

Should the Federal Reserve Pay Competitive Interest on Reserves?*

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Abstract

In 2008, Congress authorized the Federal Reserve to pay interest on commercial bank reserves, effectively giving the Fed a new instrument of monetary policy. Since then, the Fed’s “unconventional” response to the Great Recession has flooded the market with reserves, satiating bank demand. The Fed could make this the *new normal* by paying competitive interest on reserves. Some have advocated this, if for no other reason than it eliminates a distortionary tax on reserves. However, the Fed has indicated that it will slowly reduce its balance sheet to pre-crisis proportions, returning to what we call the *enhanced old normal*: open market operations would once again enforce the federal funds target, but now the Fed would have the additional policy instrument. Here, we argue that maintaining the *new normal* is an inefficient use of the new policy instrument. Using a standard DSGE model, augmented to include a banking sector and an interbank market, our benchmark calibration implies an optimal tax on reserves of about 20 to 40 basis points in the steady state, and a fluctuating tax rate in response to shocks. We also consider a bank lending externality for which a lower (possibly even negative) interest rate on reserves may be optimal.

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1 Introduction

The Federal Reserve has a new instrument of monetary policy: the interest rate it pays on commercial bank reserves. The question is, how will the Fed use it?¹ One option is to pay competitive interest on reserves; that is, the Fed sets the interest rate on reserves equal to the federal funds rate, keeping banks satiated in reserves. Doing so would eliminate the tax on transactions balances used by banks to manage the liquidity of their deposits. The reasoning behind the celebrated Friedman Rule supports such a policy: the Fed produces reserves at no cost – with the stroke of a pen – so the opportunity cost of holding reserves should be driven to zero. Goodfriend (2002), Keister et al. (2008), and more recently, Bernanke (2015) have suggested that there may be additional reasons to make this the *new normal* for monetary policy. In this scenario, the Fed would also use the interest rate on reserves (in conjunction with overnight reverse repos) to enforce its target for the federal funds rate; we will discuss this procedure in more detail below.

An alternative option is an *enhanced old normal* that features two monetary policy instruments. This in fact appears to be the Fed’s long run intention, as expressed in its press release of Sept 17, 2014: the Fed indicated that it would gradually let its balance sheet fall to traditional proportions, and (presumably) use open market operations to enforce its fed funds target. This would free up the interest rate on reserves to address additional concerns.

In this paper, we argue that the *enhanced old normal* makes sense when the Fed has competing objectives for macroeconomic stabilization. We will assume that eliminating the tax on reserves is the primary reason for paying competitive interest on reserves, but we will consider two examples in which the Fed has objectives in addition to the elimination of monetary distortions, and therefore faces a scarcity of policy instruments. The first example

¹The Fed did not have the authority to pay interest on reserves before 2008; the Fed had argued that it should be allowed to pay interest on reserves, but Congress did not want to take the budgetary hit. While the Fed was granted that authority in 2008, it has been keeping both the federal funds rate and the interest rate on reserves close to zero since 2009.

is nominal rigidities, in the form of price adjustment costs. In our benchmark calibration, we shall see that a Ramsey Planner would impose a modest, but economically relevant, tax on reserves in the steady state; moreover, the Planner would vary the tax in a systematic way in response to real and financial market shocks. The second example is a bank (over) lending externality. We do not present a serious calibration of this externality, but as we shall see, this externality is another reason to pay less than competitive interest on reserves; indeed, the optimal rate may actually be negative.

We are of course not the first to discuss the optimal interest rate on reserves. Many economists have advocated paying competitive interest on reserves: the argument goes back at least to Friedman (1960).² These arguments were generally presented in a partial equilibrium setting; it is not clear how they would fare in a full DSGE framework like ours.³ A few economists have argued against competitive interest on reserves; for example, Kashyap and Stein (2012) argued that a tax on reserves could be used to address a bank externality; their externality is different than ours, and their analysis was once again partial equilibrium. Finally, Curdia and Woodford (2011) and Cochrane (2014) found it optimal to pay competitive interest on reserves in models that assumed the limiting case of a cashless economy.⁴ Our model assumes that cash is required to purchase certain kinds of consumption goods. Consumers now have a variety of ways to make their payments, and the role of cash has indeed diminished. However, its use is still significant. This fact is well documented in the Federal Reserve Bank of Boston’s Survey of Consumer Payments Choice and the Diary of Consumer Payments Choice.⁵ We will use the latter when we calibrate our model.

²Sargent and Wallace (1985), and more recently Cochrane (2014), discussed the determinacy of equilibrium under Friedman’s proposal.

³Ireland (2014) and Benigno and Nistico (2013) have discussed the role played by the interest rate on reserves in the context of DSGE models: with two instruments of monetary policy, the central bank can pursue dual objectives. However, they did not directly address the optimality of paying competitive interest on reserves.

⁴Their models did not have any frictions that could be addressed by a tax on reserves.

⁵See Foster et al. (2013) for a description of the survey; see also Briglevics and Schuh (2014). Lippi and Secchi (2009) show that reliance on cash remains “intense” in both high and low income countries.

More generally, our model extends a standard DSGE model to include banks and a federal funds market. Banks lend working capital to firms, and fund themselves by issuing either deposits or bonds to households. Banks need reserves to manage the liquidity of their deposits. If the Fed pays less than a competitive rate on reserves, the bank incurs extra costs when funding itself by issuing deposits; so, the tax on reserves is implicitly a tax on deposits. One goal of policy is to reduce or eliminate these extra costs, and doing so is often cited as the reason for paying competitive interest on reserves. But other considerations are also important in determining optimal policy.

As we shall see, mitigating the effects of nominal rigidities or the bank lending externality requires the Ramsey Planner to raise the fed funds rate, and consequently the risk free bond rate, above zero.⁶ But a positive bond rate taxes the consumption that requires the use of cash. As explained above, a tax on reserves actually taxes the consumption that requires the use of deposits. The Planner will want to implement a tax package that minimizes these monetary distortions. However, this sets up another tradeoff for the Planner: taxing reserves to address the monetary distortions or paying more competitive interest on reserves to mitigate the transactions costs incurred by banks.

In practice, many central banks do currently pay interest on reserves, but there seems to be no consensus on what that rate should be. At one extreme, the Reserve Bank of New Zealand has essentially eliminated the tax on reserves by paying competitive interest on reserves. The Fed now pays interest on reserves, but it has kept both the federal funds rate and the interest rate on reserves near zero since 2009. Several central banks have instituted a “corridor” system, one component of which is a small spread between the policy rate and the rate on excess reserves.⁷ And in an interesting new development, the European Central Bank and the central banks of Switzerland, Sweden, Denmark and Japan have actually been

⁶In the case of price adjustment costs, the Planner raises interest rates to stabilize prices; in the case of the bank (over) lending externality, the Planner raises interest rates to discourage lending.

⁷Examples include the Bank of England and the ECB.

setting a negative rate of interest on reserves.

The rest of the paper proceeds as follows: In Section 2, we outline the model and discuss its calibration. In Section 3, we discuss general considerations in the Ramsey problem. First, we describe the set of tradeoffs that the Planner faces. These tradeoffs are complex, and an analytical derivation of the Ramsey solution is not tractable. But, by making some simplifying assumptions, we are able to derive a set of analytical results that illustrate the Planner's tendencies. In particular, we contrast the ways in which the Planner reacts to nominal rigidities and the lending externality separately. In Section 4, we use numerical methods to get the full results, and to estimate the magnitude of the optimal tax on reserves. We derive the Ramsey steady state, and we illustrate how the Planner reacts to shocks. In Section 5, we conclude and suggest directions for future work.

2 The Model

The basic economic environment is fairly simple to describe. There are three consumption goods: a cash good, a deposit good, and a credit good. Households face a cash in advance constraint to pay for the cash good, and a bank deposit in advance constraint to pay for the deposit good; households may pay for the credit good at the beginning of the next period. To model working capital, we assume that firms face a wages in advance constraint before production begins; they can only satisfy this constraint by borrowing from commercial banks. The firms' final product can be sold as a cash good, a deposit good, or a credit good; so, the marginal cost of producing the three goods is the same. Banks issue deposits and bonds to fund their loans to firms, and they face a known default rate when making these loans. Banks use reserves held at the central bank, including funds borrowed on the federal funds market, to manage the liquidity of their deposits. The central bank has two instruments of monetary policy: the federal funds rate and the interest rate it pays on commercial bank

reserves.

Each period is divided into two subperiods: a financial exchange followed by a goods exchange. In the financial exchange, after the realization of current shocks (including the loan default rate), firms borrow from banks to pay their wage bills. Households pay their taxes, they pay for the credit goods they purchased in the previous period, and they choose their asset portfolios, acquiring the cash and deposits that they will need in the goods exchange. In the goods exchange, households use cash and deposits to buy the cash and deposit goods.

2.1 Households

The representative household gets utility from consumption and disutility from work.

$$U_t = E_t \sum_{j=0}^{+\infty} \beta^j u(c_{t+j}^m, c_{t+j}^d, c_{t+j}^c, h_{t+j}) \quad (1)$$

where h_t is hours worked, and c_t^m , c_t^d , and c_t^c are respectively cash, deposit and credit good consumption. The household's budget constraint for the financial exchange, in real terms, is

$$\begin{aligned} \left(\frac{I_{t-1}^b}{\Pi_t} \right) b_{t-1} + \left[\left(\frac{I_{t-1}^d}{\Pi_t} \right) d_{t-1} - \frac{c_{t-1}^d}{\Pi_t} \right] + \left[\left(\frac{1}{\Pi_t} \right) m_{t-1} - \frac{c_{t-1}^m}{\Pi_t} \right] + w_t h_t + \Omega_t^F + \Omega_t^B \\ \geq \frac{c_{t-1}^c}{\Pi_t} + T_t + b_t + m_t + d_t, \end{aligned} \quad (2)$$

where $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross rate of inflation. The household's assets include bonds (b_t) paying a gross nominal interest rate I_t^b , deposits (d_t) paying a gross nominal interest rate I_t^d and cash balances (m_t) paying a gross nominal interest rate of 1. $w_t h_t$ is the real wage bill; as noted above, firms pay their workers at the beginning of the period. T_t is a lump-sum tax, Ω_t^F is the profits of firms, and Ω_t^B is the dividends paid by banks.

The household maximizes expected utility subject to its budget constraint, and the cash

and deposit constraints

$$m_t \geq c_t^m \quad (3)$$

$$d_t \geq c_t^d \quad (4)$$

Letting λ_t represent the Lagrange multiplier on the period t budget constraint, the household's first order conditions imply

$$\frac{\partial u}{\partial c_t^m} = \lambda_t \quad (5)$$

$$1/I_t^b = \beta E_t \left\{ \frac{\lambda_{t+1}/\lambda_t}{\Pi_{t+1}} \right\} \quad (6)$$

$$\frac{\partial u}{\partial c_t^m} = [1 + (I_t^b - 1)] \frac{\partial u}{\partial c_t^c} \quad (7)$$

$$\frac{\partial u}{\partial c_t^d} = [1 + (I_t^b - I_t^d)] \frac{\partial u}{\partial c_t^c} \quad (8)$$

$$-\frac{\partial u}{\partial h_t} = w_t \frac{\partial u}{\partial c_t^m} \quad (9)$$

(5) says that the marginal utility of wealth, λ_t , is equal to the marginal utility of the cash good, and (6) is the standard Euler equation. Interpretation of the next three conditions is straightforward once the timing of household payments is taken into account. (7) describes the tradeoff between cash and credit goods; if the household gives up one dollar's worth of the cash good, it can spend I_t^b dollars on the credit good, because it can hold bonds instead of cash. Similarly, (8) describes the tradeoff between deposit and credit goods; if the household gives up one dollar's worth of the deposit good, it can spend $1 + (I_t^b - I_t^d)$ dollars on the credit good, because it can hold bonds instead of deposits. The final equation is the labor supply curve.

Letting μ_t^m and μ_t^d represent the multipliers on the cash and deposit in advance con-

straints, the complementary slackness conditions are

$$\begin{aligned}\mu_t^m (m_t - c_t^m) &= 0 \\ \mu_t^d (d_t - c_t^d) &= 0\end{aligned}\tag{10}$$

and the multipliers themselves are given by

$$\begin{aligned}\mu_t^m &= \left(\frac{I_t^b - 1}{I_t^b} \right) \lambda_t \\ \mu_t^d &= \left(\frac{I_t^b - I_t^d}{I_t^b} \right) \lambda_t\end{aligned}\tag{11}$$

(11) says that μ_t^m is the opportunity cost (in terms of utility) of holding cash instead of bonds and μ_t^d is the opportunity cost of holding deposits instead of bonds. $\frac{I_t^b - 1}{I_t^b}$ is the traditional seigniorage tax on cash; $\frac{I_t^b - I_t^d}{I_t^b}$ is a second seigniorage tax on deposits.⁸

2.2 Banks and Financial Frictions

The banking sector is perfectly competitive. Banks make loans to the producers of intermediate goods (as described below). These firms have to borrow from banks to finance their wage bills; they cannot borrow directly from households. This restriction becomes a costly financial friction when banks incur costs in intermediating between households and firms. Banks themselves face no frictions in raising funds. So, the Modigliani-Miller Theorem (Modigliani and Miller (1958)) implies that debt and equity financing are equivalent; the effective cost of bank funding is I_t^b . Banks choose their assets and liabilities to maximize the stock market value for their owners, the households. So, banks maximize the expected present value of their dividend stream, calculated using the household's stochastic discount factor. Finally, banks must hold reserves, or federal funds, to manage the liquidity of their

⁸Strictly speaking, it is a seigniorage tax on reserves, as will be seen below.

deposits. This represents a costly financial friction unless the central bank pays competitive interest on reserves.

More specifically, the representative bank maximizes

$$E_t \left\{ \sum_{j=0}^{+\infty} \beta^j \left(\frac{\lambda_{t+j}}{\lambda_t} \right) \Omega_{t+j}^B \right\} \quad (12)$$

where cash flow, Ω_t^B , is given by

$$\begin{aligned} \Omega_t^B = & \left[d_t - \left(\frac{I_{t-1}^d}{\Pi_t} \right) d_{t-1} \right] + \left[(1 - \delta_{t-1}) \left(\frac{I_{t-1}^l}{\Pi_t} \right) l_{t-1} - l_t \right] - \psi_t d_t \\ & + \left[\frac{r_{t-1}}{\Pi_t} - r_t \right] + \frac{i_{t-1}^r}{\Pi_t} (r_{t-1} + f_{t-1}) - \left(\frac{i_{t-1}^f}{\Pi_t} \right) f_{t-1} \end{aligned} \quad (13)$$

The first two terms on the RHS of (13) arise from issuing and redeeming deposits and loans. I^l is the gross nominal interest rate on bank loans (l). We assume that a fraction δ_t of the borrowers experience a default shock and pay nothing back on their loans. The bank observes the default rate before it makes loans, but it does not know the identity of the borrowers who will ultimately default. The bank also incurs transactions costs, $\psi_t d_t$, in managing the liquidity of its deposits; the bank can lower these costs by holding reserves (as explained below). The bank's reserves at the central bank consist of own deposits (r) and reserves it borrows on the interbank market (f); the central bank sets the gross nominal interest rate on reserves, I^r , and the gross return on federal funds, I^f . The corresponding net interest rates are i^r and i^f . As shown in the last two terms on the RHS of (13), the bank receives i^r on all of its reserves at the central bank, but it has to pay i^f on the reserves it borrowed from other banks.⁹

So, what are the transactions costs, $\psi_t d_t$, that the bank faces in managing the liquidity of its deposits? In reality, a bank needs to hold reserves because of mismatches in the maturity

⁹In a symmetric equilibrium, there will be no lending on the interbank market, but we want to determine the equilibrium federal funds rate.

of its deposits and loans. In our simple model, there are no such mismatches. But to capture the demand for reserves, we assume the bank incurs transactions costs that are proportional to the amount of its deposits. Let ν_t be the “velocity” of deposits relative to reserves

$$\nu_t = \frac{d_t}{r_t + f_t} \quad (14)$$

and let ν^* be the satiation level of velocity; then, we define the factor of proportionality to be

$$\psi_t = \begin{cases} \frac{\kappa}{\nu_t} \left[\frac{\nu_t - \nu^*}{\nu^*} - \log\left(\frac{\nu_t}{\nu^*}\right) \right] & \text{if } \nu_t > \nu^* \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

where κ is a positive cost parameter. The derivation of this admittedly odd-looking functional form will be described below. The point for now is that the bank can lower its transactions costs by holding more reserves and decreasing velocity; when velocity falls to its satiation point, the cost of managing deposits falls to zero.¹⁰

In our view, most of these transactions costs are financial costs incurred by the banks. When a bank gets caught short, because it is not holding enough reserves, it has to juggle other accounts in some disadvantageous way, or it has to take a “haircut” at the discount window; for simplicity, in the model we assume that these costs are paid to the government, and redistributed to the households by a lump sum transfer. We do assume, however, that a fraction, Ψ , of these transactions costs are actual resource costs. We discuss all of this in more detail in Section 2.7, which describes the model’s parameterization.

The bank’s optimality condition for own reserves r_t , along with (6), implies

$$\frac{I_t^b - I_t^r}{I_t^b} = \kappa [\log(\nu_t) - \log(\nu^*)] \quad (16)$$

¹⁰Of course there may still be costs associated with deposits that cannot be reduced by holding more reserves. The salaries of bank tellers are an example.

linking the opportunity cost of holding reserves (instead of bonds) to the marginal benefit in terms of reducing transactions costs.¹¹ If $I_t^b > I_t^r$, the bank will not accumulate enough own reserves to drive its transactions costs to zero. Similarly, the optimality condition for borrowed reserves f_t is

$$\frac{I_t^f - I_t^r}{I_t^b} = \kappa [\log(\nu_t) - \log(\nu^*)] \quad (17)$$

linking the marginal cost of holding borrowed reserves to the marginal benefit in terms of reducing transactions costs.

(16), or equivalently (17), is the demand curve for bank reserves. We chose this functional form because it fits the data well, as described in Section 2.7. Then, we integrated the demand curve to get the bank's transactions cost, $\psi_t d_t$, and the proportionality factor (15).

We have made two assumptions along the way that simplify our analysis considerably. First, the definition of velocity, (14), implies that own reserves (r) and borrowed reserves (f) are perfect substitutes in the management of bank deposits. And more importantly, the bank faces no frictions in funding itself; so, the bank is indifferent between borrowing on the interbank market or on the bond market. As a consequence, (17) and (16) imply that the fed funds rate and the bond rate must equalize in our model; that is, $I_t^f = I_t^b$ in equilibrium.

While these assumptions bring simplicity, they may also have eliminated an important link in the transmission mechanism for monetary policy. In particular, when the central bank uses open market operations to set the fed funds rate, it is implicitly setting the rate of return on bonds. There is no wedge between money market rates and the interest rate that goes into the Euler equation.¹²

The bank's optimality condition for deposits is

$$\frac{I_t^b - I_t^d}{I_t^b} = \frac{\kappa}{\nu_t} \left(\frac{\nu_t}{\nu^*} - 1 \right) \quad (18)$$

¹¹The return, $I_t^b - I_t^r$, is not realized until next period, so it is discounted by I_t^b .

¹²Elsewhere, we have shown that this may lead to some empirical difficulties; see Canzoneri et al. (2007).

The bank could raise funds by issuing deposits or by issuing bonds. But, if the bank issues deposits, it has to hold reserves to manage their liquidity. And if the central bank does not pay competitive interest on reserves, then issuing deposits is costly, and the deposit rate will have to be lower than the bond rate.

Note that the central bank does not set I_t^d directly, but the central bank's choice of I_t^r affects the demand for reserves, and therefore ν_t . So, the central bank's choice of the federal funds rate sets the seigniorage tax on cash, and then its choice of the rate on reserves sets the seigniorage tax on deposits. Put alternatively, the tax on reserves is implicitly a tax on the activity that reserves support, deposits.

The bank's optimality condition for lending is

$$(1 - \delta_t)I_t^l = I_t^b \quad (19)$$

Banks can lend on the bond market, or they can lend to firms. When they lend to firms, they know that they face a default rate equal to δ_t . This drives a wedge between the loan rate and the bond rate: performing loans must pay for the loans that fail. This financial friction cannot be eliminated by monetary policy.

Finally, we allow for the possibility of a bank (over) lending externality. We do this by assuming that the loan default rate, δ_t , may depend upon the aggregate value of loan repayments; that is,

$$\delta_t = \delta \left(I_t^l \tilde{l}_t \right) \quad (20)$$

where $\delta'(\cdot) \geq 0$ and $\tilde{l}_t$ is the aggregate quantity of loans. Banks are perfectly competitive, and the individual bank does not think that its lending decisions affect $\tilde{l}_t$ or the default rate. But, when the bank extends a loan, it may raise the costs of default for all of the other banks; that is, there is an overlending externality when $\delta'(\cdot) > 0$.

2.3 The Federal Funds Market

(17) can be viewed as the demand for reserves (or federal funds). Using the definition of velocity, the demand curve in period t can be written as

$$\frac{I^f - I^r}{I^b} = \kappa [\log(d/\nu^*) - \log(r + f)]$$

for a given level of deposits, d . This demand curve is pictured in Figure 1. If the Fed sets $I_t^r = 1$ (as was required prior to October, 2008), and if open market operations bring the total supply of reserves to S^1 , then the intersection of supply and demand determines the fed funds rate, I_t^f . If commercial bank deposits increase, the demand curve shifts to the right, and the fed funds rate will rise; the central bank can of course accommodate the increase in demand with an open market operation that increases supply in tandem, keeping the fed funds rate constant.

This is the textbook view of the federal funds market and fed funds rate targeting. With the interest rate on reserves fixed, and the fed funds target set at I^{fT} , the supply of reserves is market determined. However, when it is recognized that the interest on reserves can be used as a separate instrument of monetary policy, new possibilities emerge.

The Fed's unconventional monetary policy greatly expanded its balance sheet, and reserves are (as of this writing) at a satiation point like S^2 in the diagram. As noted in the introduction, one option for the Fed is to make this the *new normal*. When it becomes time to raise the fed funds target, the Fed simply raises the interest rate on reserves.¹³ Bernanke (2015) has suggested that this approach would create “an elastically supplied, safe, short

¹³For institutional reasons, it is not quite that simple in the United States. The interest rate on reserves is now seen as a ceiling for the fed funds rate. This is because non-bank financial institutions do not have access to the interest rate on reserves, and they will lend to banks that do at a slightly lower rate. As explained in the September 17 press release, the Fed will offer overnight reverse repos to these institutions at a rate that is close to the fed funds target. In this way, the interest rate on reserves will be a ceiling on the fed funds rate, and the reverse repo rate will be a floor. Bernanke (2015) suggested that it might actually be easier to control the fed funds rate in this manner.

term asset for the private sector, in a world in which such assets seem to be in short supply.” Bernanke did not fully specify what the benefits of this might be. And earlier, Goodfriend (2002) and Keister et al. (2008) argued that in this *new normal*, open market operations would be “divorced” from fed funds rate targeting. The Fed could use open market operations to further stabilize financial markets in ways that he did not fully specify. We will not follow up on either of these suggestions in what follows. Instead, we will assume the benefit that comes with the *new normal* is the elimination of the bank transactions costs when the Fed pays competitive interest on reserves.

As we suggested in the introduction, the Fed actually intends to return slowly to what we have called the *enhanced old normal*; that is, there is a target path for the supply of reserves that would gradually take us back to a point like S^1 , and this path can be independent of what the Fed might want to do with the fed funds rate: as long as banks are satiated in reserves, the fed funds target can be enforced in the manner described above. Once reserves are back below satiation levels, the Fed can use the interest on reserves to set the spread, $I^{fT} - I^r$, and the supply of reserves will once again be market determined. In the *enhanced old normal*, the tax on reserves, $I^f - I^r$, will be “divorced” from fed funds rate targeting; the tax on reserves can be used to achieve other macroeconomic goals.

2.4 Firms and the Demand for Bank Loans

We consider two cases. In the first, firms are competitive and prices are flexible; in the second, monopolistically competitive firms face price adjustment costs.

In our model with flexible prices, a unit mass of competitive firms produce the economy’s final output. To generate a demand for bank loans, we assume that workers must be paid when the service is rendered, and that firms have to borrow from banks to pay their wage bills.¹⁴ More precisely, firm i takes out a bank loan $l_t(i)$ in the financial exchange to pay its

¹⁴This is a standard way of modeling working capital. See for example Christiano et al. (2005).

workers. After the financial exchange, a fraction δ_t of these firms are hit by a default shock: they pay their workers in full, and the workers put in the required effort, but ultimately the firm does not manage to bring any product to market.

If firm i does not fail, it has a linear production technology

$$y_t(i) = z_t h_t(i)$$

where z_t is a productivity shock. The firm sets its labor input to maximize profits

$$z_t h_t(i) - I_t^l w_t h_t(i)$$

taking the wage rate and the loan rate as given. The firm's first order condition is

$$I_t^l w_t = z_t \tag{21}$$

In our model with price rigidities, we model firms in two layers. The first layer consists of the competitive firms described above: these firms take bank loans, and may experience a default shock. The new element is that the output of these competitive firms is now an intermediate good that is sold to a second layer of firms; the second level firms produce differentiated goods and set prices subject to a price adjustment cost.¹⁵ The final output is the usual Dixit Stiglitz aggregate of these differentiated goods.¹⁶

More precisely, a fraction δ_t of the firms producing the intermediate good are hit by the default shock. If firm i is in the remaining fraction $1 - \delta_t$ of intermediate good firms, it

¹⁵Similar two-layer setups are often used in models with financial frictions. In our model, this is helpful because we want to allow for a default shock on bank loans, but we don't want this shock to affect the number (unit mass) of varieties produced by the firms that face price adjustment costs.

¹⁶The consumers of the final goods pay the final goods producers with cash, deposits or credit. In the subsequent financial exchange, the final goods producers pay the intermediate goods producers, who in turn repay their bank loans.

produces

$$x_t(i) = z_t h_t(i)$$

and sells the intermediate output at a price p_t^x to producers of differentiated goods. Firm i maximizes

$$\left(\frac{p_t^x}{p_t} \right) z_t h_t(i) - I_t^l w_t h_t(i)$$

which implies

$$p_t^x = \frac{I_t^l p_t w_t}{z_t}$$

and zero profits.

To model the producers of differentiated goods, we use a standard framework with price adjustment costs. Firm f faces the demand function

$$y_t(f) = \left[\frac{p_t}{p_t(f)} \right]^\sigma y_t$$

and has the production technology

$$y_t(f) = x_t(f)$$

It converts one unit of the intermediate good into one unit of differentiated product, $y_t(f)$.

The firm takes the input price as given, and sets its own price, $p_t(f)$, to maximize

$$E_t \sum_{j=0}^{+\infty} \beta^j \left(\frac{\lambda_{t+j}}{\lambda_t} \right) \left\{ \frac{S p_{t+j-1}(f) y_{t+j-1}(f)}{p_{t+j}} - \frac{p_{t+j-1}^x y_{t+j-1}(f)}{p_{t+j}} \right. \\ \left. - \frac{\varsigma}{2} \left[\frac{p_{t+j}(f)}{p_{t+j-1}(f)} - 1 \right]^2 y_{t+j} \right\}$$

subject to its demand function; the last term on the RHS represents the price adjustment

costs, and ς measures their severity. $S (= \frac{\sigma}{\sigma-1})$ is a fiscal subsidy that eliminates the price markup in the steady state.¹⁷ The optimality condition for setting $p_t(f)$ is

$$\begin{aligned} \beta E_t \left\{ \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left(\frac{S(1-\sigma) [p_t(f)]^{-\sigma} (p_t)^\sigma y_t}{p_{t+1}} + \frac{\sigma [p_t(f)]^{-\sigma-1} (p_t)^\sigma y_t I_t^l w_t}{z_t \Pi_{t+1}} \right) \right\} \\ - \varsigma \left(\frac{p_t(f)}{p_{t-1}(f)} - 1 \right) \frac{y_t}{p_{t-1}(f)} + \varsigma \beta E_t \left\{ \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left(\frac{p_{t+1}(f)}{p_t(f)} - 1 \right) \frac{p_{t+1}(f) y_{t+1}}{[p_t(f)]^2} \right\} = 0 \end{aligned} \quad (22)$$

2.5 The Limited Role of Fiscal Policy in Our Analysis

The focus of this paper is on monetary policy, and not on fiscal policy per se. However, there are two seigniorage taxes in the model; these taxes do generate revenues, but we want to abstract from their role in financing government operations.

To this end, we have set government purchases equal to zero. But, the government still has to service its outstanding debt, and it has to pay the fiscal subsidies to firms. To the extent that the seigniorage taxes do not cover these expenditures, we assume that the government resorts to a lump sum tax, T . Moreover, we assume that the government sets T_t to balance its budget; so, the Ramsey Planner does not have to worry about the level of debt.

2.6 Market Clearing Conditions

In a symmetric equilibrium with sticky prices, (22) becomes a Phillips curve

$$\begin{aligned} \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t \Pi_{t+1}} \right) \left[S(1-\sigma) + \frac{\sigma I_t^l w_t}{z_t} \right] = \varsigma (\Pi_t - 1) \Pi_t \\ - \varsigma \beta E_t \left\{ \left(\frac{\lambda_{t+1}}{\lambda_t} \right) (\Pi_{t+1} - 1) \Pi_{t+1} \left(\frac{y_{t+1}}{y_t} \right) \right\} \end{aligned} \quad (23)$$

¹⁷We don't want monetary policy to be able to exploit this markup.

If prices are flexible, (21) replaces (23).

Bank loans equal the wage bill in equilibrium

$$l_t = w_t h_t$$

And finally, the goods market clearing condition is¹⁸

$$c_t^m + c_t^d + c_t^c + \Psi \psi_t d_t = \left[1 - \frac{\varsigma}{2} (\Pi_t - 1)^2\right] (1 - \delta_t) z_t h_t \quad (24)$$

In the case of flexible prices, $\varsigma = 0$.

2.7 Model Parameters

In Section 4, we derive Ramsey solutions numerically. For this exercise, we will need to specify parameter values, and a functional form for utility. In what follows, we use a period utility function that is separable in its arguments:

$$u_t = \phi_m \log(c_t^m) + \phi_d \log(c_t^d) + \phi_c \log(c_t^c) - \frac{1}{1 + \chi} h_t^{1 + \chi} \quad (25)$$

where $\phi_m + \phi_d + \phi_c = 1$.

The parameter values we chose for these numerical exercises are reported in Table 1. The first four are standard in the literature; they need no further discussion. However, our modeling of the deposit good is new, and we must justify our values of the consumption shares – ϕ_m , ϕ_d and ϕ_c . Similarly, our modeling of the cost of banking and the demand for reserves is not standard; we have to justify our values for ν^* , κ and Ψ .

¹⁸We also have an equilibrium condition for cash. But we don't need to keep track of this market because monetary policy sets interest rates; open market operations automatically accommodate any shifts in cash demand.

2.7.1 Consumption share parameters: ϕ_m , ϕ_d and ϕ_c

The Federal Reserve Bank of Boston’s Consumer Payments Research Center conducts an annual “Survey of Consumer Payments Choice” that tracks consumers’ use of nine different payments methods. The survey provides data on the frequency with which the various methods were used between 2008 and 2013.¹⁹ The top row of Table 2 aggregates the data into the three payment instruments specified in our model: cash was used on average in 27 percent of transactions; checks and check substitutes (including debit cards and electronic bill payments) were used in 53 percent, and credit cards were used in 20 percent.

These fractions may, however, be somewhat misleading. One might expect that cash transactions, for example, are smaller on average than transactions using a credit card or a check. In October 2012, respondents were also asked to keep a diary of the value of transactions made with the alternative methods of payment.²⁰ These shares are reported in the second row of Table 2. We equate the parameters ϕ_m , ϕ_d , and ϕ_c to these value shares.²¹

2.7.2 Reserve demand parameters: κ and ν^*

We proceed in much the same way that Lucas (2000) estimated the welfare cost of inflation. We choose κ so that the relationship between velocity, ν_t and the interest rate spread, $I_t^f - I_t^r$, fits the data. We begin by plotting the data, beginning in 1981 and ending in September 2008; see Figure 2. The Fed was not authorized to pay interest on reserves during this period; in October, the Fed began paying interest on reserves and by the end of October, the interest rate on both required and excess reserves exceeded the effective federal

¹⁹See Foster et al. (2013) and Schuh and Stavins (2015) for descriptions.

²⁰This is the the Diary of Consumer Payments Choice. See Bennett et al. (2014).

²¹There are some other caveats: Payments using deposits include recurring bill payments, which for some respondents is likely to include payments servicing consumer credit, car loans, or mortgage debt. The survey responses may therefore overstate the share of deposit goods and understate the share of credit goods. On the other hand, one might think of servicing a car loan or a mortgage by writing a check as paying for the flow of services from the car or home. That is, one might think of these as deposit goods rather than credit goods, and the survey responses would not overstate the share of deposit goods. In Section 5, we perform robustness checks that increase the weight on the credit good.

funds rate.²² We do not include the period after September 2008 in our sample because once the spread is zero, reserve demand is satiated. That is, banks are on the horizontal portion of their reserve demand curve in Figure 1, and the quantity of reserves demanded is indefinite.

Our model does not include reserve requirements and therefore does not distinguish between required and excess reserves.²³ In taking the model to the data, we need to take a stand on the measure of reserves to which our model applies. We believe the spirit of the model is closer to excess reserves than to total reserves. Banks voluntarily hold reserves to reduce the costs associated with illiquidity. Their choice of reserve holdings is based on the marginal value of liquidity provided by reserves and the marginal cost of holding reserves. This suggests the concept of reserves in the model is best taken to be excess reserves.

The data on reserve holdings also point to excess reserves as the better choice. Scatter plots (not shown) suggest that using excess reserves rather than total reserves to compute velocity results in a much better fitting, and stable, relationship between velocity and the interest rate spread.²⁴ Due to changes in reserve requirements and innovations such as sweep accounts that provide banks a means of changing their level of required reserves, velocity computed using total reserves has changed significantly over time, and for reasons unrelated to interest rates.²⁵ In addition, Figure 2 indicates that a semilog specification fits the data

²²Although the Federal Reserve has set the interest rate on both required and excess reserves equal to the target federal funds rate since mid-December 2008, the effective federal funds rate has consistently been below the interest rate on reserves. Government sponsored enterprises (e.g. Fannie Mae, Freddie Mac, and the Federal Home Loan Banks) hold deposits at the Fed but are not eligible to receive interest on those deposits. They have become the largest lenders in the federal funds market. The borrowing bank pays the federal funds rate and receives the Fed’s interest rate on reserves. The puzzle is why the fed funds rate isn’t bid up to the Fed’s interest rate on reserves. Williamson (2015) points to “balance sheet costs” such as deposit insurance fees (which depend on total assets) and capital requirements to explain why the depository institutions are only willing to pay a rate below the Fed’s interest rate on reserves. Bech and Klee (2011) present and calibrate a model in which the bargaining power of the lending GSEs and the borrowing banks provides a further explanation.

²³It would be useful in future work to introduce reserve requirements and address the interesting question of whether central banks ought to set a different rate on required and excess reserves.

²⁴When computing velocity, we take deposits to be the sum of demand deposits and other checkable deposits.

²⁵See Bennett and Peristiani (2002) and Krainer (2001).

well.

Figure 2 reveals two outliers, suggesting shifts in reserve demand. The first is September 2001 when the Federal Reserve sought to mitigate the financial market disruptions by substantially expanding bank reserves; McAndrews and Potter (2002) describe this episode.²⁶ The second is September 2008, when the failure of Lehman Brothers turned the financial turmoil of the previous year into a financial crisis.²⁷

The regression equation we estimate is

$$\log(\nu_t) = \delta_0 + \frac{1}{\kappa} \left(\frac{I_t^f - I_t^r}{I_t^f} \right) + \delta_1 dum9/2001 + \delta_2 dum9/2008 + \varepsilon_t \quad (26)$$

where the dummy variables for September 2001 and September 2008 are included to capture the shifts in reserve demand. Shocks to reserve demand, unless fully accommodated, can change the spread; an ordinary least squares regression will yield an inconsistent estimate of $1/\kappa$. Valid instruments are correlated with the spread but uncorrelated with shocks to reserve demand. The Taylor rule suggests instruments: CPI inflation and the unemployment rate are correlated with the federal funds rate, and with the spread (because the interest rate on reserves was zero during our sample). And as there is no reason to believe that these will be correlated with the shocks to reserve demand, ε_t , they should be valid instruments.²⁸ We report the instrumental variables estimates of equation (26) in Table 3.

Satiation velocity, ν^* , is the other reserve demand parameter we need to pin down. We

²⁶Caballero and Krishnamurthy (2008) provide a model of liquidity hoarding that is consistent with the increased reserve demand.

²⁷Afonso and Lagos (2012) and Afonso et al. (2011) report a decline in the volume of fed funds market activity and an increase in the volatility of the spread between fed funds rates and the Fed's target rate during the crisis. These changes, along with other financial market disruptions, led to an increase in precautionary reserve demand; see Afonso et al. (2011), and Ashcraft et al. (2009). Bech et al. (2011) and others note that the Federal Reserve accommodated the increased reserve demand. Acharya and Merrouche (2013) find evidence of an increase in precautionary demand in the UK banking system during this period.

²⁸We use monthly data, and therefore need to use the unemployment rate instead of an output gap measure (which is available only quarterly). We also use an autoregressive correction and therefore include lagged values of the spread and velocity as well as lagged values of inflation and unemployment as instruments.

could of course have used the intercept from our regression equation. Estimating ν^* in this way raises two concerns. First, it would require that we lean heavily on our choice of functional form. Although the regression fits the data well, we are concerned about extrapolating to determine the behavior of velocity when the spread is zero. Second, doing so ignores important information; we have observed velocity when the interest rate spread was eliminated. So, we obtain an estimate of ν^* in a different way.²⁹ The Federal reserve began paying interest on reserves on October 9, 2008. On October 17, 2008, the effective federal funds rate fell below the interest rate on excess reserves. At this point, reserve demand was satiated. We take the value of excess reserves for the two-week reporting period running from October 16, 2008 to October 29, 2008 and compute satiation velocity. The second half of October 2008 was a period of extreme stress in nancial markets and reserve demand during those two weeks does not represent demand during normal times, as our estimates show. We therefore adjust for the shift in reserve demand associated with the crisis (captured by δ_2), and obtain an estimate of ν^* equal to 61.74.³⁰ We then integrate our estimated reserve demand function to obtain our specification for transactions costs, (15).

2.7.3 Fraction of bank transactions costs that are resource costs: Ψ

In our model, banks hold reserves to reduce transactions cost associated with liquidity management. A bank holding fewer reserves risks shortages due to unexpected deposit outflows and other unforeseen events. Managing these risks incur costs, which we divide into financial costs and resource costs. The resource costs consist of the salaries paid to staff who manage the bank's reserve position and the cost of the systems used. The most important financial cost arises from changes in the composition of the bank's assets. If a bank holds fewer reserves, it might have to change the mix of its assets toward more liquid securities

²⁹We thank a referee for suggesting this approach.

³⁰In doing so we are implicitly assuming that the increase in reserve demand estimated for September 2008 is also relevant for the middle of October 2008.

and make fewer loans. In doing so it incurs a financial cost in the form of a lower return on those more liquid assets. In addition, should the bank find itself short, it might need to sell some less liquid assets at a price below their full value. Finally, the financial cost would also include the interest penalty associated with discount window borrowing and daytime overdraft charges (although these are a relatively small part of the story). The distinction between resource and financial costs is important because the latter represent a transfer from the bank's shareholders to others. The resource costs are real costs to the economy as a whole.

We use our estimates of κ and ν^* to compute total transactions costs, (15).³¹ Then, we estimate financial costs by multiplying depository institutions' holdings of Treasury securities by the spread between the prime rate and the rate on three-month Treasury bills.³² And finally, our estimate of Ψ is one minus the ratio of financial costs to total transactions costs, which comes to 0.03.

3 Optimal Monetary Policy: analytical results

The Ramsey Planner has two monetary policy instruments: the federal funds rate (I_t^f), and the interest rate on reserves (I_t^r). The fed funds rate is equal to I_t^b in our model, and we will generally refer to the latter as the instrument of monetary policy. So, the Planner's problem is to choose the I_t^b and I_t^r that maximize household utility, subject to the market clearing conditions and the first order conditions of households, firms and banks.

First, we review the various costs and distortions that the Ramsey Planner would like to

³¹This estimate of transactions costs averages 0.34 percent of deposits in our sample.

³²The interest rate data are taken from the Federal Reserve's release H.15 and the Treasury securities holdings are taken from the Financial Accounts of the United States. The sample is the same as above.

eliminate:

$$\frac{\partial u}{\partial c_t^m} = [1 + (I_t^b - 1)] \frac{\partial u}{\partial c_t^c} \quad (27)$$

$$\frac{\partial u}{\partial c_t^d} = [1 + (I_t^b - I_t^d)] \frac{\partial u}{\partial c_t^c} \quad (28)$$

$$-\frac{\partial u}{\partial h_t} = w_t [1 + (I_t^b - 1)] \frac{\partial u}{\partial c_t^c} \quad (29)$$

$$c_t^m + c_t^d + c_t^c + \Psi \psi_t d_t = \left[1 - \frac{\varsigma}{2} (\Pi_t - 1)^2\right] [1 - \delta (I_t^l l_t)] z_t h_t \quad (30)$$

where

$$I_t^b - I_t^d = \frac{\kappa}{\nu_t} \left(\frac{\nu_t}{\nu^*} - 1 \right) I_t^b \quad (31)$$

$$I_t^b - I_t^r = \kappa [\log(\nu_t) - \log(\nu^*)] I_t^b \quad (32)$$

As explained in section 2.1, $I_t^b - 1$ is the traditional seigniorage tax on cash, and $I_t^b - I_t^d$ is a new seigniorage tax on deposits. The tax on deposits is imposed by taxing reserves, as illustrated by equations (31) and (32); the tax on reserves is implicitly a tax on the activity that reserves support, that is, deposits. And a tax on reserves imposes real resource costs if $\Psi > 0$.

The firms' final product may be sold as a cash good, a deposit good or a credit good. So, efficiency requires that the marginal rates of substitution in consumption must be equal to one. The first two equations above show how the seigniorage taxes on cash and deposits can distort household consumption decisions; similarly, the third equation shows how the seigniorage taxes can distort household labor-leisure decisions. All of these "monetary" distortions can be eliminated by implementing the Extended Friedman Rule: $I_t^b = I_t^r = 1$ (which also implies that $I_t^d = 1$). We show in section 3.1 below that this is indeed the Ramsey Planner's policy if (1) there is no lending externality ($\delta'(\cdot) = 0$) and (2) prices are flexible

($\varsigma = 0$).

If, however, either the lending externality or the price adjustment costs are present, then the Planner will want to set $I_t^b > 1$. In the case of the lending externality, raising I_t^b will increase the interest rate banks charge firms for loans – recall equation (19) – thereby curbing the excessive lending. In the case of price adjustment costs raising I_t^b will ameliorate the deflation associated with the Friedman Rule. But, raising I_t^b imposes the monetary distortions to household decision making described above. In either case, the Planner can use the tax on reserves, $I_t^b - I_t^r$, to minimize the distortions, but in so doing, the Planner will incur resource costs if $\Psi > 0$.

Our full model implies a complex set of tradeoffs for the Planner. To calculate the actual Ramsey solution, we will have to resort to numerical methods. But before going on to that exercise, we try to gain some analytical insight into the directions price adjustment costs and the lending externality tend to pull the optimal values of I_t^b and I_t^r . We will of course have to make some simplifying assumptions in doing this. The first of them is to set $\Psi = 0$. The role that these resource costs play is already clear: they push the Planner closer to paying competitive interest on reserves.

In what follows, we consider three cases. In case 1, flexible prices ($\varsigma = 0$) and no lending externality ($\delta'(\cdot) = 0$), we establish a baseline in which optimal policy is characterized by the Extended Friedman rule. In case 2, we keep the flexible prices ($\varsigma = 0$), but we add a lending externality ($\delta'(\cdot) > 0$). And in case 3, we consider extreme price adjustment costs ($\varsigma \rightarrow \infty$), but we drop the lending externality ($\delta'(\cdot) = 0$).

3.1 The Ramsey Problem with Flexible Prices

With flexible prices, the Ramsey problem is actually a static one. The only equation linking this period with the next is the consumption Euler equation, (6). The rate of inflation does not appear in any equation other than the Euler equation; the sole purpose of the Euler

equation is to pin down the (expected) rate of inflation. So, the Planner's problem boils down to maximizing the household's period utility function, (25).

First, we use the various first order conditions to derive an indirect period utility function in terms of I_t^b , I_t^d , and h_t . Second, we reduce the goods market clearing condition to a resource constraint in the same three variables. Third, we derive the Planner's first order conditions (and complementary slackness conditions) for I_t^b , I_t^d , and h_t . And fourth, we back out the implied value for I_t^r .

3.1.1 The indirect utility function and the resource constraint

The period utility function (25) can be reduced to an expression in I_t^b , I_t^d , and h_t :

$$u_t = \log(1 - \delta_t) - \phi_d \log(1 + I_t^b - I_t^d) - \phi_m \log(I_t^b) - \chi \log(h_t) - \frac{1}{1 + \chi} h_t^{1+\chi} + C_1 \quad (33)$$

where C_1 is a policy invariant term. This is done by using the household's first order conditions to eliminate c_t^d and c_t^c , and then using firm's first order condition, the bank's first order condition for loans and the household's first order condition for labor to eliminate c_t^m .

The goods market clearing condition (24) can also be reduced to an expression in I_t^b , I_t^d , and h_t . Using the first order conditions of the households, firms and banks, the market clearing condition becomes the resource constraint:

$$h_t^{1+\chi} = \frac{\phi_m}{I_t^b} + \phi_c + \frac{\phi_d}{1 + I_t^b - I_t^d} \quad (34)$$

3.1.2 The Ramsey Planner's first order conditions for I_t^b , I_t^d , and h_t

The Ramsey planner chooses I_t^b , I_t^d , and h_t to maximize (33), subject to the resource constraint (34) and the non negativity conditions. Letting $\eta_t \geq 0$ be the Lagrangian multiplier

for the resource constraint, the *optimality condition* for I_t^b is:

$$-\frac{\phi_d}{1 + I_t^b - I_t^d} - \frac{\phi_m}{I_t^b} + \eta_t \left[\frac{\phi_d}{(1 + I_t^b - I_t^d)^2} + \frac{\phi_m}{(I_t^b)^2} \right] \leq 0 \quad (35)$$

and $I_t^b - 1 \geq 0$ with complementary slackness. The *optimality condition* for I_t^d is:

$$\frac{\phi_d}{1 + I_t^b - I_t^d} - \eta_t \left[\frac{\phi_d}{(1 + I_t^b - I_t^d)^2} \right] \geq 0 \quad (36)$$

and $I_t^b - I_t^d \geq 0$ with complementary slackness. The *optimality condition* for h_t is:

$$\frac{\chi}{h_t} + h_t^\chi = (1 + \chi) h_t^\chi \eta_t \quad (37)$$

3.2 Case 1: flexible prices and no lending externality ($\varsigma = 0$ and

$$\delta'(\cdot) = 0)$$

We begin with a case in which neither the lending externality nor the price adjustment cost are present, and we establish that the Extended Friedman Rule is indeed optimal in this baseline case. The following proposition summarizes optimal policy:

PROPOSITION 1: *When prices are flexible ($\varsigma = 0$) and there is no lending externality ($\delta' = 0$), the Planner implements the Extended Friedman Rule: $I_t^b = I_t^r = 1$. The Planner pays competitive interest on reserves.*

The proof of this proposition, which appears in the Appendix, proceeds by showing that $I_t^b = I_t^d = 1$ is an interior solution to the Planner's first order conditions. Then, (31) and (32) imply that $\nu_t = \nu^*$ and $I_t^b = I_t^r$.

3.3 Case 2: flexible prices and a lending externality ($\varsigma = 0$ and $\delta'(\cdot) > 0$)

We write the equilibrium default rate as:

$$\delta_t = \delta(I_t^l l_t) = \delta(z_t h_t)$$

This is done by noting that $I_t^l l_t = I_t^l w_t h_t$, and using (21) to eliminate the real wage. When there is a lending externality, the *optimality condition for h_t* becomes:

$$\frac{z_t \delta'(z_t h_t)}{1 - \delta(z_t h_t)} + \frac{\chi}{h_t} + h_t^\chi = (1 + \chi) h_t^\chi \eta_t \quad (38)$$

From the bank's first order condition for loans (19), increasing I_t^b will drive up the lending rate (I_t^l), and discourage the excessive lending.

PROPOSITION 2: *If $\varsigma = 0$ and $\delta'(\cdot) > 0$, the Planner sets $I_t^d = 1$, $I_t^b > 1 > I_t^r$. The Planner does not pay competitive interest on reserves, and in fact the (net) interest rate on reserves is negative.*

In the Appendix, we show that the optimality conditions for I_t^b and I_t^d imply setting $I_t^d = 1$, for any given value of h_t . We then use the optimality condition for h_t to show that a lending externality is inconsistent with $I_t^b = 1$ and that an interior solution to the Planner's first order conditions exists with $I_t^b > 1$. From (31), $I_t^b > 1 = I_t^d$ implies $\nu_t > \nu^*$. And in addition, we show that $I_t^b > 1 > I_t^r$, in the Appendix.³³

If a Pigovian tax could be levied on borrowing, then the Friedman Rule would be optimal and the central bank would pay competitive interest on reserves (as we show in the

³³This last result is somewhat model specific: the optimal interest rate on reserves need not be negative if there were other costs to issuing deposits that make $I_t^b > I_t^d$.

Appendix). Some might find this a more natural way to address a lending externality. However, we think there are institutional reasons for the use of monetary policy. First, the Pigovian tax rate – like the seigniorage tax on deposits – would not be constant; it would have to be continually adjusted according to economic conditions. The Fed staff is better suited to do this than is Congress. And as Blanchard (2012) has noted, this kind of macro prudential policy would interact in complex ways with monetary policy (especially when nominal rigidities are introduced); it is better to let one agency do it. Blanchard (2012) also notes that politics could get in the way of a time varying macro prudential policy; the Fed is relatively immune to political pressures from financial interests.

None of this addresses the more interesting theoretical question of which policy instrument might be the most efficient in addressing our lending externality. After all, Congress could simply delegate the administration of a Pigovian tax to the Fed.³⁴ Or more generally, the Fed could administer all sorts of macro prudential policies in a state dependent manner: capital requirements, leverage ratios and supervisory policies come to mind. Is it better, for example, to use price tools or quantity tools? And how would the setting of these alternative instruments interact with the macroeconomic aspects of monetary policy? Unfortunately, our modeling of the lending externality is not sufficiently structural to address these issues in an interesting way, and we have not modeled these alternative instruments. That must be left to future work.

Kashyap and Stein (2012) have a result that is similar to ours in some ways, and they do have a more structural modeling of the externality. In particular, they present a stylized version of Stein (2012) in which the possibility of a fire sale means that banks' reliance on short-term deposits is excessive. Remedying this over reliance on short-term deposits provides an additional objective for the central bank. They argue that the federal funds rate should be used for the central bank's first objective, macroeconomic stabilization, while the

³⁴The Fed already has, for example, the authority to set bank reserve requirements in a state contingent way.

interest rate on reserves could be used as a Pigovian tax on deposits. Although they provide a model of the distortion that creates the central bank's second objective, they use a partial equilibrium framework that does not allow them to consider the joint determination of the federal funds rate and the interest rate on reserves. Here we introduce a simpler externality into our general equilibrium framework. While our approach does not have the richness of Kashyap and Stein's modeling of the externality, it does allow a more complete examination of the policy tradeoffs.

3.4 Case 3: Price stability and no lending externality ($\varsigma \rightarrow \infty$ and

$$\delta'(\cdot) = 0)$$

As is well known, even modest nominal rigidities create a strong incentive for the Planner to minimize price fluctuations.³⁵ These incentives conflict with setting I_t^b to satisfy equation (35). Here we consider an extreme case in which $\Pi_t = 1$, and $I_t^b = 1/\beta$ replaces (35). With $\Pi_t = 1$, the Phillips curve (23) reduces to (21), which is the same as with flexible prices.

PROPOSITION 3: *With $\Pi_t = 1$, $I_t^b = 1/\beta$ and $\delta'(\cdot) = 0$, the Planner sets $I_t^b > I_t^d > 1$ and $I_t^b > I_t^r > 1$. The Planner does not pay competitive interest on reserves, but the (net) interest on reserves is positive.*

The proof in the Appendix uses the optimality conditions for I_t^d and h_t along with the resource constraint to show that optimal policy sets I_t^d between I_t^b and one. And while the Planner does not pay competitive interest on reserves, the net interest on reserves is at least positive.

³⁵See Canzoneri et al. (2010); Siu (2004); Schmitt-Grohe and Uribe (2004) and the results in section 4.

3.5 The intuition behind Propositions 2 and 3

Absent other considerations (like mitigating externalities or reducing resource costs), the Ramsey planner would want to equalize the marginal utilities of the three goods—taxing the three consumption goods at a uniform rate. With flexible prices and a lending externality, the planner wants to mitigate the externality by reducing loans and therefore h_t . But it is impossible to mitigate the externality and at the same time tax the three consumption goods uniformly. The only way the planner can reduce h_t is by raising I_t^b above 1, and this distorts the consumption margin across cash and credit goods because currency pays no interest. So the Planner sets I_t^b and I_t^d with two goals: (1) to mitigate the externality by reducing h_t and (2) to minimize the utility cost of achieving the first goal. Optimal policy taxes cash and deposit goods equally by setting $I_t^d = 1$. Setting $I_t^d > 1$ would tax deposit good consumption less. But since the reduction in h_t must be matched by a corresponding reduction in the sum, $c_t^m + c_t^d + c_t^c$, a smaller tax on deposit goods consumption would require a greater increase in I_t^b to achieve any given decrease in h_t .

With price adjustment costs and no externality, the reason behind the optimal departure from uniform taxation is different. The Planner reduces price adjustment costs by getting Π close to one, which requires raising I_t^b above 1. In this case, the reduction of aggregate consumption is an unwelcome side effect, and not a desired policy goal. Our extreme case with $\Pi = 1$ and $I_t^b = \beta^{-1}$ highlights the point, but the intuition is the same for any I_t^b above 1: the planner wants to minimize the utility cost of the decrease in aggregate consumption that has to be tolerated in the interest of reducing price adjustment costs. It is optimal to spread the consumption distortion across the three goods by setting $I_t^b > I_t^d > 1$. It is not optimal to set $I_t^b = I_t^d > 1$; this would eliminate the distortion of the margin between deposit good and credit good consumption at the expense of a greater distortion of the margin between deposit goods and cash goods. The cost outweighs the benefit because the utility function is concave. And it is not optimal to set $I_t^b > I_t^d = 1$; this would eliminate the

distortion of the margin between deposit good and cash good consumption at the expense of aggravating the distortion of the margin between deposit goods and credit goods.

The difference in the optimal values of I_t^d in these two cases is due to the different motivations for setting $I_t^b > 1$ in the first place. In the first case, the Planner's goal in setting I_t^b is explicitly to reduce h_t . Setting $I_t^d > 1$ to spread the consumption distortion across the two margins would require a greater increase in I_t^b to obtain the desired reduction in h_t . In the second case, I_t^b is set to β^{-1} to be consistent with $\Pi = 1$ (or, more generally, I_t^b is set to any value dictated by price adjustment costs). Setting $I_t^d > 1$ to spread the consumption distortion can be achieved without any effect on the optimal value of I_t^b .

4 Ramsey Solution: numerical results

In this section we present numerical results for optimal policy in a calibrated version of our full model. Our benchmark model includes price adjustment costs ($\varsigma = 4$) and assumes that a fraction of banks' reserve management costs are resource costs ($\Psi = 0.03$). We do not include the lending externality in our benchmark model, but we will consider it as a special case.

Since we cannot calculate the Ramsey solution analytically, we have to resort to numerical simulations.³⁶ This comes at the cost of some generality, but it has the advantage that we can assess the quantitative relevance of our results. As mentioned in Section 2.7, some of our parameters are not standard in the literature, and we had to estimate them. After presenting results based on these estimates, we will perform some robustness checks to see which of the parameter settings matter most for our results.

We begin with a discussion of the Ramsey solution in the steady state. Then, we show the Planner's dynamic response when a default rate shock or a productivity shock bounces

³⁶More specifically, we use the "Get Ramsey" program; see Levin and Lopez-Salido (2004).

the economy out of the steady state.

4.1 Optimal policy in the steady state

Table 4 reports optimal steady state values for six different cases. To put these results in context, we note that if there were no price adjustment costs (or lending externality), the Extended Friedman Rule – $I^b = I^r = 1$ – would be optimal, with deflation equal to minus the real rate of interest (4% per annum in our parameterization).

In our benchmark case, the Ramsey Planner is pulled between holding prices constant to eliminate the price adjustment costs and deflating to eliminate the seigniorage taxes. We see that the price adjustment costs are much more important than the monetary distortions:³⁷ the inflation rate is close to zero, but slightly negative, and the bond rate is about 10 basis points shy of 4%. This bond rate distorts the cash good - credit good margin, as illustrated by (27). The deposit good - credit good margin is illustrated by (28). Since it is optimal to spread the consumption distortions across these two margins, the Planner will also raise I^d .

Once again, I^d is not a policy instrument. As explained in Section 3, the Planner imposes this tax on deposit goods by taxing bank reserves. But, taxing reserves increases bank transactions costs, a fraction $\Psi = 0.03$ of which are real resource costs. The Planner has to weigh all these factors in setting the two instruments of monetary policy, I^b and I^r . In our benchmark calibration, the tax on excess reserves is modest, but economically relevant: $I^b - I^r$ is 41 basis points. And of course bank reserves are not satiated, as measured by the spread $\nu - \nu^*$.

In the remaining cases reported in Table 4, we consider alternative parameter values. And in particular, we focus on those parameters that are unique to our modeling. Perhaps the first thing to note is that price adjustment costs dominate other considerations in all of

³⁷This result is common in the literature; see for example Schmitt-Grohe and Uribe (2004), Siu (2004) and Canzoneri et al. (2010).

these cases: the bond rate is very close to 4% and the inflation rate is very close to zero.

In cases 2 and 3, we raise Ψ (the proportion of bank transactions costs that are actual resource costs) from 0.03 (our benchmark) to 0.05, and then to 0.10. This makes the Planner less willing to use the tax on reserves to smooth the consumption distortions. The tax on excess reserves falls from 41 basis points to 25 basis points, and then to 13 basis points. Clearly, our results are sensitive to the size of this parameter.

Our results are also very sensitive to the strength of the lending externality, if we now extend our benchmark model to include one. In particular, we model the lending externality as

$$\delta_t = \gamma_t (z_t h_t)^\theta$$

where the parameter θ measures the strength of the externality. We do not have a good estimate of θ , but here we set it conservatively at 0.25.³⁸ Case 4 keeps Ψ at 0.10, but adds the lending externality. The tax on excess reserves rises from 13 basis points to 35 basis points.³⁹

Cases 5 and 6 alter the consumption share parameters. One might think that lowering the shares of the goods requiring either cash or deposits would reduce the consumption distortions that the Planner has worry about. Case 5 does just that: both ϕ_m and ϕ_d are lowered from their benchmark values. And we see that this lowers the tax on excess reserves from 41 basis points (in Case 1) to 28 basis points. There is some reason to believe that the benchmark parameterization gives too much weight to the deposit good. So, Case 6 shifts weight from the deposit good to the credit good. This alteration makes almost no difference. The results for Case 6 are virtually identical to those in the benchmark case.

³⁸Default rises with the value of loans in the data. Regressing the log of the charge-off rate for commercial bank loans on a constant and log of commercial bank loans yields a slope coefficient 1.1. But not all of the increase in default rates need reflect an externality.

³⁹We also note that if θ is big enough, the interest rate on reserves can be negative.

4.2 Dynamic Ramsey Responses to Real and Financial Shocks

Here we calculate the Ramsey responses to a productivity shock and a default rate shock in our benchmark calibration. We assume that the logs of z_t and δ_t follow AR(1) processes with an autoregressive parameter of 0.9.

4.2.1 A negative productivity shock:

Figure 2 illustrates the Planner's response to a decrease in productivity. This increases firms' marginal cost, and it would be inflationary. But, once again, the Ramsey Planner wants to avoid price movements; so, the Planner raises the interest rate on bonds, keeping inflation virtually constant (not pictured). The increase in the bond rate leads banks to increase their loan rate (labeled IL); this, and of course the decrease in productivity, makes firms contract. The higher bond rate taxes the cash good - credit good margin, and the Planner wants to spread the consumption distortions by taxing the deposit good - credit good margin. As explained earlier, the Planner does this by taxing bank reserves. The demand for reserves falls and velocity increases, increasing bank transactions costs.

4.2.2 A positive default rate shock:

Figure 3 illustrates the Planner's response to an increase in the default rate. The impulse response functions are very similar to those in Figure 2. An increase in the default rate lowers the amount of output that actually makes it to market for a given work effort; this is exactly what a negative productivity shock does. And, a higher default rate immediately causes the banks to increase the loan rate to firms; recall (19). This increases firms' marginal cost and would be inflationary. The Planner raises the bond rate to keep prices virtually constant, and the story continues as before.

4.3 Discussion

When a central bank has a scarcity of instruments, paying competitive interest on reserves is an inefficient use of the second instrument of monetary policy. In our model with nominal rigidities, the Ramsey Planner must raise the interest rate on bonds to stabilize prices. In the steady state, there is an optimal tax on reserves. That tax depends on the structure of the economy. Taken as a whole, Table 4 indicates the optimal tax is in the range 20 to 40 basis points. But, the Planner does not maintain a constant spread between the Fed funds rate and interest rate on excess reserves. When a shock bounces the economy out of the steady state, the Planner moves the spread in a systematic way to maximize household utility.

5 Conclusion

The Federal Reserve has a couple of options as the Great Recession fades into the history books. Bank demand for reserves has been satiated for several years. The Fed could make this the *new normal* by paying competitive interest on reserves; eliminating the distortionary tax on reserves was one of the arguments the Fed originally made when it sought the authority to pay interest on reserves. Moreover, Goodfriend (2002), Keister et al. (2008), and others have argued that the *new normal* frees open market operations to address additional liquidity concerns, and Bernanke (2015) has argued that the *new normal* provides an elastic supply of a safe short term asset for the private sector. These arguments have yet to be modeled in a full DSGE setting, and here we have taken the elimination of the distortionary tax on reserves to be the primary argument in favor of the *new normal*.

Alternatively, the Fed could return to what we have called the *enhanced old normal*. Open market operations would once again enforce the federal funds target, but now the Fed would have a new instrument of monetary policy – the interest rate on reserves, or

equivalently, the tax on reserves. In a fully articulated DSGE model, we have shown that the additional policy instrument comes in handy when a central bank has macroeconomic goals in addition to the Friedman monetary distortions.

The additional macroeconomic goals we have considered are the elimination of price adjustment costs and the elimination of a bank lending externality. The benchmark calibration of our model only includes the price adjustment costs. We find that the optimal tax on excess reserves is about 20 to 40 basis points in the steady state, and that the optimal tax rate fluctuates in response to macroeconomic shocks. When we add the bank lending externality, the optimal tax on reserves increases. Indeed, we showed that it is at least theoretically possible that the optimal rate on reserves may be negative in this case; however, we have not been able to establish the empirical relevance of this last result.

A more complete description of optimal policy in the *enhanced old normal* is an interesting direction for future work. Including a richer array of policy tools, such as reserve requirements, capital requirements, leverage ratios, and supervisory policies would provide insights into questions we are unable to address in our simple model. For example, should central banks pay different interest rates on required and excess reserves? Which tools or combinations of tools should be used to remedy lending externalities and other market failures?

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Table 1: Parameter Values

β	σ	ς	χ	ϕ_m, ϕ_d, ϕ_c	κ	v^*	Ψ
0.99	6	4	1	0.15, 0.65, 0.20	0.044	4	0.03

Table 2:

Share in	Cash	Deposit	Credit
Number of Transactions	0.27	0.53	0.20
Value of Transactions	0.14	0.64	0.16

Table 3:

Variable	Coefficient	Std. Error	P-Value
Constant	5.95	0.09	0.00
$\left(\frac{I_t^f - I_t^r}{I_t^f}\right)$	22.91	5.04	0.00
Dummy 9/01	-2.65	0.03	0.00
Dummy 9/08	-3.44	0.02	0.00
AR(1)	0.75	0.05	0.00

Table 4: Steady State (per annum for interest rates and inflation)

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
interest on bonds	3.89	3.89	3.89	3.90	3.93	3.89
interest on reserves	3.47	3.64	3.76	3.56	3.65	3.47
tax on reserves	0.41	0.25	0.13	0.35	0.28	0.41
interest on deposits	3.89	3.88	3.88	3.90	3.92	3.88
inflation rate	- 0.001	- 0.001	- 0.001	- 0.001	- 0.001	- 0.001
velocity, $\nu - \nu^*$	1.31	0.78	0.40	1.098	0.877	1.30

Notes:

Case 1, benchmark: Table 1 parameters, including $\phi_m = .15$, $\phi_d = .65$, $\phi_c = .20$, $\Psi = .03$

Case 2: Table 1 parameters, but with $\Psi = .05$.

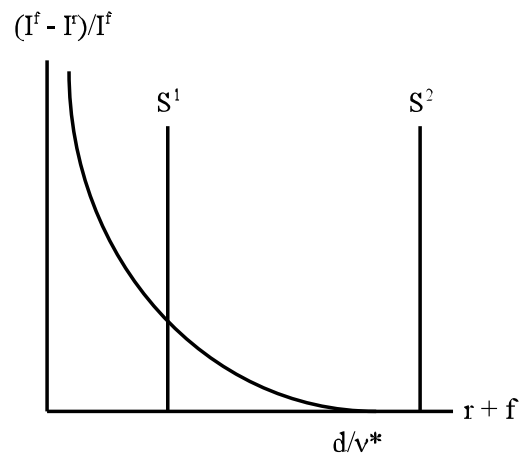
Case 3: Table 1 parameters, but with $\Psi = .10$.

Case 4: Table 1 parameters, but with $\Psi = .10$, $\delta_t = \gamma_t (z_t h_t)^\theta$ and $\theta = 0.25$.

Case 5: Table 1 parameters except $\phi_m = .10$, $\phi_d = .50$, $\phi_c = .40$ (and $\theta = 0$).

Case 6: Table 1 parameters except $\phi_m = .15$, $\phi_d = .45$, $\phi_c = .40$ (and $\theta = 0$).

Figure 1



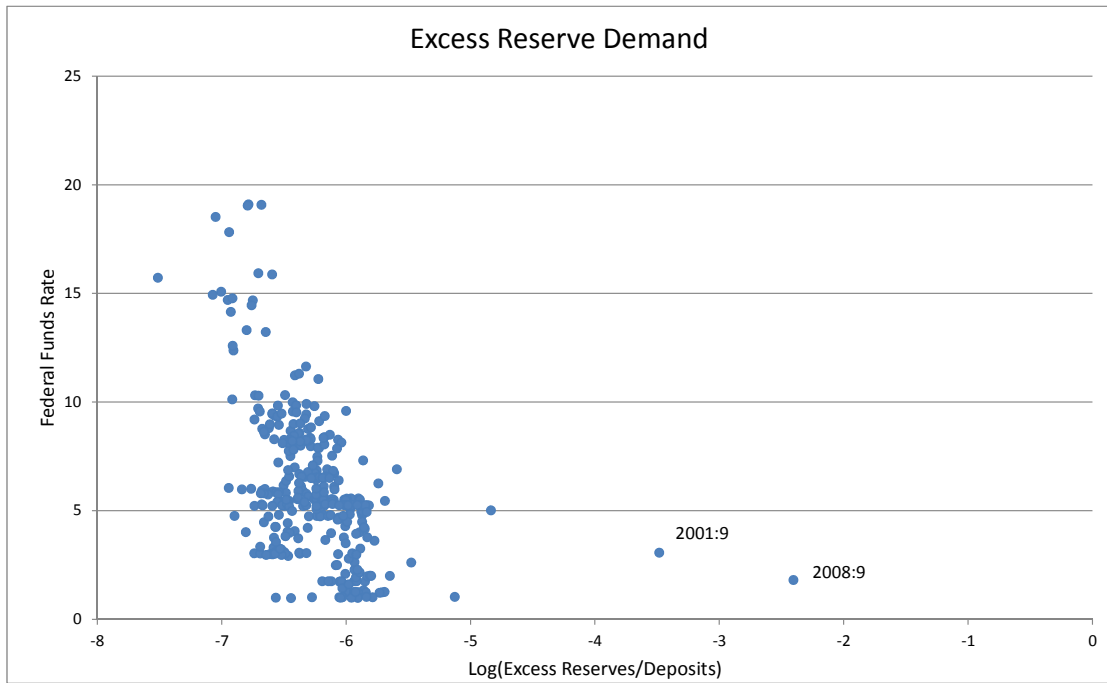


Figure 3: Ramsey response to a negative productivity shock

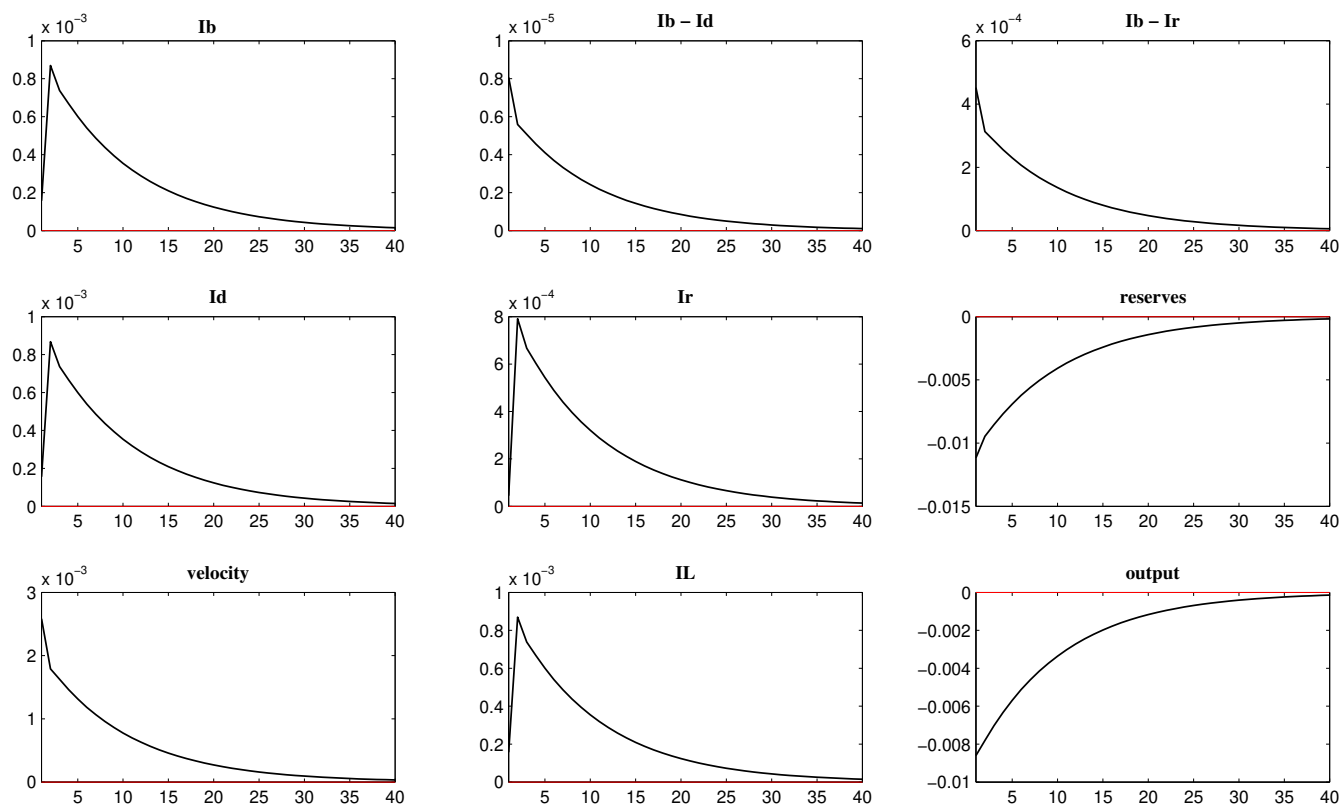


Figure 4: Ramsey response to a positive default shock

