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Comparative Monetary Tools: Open Market Operations and Interest on Reserves

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Abstract

In 2008, the Federal Reserve implemented several new monetary policy tools. One of these tools included that it began to pay interest on a commercial bank's reserves, which created a channel system. A channel system describes a scenario where the central bank can establish an upper and a lower bound around an announced benchmark interest rate such as the federal funds rate. The penalty rate establishes the upper bound since a bank will not borrow from another commercial commercial bank above this rate. A benefit of paying interest on reserves is that IORs place a lower bound on the federal funds rate. In order to analyze this new policy, this paper utilizes a DSGE model with a banking sector. The banking sector includes excess reserves in its balance sheet that receive interest that can be adjusted by the monetary authority. Exogenous shocks are applied to a deterministic model, where agents anticipate future shocks, and a stochastic model, where agents react to an unexpected shock, in order to analyze the impact on macroeconomic variables. I find that an expansionary IOR policy results in a lower price level compared to applying an expansionary OMO policy.

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1 Introduction

The purpose of this monograph is to examine the dynamics of a DSGE model when a monetary authority has the ability to adjust the interest rate that it pays on a bank's reserves. The experience of Canada, New Zealand, and Australia is that their respective central banks have been able to maintain tighter control over their target interest rates compared to the Federal Reserve by implementing a "channel system." This is where the target interest rate's ceiling is the penalty rate (commonly referred to as the discount rate) and the target rate's floor is the interest paid by the monetary authority on a banks reserves. Figure 1 presents a channel system. A Channel System describes a inter-bank market for funds where the central bank sets an upper and lower bound. In the federal funds market, the upper bound on the federal funds rate is the discount rate and the lower bound is the interest on reserve rate. The market determines the effective federal funds rate as long as the rate is between the two bounds such as point A. The conventional tool for adjusting the federal funds rate is open market operations. An open market operations purchase increases the amount of reserves in the federal funds market. The supply of reserves curve will shift to the right, which lowers the effective federal funds rate. An open market operation sale will decrease the amount of reserves in the market. The supply of reserves curve will shift to the left and the effective federal funds rate will increase.

In the aftermath of Quantitative Easing, traditional open market operations were no longer an option as reserve balances reached 2.6 trillion dollars at the end of 2014. This was up from 14 billion dollars in 2007. Hence, the interest on reserves (IOR) tool has been the policy used since the FOMC began rising rates in December, 2015. This scenario is shown graphically in Figure 2. Until the implementation of IOR policy, the lower bound has been zero. As a result, the central bank now has the ability to lift the federal funds rate when it is at the lower bound. This is the horizontal segment of the demand for reserves curve. The monetary authority can lift the federal funds rate from point B to point C by increasing the interest on reserve rate. That is, when the equilibrium exists on the lower bound, the central bank can adjust the inter-bank rate without adjusting the amount of non-borrowed reserves.

This paper develops a general equilibrium model that includes a banking sector that earns interest on its reserves. Simulations are then conducted to analyze the impact on the model's endogenous variables as a result of changing the interest paid on reserves. Specifically, I am interested to see how excess reserves can be manipulated through interest on reserves in order to influence the equilibrium price level and aggregate output. I compare expansionary Open Market Operations (OMO) policy with IOR policy. The paper's model finds that an expansionary IOR policy results in a lower price level compared to an expansionary OMO policy.

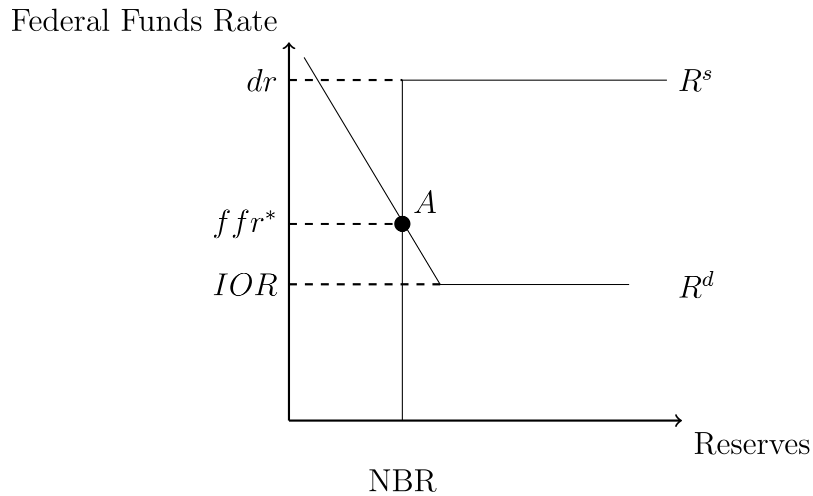

Figure 1: A channel system with the upper bound at the discount rate, dr, and the lower bound at the interest on reserve rate, IOR. The effective federal funds rate, ffr^*, is determined by the supply and demand for reserves at point A.

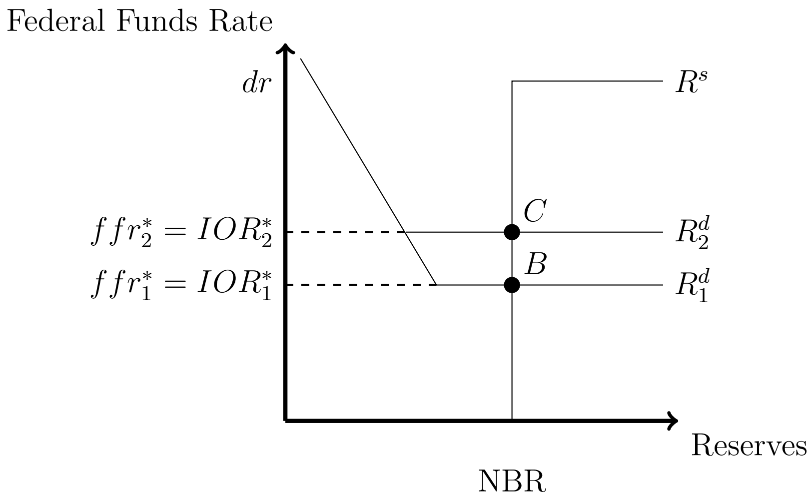

Figure 2: Initially, the equilibrium takes place on the vertical segment of the supply for reserve curve and the horizontal segment of the demand for reserve curve R_1^d. This takes place at point B. IOR policy allows the monetary authority to raise the federal funds rate by increasing the IOR rate from IOR_1^* to IOR_2^*. As a result, the vertical segment of the demand for reserves curve shifts up from R_1^d to R_2^d and the federal funds rate simultaneously increases from ffr_1^* to ffr_2^*.

2 DSGE Model

The model in this paper follows closely Nason and Cogley (1994) and Schorfheide (2000). There are three sectors in this hypothetical economy: the household, the firm, and the banking sectors. The monetary authority is a minor fourth agent in this scenario. Firms and banks are owned by the households and therefore pay dividends to the households. Households choose to hold money and how much money to deposit in their interest-bearing deposit accounts. Firms are perfectly competitive.

The modification I make to the original model is that I include excess reserves in the bank's balance sheet. In addition, I also include a default rate for the loans that are made to firms. An additional assumption I make is that the central bank follows a standard form of the Taylor rule. Also, firms borrow money from the bank in order to rent capital in each time period. This is in contrast to Nason and Cogley (1994), where firms borrow money in order to pay workers' wages. An infinitely lived, representative household maximizes its expected utility by choosing the optimal path of consumption spending, c_t; the amount it holds as bank deposits, d_t; and how much labor to supply; h_t. At the beginning of each time period, the household receives the money stock from the previous time period. The household solves the expected utility function described by

$$\max_{\{c_t\}_{t=0}^{\infty},\{H_t\}_{t=0}^{\infty},\{M_{t+1}\}_{t=0}^{\infty},\{D_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[(1-\psi)\ ln\ c_t + \psi\ ln\ (1-h_t)\right\} ,\ \ 0 < \beta,\ \psi < 1$$

subject to two constraints. The first is the CIA constraint:

$$P_t c_t \leq W_t h_t + M_t - d_t, \quad 0 \leq d_t.$$

The price level of consumption is P_t, and W_t is the wage rate in nominal terms. This constraint is specified so that cash minus deposits from the end of the previous time period plus labor wages can be used for consumption spending in the current time period. Since deposits can never be negative, the qualifier $0 \leq d_t$ is included. The second constraint is the households resources constraint. Money carried into the next time period is a function of current period dividend income from firms and banks, interest earned on deposits, income from supplying labor, and current money holdings net of current period deposits and consumption spending. The intertemporal budget constraint is thus

$$M_{t+1} \leq f_t + b_t + RH_t d_t + W_t h_t + M_t - d_t - P_t c_t,$$

where f_t and b_t are dividend income from firms and banks, respectively. The gross nominal interest rate that households earn from holding deposits is RH_t.

The objective of the representative bank is to maximize the dividends, b_t, that it pays to the households over time. Dividends are discounted by $t+1$ to reflect that the marginal utility of consumption by households take place in the time period after the dividend payments are made. The problem that banks solve is:

$$\max_{\{b_t\}_{t=0}^{\infty},\{l_t\}_{t=0}^{\infty},\{d_t\}_{t=0}^{\infty},\{ER_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^{t+1} \frac{b_t}{c_{t+1}P_{t+1}} \right\},$$

subject to three constraints. The first constraint is the bank's budget constraint

$$b_t \leq RF_t \cdot l_t(1-\eta(l_t)) - l_t \cdot (1-\eta) + d_t - RH_t \cdot d_t + R_{ior}ER_t,$$

where l_t are the loans that banks make to firms, and RF_t is the interest rate that firms must pay on those loans. A fraction of the loans are never paid back. The default rate of loans is η. In addition, ER_t are the bank's excess reserves, and R_{ior} is the interest rate that the central bank pays the bank for holding reserves.

Because a bank's liabilities must be less than or equal to its assets, the banks balance sheet is its second constraint:

$$d_t \leq l_t \cdot (1-\eta(l_t)) + ER_t.$$

Since we assume that banks do not hold capital, the inequality becomes an equality.

The amount of reserves that banks want to hold is determined by solving a revenue optimization problem subject to the bank's balance sheet:

$$\begin{aligned} E(revenue) &= ER_t \cdot R_{t,ior} + l_t \cdot (1-\eta(l_t)) \cdot RF_t \\ s.t.\ d_t &= ER_t + l_t. \end{aligned}$$

The default rate η is a function of the shock parameter to the default risk, ϕ. Thus, banks internalize the default risk shock parameter:

$$\eta = \phi \cdot l_t^{\upsilon}, \quad \upsilon > 1 \tag{1}$$

$$\eta' = \upsilon \cdot \phi \cdot l_t^{\upsilon-1}. \tag{2}$$

The term ν implies defaults increase at an increasing rate as banks lend to the least risky borrowers first. As the amount of lending increases, banks lend to riskier borrowers at an increasing rate. Also, $RF_t > R_{ior}$ since commercial banks would not have an incentive to lend otherwise. Solving for the optimal level of loans:

$$l_t = \left(\frac{1}{\phi(1+\upsilon)} \right)^{\frac{1}{\upsilon}} \left\{ 1 - \frac{R_{ior}}{RF} \right\}^{\frac{1}{\upsilon}}$$

Substitute the optimal level of loans back into the balance sheet in order to determine the optimal level of excess reserves:

$$ER_t = d_t - l_t.$$

The derivation of the optimal amount of loans are relegated to the appendix. Firms attempt to maximize the dividends they pay to households over time analogous to the bank. In addition, a firm chooses how much dividends to pay and how much capital to accumulate during each time period. The firm's choice variables are dividends, next period's capital stock, how much labor to hire, and the amount of loans. Furthermore, the firm faces a trade-off between increasing dividend payoffs and its capital accumulation. Just like in the case for banks, dividends are discounted by $t+1$. The other choice variables are loans, deposits, and excess reserves. The firm's objective function is

$$\max_{\{f_t\}_{t=0}^{\infty},\{k_{t+1}\}_{t=0}^{\infty},\{n_t\}_{t=0}^{\infty},\{l_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^{t+1} \frac{f_t}{c_{t+1} P_{t+1}} \right\},$$

subject to three constraints. The budget constraint of the firm is

$$f_t + RF_t \cdot l_t(1 - \eta(l_t)) + W_t n_t - l_t(1 - \eta(l_t)) \leq P_t[y_t - i_t],$$

where gross investment is described by the law of motion of capital:

$$i_t = k_{t+1} - (1 - \delta)k_t, \quad 0 < \delta < 1,$$

and the firms output is produced with a CRS production function:

$$y_t = k_t^{\alpha}[A_t n_t]^{1-\alpha}, \quad 0 < \alpha < 1.$$

The second constraint that the firm faces is that it must finance its current capital costs by borrowing from the bank, such that

$$R_t k_t \geq l_t. \tag{3}$$

Kiyotaki and Moore (1997) note that the value of capital cannot be more than the loan since the capital is also collateral for the loan. Hence, equation (3) is the firm's collateral constraint.

The central bank follows the Taylor rule when choosing the interbank lending rate, i.e., the federal funds rate (ffr). The monetary authority responds to a convex combination of a GDP gap and inflation gap. The ffr is represented as

$$ffr_t = \Phi \cdot ffr^*_{t-1} + (1-\Phi) \cdot [\phi_y \cdot (y_t - y^\star) + \phi_\pi \cdot (\pi_t - \pi^\star)], \tag{4}$$

where $\pi_t = \frac{P_t}{P_{t-1}}$ is the inflation rate, $\pi^\star$ is the inflation target, $(y_t - y^\star)$ is the GDP gap, $(\pi_t - \pi^\star)$ is an inflation gap, and ffr^* is the equilibrium federal funds rate. The persistence of the inflation target is reflected in Φ. In this model we assume that the monetary authority sets the interest on reserve rate equal to the federal funds rate.

2.1 Equilibrium

Because not all loans to firms are paid back to the bank, there is a default wedge of $1-\eta$ between the interest paid on deposits and the interest charged for loans. As a result, the interest rate that firms pay for loans is higher than the interest rate that households receive from holding deposits to account for the difference in risk. In equilibrium,

$$RF_t(1-\eta(l_t)) = RH_t. \tag{5}$$

Equation (5) tells us that a bank must charge a higher rate on loans than it pays deposits in order to make a normal profit. The interest rate that households receive on their deposits equals interest paid on reserves:

$$RH_t = R_{t,ior}. \tag{6}$$

From the last two optimality conditions, we can write

$$RF_t(1-\eta(l_t)) = RH_t = R_{ior} \equiv R. \tag{7}$$

We restrict $R \leq RF$ in order to reflect a financial friction that results from default loans. Labor supply equals labor demand in the labor market $h_t = n_t$. Equilibrium in the money market is described by $P_t c_t = M_t$, which is the equation of exchange where velocity is equal to one. Equilibrium in the goods market implies that consumption and investment spending is equal to aggregate output

$$c_t + k_{t+1} - (1-\delta)k_t = k_t^\alpha [A_t n_t]^{1-\alpha}.$$

The model's optimality conditions are presented in the appendix.

3 Exogenous Disturbances

In this section, I explore the reaction of agents to unanticipated shocks to the exogenous variables by utilizing a stochastic model. The growth rate of a monetary injection follows the exogenous stochastic process

$$ln\ m_t = (1-\rho)\ ln\ m^* + \rho\ ln\ m_{t-1} + \epsilon_{M,t}, \quad \epsilon_{M,t} \sim \mathrm{N}(0, \sigma_M^2).$$

This equation is interpreted as a simple monetary rule, where the growth rate of the money stock is $m_t = \frac{M_{t+1}}{M_t}$. The parameters m* and ρ imply a significant shift in the conduct of monetary policy. Schorfheide (2000) describes changes in these two parameters as reflecting "rare regime shifts."

The modification made to the Taylor Rule in this paper's stochastic model is that the central bank sets the ior rate equal to the ffr rate as shown in Figure **??**. The central bank follows the Taylor Rule when choosing the interbank lending rate, which is also the IOR rate. The ffr is determined by the Taylor rule as described above with an additive structural shock term:

$$R_h = ffr_t = \Phi \cdot R^*_{t-1} + (1-\Phi) \cdot [\phi_y \cdot (y_t - y^\star) + \phi_\pi \cdot (\pi_t - \pi^\star)] + \varepsilon_{ffr,\ t}.$$

In this stochastic model setting, the Taylor rule now includes the serially uncorrelated innovation ε_{ffr}, which has mean zero and variance σ^2_{ffr}: $\quad \varepsilon_{ffr} \sim \mathrm{N}(0, \sigma^2_{ffr})$.

3.1 Impulse Response Functions

In this section, I demonstrate how an unanticipated structural shock passes through the model with impulse response functions. The model is perturbed by a one standard deviation impulse to the structural shocks ϵ_M and, ϵ_{ffr} in the first time period. Figure 3 shows the impulse responses from a temporary money supply shock on the endogenous variables. The money supply, price level, and thus inflation all jump up from their steady states on impact. The money supply returns to its steady state in about 10 quarters while the price level and inflation rate fall slightly below their respective steady states. Because of the higher prices, consumption initially decreases but recovers in 10 quarters as the price level falls. Consumption remains above the steady state as long as the price level stays below its own steady state. The higher price level and inflation rate prompt the monetary authority to increase its benchmark rate. Thus, the lending, deposit, and IOR rates also increase. The higher interest rates result in an increase in the demand for excess reserves and also in an increase in deposits. The unanticipated money shock stimulates output by the firm. The firm raises wages to attract more worker hours. Despite the higher

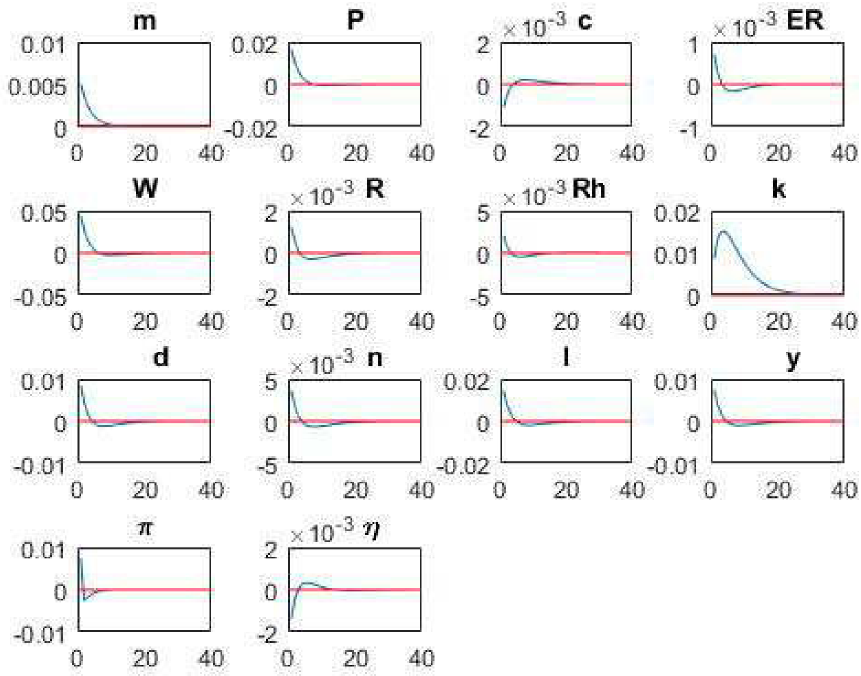

Figure 3: Orthogonalized shock to ϵ_M. The y-axis is the deviations from the steady state.

borrowing rate, firms rent more capital so the amount of loans increases. Capital has a smooth transition because it follows the law of motion. At first, defaults on loans fall, but over time as banks lend to relatively more risky borrowers, the default rate increases. The higher interest on reserve rate also causes an increase an excess reserves. That is, the increases in deposits are allocated between both more loans and more excess reserves. Since capital and labor are complements, labor hours increase, and aggregate output also increases.

The impulse responses from an unanticipated shock to interest rates are presented in Figure 4. In this scenario, the monetary authority decreases its benchmark rate which simultaneously decreases the deposit rate and the bank's lending rate. When the benchmark interest rate decreases, firms expect a lower inflation rate so decrease the price level. As the price level decreases, consumption spending increases. A lower lending rate encourages firms to borrow more in order to rent more capital. There is a smooth increase in capital accumulation as it follows the law of motion before decreasing back to its initial steady state. Output increase on impact and then falls back to its steady state. Because of the initial increase in production, labor demand

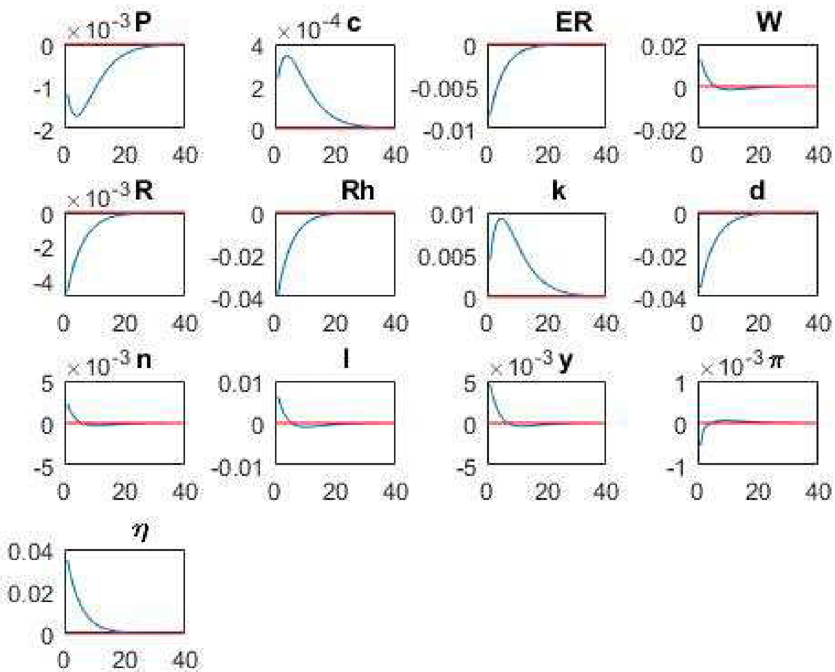

Figure 4: Orthogonalized shock to ϵ_{ffr}. The y-axis is the deviations from the steady state.

increases since capital and labor are compliments. The increase in labor demand raises wages so that workers provide more labor hours. The increase in consumption spending results in less deposits. In addition, lower consumption spending along with a lower IOR rate causes excess reserves to decrease.

We can now make some observation regarding these two stimulative monetary policy tools. As we saw above, an increase in the money supply raises the price level along with the deposit and lending rates. This was in contrast to the monetary authority reducing the IOR rate, which caused the lending and deposit rates to decrease along with the price level.

Moreover, the positive monetary shock also led to more deposits and an increase of excess reserves in contrast to lowering the IOR rate. Even though both tools increased output, the increase in output resulting from the money supply shock caused only an increase in capital accumulation but not an increase in consumption good production. Simultaneously, household income was deposited instead of spent on the consumption good because of the relatively higher price level. As a further result, excess reserves increased.

However, the output increase that resulted from the stimulative IOR policy increased capital accumulation as well as consumption good production. Another difference is that because of the increase in consumption spending, deposits decreased and therefore so did excess reserves. An unexpected difference is that loan defaults decreased with more lending in the money supply shock case.

4 Conclusion

Dynamic stochastic general equilibrium models are the workhorse of macroeconomics. With the relatively new Federal Reserve policy of paying interest paid on a commercial bank's reserves, incorporating an interest rate on excess reserves within a DSGE model is a natural extension of the DSGE model literature. This paper has modeled interest on reserve policy into a stochastic model in order to analyze the effects on the macro-economy. Using this new tool of monetary policy, the Federal Reserve no longer has to face a trade-off between interest rates and the money supply.

This paper compares the effects of stimulative OMO policy with IOR policy. Even though both MP tools increased output, I find that IOR policy is deflationary while OMO policy is inflationary. While increasing the money supply will decrease nominal interest rates, the model shows that real interest rates will increase which leads to higher prices. As a result, consumption spending increases from IOR policy, but decreases from OMO policy. The increase in the money supply from OMOs get absorbed in excess reserves.

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Appendix: Optimal Loans and Excess Reserves

The following describes the optimal level of lending, and thus, the optimal level of reserves:

The amount of reserves that banks want to hold is determined by solving a separate optimization problem subject to the bank's balance sheet:

$$\begin{aligned} E(R) &= ER \cdot R_{ior} + l \cdot (1 - \eta(l)) \cdot RF_t \\ s.t.\ d &= ER + l. \end{aligned}$$

The default rate on loans is η, which is a function of the shock parameter to the default risk, ϕ. Thus, it is the banks that internalize the default risk shock parameter. The first derivative of η with respect to loans implies the probability of default, η' .

$$\eta = \phi \cdot l^{\upsilon}, \quad \upsilon > 1 \tag{8}$$

$$\eta' = \upsilon \cdot \phi \cdot l^{\upsilon - 1} \tag{9}$$

The quadratic term ν implies defaults increase at an increasing rate as banks lend to the least risky borrowers first. As the amount of lending increases, banks lend to riskier borrowers at an increasing rate. Also, $RF_t > R_{ior} ER_t$ since commercial banks would not have an incentive to lend otherwise.
Rearrange the balance sheet so that $ER = d + l$ and then substitute into the objective function.

$$E[R] = (d - l) \cdot R_{ior} + l \cdot (1 - \eta(l)) \cdot RF$$

Take the FOC with respect to loans and solve for the optimal level of loans:

$$\begin{aligned} 0 &= -R_{ior} + (1 - \eta(l)) \cdot RF - l \cdot \eta'(l) \cdot RF \\ 0 &= -R_{ior} + (1 - \phi \cdot l^{\upsilon}) \cdot RF - l \cdot \upsilon \cdot \phi \cdot l^{\upsilon - 1} \cdot RF \\ R_{ior} &= RF - RF \cdot \phi \cdot l^{\upsilon} - RF \cdot \upsilon \cdot \phi \cdot l^{\upsilon} \\ RF - R_{ior} &= RF \cdot \phi \cdot l^{\upsilon} + RF \cdot \upsilon \cdot \phi \cdot l^{\upsilon} \\ &= RF \cdot l^{\upsilon} \cdot \phi(1 + \upsilon) \end{aligned}$$

Solving for the optimal level of loans:

$$\begin{aligned} l^{\upsilon} = \frac{RF - R_{ior}}{RF \cdot \phi(1+\upsilon)} \rightarrow l &= \left(\frac{RF - R_{ior}}{RF \cdot \phi(1+\upsilon)} \right)^{\frac{1}{\upsilon}} \\ &= \left(\frac{1}{\phi(1+\upsilon)} - \frac{R_{ior}}{RF \cdot \phi(1+\upsilon)} \right)^{\frac{1}{\upsilon}} \end{aligned}$$

$$
\begin{aligned}
&= \left(\frac{1}{\phi(1+\upsilon)}\left\{1-\frac{R_{ior}}{RF}\right\}\right)^{\frac{1}{\upsilon}} \\
&= \left(\frac{1}{\phi(1+\upsilon)}\right)^{\frac{1}{\upsilon}}\left\{1-\frac{R_{ior}}{RF}\right\}^{\frac{1}{\upsilon}} \\
&\equiv \chi.
\end{aligned}
$$

Substitute the optimal level of loans back into the balance sheet in order to determine the optimal level of excess reserves:

$$ER = d - \chi$$

Appendix: Optimality Conditions

The first Euler equation in this model describes optimality in the goods market

$$E_t\left\{\frac{P_t}{c_{t+1}P_{t+1}} = \beta\frac{P_{t+1}[\alpha k_{t+1}^{\alpha-1}A_{t+1}\,n_{t+1}^{1-\alpha}+(1-\delta)]}{c_{t+2}P_{t+2}}\right\}.$$

Solving for the interest rate R, in equation (3), we get the borrowing constraint of the firm

$$R_t = \frac{l_t}{k_t}.$$

Equating the supply of labor, the demand for labor, and the marginal rate of substitution between consumption and leisure, the optimality condition for the intratemporal labor market becomes

$$\left(\frac{-\psi}{1-\psi}\right)\frac{c_tP_t}{1-n_t} + W = 0.$$

The second intertemporal Euler equation describes optimality in the credit market:

$$\frac{1}{c_tP_t} - \beta R_t E_t\left\{\frac{1}{c_{t+1}P_{t+1}}\right\}.$$

The credit market is in equilibrium when the nominal interest rate equals the marginal product of capital. Thus,

$$RF_t = P_t\alpha k_t^{\alpha-1}A_t^{1-\alpha}n_t^{1-\alpha}.$$