Abstract

I explore quantitative easing and interest on reserves policies in a model monetary economy that takes into account advances in transaction and information processing technology. In this economy, money is interest bearing government debt, the services of real cash balances are a factor of production, and the economy can be satiated in money. In this economy, Quantitative Easing is an effective response to liquidity crises because it drives the marginal product of money to zero. However, positive Interest on Reserves policies work against Quantitative Easing in responding to money scarcity. This study suggests that a central banking authority operating in this model world would insulate against liquidity crises by maintaining a permanently large balance sheet and setting the rate for interest on reserves to zero.

1 Introduction

The purpose of this paper is to evaluate unconventional monetary policy tools within a model that takes into account advances in transaction and information processing technology.

Technology is changing the way in which modern industrial economies interact with money. Electronic transfers make the velocity of circulation virtually infinite. Cash is no longer a dominant medium of exchange, with many individuals choosing instead to go “paperless” and make purchases purely on credit cards. Stiglitz and Greenwald (2003) argue that with current technology, there is no longer an opportunity cost of holding money at the margin, rendering obsolete monetary economics based on a money demand
equation in which there is an opportunity cost for holding money. Prescott and Wessel (2015) argue that current theory lags advances in payment and information processing technology and therefore does not provide predictions about the consequences of monetary policy. New theory is needed.

Following the valuation theory model of Prescott and Wessel (2015), I work in a model based on three assumptions designed around this new paradigm of money. The assumptions are:

1. Money is interest bearing government debt.

2. The services of money are a factor of production.

3. There is a satiation level of money stock, above which the marginal product of money is zero.

Using this model, I evaluate two unconventional monetary policy tools: Quantitative Easing (QE) and Interest on Reserves (IOR).

Following the 2008 financial crises, the United States Federal Reserve engaged in QE by purchasing government debt and real assets with central bank notes. This swelled the size of the central bank’s assets from 5% of GDP in 2008 to 25% of GDP in 2015. This is the largest the Fed’s balance sheet has ever been and is only comparable to size of the Feds balance sheet during the great depression (23% of GDP) and the end of WWII (20% of GDP).

Additionally, on October 1, 2008, the Fed began paying interest on reserves held by depository institutions at reserve banks, a policy authorized by the Financial Services Regulatory Relief Act of 2006 and the Emergency Economic Stabilization Act of 2008. Since 2008, the IOR rate has varied between 25 and 140 basis points and is currently 50 basis points for both required and excess reserves. This is the first time the the bank has ever paid interest on excess reserves.

In this model, QE is a welfare increasing response to a liquidity crisis. QE works by driving the marginal product of money to zero, thus eliminating a gap between the marginal product of money and the marginal cost of producing money (assumed zero). This “satiates” the economy in money, which increases total output and welfare. Further, QE in excess of the economy’s satiation level has no effect, nominal or real. Thus, in anticipation of a future liquidity crisis, there is an advantage to maintaining a perpetually large Fed balance sheet.

I also find that a positive IOR policy works against QE. While QE increases welfare by satiating the economy in money, a positive IOR rate drains
money from the economy by inducing agents to deposit money at the central bank. This creates a positive lower bound on the marginal product of money equal to the IOR rate. Welfare increasing “monetary satiation” cannot be achieved when the IOR rate is positive. Thus, a positive IOR rate policy exacerbates a liquidity crisis and is welfare decreasing.

I then ask whether reducing the IOR rate to zero would cause excess inflation. If member banks were not incentivized to hold money at the central banks, would the outflow of money cause the price level to jump up significantly? The answer is no. Even if the almost $4 Trillion in bank reserves currently on deposit at the Federal Reserve were withdrawn, the price level would not significantly raise because money in a satiated economy is identical to bonds. Above the satiation point, withdrawing money from the central bank is analogous to swapping one type of government debt instrument for another identical type, a shuffling of the central bank balance sheet with no real or nominal effects.

The paper is arranged as follows. Section II describes the model. Section III explores the effects of Quantitative Easing (QE) and Interest on Reserves (IOR) policies in response to a liquidity crisis within the model. Section IV concludes.

2 The Model Economy

In this model, money is defined as interest bearing government debt. With modern technology, individuals can use government debt for transactions. While this is possible through many technological channels, cash management accounts (CMAs) provide a clear example. Fidelity, Merrill Lynch, TD Ameritrade, and many other companies offer combined T-bill/checking accounts. When a check is presented, a zero-balance checking account is simultaneously credited and debited for the amount drawn. Odd amounts not covered because of the indivisibility of the T-bill are floated by the firm. Thus money earns interest, paid by the government. The interest rate for CMAs and T-bills is not the same, however. The difference is the transaction cost.

A second assumption of the model is that transaction services are needed for production and are paid the factor share of money. This differs from shopping time or cash-in-advance models in that money services are needed on the production side, not the consumption side. Stokey and Lucas (2011)

\(^1\)Sinai, Allen, Stokes 1972 and Fischer 1974 did pioneering work with money in the production function
argue that some liquid assets, defined as cash or other securities that can be exchanged easily for cash at a known price, are required for carrying out firm transaction. Liquid assets can resolve time inconsistency of production needs, have high option value in times of uncertainty, and can provide tax shelter as overseas earnings are booked as foreign earnings but invested domestically (Hodrick 2013). The simple reality is that profit maximizing firms find some value in holding cash.\(^2\)

I also assume a satiation level of money stock, above which the marginal product of money is zero. While some liquid assets are needed to facilitate the underlying transactions needed in production, too much is unnecessary. Just as nine renting firms in a stylized market with available 10 warehouses will store goods rent-free, satiation drives the marginal value to zero. As will be shown, this assumption is at the heart of the results of this paper.

The agents in this model are an infinitely-lived household, a government, and an aggregate production firm. There is constant growth and no uncertainty in living standards. While this model is based on the model of Prescott and Wessel (2015), the liquidity crisis shock and policy response explorations are unique to this paper.

2.1 Preferences

There is a measure 1 of identical households with preferences ordered by

\[
\sum_{t=0}^{\infty} \beta^t [\log(c_t) + \alpha \log(1 - h_t)]
\]

where \(c_t > 0\) is consumption and \(h_t \in [0, 1]\) is the fraction of the time endowment allocated to the market. The parameter \(\beta \in (0, 1)\) is the discount factor. The parameter \(\alpha\) determines the relative shares of consumption and leisure. Since labor response is of secondary concern in this study, the exact form of the utility function is unimportant.\(^3\)

2.2 Technology

Inputs to the business sector are the services of non-human capital \(k_t\), the services of human capital \(h_t\), and the services of the money stock \(m_t\). There is labor augmenting technical growth. The aggregate production function is

2In 2015, Apple had more cash than the Federal Reserve!

3Repeating the exercise with a different Frisch elasticity of labor supply does not qualitatively effect the results.
\begin{align*}
y_t &= \begin{cases} 
A\lambda^{1-\phi}z_t & \text{if } m_t \geq \lambda z_t \\
Az_t^\phi m_t^{1-\phi} & \text{if } m_t < \lambda z_t 
\end{cases} 
\quad (2)
\end{align*}

where

\[ z_t = k_t^\theta [(1 + \gamma) h_t]^{1-\theta} \quad (3) \]

Figure 1 shows an output isoquant of the aggregate production function. The aggregate production function is increasing, weakly concave, and displays constant returns to scale. It has a kink at the satiation point; the marginal product of money \( m \) is zero if \( m \geq \lambda z \).

\( \lambda \) is a parameter that determines the point at which the economy is satiated with money. This is a key parameter of the model.

\[ \text{[Figure 1 about here]} \]

2.3 Budget Constraints

Households hold three stocks of assets: capital \( k_t \), money \( m_t \), and government debt \( b_t \). These are the individual state variables. Households also supply labor services \( h_t \). The inflation rate, possibly negative, is \( \pi_t = \frac{p_{t+1}}{p_t} - 1 \); government lump-sum transfers in cash or in kind are \( \psi \); \( r_k \) and \( r_m \) are the rental price of capital \( k \) and money \( m \); and \( i_b \) and \( i_m \) are the interest rates paid on the two forms of government debt, \( m \) and \( b \). I use capital letters to denote nominal quantities.

2.3.1 Household

In units of dollars, the date \( t \) household budget constraint is

\[ C_t + X_t + M_{t+1} + B_{t+1} = (1-\tau_t) W_t h_t + (1+r_k)K_t + (1+i_b)B_t + (1+i_m+r_m)M_t + \Psi_t \quad (4) \]

where

\[ X_t = K_{t+1} - (1-\delta)K_t \quad (5) \]

Insert equation (5) into (4) and divide by the date \( t \) price level. In units of the consumption/investment good, the date \( t \) household real budget constraint is
\[ c_t + k_{t+1} + (1 + \pi_t) m_{t+1} + (1 + \pi_t) b_{t+1} = (1 - \tau) w_t h_t + (1 - \delta + r_k) k_t + (1 + i_b) b_t + (1 + i_m + r_m) m_t + \psi_t \] (6)

This states that expenditures are for consumption, investment in capital, currency acquisition, and government debt acquisition. Receipts are equal to the after-tax labor income, rental income on (non-human) capital less depreciation, rental income on money, interest payments on the two forms of government debt, and lump-sum transfers received from the government.

2.3.2 Firm

Given constant returns to scale, revenue is equal to costs, or

\[ y = w h + r_k k + r_m m \] (7)

2.3.3 Government

The government’s pure public consumption in units of dollars is \( G \). The interest rates on the two types of government debt are \( i_m \) and \( i_b \). The government’s nominal budget constraint is

\[ G_t + \Psi_t + i_m M_t + i_b B_t = \tau W_t h_t + (M_{t+1} - M_t) + (B_{t+1} - B_t) \] (8)

Equivalently, the government budget constraint can be written in real terms as

\[ g_t + \psi + i_m m_t + i_b b_t = \tau w_t h_t + [m_{t+1} (1 + \pi) - m_t] + [b_{t+1} (1 + \pi) - b_t] \] (9)

The government can finance expenditures through the labor tax (\( \tau \)), increasing the money supply \((m_{t+1} - m_t)\), running a deficit \((b_{t+1} - b_t)\), or taxing through inflation \((\pi)\).

2.4 Equilibrium

Prices are \( \{w_t, r_k, r_m, i_b, i_m, \pi_t\}_{t=0}^\infty \). Equilibrium conditions are

1. Households choose an optimal sequence of \( \{c_t, h_t, k_{t+1}, m_{t+1}, b_{t+1}\}_{t=0}^\infty \) given prices and their budget constraints.

2. Firms choose the value maximizing \( \{h_t, k_t, m_t\} \) given period rental prices for all \( t \).

3. The government selection of \( \{g_t, \psi_t, \tau_t, m_{t+1}, b_{t+1}\}_{t=0}^\infty \) are such that its budget constraints for all \( t \), given prices, are satisfied.
2.5 Steady State

To define a baseline economy, I start with balanced growth. The state of the household is its holdings at the beginning of the period of money stock \( m_t \), government debt stock \( b_t \), and capital stock \( k_t \). In steady-state, these stocks grow at a constant rate \( \gamma \).

2.6 Baseline Economy

The baseline economy has a steady-state that roughly matches the U.S. economy in consumption and investment shares, fraction of time worked, asset stocks to output ratios, and factor income shares. The growth rate is assumed 2.2%.

Table 1 is the government policy regime chosen for the baseline economy. I choose a high value of the money stock (1.5 GNP) to take into account what Williamson (2012) calls private and public liquidity. Businesses make large payments using shadow banking and small payments using the banking sector. The high value for the money stock takes this into account.

Table 2 presents the calibration results. The only parameter of note is the money cost share \( (1 - \theta) \). This parameter is not in standard models, and was first introduced by Prescott and Wessel (2015). This parameter effects the size of the jump in outputs that occurs when an economy switches from non-satiation to satiation. In this analysis, jump size is second order. However, as a robustness check, I did all experiments in the range \( 1 - \theta = [0.001, 0.05] \) and the results were qualitatively identical. Further work in defining an appropriate range of values for this parameter is needed.

3 Quantitative Easing and Interest On Reserves

In this section, I evaluate Quantitative Easing (QE) and Interest on Reserves (IOR) policies in response to a liquidity crisis.
3.1 Satiation Parameter Shock

Stokey and Lucas (2011) argue that the recession of 2008 was exacerbated by a liquidity crisis where economic agents hoarded cash and the repo market experienced something similar to a bank run. I model a liquidity crisis as an increase in the parameter $\lambda$ that controls the satiation level of money stock. Satiation means that the marginal product of money is zero and occurs when the ratio of money to a composite of capital and labor $z$ is sufficiently high, or $m \geq z/\lambda$.

A simple example will help explain monetary satiation. Consider an economy with one factory that produces output using capital and labor. Capital can only be rented using government debt certificates called money. Suppose the factory needed $10 resolve the time inconsistency between when the labor needed to be paid and when the output could be sold. If the government fixed the price level and only provided $8 in money to the economy, the factory would face a money constraint keeping it from producing maximum output. The marginal product of an additional dollar would be strictly positive. Now suppose the government fixed the price level and provided $12 in money. In this case, the marginal product of an additional dollar would be zero. In this simple example, the satiation level is $10$.

For the experiments in this section, I raise $\lambda$ from 1.8 to 1.9. This represents 5.5% increase in the stock of money needed for the economy to be satiated. These values were chosen such that the economy switches from just satiated to just non-satiated. Switching from satiated to non-satiated is the important change; larger increases in $\lambda$ have no effect.

What might cause an increase in the satiation level of the economy? Anything that raises the level of money stock needed to transact business: cash hoarding, increased counter-party risk, decreased willingness to provide business to business credit, decreased bank lending, etc. Ivashina and Scharfstein (JFE 2010) shows that bank lending decreased substantially during the financial crisis. They find that new loans to large borrowers during the peak of the financial crisis (2008Q4) fell by 79% relative to the peak of the credit boom (2007Q2). Becker and Ivashina (2011) argue that there was a sharp decrease in bank loan supply associated with the financial crisis. Further, from 2008 to 2012, U.S. Nonfinancial Corporate Businesses increased aggregate liquid assets from $1.5$ Trillion to $1.8$ Trillion, a 20% increase (Flow of Funds F.103).

Figure 2 shows what happens to the balanced growth path when the satiation parameter is shocked. In the figure, the shock happens unexpectedly
at the end of period 3 and there is no policy response to the shock. The economy converges (convergence not shown) to a new balanced growth path characterized by a lower level of output. Output is lower because there is an inefficiency created by a gap between the marginal cost of producing money (assumed zero) and the now positive marginal product of money. Interestingly, steady-state capital stock and labor supply change by less than 0.002% in response to the shock. This suggests that I have effectively isolated the effect of a liquidity shock on output.

Figure 3 shows historical values of U.S. log GDP. From 2009 to 2015, GDP was about 7% below historical trend. The model predicts that a shock to the satiation parameter at the levels chosen can account for about 15% of the reduction in output.

[Figure 2 about here]

3.2 Quantitative Easing

Beginning in 2008, the Federal Reserve engaged in three rounds of QE, greatly increasing the size of its balance sheet. Figure 4 shows that the increase in assets came primarily from purchasing Mortgage Backed Securities and U.S. Treasury Securities. On the liability side, bank deposits significantly increased. Base money, defined as the sum of (1) coin and currency held outside the Fed and Treasury and (2) deposits held by banks at the Federal Reserve, increased by almost 400%.

[Figure 4 about here]

In this section, I will show how QE can be an effective response to a satiation parameter shock. QE is a change in the government policy regime to a regime with higher money stock and lower bond stock. Modeling QE in this way has the advantage of specifying the mechanism by which QE money is injected into the economy, namely it is traded for bonds.

To conveniently model a swap of money for government debt, let $d_t$ be the total stock of government debt (money plus bonds) in real terms, and let $\eta_t \in [0, 1]$ be the fraction of total government debt held as money. Thus

$$d_t = m_t + b_t$$  \hspace{1cm} (10)

$$m_t = \eta_t d_t$$

$$b_t = (1 - \eta_t)d_t$$
With this change of variable, a government policy regime is defined as

$$\text{regime}_t = \{g_t, \psi_t, \tau_t, d_{t+1}, \eta_{t+1}\}$$ (11)

I compare the steady state equilibrium of government policy regimes that differ only in $\eta$, the fraction of government debt held as money. Government spending ($g$), government transfers ($\psi$), labor tax rate ($\tau$), and total government debt ($d$) are held fixed. Output, inflation, and interest rates are determined in equilibrium.

My measure of welfare is consumption equivalent variation (CEV), meaning the percent by which an individual’s consumption must be changed in order to make him indifferent among policy regimes. This measure of welfare is for only one type and does not take into account transitions, but it is suggestive.

In the top panel of Figure 5 we see that welfare increases with the fraction of debt held as money ($\eta$) in the economy. Welfare jumps when $\eta$ is sufficiently high such that the economy is satiated and the marginal product of money is zero. Call this point $\eta^*$. For the baseline economy with $\lambda = 1.8$, the satiation point is $\eta^* = 0.73$. Additional QE above the satiation point has no effect on welfare.

Above the satiation point ($\eta^*$), adding more money to production does not increase or decrease welfare. Output does not increase because the economy is satiated in money. On the production function isoquant in Figure 1, this is the kink point. Because more money does not increase output, there is no balancing increase in capital stock or labor supply. Further, adding more money to the economy has no negative effects. Since the marginal product of money is zero, money and government debt are identical government debt instruments. QE above the satiation point is simply a balance sheet shuffle where one type of government debt instrument is traded for another identical government debt instrument. Neither the labor tax rate nor the inflation rate need to adjust to balance the government budget.

This theoretical finding is consistent with empirical observations that the first round of QE had a much larger influence on the U.S. economy than QEII and QEIII (Nellis 2013, Gagnon, et.al 2010, Krishnamurthy and Vissing-Jorgensen 2011). Perhaps this is because the first round of QE pushed the economy over the point where additional QE would be effective.

In the bottom panel of Figure 5 we see that when the satiation parameter is higher, a higher $\eta$ is needed to maximize this measure of welfare. In this case, with $\lambda = 2$, the satiation point occurs at $\eta^* = 0.82$.

Given a satiation parameter $\lambda$, any government policy regimes with
\( \eta > \eta^* \) is welfare maximizing. Since \( \eta \in [0, 1] \), the policy that most effectively insulates against satiation parameter shocks is one where \( \eta = 1 \). To the extent that this model replicates reality, this implies that government policy can insulate against future liquidity crises by maintain a permanently Federal Reserve large balance sheet.

[Figure 5 about here]

### 3.3 Interest on Reserves

In the previous subsection, it was shown that QE can be a welfare increasing policy response to an upward shock to the satiation parameter \( \lambda \). In this section, I will show that positive Interest on Reserves (IOR) policies can work against QE in increasing the available stock of money in the economy, undoing the positive effects of QE.

Paying interest on excess reserves was legalized when Congress passed the Financial Services Regulatory Relief Act of 2006 and the Emergency Economic Stabilization Act of 2008. These acts authorized the Federal Reserve to pay interest on balances held by depository institutions at reserve banks beginning October 1, 2008. The Federal Reserve chose to immediately exercise that option. The IOR rate has varied between 25 and 115 basis points and is currently 50 basis points. The current IOR policy regime allows an unlimited amount of money to be deposited at the Federal Reserve with a risk-free 50 basis point return.

Without interest on reserves, a no arbitrage condition of the model economy is that the rate of return on bonds \( i_b \) is equal to the total rate of return on money, where money is paid both from the government \( i_m \) and from the business sector \( r_m \).

\[
i_b = i_m + r_m
\]  

(12)

In a satiated economy, the rental price of money services in the business sector \( r_m \) is zero; money and bonds are identical debt instruments. QE is a welfare increasing response to an increase in the satiation parameter because

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4While not shown, increasing the fraction of debt held as money such that \( \eta > 1 \) decreases welfare because the total government debt is increased. This is a fiscal policy decision and is not the subject of this monetary policy study.

5For approximately 1 month in October 2008, the Federal Reserve paid a different rate of interest on required reserves than on excess reserves. For the sake of this analysis, I tread excess reserves and required reserves as identical.
it drives the marginal product of money back to zero. Figure 6 shows the marginal product of money (in basis points) associated with various money stock policies.

[Figure 6 about here]

Under a positive IOR regime in a satiated economy, a rational agent would redeployed money from the business sector to the Fed because the Fed offers a higher return. This reduces the stock of money available to the business sector. As money is deposited at the Fed, the government works down a money supply schedule. This means that both the stock of money and the interest paid by the government \(i_m\) are lower.

In equilibrium, money deployed to the business sector and money deposited at the Fed earn the same rate. Thus

\[
i_m + r_m = i_m + i_{IOR} \implies r_m = i_{IOR}
\]

A strictly positive IOR policy regime bounds the marginal product of money away from zero (Figure 7). If the government, in an effort to drive the marginal product of money to zero, created an additional dollar, that dollar would be immediately deposited at the central bank in equilibrium. That dollar would not be deployed to the business sector and the marginal product of money would remain strictly positive. In effect, a positive IOR policy makes it impossible for QE to be completely effective.

[Figure 7 about here]

3.4 Inflation

Currently there is public discussion surrounding the inflation rate. If base money (cash plus deposits held by banks at the Fed) has increased by 400% since 2008, why has the price level not increased more drastically? Inflation is near zero and is expected to stay under 2% for the next 30 years.\(^6\) One explanation is that money velocity has drastically decreased. Even though QE created a large stock of money, most of that money is on deposit at the Federal Reserve and is not involved in transactions.

\(^6\)To see this, subtract the expected return on inflation-indexed Treasury securities from the expected return on nominal Treasury securities.
Suppose member banks decided to withdraw their deposits from the Federal Reserve, perhaps in response a zero IOR rate policy. Would this drastically increase the price level? In this model, the answer is no.

This model relies on a fiscal theory of the price level to determine the inflation rate, meaning that the government’s choice of tax and debt policy plays a crucial role in determining inflation. In steady state, the government budget balances, or

\[ g + \psi + i_m m + i_b b = \tau w h + \pi (m + b) \]  

(14)

The government policy regime fixes government expenditures \((g)\), transfers \((\psi)\), and labor tax rate \((\tau)\). Ignore those values as constant. Further, adjustments in labor supply \((h)\) and wage \((w)\) are second order to the results of this analysis. This leaves money stock \((m)\) and debt stock \((b)\) as the main drivers of the inflation rate \((\pi)\).

Recall that no arbitrage means the return on money is equal the the return on bonds minus the liquidity services money provides: \(i_m = i_b - r_m\). Substitute this into (14):

\[ g + \psi + i_b (m + b) - r_m m = \tau w h + \pi (m + b) \]  

(15)

Only when the marginal product of money \((r_m)\) is non-zero does a change in the composition of total government debt \((m + b)\) have an effect on the government budget equation. When the marginal product of money is zero, money and debt are identical. Therefore, withdrawing cash from the Fed can only influence the price level up to the satiation point. Beyond satiation, the composition of total government debt can have no effect.

4 Conclusion

Advances in information processing and transaction technology have changed the definition of money. This necessitates new theory that can make predictions about monetary policies enacted in this new money environment.

To begin to contemplate unconventional monetary policy in this new monetary paradigm, I made three assumptions. First, I defined money as interest bearing government debt. Second, I assumed that the services of real cash balances are a factor of production. Third, I assumed the existence of a satiation level of money stock, above which the marginal product of money is zero.

7See Kocherlakota and Phelan (1999) for a critique of the fiscal theory of the price level.
Using valuation theory combined with these three assumptions, I showed that Quantitative Easing can be a welfare increasing policy response to a satiation shock. This work suggests that a permanently large central bank balance sheet would insulate the economy against future satiation shocks.

I also showed how a positive interest of reserves regime works against quantitative easing in driving the marginal product of money to zero. Further, I showed that even if the large stock of bank reserves at the Federal Reserve were withdrawn for cash, a drastic increase in the price level need not be expected.

References


5 Tables and Figures

Figure 1: A Production Function Isoquant

<table>
<thead>
<tr>
<th><strong>Government Policy</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$g/y$  government public goods share</td>
<td>0.05</td>
</tr>
<tr>
<td>$\psi/y$ transfer share</td>
<td>0.20</td>
</tr>
<tr>
<td>$\tau$ labor tax rate</td>
<td>0.52</td>
</tr>
<tr>
<td>$b$  government debt to output</td>
<td>0.5</td>
</tr>
<tr>
<td>$m$  money debt to output</td>
<td>1.5</td>
</tr>
<tr>
<td>$\pi$ inflation rate</td>
<td>2.0%</td>
</tr>
</tbody>
</table>

Table 1: Government policy regime for the baseline steady-state economy.
Figure 2: Model simulation of a shock to the satiation parameter in the economy. For periods one through three, $\lambda = 1.8$. For periods four through 11, $\lambda = 2$.

Figure 3: U.S. log GDP over time. Data from research.stlouisfed.org and author’s calculations.
Figure 4: Federal Reserve Balance Sheet. Data from H.4.1 statistical release (weekly) and author’s calculations.
Figure 5: Model predictions of welfare for various regimes of total government debt held as money. Quantitative easing is an increase in money to total debt ratio. Comparing the top and bottom panel, we see that a higher money to total debt policy ($\eta$) is needed to satiate the economy when the satiation parameter ($\lambda$) is higher. This implies that QE can be a welfare increasing response to upward satiation parameter shocks.
Figure 6: Model predictions of marginal product of money for various regimes of total government debt held as money where $\lambda = 1.8$. Quantitative easing is an increase in money to total debt ratio. The marginal product of money jumps down to zero at the same point where welfare jumps up (see Figure 5).

Figure 7: Model predictions of marginal product of money for various regimes of total government debt held as money. Quantitative easing is an increase in money to total debt ratio. The marginal product of money jumps down to zero at the same point where welfare jump up (see Figure 5). A positive IOER policy regime puts a lower bound on the marginal product of money.
Parameter | Value | Targets
--- | --- | ---
α relative preference for leisure | 0.64 | hours worked
β discount rate | 0.96 | capital stock
δ depreciation rate | 0.05 | investment
1 – θ labor share | 0.65 | labor income
1 – φ money cost share | 0.01 | Prescott and Wessel 2015

Table 2: Preference and Technology parameter values and targets for the baseline steady-state economy. All values are jointly determined. Total output normalized to 1 by setting Λ=1.2. Therefore, levels and shares are identical.