# BANK RESERVES AND BROAD MONEY IN THE GLOBAL FINANCIAL CRISIS: A QUANTITATIVE EVALUATION

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# Bank reserves and broad money in the global financial crisis: a quantitative evaluation


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## *Abstract*

The Federal Reserve responded to the global financial crisis by initiating an unprecedented expansion of central bank money (bank reserves) once the policy rate had reached the lower bound. To capture the salient features of the crisis, we develop a model where the central bank can provide reserves on demand and also use reserves to buy government bonds. We show that the provision of reserves through either channel reduces the cost of providing loans as they act as a substitute for private sector collateral and costly monitoring activity. We illustrate this mechanism by examining the role of reserves in projecting stable growth in broad money after the financial crisis. We also run a counterfactual which suggests that, if the Federal Reserve had not provided bank reserves on such a large scale, broad money would have fallen, the economy might have experienced a deeper contraction, and the recovery would have been more protracted, taking perhaps twice as long to return to equilibrium.



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## Non-technical summary


The Federal Reserve responded to the global financial crisis by initiating an unprecedented expansion of central bank money (bank reserves) once the policy rate had reached the lower bound. To capture the salient features of the crisis, we develop a model where the central bank can provide reserves on demand and also use reserves to buy government bonds as part of quantitative easing (QE). We show that the provision of reserves through these channels reduces the cost of providing loans as they act as a substitute for private sector collateral and costly monitoring activity. We illustrate this mechanism by examining the role of reserves in projecting stable growth in broad money after the financial crisis.

When the crisis struck, falling asset prices, increased risk premia and heightened demand for liquidity led to the cost of credit rising and the supply of new lending weakening significantly. We model this process and investigate a range of policy responses. We find that when central banks injected reserves into the banking sector, this met the increased demand commercial banks had for safe, liquid assets and helped support lending to the real economy. Furthermore, by employing QE – where they buy assets with newly created money – central banks can boost asset prices and support credit by directly creating new deposits.

When applied to a simulation that approximates the shock of the global financial crisis, the model suggests that the actions of the Federal Reserve helped the US economy avoid a significantly worse economic outcome than would otherwise have been the case. For this, we run a counterfactual which suggests that, if the Federal Reserve had not provided bank reserves on such a large scale, broad money would have fallen, the economy might have experienced a deeper contraction, and the recovery would have been more protracted, taking perhaps twice as long to return to equilibrium. We show that the Federal Reserve's decision to employ QE boosted nominal GDP by some 3 percentage points and prevented a rise of some 2 percentage points in unemployment. Our simulations also suggest that QE policies, if carried out quickly and in sufficient volumes, can significantly insulate the real economy from an extreme economic shock, even when the Federal Reserve's primary instrument of policy – the fed funds rate – is constrained at the lower zero bound.

Finally, the model matches the observed behaviour in monetary aggregates, providing an explanation for why the money multiplier (the ratio of broad money to central bank money) fell so dramatically over this period. This is a key contribution as it provides a deeper understanding of the role of different forms of money in the economy.

# 1 Introduction

Modelling the demand for narrow and broad money once formed an integral part of macroeconomic models, and the judgement on disequilibrium holdings was a key monetary policy judgement (see, for example, Brunner and Meltzer, 1966). The financial crisis of 2007-09 brought into sharp relief the observation that macroeconomic models had increasingly used money as a veil, which was always cut to match the optimized nominal spending plans of households and firms. This meant that when shocks actually originated in the monetary and financial sector and exhausted the standard policy interest rate channel (by driving policy rates to the zero lower bound), the correct policy response became problematic. The post-crisis collapse in the ratio of narrow to broad money, which has accompanied huge expansions of central bank money, forces us to think about the mechanism by which the expansion of reserves can stabilise the economy.[1] Accordingly in this paper, we supplement the optimization problems of households and firms with a formal optimization problem for commercial banks in the management of the assets side of their balance sheets. This allows us to understand the stabilising properties of the central bank offering money in a demand-driven manner to offset shocks at the zero lower bound, as well as the effects of quantitative easing (QE) policies on broad money.

Prior to the 2007-09 crisis, the Federal Reserve conducted monetary policy by manipulating its short-term nominal interest rate.[2] Many models employing a short-term nominal interest rate do still characterize monetary policy as controlling the quantity of central bank (narrow) money in order to sustain a desired interest rate. This is achieved by withdrawing supply in open market operations to raise rates and increasing supply to lower rates. Disyatat (2008) explains how this policy amounts to an exercise in reverse causality. Outside of periods of explicit QE, what happens in practice is that policy makers set the lending rate at which they will conduct operations and then provide as much narrow money through open market operations as commercial banks demand at that rate. Narrow money is thus driven by demand. Commercial banks then supply loans at the market interest rate, which reflects the costs of financial intermediation. A key insight here is that the evolution of monetary aggregates "reflects prevailing interest rates rather than determines them" and we seek to capture this interaction between interest rate spreads and lending in our model.[3]

We suggest thinking about variations in the quantity of broad and narrow money as an optimal

[1]See Garfinkel and Thornton (1991) for a precursor to our argument that the multiplier cannot be thought to be exogenous and should be interpreted with reference to policy and underlying economic conditions, including financial spreads. In a paper focusing on the empirical evaluation of the relationship between central bank reserves and broader money and bank lending, Carpenter and Demiralp (2012), echoing Johannes and Rasche (1983), find little evidence supporting the standard money multiplier narrative, but suggest that a more complex relationship between monetary policy and the quantity of lending, one where demand for loans and reserves, which are dependent on interest rates, could play a role.

[2]The consensus rationale for this can be found in Poole (1970).

[3]See Chadha et al. (2014) for a thorough analysis of this issue.

choice on the part of commercial banks that matches the demand from households for deposits with some combination of reserves or loans.[4] The use of non-conventional monetary policies, which have increased the supply of narrow money to commercial banks, gives us a background against which to judge our model. Accordingly, we build on the money and banking sector model of Goodfriend and McCallum (2007), in which the overall level of deposits is determined by narrow money and loans produced by commercial banks. In contrast to their model, which has a fixed ratio between the two monetary aggregates, however, we derive a demand schedule for narrow money from banks' profit-maximizing condition and allow the central bank to meet this demand perfectly elastically. The volume of loans is then derived from the bank's optimizing condition and loan production function, allowing us to observe richer narrow and broad monetary dynamics with the two aggregates evolving in response to macroeconomic and financial conditions.

A further innovation is the inclusion of open market operations as a practical mechanism to effect these changes in narrow money. In our model the central bank exchanges newly created narrow money for bonds held by the private sector via the commercial bank. This necessarily leads to an expansion of narrow money. QE policies are introduced through an endogenous central bank feedback rule which responds to changes in output and deviations of inflation from its target rate.

The rest of the paper is structured as follows. In Section 2, we briefly outline recent developments in narrow and broad money with particular reference to policy at the Federal Reserve. We then outline a model of money, banking and reserves. In Section 4, we discuss the implications of our model for the evolution of broad and narrow money, and how this affects banks and the wider economy. Much of our discussion focuses on the behaviour of the external finance premium (EFP) as a critical part of the transmission mechanism. In this model, injecting narrow money into the banking sector reduces the marginal cost of producing loans and acts to limit the increase in the external finance premium. To illustrate these points more clearly in Section 6 we present the impulse responses of the models key variables to both real and financial shocks and compare the responses when narrow money or the interest rate is pegged, and when the central bank employs QE. To strengthen this conceptual point, in Section 7 we carry out welfare analysis by deriving a welfare loss function for the representative household from a second-order approximation to utility.

Finally, in Section 8 we apply the model to the global financial crisis and find it matches the evolution of key variables in the US economy in the wake of the global financial crisis. We then investigate what the results of the model imply for the monetary aggregates and find that following a shock similar to that experienced by the United States during the global financial crisis,it is optimal for banks to demand much more narrow money and for credit money in the form of loans to contract. This leads to a significant fall in the money multiplier consistent with

[4]See Gale (2011) on this point.

that observed in the data. We then perform a counterfactual exercise in which we subject the model to the same shock but hold the quantity of reserves fixed. The model implies that, had the Federal Reserve not expanded narrow money instead of maintaining a fixed multiplier, broad money would have fallen by significantly more and the US economy might have experienced a contraction in output that was 1% greater, inflation would have fallen by an additional 2.5% and employment would have been 2% lower. The recovery would also have been more protracted, taking roughly twice as long to return to equilibrium. Complementing these results, we show that an active QE policy, which stabilized asset prices, helped mitigate the economic slump.

## 2 Broad and Narrow Money

Ever since, at least, Friedman and Schwartz's (1963) magisterial analysis of the Great Depression at the latest, the question of maintaining the level of broad money growth in response to a shock has been a key aspect of financial crisis management. Figure 1 shows how total bank deposits continued to grow after the financial crisis shock compared with the immediate preceding period. Indeed, without an increase in bank reserves, the total quantity of bank deposits would have fallen, broadly-speaking in line with commercial bank credit. The contraction of new credit and lending by commercial banks to the wider economy in the post-crisis period followed heavy losses and heightened uncertainty, after which banks became more cautious in their new lending and sought to repair balance sheets and shrink loan books. Figure 2 (bottom panel) illustrates the nature of the negative credit supply shock as it shows a sharp increase in both the corporate bond credit spread and the spread of commercial paper over the federal funds rate in late 2008; subsequently we can note year-on-year growth in loans from a nadir of nearly -10% İt is the consequences of this large credit shock that we seek to understand in this model.

The second factor, which is clear in Figure 1, is that the Federal Reserve massively expanded the quantity of central bank money as part of its response to the 2008 crisis. Figure 3 shows how the Federal Reserve's balance sheet has evolved with an unprecedented rise in the level of reserves. Initially, the Federal Reserve supplied reserves to banks through the Term Auction Facility (TAF) and other facilities but sterilized the effect of this lending on the base. Immediately after the collapse of Lehman Brothers, the monetary base exploded, but only because the Federal Reserve no longer had the resources to sterilize. This initial increase in the base was thus largely driven by demand. However, subsequent increases in reserves driven by the Federal Reserves's large scale asset purchases (LSAPs) were probably not fully demand-driven, as they expanded reserves beyond the point that commercial banks may have wanted to hold, but that the banking system in aggregate was forced to accommodate. This represented an explicit QE policy in regards to its impact on the monetary base relative to demand. We will try to tease out the impact of both types of reserve accumulations in our model.

Obviously, if there were a fixed money multiplier, this huge expansion in narrow money would be expected to lead to an equivalent boom in broad money. Similarly, a contraction in the credit supply and loan issuance by commercial banks would serve to reduce broad money. As already observed though, the growth in the level of broad money has been reasonably constant, implying that the increase in narrow money has worked to almost exactly offset the contraction in credit money. Whilst these two effects pull in opposite directions on the broad monetary aggregate, they both act to move the money multiplier in the same way, down, as narrow money has formed an increasing fraction of the total money supply. We will go on to show how this fall in the multiplier may be explained in part by banks' optimizing behaviour causing them to rebalance their portfolio between narrow and credit money as the relative returns/costs of each vary and this may have acted to reduce the duration and severity of the economic downturn by offsetting an escalation in market-determined premia.[5]

## 2.1 The Central Bank Balance Sheet

We now aim to set out a simple framework for analyzing extraordinary central bank balance sheet monetary policies, which have expanded reserves.[6] For simplicity, we abstract from other forms of central bank money and concentrate on bank reserves alone in this discussion, so that high powered money is identical to reserves. More traditionally the central bank controls the stock of fiat money (outside money) and financial intermediaries creates other forms of inside money, which are intra-private sector claims. As financial intermediation allows deposits also to serve as money, they offer a close substitute to (outside) fiat money, which means that the ability of the central bank to determine the overall nominal level of the broad money stock depends on the relationship between outside money and inside money. In principle, the central bank has a powerful tool to regulate the balance sheet of financial intermediaries and to affect the quantity of money in circulation: reserves, which may be either or both of fractional and/or voluntary.

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

[5]See Walsh (2009) for an interesting attempt to understand policy at the Zero Lower Bound.
[6]See Chadha et al. (2012) for more detail.

| Commercial Banks | | | |
|---|---|---|---|
| Assets | | Liabilities | |
| Reserves | $r$ | Deposits | $D$ |
| Loans | $(D \quad r)$ | | |

| Central Bank | | | |
|---|---|---|---|
| Assets | | Liabilities | |
| Bonds | $(1 \quad \gamma)B$ | Reserves | $r$ |
| Capital | $(1 \quad \gamma_k)K$ | | |

We first look at the private sector balance sheet. The private sector has three forms of assets: deposits, $D$, held at banks and some fraction of bonds, $\gamma B$, issued by the government and a fraction of total capital.[7] The liabilities are loans, $D \quad r$, provided by banks and taxes. Capital lies on the assets side of household balance sheets because households own the firms and firms treat capital as an asset. 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, $D \quad r$, is available to be lent to the private sector. The central bank holds assets in the form of some fraction of government bonds, $(1 \quad \gamma)B$, and a fraction of capital, $(1 \quad \gamma_k)K$, with liabilities determined by central bank money, which are bank reserves.[8] The net assets of commercial banks and of the central bank are both zero. The private sector has net assets given by $D+\gamma B+ \ \gamma_k K \quad (D \quad r + \sum_{i=0}^{\infty} \beta^i t_i)$ and so because $r = (1 \quad \gamma)B + \gamma_k K$ and $\sum_{i=0}^{\infty} \beta^i t_i = B$, we can note that the net private sector assets are also zero.

From this flow of funds we can see the mechanism by which extraordinary policies operate. The central bank can perform QE which involves the expansion of its balance sheet by the issuance of bank reserves that are backed by increased holdings of either bonds or capital. The bank reserves are lodged with commercial banks against which the private sector, which has sold the bonds or capital to the central bank, has a deposit claim. Alternatively, credit easing is conducted by changing the composition of the balance sheet and increasing holding of "risky" capital compared to "less risky" bonds - in effect reducing the volume of credit risk lodged within the private sector. With the overall quantity of 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 assets at zero. Due to the differing properties of bonds and capital as collateral in loan production, this exchange has implications for levels of deposit demand which we will discuss later.

[7] In this example we assume that the private sector is represented by households, so firms are included here.
[8] If we operate in an open economy, central bank assets would also include foreign exchange reserves $r^f$.

# 3 The Model of Broad and Narrow Money

We now outline our model, which is an extended version of the one developed by Goodfriend and McCallum (2007) and extended by Chadha and Corrado (2012). This primarily consists of a Calvo-Yun monopolistically competitive production economy with sticky prices and four main agents; households, who can work either in the goods-production sector for firms or for banks monitoring loan quality for banks, who meet consumer deposit demand with reserves and a loan production function, and the monetary authority.[9]

## 3.1 Households

Households are faced with a utility function in real consumption, $c_t$, and leisure:

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

They can supply labour to the goods production sector, $n_t^s$, or to financial intermediaries in the form of monitoring work, $m_t^s$. They are also subject to the budget constraint:

$$\begin{aligned} &q_t(1 \quad \delta)K_t + \frac{\gamma B_t}{P_t^A} + \frac{D_{t-1}}{P_t^A} + w_t(n_t^s + m_t^s) + c_t^A(\frac{P_t}{P_t^A})^{1-\theta} + \Pi_t \\ &w_t(n_t + m_t) \quad \frac{D_t}{P_t^A} \quad tax_t \quad q_t K_{t+1} \quad \frac{\gamma B_{t+1}}{P_t^A(1+R_t^B)} \quad c_t = 0 \end{aligned} \tag{2}$$

where $q_t$ is the price of capital, $K_t$ is the quantity of capital, $P_t$ is the price of goods produced by households, $P_t^A$ is the consumption good price index, $n_t$ is the labour demanded by household as producer, $m_t$, is the labour demanded by households' 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, $\Pi_t$, goes to the household sector. The Lagrange multiplier of this constraint is denoted as $\lambda_t$ and $\theta$ is the elasticity of household demand.

In addition, households have a "deposit-in-advance" constraint which requires them to hold deposits with a financial intermediary in order to implement their consumption plans, where $v_t$ is the velocity of broad money,

$$c_t = v_t D_t / P_t^A. \tag{3}$$

[9] There is also a fiscal authority which runs a balanced budget. We fix levels of government debt as constant unless exogenously shocked, thus the government's role within this set-up is benign. The annex outlines the model in more detail.

## 3.2 Firms

The production sector, characterized by monopolistic competition and Calvo pricing, employs a Cobb-Douglas 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:

$$K_t^{\eta}(A1_t n_t)^{1-\eta} \quad c_t^A (P_t/P_t^A)^{-\theta} = 0, \tag{4}$$

where $\eta$ 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 $\varrho$ and $\theta$ denotes the elasticity of aggregate demand, $c_t^A$. The Lagrange multiplier of this constraint is denoted as, $\xi_t$. By clearing the household and production sectors,[10] we can define the equilibrium in the labour market and in the goods market. Specifically, the demand for monitoring work:

$$m_t = \left( \frac{\phi}{\lambda_t c_t} \quad 1 \right) \frac{1 \quad \alpha}{w_t} c_t \tag{5}$$

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

## 3.3 Banks

The role of banks in our economy is to meet the deposit demand of liquidity constrained consumers confronted with the deposit-in-advance constraint. These deposits are created in two ways. They are either created by the central bank in the form of narrow money (reserves) which are lent to or lodged with commercial banks or commercial banks can create deposits themselves by producing loans which generate an equivalent deposit on the liabilities side of the bank's balance sheet. Thus

$$L_t + r_t = D_t \tag{6}$$

and broad money is determined in part by the central bank, but also mostly by the banking system. $\frac{D}{r}$ therefore represents the money multiplier and, as the only source of narrow money in our model is reserves, $\frac{1}{MM} = \frac{r}{D}$, which equals the reserve ratio.[11]

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

[11] Under a 100% reserve system, the broad money supply, and thus consumption within our model, would be restricted by the creation of narrow money by the central bank. In this variant $D_t = r_t$ and the subsequent problem of reserve demand simplifies to depend purely on demand for consumption at the given policy rate.

### 3.3.1 Reserves and Loans

We abstract from cash and assume that narrow money consists solely of reserves, which in normal times the central bank supplies to commercial banks perfectly elastically in response to their demand. In order to obtain any excess reserves commercial banks face a cost, which is the central bank's policy rate, paid via open market operations conducted at a discount window (see Section 4.1).[12]

Alternatively, commercial banks can create deposits themselves by producing loans, which generate an equivalent deposit on the liabilities side of the bank's balance sheet but also incur a cost. Banks produce these loans by applying a production technology to collateral posted by households in the form of bonds, $b$, or capital, $qK$. This process is captured by a Cobb-Douglas production function for loans where collateral is combined with monitoring work, $m$:

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

$A2_t$ 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,[13], while $\alpha$ is the share of collateral in loan production. 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.

### 3.3.2 A demand curve for reserves

We next look to derive a demand curve for reserves. To do this we follow Baltensperger (1980) and frame the bank's decision as an optimal choice between two assets subject to the costs payable on liabilities. The decision is made in two stages. First, interest rates are determined and then, given the constellation of spreads, banks decide on or choose a level of reserves and loans with a view to maximizing expected returns. This approach directly addresses the reverse causality criticism of Disyatat (2008). More formally, the bank seeks to maximize total returns within the period subject to the returns from loans, $L_t$, which are lent out at the collateralized interest rate of $R_t^L$, the cost of obtaining reserves, $R_t r_t$, and the payment of interest on deposits, $R_t^D$:

$$\max_{r_t} \Pi_t = R_t^L L_t \quad R_t r_t \quad R_t^D D_t, \tag{8}$$

$$\text{s.t. } C_t = \frac{1}{2} R_t^T (\bar{r} \quad r_t)^2 + \tau_t (\bar{r} \quad r_t). \tag{9}$$

[12] See Freeman and Haslag (1996).

[13] Capital is considered inferior as there are increased costs to the bank of verifying its physical quality and condition as well as its market price. It is also less liquid should it be needed in the event of default.

The final two terms in equation 8 are costs associated with reserve management. There is a symmetric smoothing term intended to capture a preference for avoiding large deviations from the steady-state level of reserves, $\bar{r}$. In the model the cost of such deviations from target is the uncollateralized interest rate, $R_t^T$, because if $r_t < \bar{r}$, the commercial bank will fund its shortfall at the penalty rate, and if $r_t > \bar{r}$ the commercial bank will have missed the opportunity to lend out those reserves at the same penalty rate and thus incurs the opportunity cost, $R_t^T$.

The second term reflects the need to hold a minimum level of reserves in any given period.This could most obviously be motivated by regulation (Bank for International Settlements (2010)) but may also be influenced by precautionary motives for holding reserves as a safe, liquid asset. The second term, $\tau_t$, can be thought of as an exogenous shift in the ex ante probability of a reserve shortfall or a change in the propensity to hold reserves, which might be policy-induced. It represents shifts in the level of reserves necessary to meet the bank's target holdings, so an increase in $\tau_t$ corresponds to bank reserves expected to remain below the target level $\bar{r}$.

Solving equations (8) and (9) with respect to reserves, the optimal, profit-maximizing level of reserves gives us the commercial bank demand curve, which can be written as:

$$\hat{r}_t = \frac{\hat{\tau}_t}{\hat{R}_t^T} \quad \left[ \frac{\hat{R}_t + \hat{R}_t^L}{\hat{R}_t^T} \right] + \bar{r}. \tag{10}$$

It is a positive function of the probability of the commercial bank being short its obligated level of reserves, $\bar{r}$, and negative in $\hat{R}_t$, and, $\hat{R}_t^L$, which is the cost of reserves and the opportunity cost of reserves, the loan rate. We therefore emphasize that the relative cost and returns of the two mechanisms for meeting deposit demand change, as do the bank's optimal quantities of each.

Any consumption above the level equivalent to the quantity of reserves requires households to borrow from the commercial banks, and thus receive a deposit which can be used to conduct transactions.[14] Loan demand can thus be pinned down to the difference between deposit demand and the quantity of reserves demanded by the commercial bank. By combining equations (6), (7) and (10), we can write the quantity of credit money the banking sector should extend in the form of loans as

$$L_t = D_t \quad \frac{\hat{\tau}_t}{\hat{R}_t^T} + \frac{\hat{R}_t + \hat{R}_t^L}{\hat{R}_t^T} \quad \bar{r}.$$

We can then show how total deposits depend on both money created by the central bank in response to commercial bank demands or reflecting reserves imposed on commercial banks through policy and that created by the banking sector through loans:

[14] Our model differs in this way from others where loans are used to fund investment and have a direct productive purpose. However, by creating broad money and funding consumption, they are acting to achieve a similar effect through the sales equal net production constraint.

$$D_t = \frac{\hat{\tau}_t}{\hat{R}_t^T} \quad \left[\frac{\hat{R}_t + \hat{R}_t^L}{\hat{R}_t^T}\right] + \bar{r} + F(\gamma b_{t+1} + A3_t k q_t K_{t+1})^{\alpha}(A2_t m_t)^{1-\alpha}.$$

Finally, we can put this back in to the deposit-in-advance constraint which allows us to show the interconnectivity between the real economy, the financial sector and the bank's decision between monetary aggregates:

$$c_t = v_t \frac{F(\gamma b_{t+1} + A3_t k q_t K_{t+1})^{\alpha}(A2_t m_t)^{1-\alpha}}{P_t^A(1 \quad rr_t)}. \tag{11}$$

And this can be re-written as:

$$c_t = v_t \left[\underbrace{\frac{\hat{\tau}_t \quad \hat{R}_t \quad \hat{R}_t^L}{\hat{R}_t^T P_t^A} + \bar{r}}_{base} + \underbrace{\frac{F(\gamma b_{t+1} + A3_t k q_t K_{t+1})^{\alpha}(A2_t m_t)^{1-\alpha}}{P_t^A}}_{credit}\right].$$

The first two terms inside the square bracket represent narrow money, comprising base demand and an exogenous term, whilst the third is money created by the banking sector. If it becomes optimal for commercial banks to create less credit money through loans, then the only way to support a given level of broad money, and thus activity, is to increase the quantity of narrow money accordingly. As the central bank is the only agent that can create narrow money, it must increase the supply of reserves, and in our benchmark framework this is exactly what it does, meeting the increased demand for reserves elastically and injecting reserves to meet policy objectives. This allows commercial banks to achieve a given asset mix.

## 3.4 Interest Rates and Spreads

The inclusion of this banking sector gives rise to a number of interest rates and financial spreads. The benchmark theoretical interest rate $R^T$ is the standard intertemporal nominal pricing kernel, priced from expected real consumption growth and inflation. Basically it boils down to a one-period Fisher equation:

$$R_t^T = E_t(\lambda_t \quad \lambda_{t+1}) + E_t \pi_{t+1}. \tag{12}$$

The central bank policy rate is the market clearing rate for reserves and is set by a feedback rule responding to inflation, $\pi_t$, and output, $y_t$, with parameters, $\phi_\pi$ and $\phi_y$, respectively. Policy rates are smoothed so that $1 > \rho > 0$:

$$R_t = \rho R_{t-1} + (1 \quad \rho)(\phi_\pi \pi_t + \phi_y y_t). \tag{13}$$

To find the excess of the loan rate $R^L$ over funding costs, $R$, as the real marginal cost of loan production, we divide the factor price, $\frac{w_t}{P_t^A}$, by the marginal product of labour which equates the marginal product of loans per unit of labour $(1 \quad \alpha)\frac{L_t}{m_t}$ where loans are defined by the following relationship $L_t = D_t(1 \quad rr_t) = \frac{c_t P_t^A}{v_t}(1 \quad rr_t)$:

$$EFP_t = \frac{w_t v_t m_t}{(1 \quad \alpha)(1 \quad rr_t)c_t}.$$

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.

$$R_t^L \quad R_t = \underbrace{[v_t + w_t + m_t + rr_t \quad c_t]}_{EFP_t}. \tag{14}$$

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 the reserve ratio, $rr_t$, and decreasing in consumption, $c_t$. Recall that $rr_t = \frac{1}{MM_t}$ the EFP is also decreasing in the money multiplier, meaning that in this model, banks switch to narrow money taking more of the burden of meeting deposit demand, when the external finance premium is higher.

The yield on government bonds is derived by maximizing households' utility with respect to bond holdings, $R_t^T \quad R_t^B = \left[\frac{\phi}{c_t\lambda_t} \quad 1\right]\Omega_t$. In its log-linear form, it is the risk-free rate, $R_t^T$, minus the liquidity service on bonds, which can be interpreted as a liquidity premium (LP):

$$R^B R_t^B = R^T R_t^T \quad \underbrace{\left[\left(\frac{\phi}{c\lambda} \quad 1\right)\Omega\Omega_t \quad \frac{\phi\Omega}{c\lambda}(c_t + \lambda_t)\right]}_{LP_t}, \tag{15}$$

where $(c_t + \lambda_t)$ measures the household marginal utility relative to households' shadow value of funds, while $\Omega_t$ is the marginal value of the collateral. It is in fact these key margins - the real marginal cost of loan management versus the liquidity service yield - that determine the behaviour of spreads. In the above expression, $\phi$ denotes the consumption weight in the utility function whereas $\lambda_t$ is the shadow value of consumption, $c_t$. The interest rate on deposits is the policy rate, $R_t$, minus a term in the reserve/deposit ratio:

$$R_t^D = R_t \quad \frac{rr}{1 \quad rr} rr_t. \tag{16}$$

As these spreads influence the asset allocation of banks they also have an impact on the resulting path of consumption. When we come to the analysis of the model we will discuss these premia as a way of understanding our key results.

# 4 Monetary Policy

This model framework allows us to capture a number of interesting elements of monetary policy. First, the direct instrument of monetary policy in our benchmark model is the short-term nominal interest rate, which we have seen is set in response to a standard active interest rate rule. By varying this rate, the policy-maker changes the cost to commercial banks of obtaining reserves. The endogenously determined external finance premium also changes the return on loans. The liquidity premium has an impact on the value of collateral available to households and the deposit rate, a cost of funding, is a negative (positive) function of the reserve/deposit ratio (money multiplier). These effects will change the opportunity cost of meeting deposit demand with narrow money from the central bank rather than extending loans and cause the bank to reset its mix between narrow money and loans. The central bank can also decide not to change the interest rate and allow the demand for reserves to stabilize the economy. We will show the implications of these alternatives for the wider economy in Section 6.

## 4.1 Open Market Operations: A Mechanism to Control Reserves

Under both conventional and non-conventional monetary policies, the central bank varies the size of its balance sheet, thus increasing or decreasing the quantity of reserves in the economy to meet the demand of commercial banks at its target policy rate.[15] Previous models have lacked a mechanism by which the quantity of reserves in the economy can be controlled by the central bank. We aim to provide a more accurate approximation of the practicalities of reserve management by modelling open market operations whereby an asset, primarily bonds, is bought from the private sector in exchange for newly created money. The central bank now holds more bonds on its balance sheet. The private agent from which the bonds have been purchased receives a newly created deposit in its commercial bank account, whilst its commercial bank's own account with the central bank is credited with an equal increase of freshly created reserves.[16]

To incorporate this mechanism into our model we assume the central bank must match its only liability, reserves, by holding just one class of assets, government bonds, the total supply of which is held fixed unless subject to an exogenous shock.[17] When the central bank buys bonds in an open market operation, it increases the fraction of the total bond supply which it holds and decrease that held by the private sector. We can therefore define total bond holdings as the

[15] See Berrospide (2012) for an analysis of the demand for liquidity.

[16] We abstract from the possibility of banks themselves holding bonds and acting as the central bank's counterparty in an open market operation. Whilst this would be closer to how traditional open market operations have been carried out, it is not consistent with recent large scale asset purchases carried out by central banks which avoided buying assets directly from banks. In the context of our model, the distinction between the two frameworks is of little importance.

[17] Variants of the model in which the central bank can swap reserves for capital, or even capital for bonds can be explored in future work.

sum of private sector and central bank bond holdings,

$$b_t = b_t^{CB} + b_t^{P}, \tag{17}$$

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

$$b_t^p \hat{b}_t^p = b_t \hat{b}_t \quad r_t \hat{r}_t \tag{18}$$

It is this newly defined variable $b^p$ which determines the amount of collateral households have available and thus $b^p$ which features in our equations for loan supply and the marginal value of collateralized lending as well as the consolidated government budget constraint.[18]

The mechanism outlined here abstracts from sterilized open market operations in which the purchases of assets are funded by the sale of other assets on the central bank's balance sheet rather than the creation of new reserves, but rather and act through "credit easing" channels as defined by Bernanke (2009):

'In a pure QE regime, the focus of policy is on the quantity of bank reserves, which are liabilities of the central bank; the composition of loans and securities on the assets side of the central bank's balance sheet is incidental....By 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.'

## 4.2 A Policy Function for Quantitative Easing

Whilst in the first phase of QE the provision of liquidity followed the demand of commercial banks for liquidity, the motivation for QE shifted towards the goals stated in the Federal Reseerve's mandate in the second phase becoming disconnected from the demand from commercial banks for liquidity. The Federal Open Market Committee (FOMC) raised concerns about "subdued inflation" (FOMC September 2010) and, as stated in its announcement of additional purchases of Treasuries (QE2), the Federal Reserve explicitly aimed to "promote a stronger pace of economic recovery and to help ensure that inflation, over time, is at levels consistent with its mandate". We incorporate active QE policy by assuming that the central bank adopts the following countercyclical feedback rule with the size of reserves as policy variable, i.e.

$$r_t = \bar{r}(r_{t-1})^{\rho_r} \left(\frac{y_t}{y}\right)^{-\psi_y(1-\rho_r)} \left(\frac{\pi_t}{\pi}\right)^{-\psi_\pi(1-\rho_r)},$$

[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.

with $\bar{r}$ being the steady state reserves, $\psi_y$ and $\psi_\pi$ being the weights of output and inflation in the policy function. We assume that the central bank does not react to the loss in collateral value in real time.[19]

# 5 Calibration

Table 2 reports the values for the parameters and Table 3 the steady-state values of relevant variables.[20] Following Goodfriend and McCallum (2007), we choose the consumption weight in utility, $\phi$, to yield one-third of available time in either goods or banking services production. We also set the relative share of capital and labour in goods production $\eta$ at 0.36. We choose 11 for the elasticity of substitution of differentiated goods, $\theta$. The discount factor, $\beta$, is set at 0.99, which is close to the canonical quarterly value, while the mark-up coefficient in the Phillips curve, $\kappa$, is set at 0.1. The depreciation rate, $\delta$, is set at 0.025 while the trend growth rate, $\varrho$, is set at 0.005, which corresponds to 2% per year. The steady-state value of bond holding level relative to GDP, $b$, is set at 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 US Treasury securities as of end of year 2006.[21]

The deep 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 in the fourth quarter of 2005, yielding 0.31. The fractional reserve requirement, $rr$ , is set at 0.1. This is consistent with the reserve ratio set by the Federal Reserve on all liabilities above the low reserve tranche and approximately equal to the average Tier 1 capital ratio in the United States since the mid 2000s.

This leaves us to manipulate three key deep parameters which may influence the rest of the steady-state variables. Interestingly, these are three financial variables and so are of particular relevance for our debate on policies. $\alpha$ is the Cobb-Douglas weight of collateral in loan production. This is the degree to which banks base their lending on collateral as opposed to monitoring work or information based lending. The benchmark calibration in Goodfriend and McCallum (2007) of 0.65 is within a range throughout the literature of 0.6 to 0.89, Zhang (2011), so we follow this. $k$, is the degree to which capital is less efficient as collateral than bonds, as it entails higher costs to the bank in order to check its physical condition and market price. It is also less liquid should default occur and the collateral be called upon to repay the value of the loan. We set this

[19] Wu and Xia (2015), among others, calculate shadow rates from long-term yields of government bonds during phases of QE while the policy rate was at the zero lower bound. In principle, a QE rule could link the size of monetary intervention to the desired shadow rate. As the model setup incorporates only short-term bonds, we apply the reserves rule.

[20] The equations for the steady-state equations are listed in the technical appendix, which is available on request.

[21] 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 $mc = \frac{\theta-1}{\theta}$.

parameter at 0.2, which not only follows Goodfriend and McCallum (2007), but is validated by data on the Term Securities Lending Facility, which found that less liquid assets were swapped for bonds in a ratio of 0.21. $F$, can be thought of as total factor productivity in loan production, or a measure of the efficiency with which banks use the factors of production to produce loans.[22] As in Goodfriend and McCallum (2007), we set this to ensure the rest of our steady-state values meet three criteria as closely as possible:

- a 1% per year average short-term real "risk-free rate" that is the benchmark in the finance literature,
- a 2% average collateralized external finance premium that is in line with the average spread of the prime rate over the federal funds rate in the postwar United States,
- a share of total U.S. employment in depository credit intermediation as of August 2005 of 1.6% as reported by the Bureau of Labor Statistics.

The value this yields is $F = 9.14$. With these parameter values we see that the steady state of labour input, $n$, is 0.31 which is close to one-third as required. The ratio of time working in the banking service sector, $\frac{m}{m+n}$, is 1.9% under the benchmark calibration, is not far from the 1.6% share required. As the steady-states are computed at zero inflation we can interpret all the rates as real rates. The risk-free rate, $R^T$, is 6% per year. The interbank rate, $R$, is 0.84% per year, which is close to the 1% per year average short-term real rate. The government bond rate, $R^B$, is 2.1% per year. Finally, the collateralized external finance premium is 2% per year, which is in line with the average spread of the prime rate over the federal funds rate in the United States. 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. For the impulse response analysis and simulation exercise, we consider the real and financial shocks set out in Table 4, which reports the volatility and persistence parameters. These are standard parameters in the literature.

# 6 Why Money Matters

Having outlined a model which incorporates both narrow and broad money, we can begin to think deeply about how the balance between the two may affect banks and the wider economy. Banks, with two sources for meeting deposit demand, choose between obtaining narrow money

[22] Some authors have also described it as a measure of credit conditions within the economy. The rationale for this seems plausible as banks will require more collateral when credit conditions are tight and will employ more monitoring work to provide the same amount of loans to the economy.

from the central bank and creating their own deposits by issuing loans. As the policy rate falls, narrow money becomes a relatively cheaper way of meeting deposit demand.[23] Similarly, if the return on loans were to fall, or the cost of producing them to rise, it becomes less profitable for banks to originate deposits in this way. The optimal quantity of narrow money has now increased, whilst the amount of loans has fallen, meaning that the optimizing money multiplier is now lower. Central banks can effectively subsidize deposit creation by providing more narrow money as a cheaper means of meeting deposit demand when loan production becomes more costly . If the central bank were to increase the cost of narrow money by raising the policy rate, or the cost of producing loans were to fall (and their returns to rise) then the opposite would be true and it would be optimal for the money multiplier to rise.

## 6.1 Collateral Shock and Bank Liquidity Demand

Using our model we are able to trace this narrative through to the wider economy by analyzing the response of the model to various shocks. First, Figure 4 shows the impulse responses of the model's key variables to a negative shock to the value of collateral, the asset prices, that households have available to provide in return for loans. It can be thought of as similar to the shock, see Figure 2, which hit the United States following the collapse of Lehman Brothers. We first analyze the response of our artificial economy when the policy rate moves to offset the shock and then when the policy rate is held at the steady state and the commercial banks increase their demand for reserves instead. When the shock hits, asset prices fall, eroding the value of the collateral available for loan production. To produce the same quantity of loans, banks now need to employ more monitoring work relative to the quantity of loans, as they cannot rely on collateral. Not only does this push up the cost of loan production, but it also draws resources out of the production sector, causing a fall in production and employment in the real economy. The higher cost of loan production leads to a fall in loan supply, whilst the lower production reduces deposit demand both of which lower the level of broad money in the economy. If, on the other hand, the policy rate is held constant, even though the impact on output and inflation is broadly similar, the increase in reserves allows monitoring work to fall in line with loans and so limit the increase in the external finance premium. The loan rate though, which is the sum of the policy rate and the external finance premium shows somewhat more volatility and hence

[23] An interesting point of note here is that this framework allows for the possibility of paying interest on reserves, although it is not the purpose of our paper. Without a zero lower bound imposed, the policy rate charged at the discount window can turn negative. In such a setting, charging a negative rate to borrow reserves is equivalent to paying banks to take reserves. This turns the cost implied by $R_t r_t$ in equation (8) into an income stream paid by the central bank. This is a useful way of thinking about the expansion of reserves under recent QE programmes and the need for interest on reserves. With rates charged at discount windows cut to zero, and central banks seeking to expand reserve supply either further, interest on reserves (or a negative cost of holding reserves in our framework) was essential to maintain demand for the increased supply.

output and inflation fall slightly more in this alternate policy world. In the next section, we show the results of the model with all shocks and measure the welfare of the household with under a policy regime of active interest rate rules and reserves on demand.

## 6.2 Exogenous Increase in Reserves

Figure 5 shows the impact on our economy of an exogenous increase in reserves as outlined in section 4.1. The exogenous increase in reserves draws away work in monitoring at banks, reduces the external finance premium and leads to some switch into goods employment. Asset prices and loans are bolstered, so that overall nominal deposits increase. Output and inflation raise and so the reserves injection acts somewhat like a positive demand shock, or a subsidy to banking intermediation. In this sense, following a negative shock to intermediation if loans become a relatively more expensive way of creating deposits the central bank can step in to increase the supply of relatively cheaper narrow money, which it injects through open market operations. As mentioned, this supports deposit creation. With fewer resources being drawn away from the production sector into monitoring work and broad money being supported both by increased narrow money and a smaller reduction in loan creation, output and inflation might fare better, falling by less and returning to equilibrium more quickly. In this instance, if associated with a cut in the central bank policy rate, it will act to make reserves an even cheaper way for banks to meet deposit demand and further increases their demand. When met by the central bank with increased supply this adds to the shock-attenuating effect of reserve provision.

We therefore have two strands to consider: the correct response of the central bank to a negative credit, or collateral, shock in terms of the policy rate or the supply of narrow money (reserves); and the role of exogenous increases in reserves, which might be thought of as policy-induced changes in the asset mix held by commercial banks. All of these are stabilizing according to our impulse responses but in order to choose, we need to examine the response of the whole model and also conduct some welfare analysis.

## 6.3 A Policy Rule for Supplying Reserves

We consider a world in which the policymaker determines the quantity of reserves by applying an endogenous policy rule as described in Section 4.2 in the case of no policy reaction. Figure 6 shows the QE response of the central bank to falling asset prices, increased risk premia and heightened demand for liquidity. When the collateral shock hits, output and inflation fall. The central bank reacts according to its rule and creates reserves to buy assets from the private sector. The reaction of the central bank only has an impact with some time lag. Given the parametrization of the model the percentage reaction of reserves is larger than the initial asset price fall. Quantitative easing in this economy has two effects. First, the collateral shock is bolstered by the bond purchases which immediately stabilize asset prices. As the collateral enters loan creation, the fall in nominal loans is reduced. Second, buying bonds from the private sector also injects deposits into the economy, which limits the fall in transaction money, so consumption is not affected as much. Monitoring work falls significantly as cheap central bank money replaces costly loans. After an initial surge, the loan spread (EFP) also normalizes relatively quickly allowing for lower costs of the private sector with respect to their loan demand.

Half of the fall in asset prices is stabilized with a strong QE reaction, entailing a stronger relative reaction of reserves than the asset price decrease. The fall in output is reduced by up to one third and output returns to steady state after five quarters instead of ten. The inflation impact is stabilized to one-third of the response without a policy reaction. Thus, we are able to show how QE acts against low inflation or deflation, which is the major motivation for the use of non-conventional monetary policies. Providing reserves through QE causes the liquidity premium to decline, which acts against the fall in loans. By forcing deposits into the banking system, the decrease in deposits amounts to only half of the losses on loans. This suggests that QE policies, if carried out quickly and in sufficient volumes, can significantly insulate the real economy from an extreme economic shock, even when the Federal Reserve primary instrument of policy, the federal funds rate, is constrained at the lower zero bound.

# 7 Welfare Analysis

Having discussed why variance in the money multiplier can improve welfare over the cycle in the previous section, we seek to reinforce this result by quantifying its impact on the representative household. To do this we carry out some more stringent welfare analysis by deriving a welfare loss function from a second order approximation to utility.

## 7.1 Deriving The Welfare Loss Function

The welfare approximation derived from the canonical New Keynesian model finds that the 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. Using the approximation allows us to quantify precisely the welfare rankings arising from each of our policy rules, possibly allowing some normative statements to be made. 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.[24] Once this is re-ordered and simplified we are left with a

[24] 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

loss function with relevant terms in the variances of consumption, inflation, wages, employment in the goods sector and the marginal cost.

$$\begin{aligned} U_t \quad U &= \frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta^t L_t + O3 \\ \text{with } L_t &= \frac{1}{2} \begin{bmatrix} \sigma_c^2 + \frac{\theta}{\chi} \left[ \frac{\frac{w}{c} - \frac{n}{c}}{1-\eta} \right] \sigma_\pi^2 \\ \frac{w}{c} \sigma_w^2 \quad \frac{n}{c} \sigma_n^2 + \frac{mc}{c} \sigma_{mc}^2 \end{bmatrix} \end{aligned} \tag{19}$$

where $\chi = \frac{(1-\theta)(1-\beta\theta)}{\theta} \frac{1-\eta}{1+\eta(\theta-1)}$. Given that $\frac{w}{c} > 0$ *and* $\frac{n}{c} > 0$, more flexible wages and employment improves welfare, whilst $\frac{mc}{c} > 0$ *and* $\frac{\theta}{\chi} \left[ \frac{\frac{n}{c} - \frac{w}{c}}{1-\eta} \right] > 0$, so more stable marginal cost, consumption and inflation improves welfare.[25] 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 only have an impact on utility in so far as they impact on the variance of consumption, inflation, wages, labour supply hours and marginal costs.

Table 5 shows the asymptotic standard deviations and the contemporaneous cross-correlations with consumption from a simulation of each model. Broadly speaking, the results are similar with the correlations between real and financial variables unchanged across policy regimes. The key difference is that the interest rate spreads become more countercyclical as does monitoring employment, which tends to slightly drive up the overall variance of output and inflation when reserves are used rather than interest rates to stabilize the economy. We use these values in Table 6 to calculate the welfare loss in from each model. We can see that the welfare loss under a regime where the central bank uses an active interest rate policy is smaller than one in which reserves are used. In part this is because a reserves policy cannot offset exogenous increases in reserves whereas an interest rate rule can for Poole-type reasons. But it also tells us that if the interest rate cannot be used at the zero lower bound, for example, reserves may be able to have a role in substituting.

# 8 Capturing the Global Financial Crisis

We now look at the ability of the model to help us understand the response of the economy and the financial sector to the initial shock of the global financial crisis and examine what it may

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.

[25] Whilst it is likely to derive a different loss function through a different sequence of substitutions, ours seems both plausible and conservative.

tell us about the behaviour of the multiplier during this period. The obvious problem is how to replicate the shock(s) that afflicted the US economy, culminating in the recession of 2008. This particular crisis had a number of characteristics which are compatible with our model. House prices fell, reducing the value of collateral the private sector had available to post against loans from the financial sector. Banks also tightened credit conditions and increased their preference for liquidity due to increased precautionary motives and economic uncertainty. Whilst for practical purposes the exact sizes and interconnected nature of each of these factors may be intractable, it seems plausible that some combination of shocks along these lines is an appropriate, though rudimentary way to think of the origins of the crisis, and one that it is within the capabilities of our model to capture. We therefore subject the model to collateral shock. We run two simulations. One where there are no reserve injections but where the policy rate falls and one where the policy rate is held constant but there is a reserves injections.

Whilst, as with any model of this kind, there remains a degree of oversimplification, the model we have outlined manages to capture the general evolution of the US economy in the second half of 2008 quite well. Figure 7 plots the impulse responses of variables following the collateral shock. What we see is that, following a collateral/credit shock implying a fall of around 0.7% in nominal lending, reserves increase by around 1% of GDP for a fall in output of around 0.2% and the equivalent policy rate response is some 25 basis points. A 10% fall in loans would therefore imply an increase in reserves of just under 14% of GDP or a cut of some 3.5% in interest rates. The narrative from our model is that, as the external finance premium rose and loans became more expensive to verify and produce, banks maximizing behaviour would drive them to reduce loan production and shrink the supply of broad money. However, this effect was attenuated by the increased supply of narrow money, demanded by banks and supplied by the Federal Reserve through large-scale asset purchase programmes and the massive expansion of its balance sheet, which was akin to a negative interest rate.

The implication is that if the Federal Reserve had been able to choose negative interest rates, this might also have offset the broad money contraction and limited the increase in financial spreads. The model suggests that the policies used might be associated with limiting the contraction in output by some 1% or more, preventing a fall in inflation of an additional 2.5% and unemployment increasing by some 2%. In the absence of such policies, the recovery would also have been more protracted, taking roughly twice as long to return to equilibrium.

# 9 Conclusion

In a prophetic final note, Milton Friedman (2006) argued that the Federal Reserve had offset the impact of the collapse of the dotcom bubble by maintaining the level of broad money growth, arguing that: “ monetary policy deserves much credit for the mildness of the recession that followed the collapse of the U.S. boom in late 2000." Subsequently, it seems that rumours of the death of money as a useful concept may, as the saying goes, have been greatly exaggerated. Following the financial crises of 2007-09, the Federal Reserve seems to have used these ideas again by stabilizing the growth in broad money. Accordingly, this paper provides a way of framing the components of broad money for the post-crisis world: there is an optimal choice for commercial banks as to how they collectively meet deposit demand with reserves or loans.[26] But the Federal reserve has also generated off-equilibrium holdings of reserves via QE. And yet, the post-crisis variation in the quantity of reserves may have acted to stabilize broad money and may have been welfare enhancing compared to a no-policy alternative. Of course, some of the stabilizing properties of broad money growth in terms of generating confidence may be important but are not modelled here.

We have also gone some way to addressing the common criticisms levelled at modelling money and its role in monetary policy. We provide a framework which is hopefully more recognizable to monetary policy practitioners by modelling reserves as demand-determined, conditioned on the prevalent interest rates in the economy and allowing the central bank to set the interest rate and then provide this narrow money perfectly elastically through open market operations to meet the demand from commercial banks . As far as non-conventional monetary policies are concerned, we do not think they necessarily depart from standard open market operations, other than in their size or duration. In our model, we find that the supply of central bank money, or reserves, whilst not preventing an extended downturn may have played a substantive role in preventing the downturn turning into a sustained depression.

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Table 1: 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 |
| $\pi$ | 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 |
| $\Omega$ | 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 |
| $R$ | Policy Rate |
| $R^L$ | Loan Rate |
| $R^D$ | Deposit Rate |
| $\lambda$ | Lagrangian for Budget Constraint (shadow value of consumption) |
| $\xi$ | Lagrangian for Production Constraint |
| $T$ | Real transfer (%) |

Table 2: Parameterization

| Parameter | Description | Value |
|---|---|---|
| $\beta$ | Discount factor | 0.99 |
| $\kappa$ | Coefficient in Phillips curve | 0.1 |
| $\alpha$ | Collateral share of loan production | 0.65 |
| $\phi$ | Consumption weight in utility | 0.4 |
| $\eta$ | Capital share of firm production | 0.36 |
| $\delta$ | Depreciation rate of capital | 0.025 |
| $\varrho$ | Trend growth rate of shocks | 0.015 |
| $\rho$ | Interest rate smoothing | 0.8 |
| $\phi_\pi$ | Coefficient on Inflation in Policy | 1.5 |
| $\phi_y$ | Coefficient on Output in Policy | 0.5 |
| $F$ | Production coefficient of loan | 9.14 |
| $k$ | Inferiority coefficient of capital as collateral | 0.2 |
| $\theta$ | Elasticity of substitution of differentiated goods | 11 |

Note: The parameterization chosen for these coefficients is explained in Section 5.

Table 3: 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 |
| $\gamma$ $(b^p/b)$ | 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 |
| $\lambda$ | Shadow Value of Consumption | 0.457 |
| $\nu$ | Velocity | 0.31 |
| $\Omega$ | 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 |

Note: The parameterization chosen for these coefficients is explained in Section 5.

Table 4: 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 |
| Reserves | 1.00% | 0.33 |

Table 5: Impact of Flexible or Constant Interest Rates on the Economy

| Policy | Flexible Interest Rates | | Constant Interest Rates | |
|---|---|---|---|---|
| | St.Dev | Corr | St.Dev | Corr |
| Real Consumption/Output | 1.05 | 1 | 1.17 | 1 |
| Inflation | 0.40 | 0.62 | 0.42 | 0.69 |
| Employment in Monitoring | 3.55 | -0.74 | 3.28 | -0.83 |
| Employment in Goods Sector | 1.60 | 0.96 | 1.81 | 0.97 |
| Real Wage | 1.69 | 0.99 | 1.91 | 0.99 |
| Private Sector Bond Holdings | 1.79 | -0.34 | 1.85 | -0.40 |
| Asset Prices | 1.02 | 0.98 | 1.14 | 0.99 |
| Loans | 1.10 | 0.29 | 1.15 | 0.40 |
| Reserves | 1.62 | 0.73 | 1.83 | 0.77 |
| Policy Rate | 1.05 | -0.08 | 0.80 | -0.36 |
| Loan Rate | 0.68 | -0.83 | 0.70 | -0.88 |
| Bond Rate | 3.99 | 0.49 | 3.24 | 0.50 |
| Deposit Rate | 1.04 | -0.16 | 0.85 | -0.45 |
| External Finance Premium | 1.37 | -0.35 | 0.82 | -0.46 |
| Liquidity Premium | 4.52 | -0.56 | 3.68 | -0.62 |

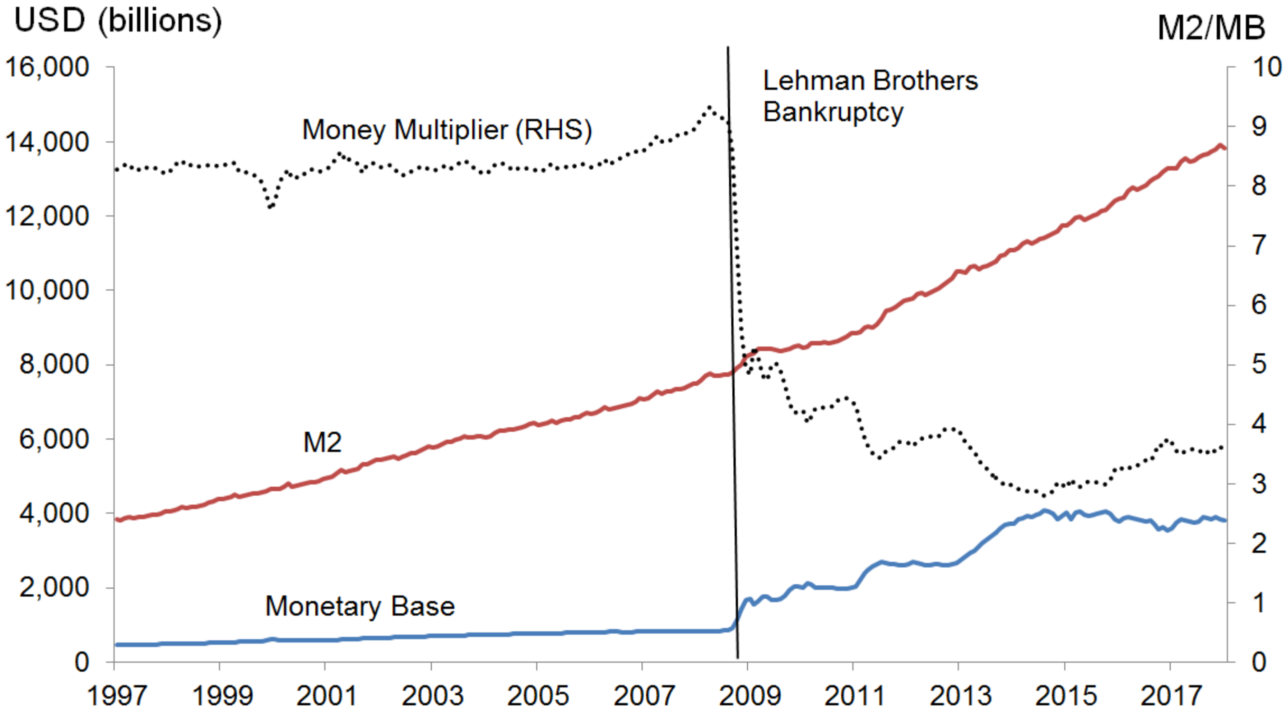
Note: The first two columns of results correspond to the model with an active interest reaction function and in the final two columns the policy rate is held constant. All shocks are included in these results as given by Table 4.

Table 6: Relative Welfare Analysis

| Money Multiplier | Interest Rates | Welfare Loss |
|---|---|---|
| Fixed | Constant | 10.921 |
| Fixed | Flexible | 7.829 |
| Flexible | Constant | 4.293 |
| Flexible | Flexible | 3.908 |

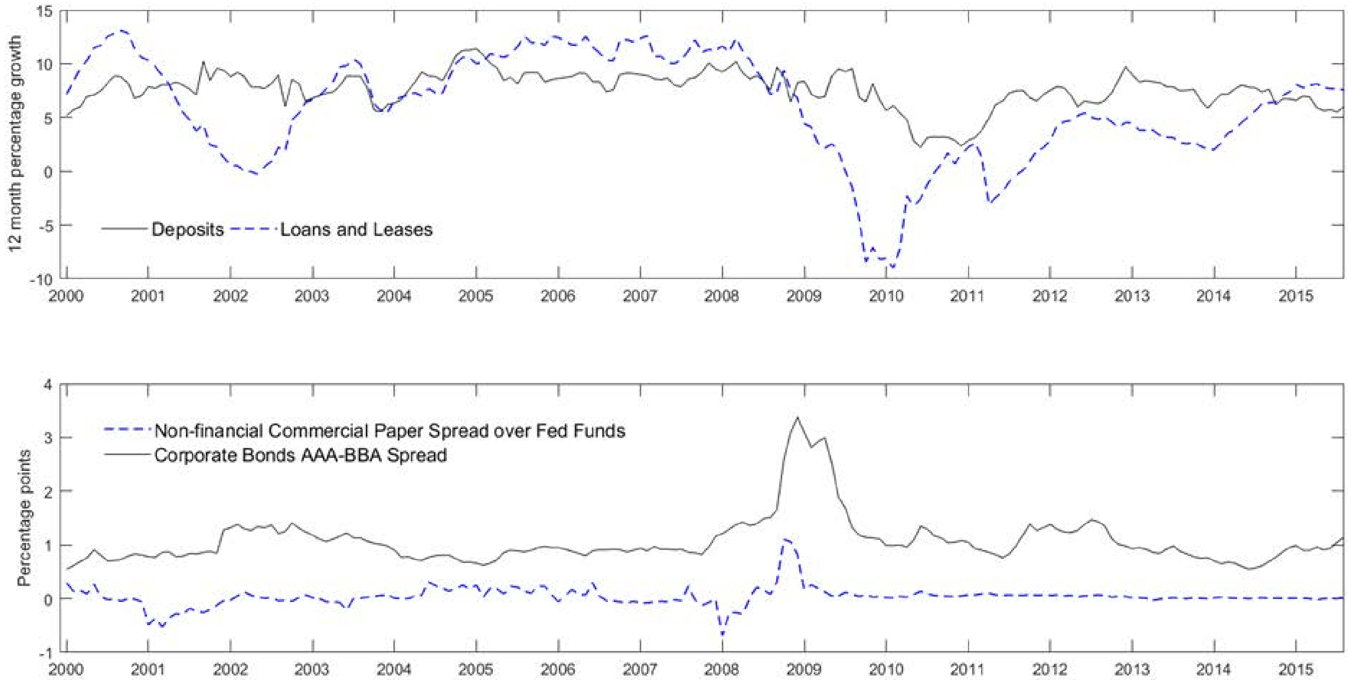
Note: Loss determined by a quadratic loss function derived using a second-order Taylor approximation to utility. The welfare loss is based on all shocks. See Section 7.1

Figure 1: US Money Aggregates and Bank Credit



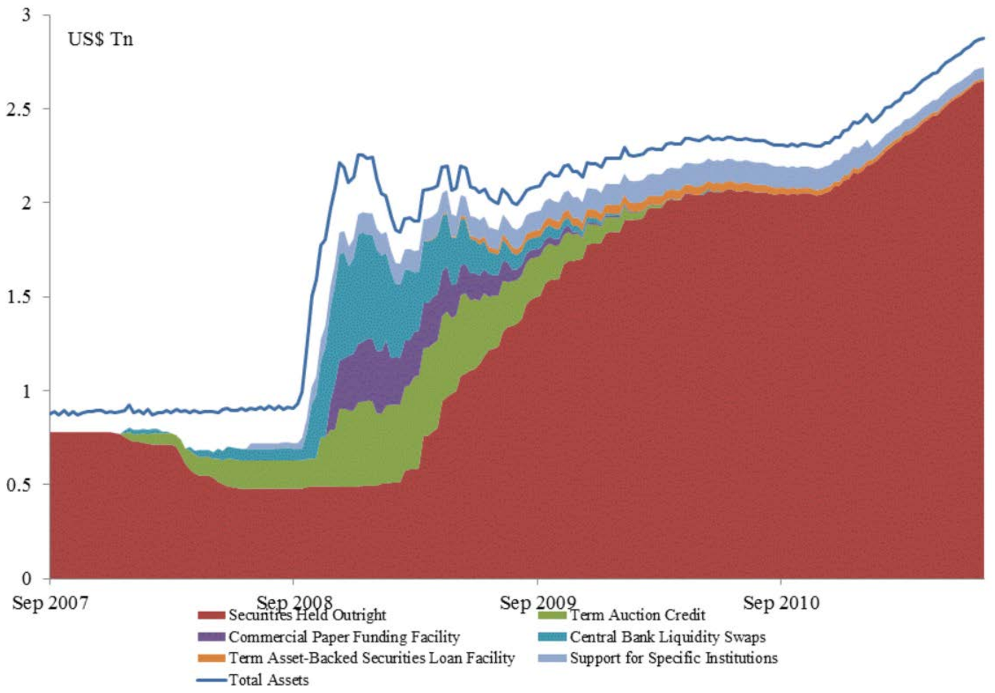

Source: Federal Reserve Economic Data (FRED)

Figure 2: Deposit and Lending Growth and Financial Spreads

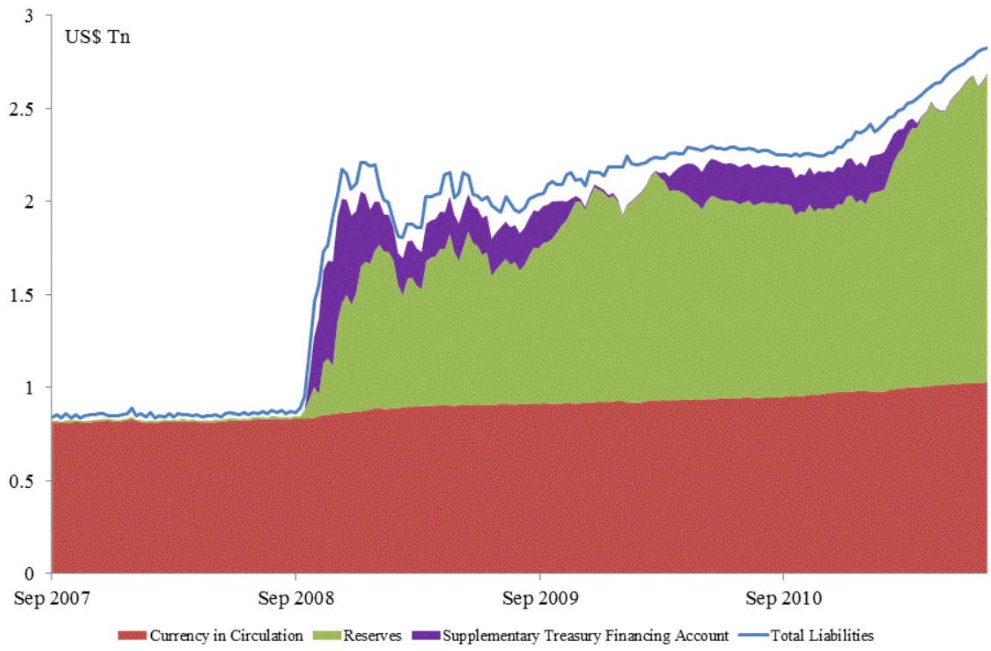



Source: Federal Reserve Economic Data (FRED)
*Note:* The top panel shows year-on-year growth.

Figure 3: Federal Reserve Balance Sheet




(a) Assets




(b) Liabilities

Source: Federal Reserve Economic Data (FRED)

Figure 4: Negative shock to collateral

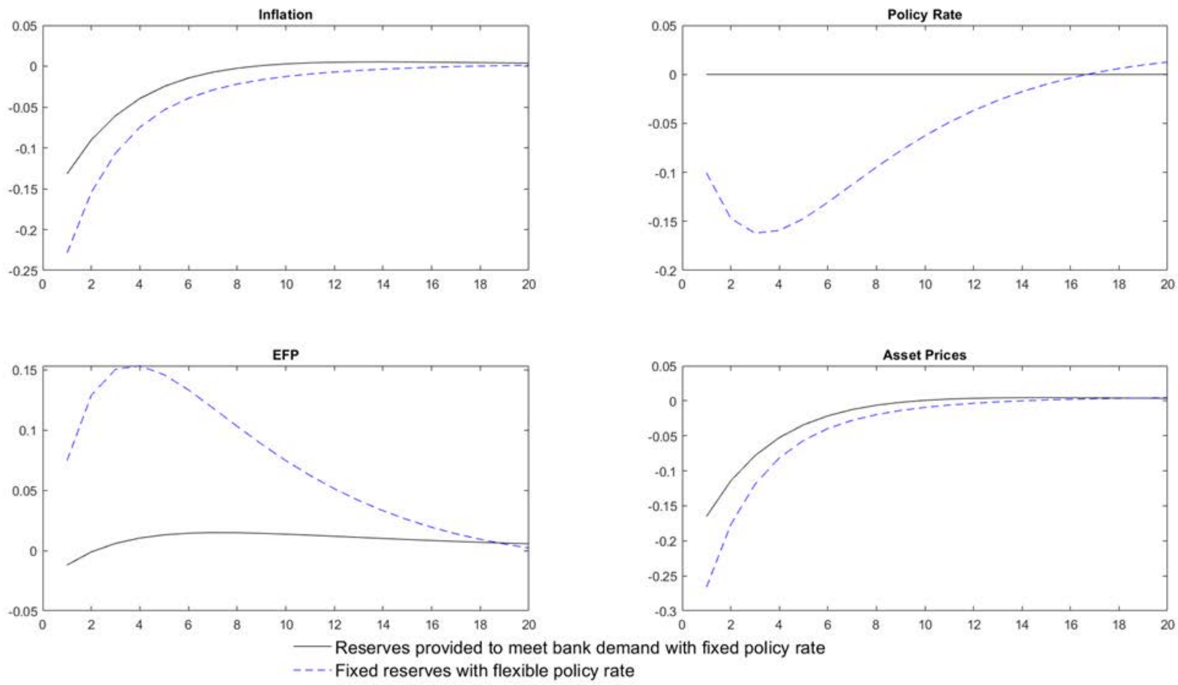



Figure 5: Exogenous shock to reserves

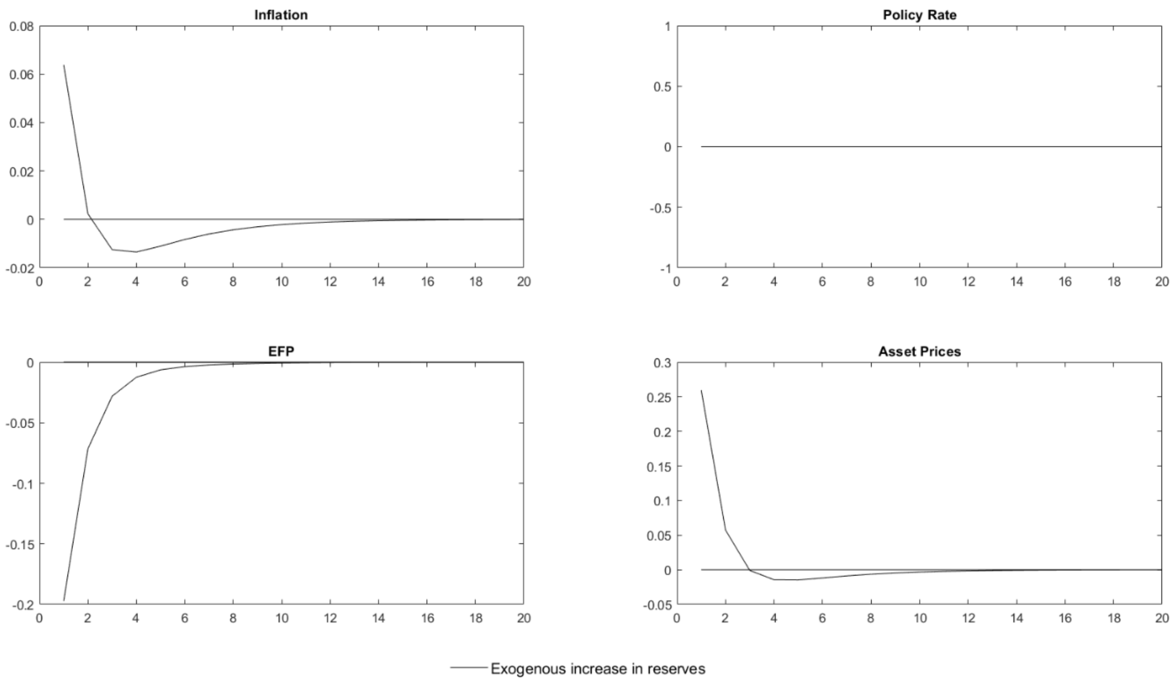


Figure 6: Negative shock to collateral with and without reserve injection through QE

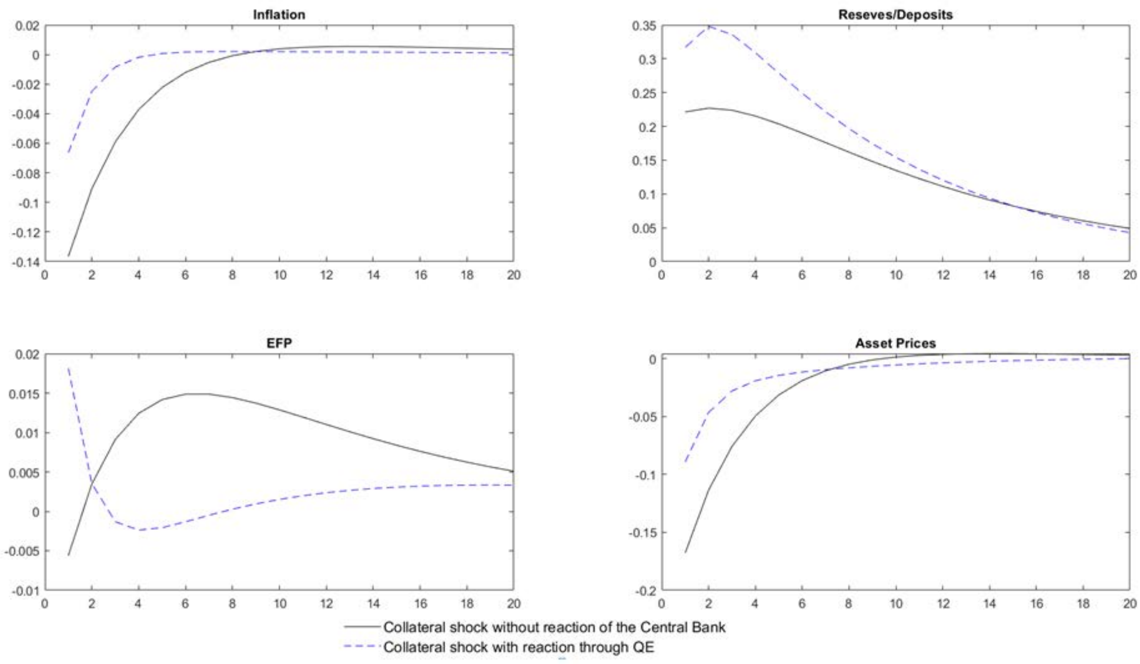
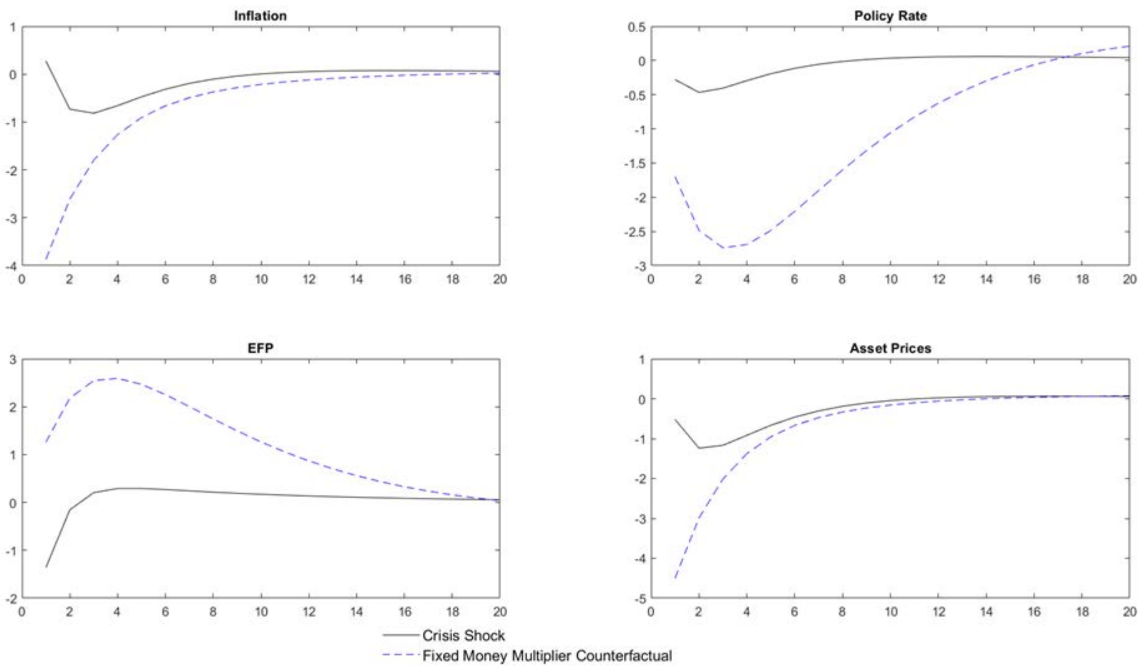



Figure 7: Crisis shock with and without reserve injection



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