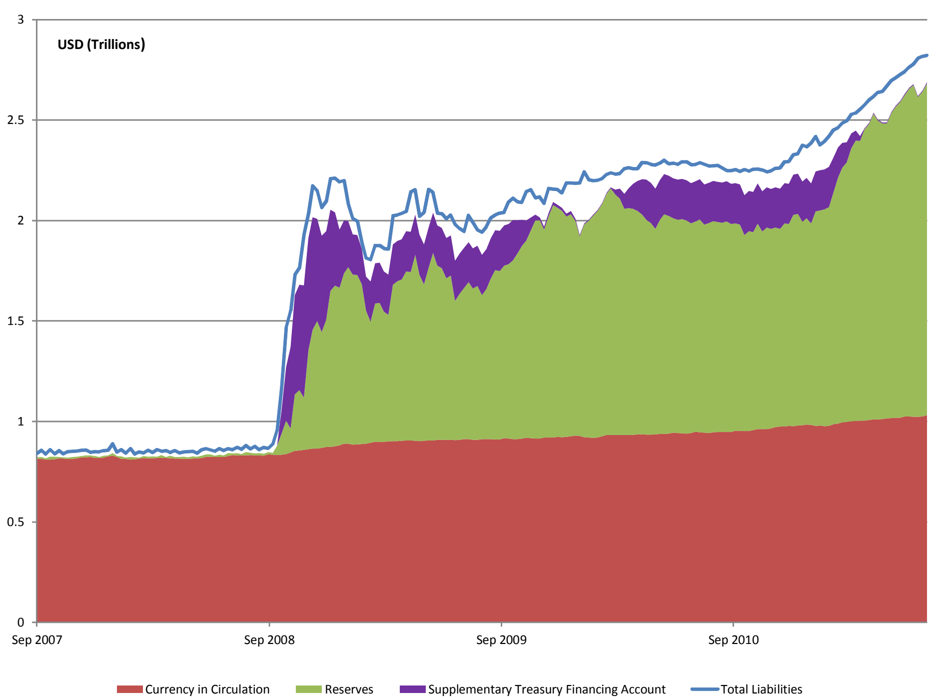

Figure 2: Federal Reserve Liabilities

[37] Total may differ from constituent parts due to rounding.

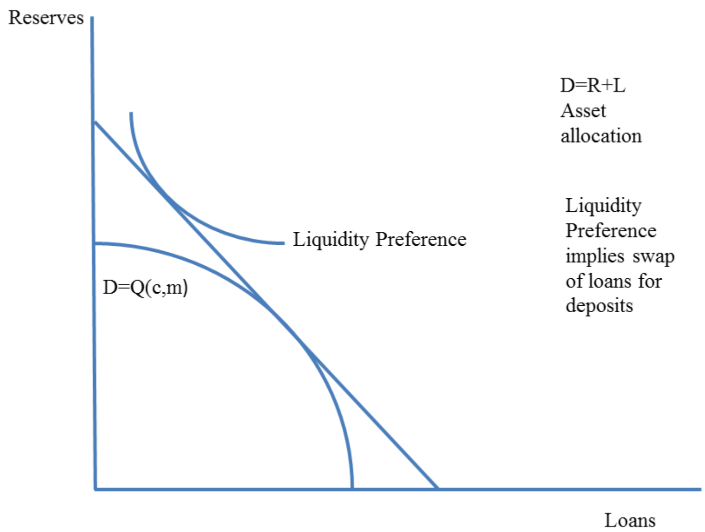

Figure 3: Production of Loans and Liquidity Preference of Banks

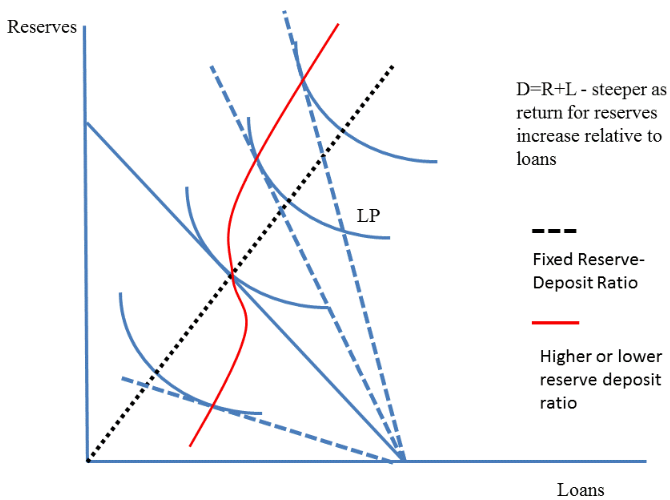

Figure 4: Reserves over the Business Cycle

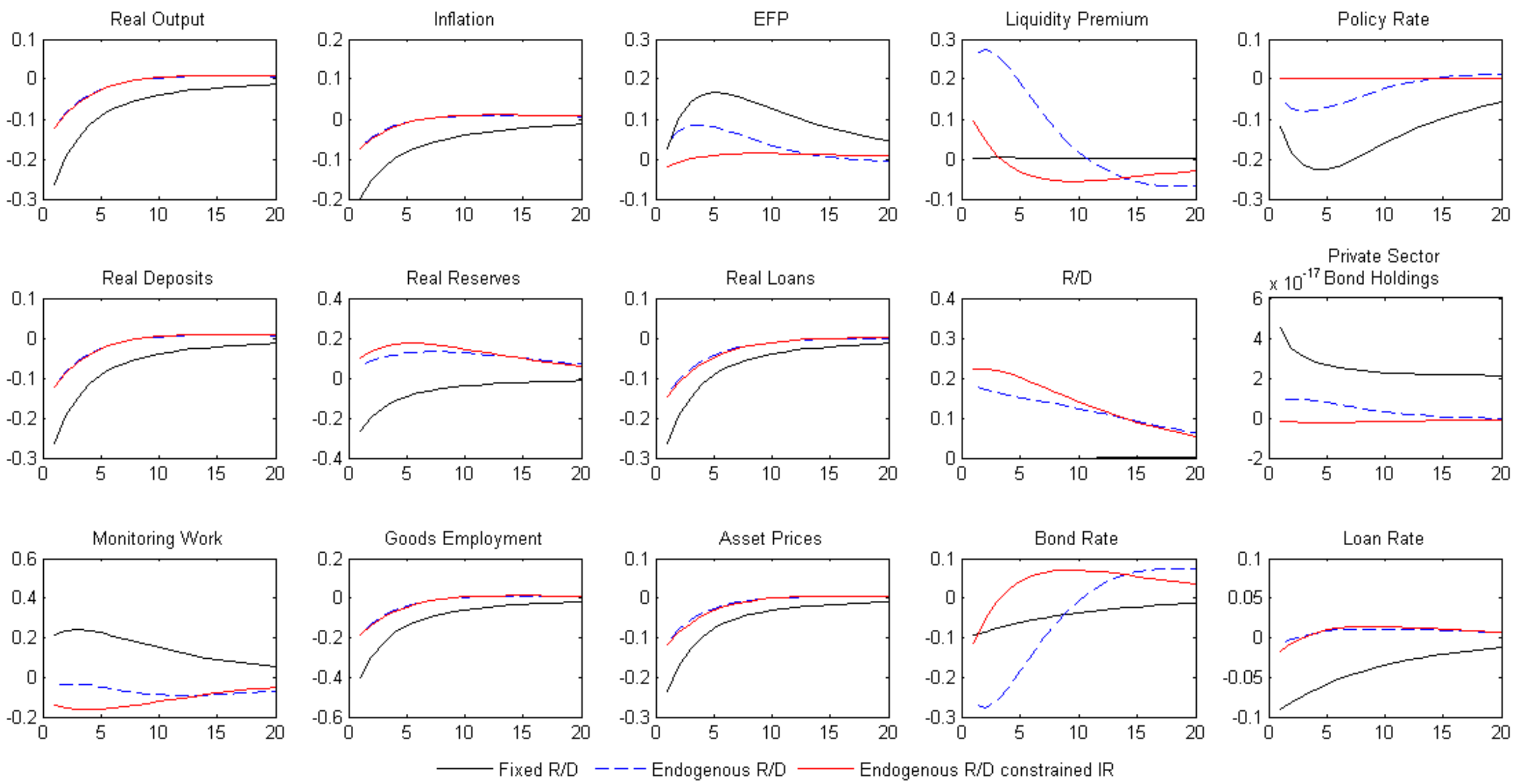

Figure 5: Response to a negative 1 standard deviation shock to the value of collateral under fixed and endogenous reserve deposit ratios and with the nominal interest rate constrained.

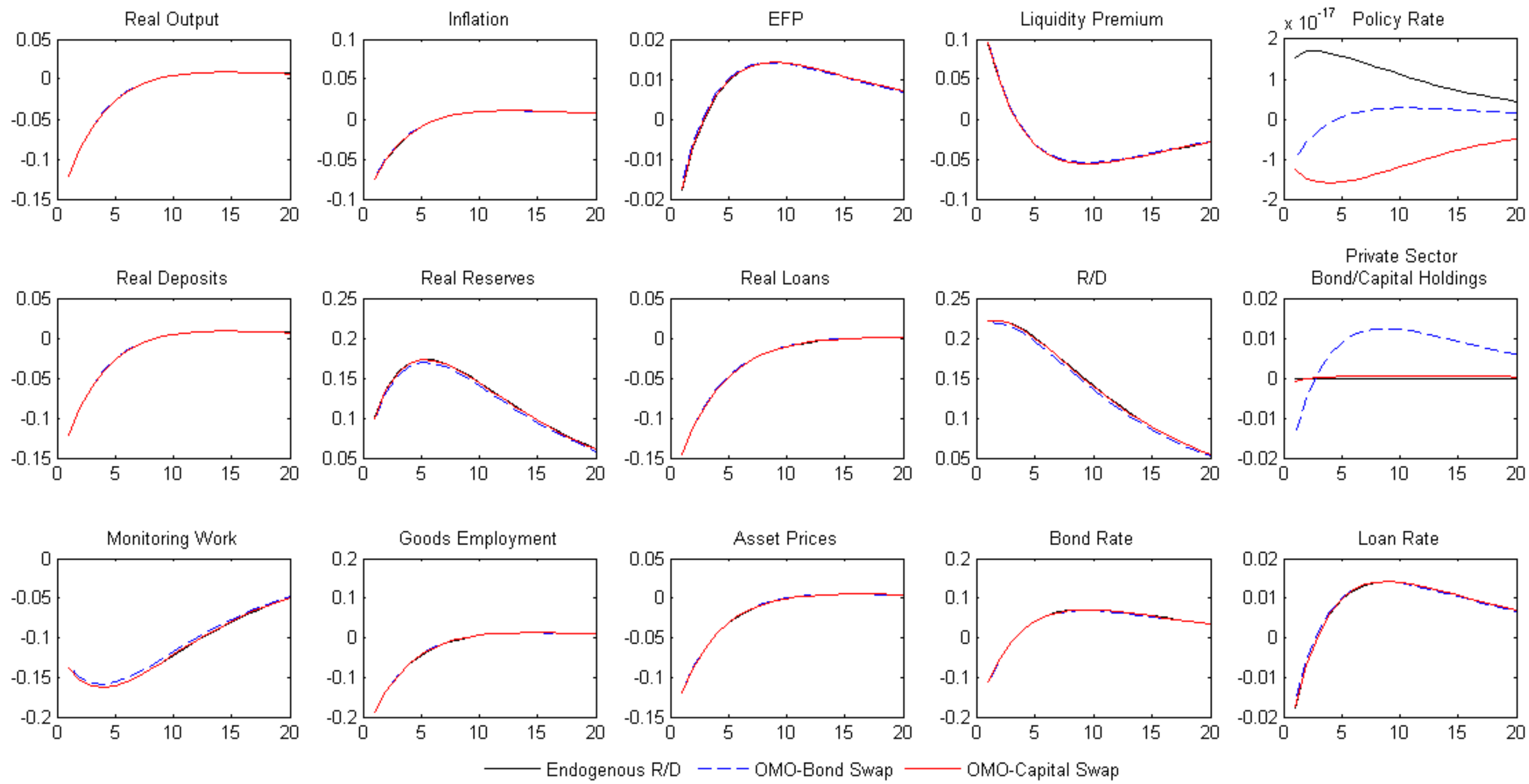

Figure 6: Response to a negative 1 standard deviation shock to the value of collateral under different styles of OMO with a constrained short-term nominal interest rate.

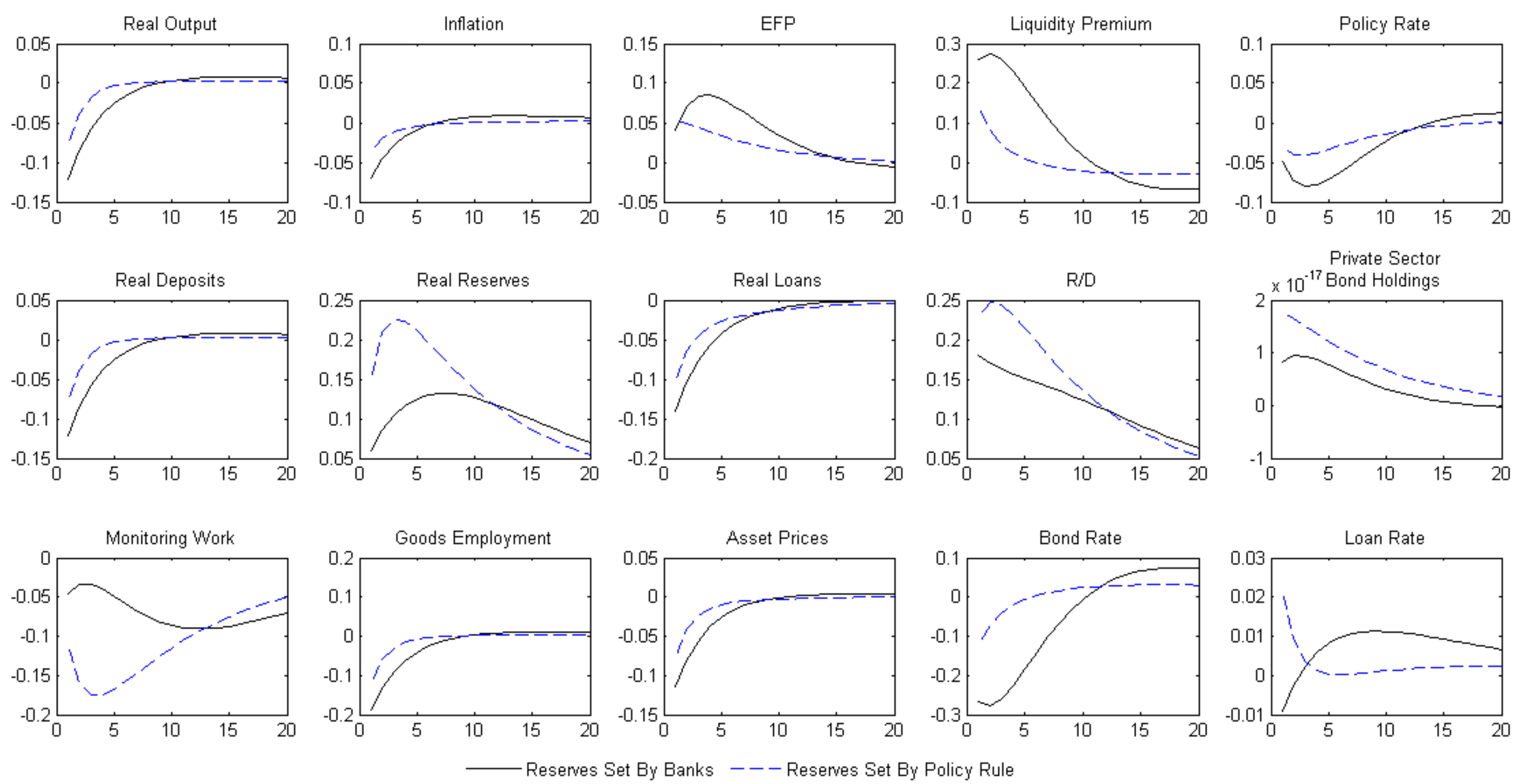

Figure 7: Response to a negative 1 standard deviation shock to collateral under different reserve setting regimes.

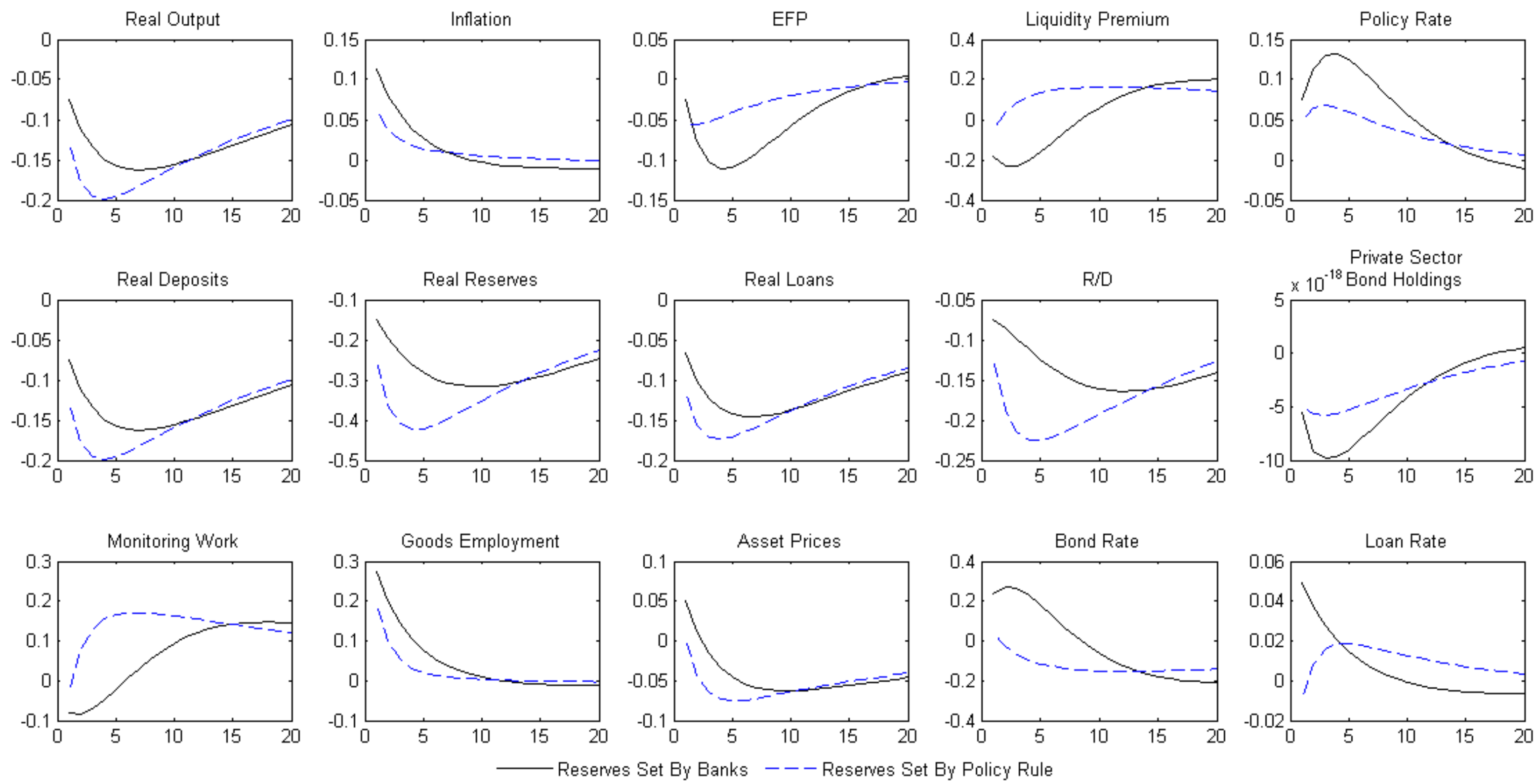

Figure 8: Response to a negative 1 standard deviations shock to productivity in manufacturing under different reserve setting regimes.

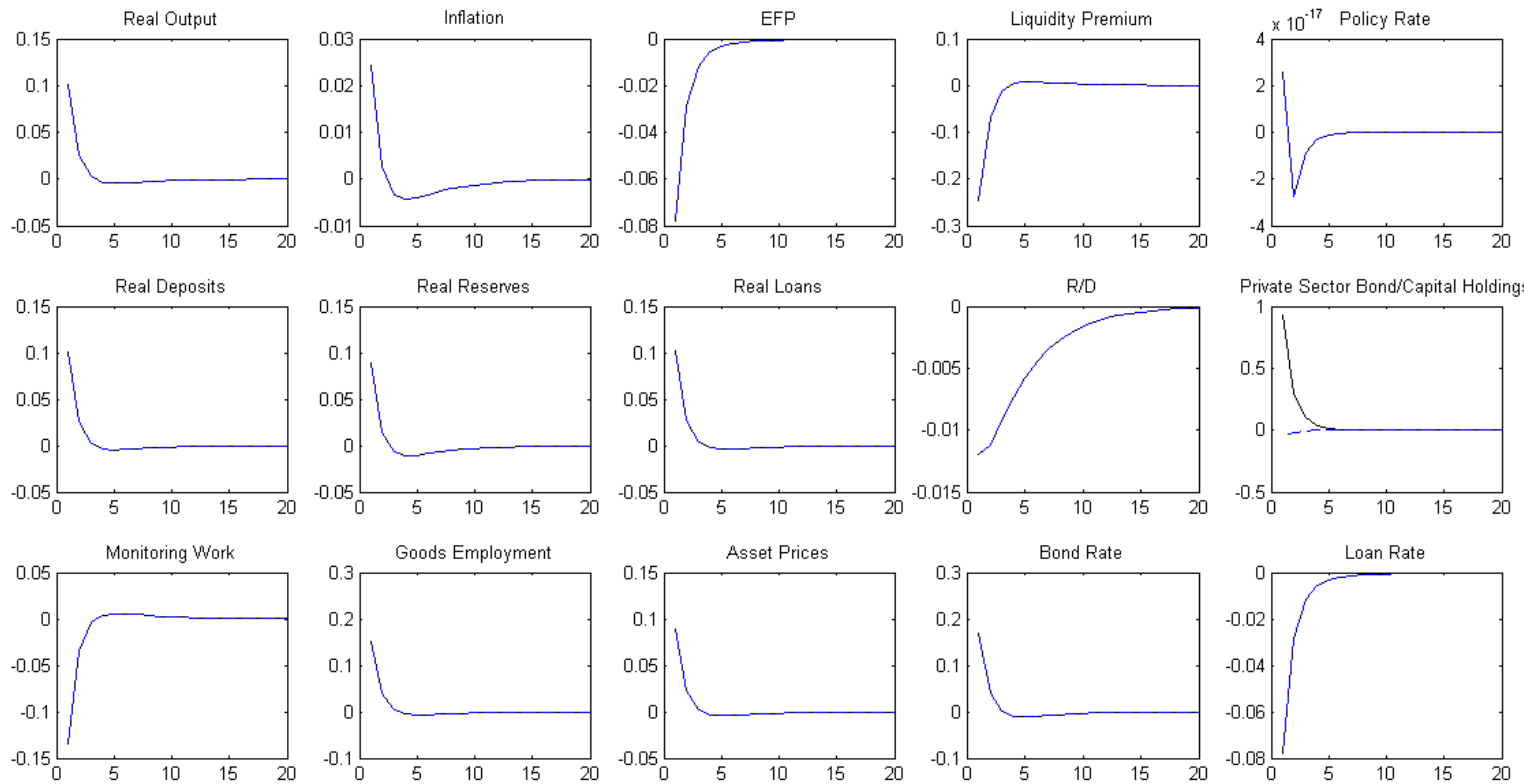

Figure 9: Response to a primitive credit easing policy controlled by equal and inverse exogenous shocks to private sector bond holdings and private sector capital holdings.

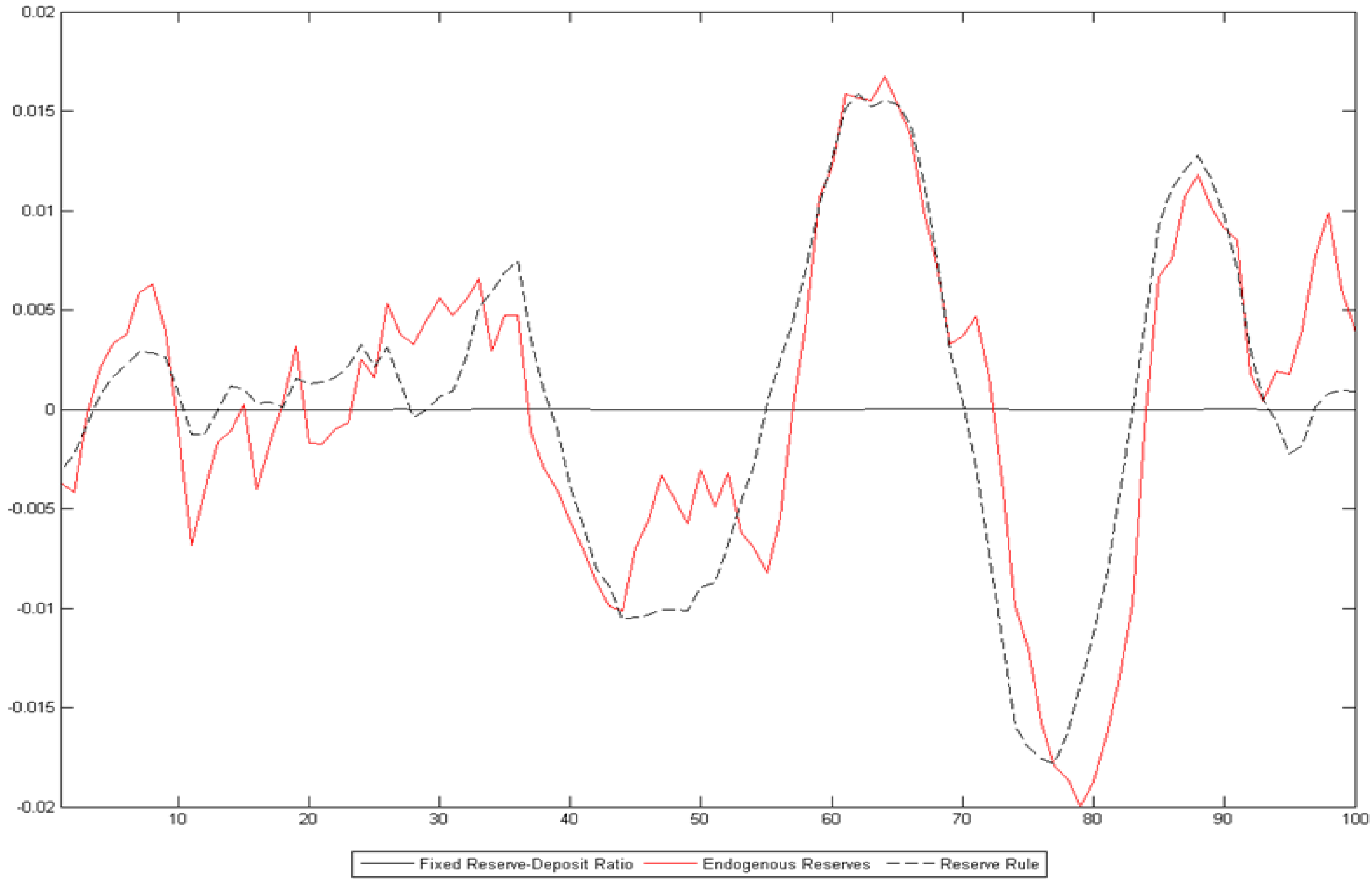

Figure 10: Simulation of Two-year Moving Average Series of HP Filtered Reserve-Deposit Ratio Under Three Reserve Regimes[38]

[38] Figure 10 shows the middle segment of a simulation of 10,000 data points based on each model of reserve setting. The simulated data are HP filtered ($\lambda = 1600$)