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Liquidity Regulation, Monetary Policy and Welfare

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Abstract

In the aftermath of the Great Recession, when various policies for regulating credit liquidity were introduced, the US Fed and other central banks placed more emphasis on the interest on reserves than the more traditional required reserve ratio. This paper employs a model with endogenous credit risk, a balance sheet channel, a cost channel and bank equity requirements, to examine the macroprudential role of the interest on reserves and the required reserve ratio and compare their welfare implications. Two transmission channels are identified, the *deposit rate* and the *balance sheet channels*. The required reserve ratio is shown to have conflicting effects through these two channels mitigating its policy effectiveness as a credit regulation tool. Conversely, with the interest on reserves both these channels complement each other in reducing the output gap, the cost channel and inflation. The results show that as a credit regulation tool the interest on reserves requires lower policy rate intervention and yields superior welfare outcomes to both the required reserve ratio and credit-augmented Taylor rules.

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Keywords: credit liquidity regulation; cost channel; macroprudential policy; interest on reserves; required reserve ratio; welfare; DSGE models.

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1 Introduction

Since the aftermath of the Great Recession there has been a renewed focus on the effectiveness of various macroprudential policy measures aimed at insulating the real economy from the adverse externalities flowing from the financial system.[1] Basel III type bank capital regulation has so far attracted most attention. Repullo and Suarez (2013), Benes and Kumhof (2015) and Angelini et al. (2015) are a few among many papers which highlight the significant role of Basel III regulation in enhancing financial and macro stability. Others such as Angeloni and Faia (2013), Angelini, Neri and Panetta (2014) and Rubio and Carrasco-Gallego (2014) stress the necessity of coordinating monetary policy and countercyclical financial regulation to minimize welfare losses, especially following shocks originating in the credit markets.

Beyond the Basel Accords, central banks have also introduced less conventional monetary policies that are also macroprudential in nature and aim to regulate credit liquidity at the national level. One of such policies that has attracted much attention recently is that on the interest rate offered on reserves. On October 6, 2008, the U.S. Fed, introduced interest payments on depository institutions' required and excess reserves, as it was believed that this would give the Fed *"greater scope to use its lending programs to address conditions in credit markets while also maintaining the federal funds rate close to the target..."*. (Board of Governors, Federal Reserve System, October 6, 2008).[2] Following the introduction of interest on reserves in 2008, excess reserves increased dramatically, while the Fed chose not to place any policy emphasis on required reserves (see Graph 1).[3] Similar policies were adopted by the ECB, Bank of Japan, Bank of Canada and other

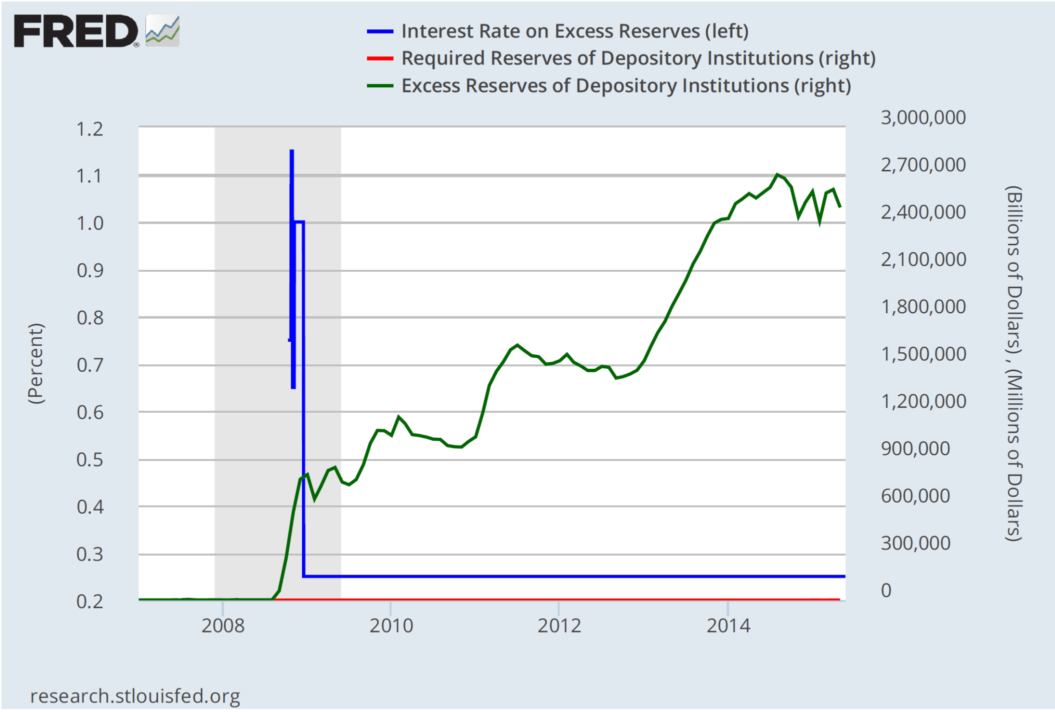
[1] For an overview of the macroprudential literature see Galati and Moessner (2013)

[2] Note prior to this, the rates paid on required and excess reserves had not always been the same, (see also Bech and Klee 2011).

[3] Up to that point required reserves in the US had been very close to total reserves, with excess reserves historically being less than 10% of total reserves.

central banks in recent years.[4]

Graph 1. Interest on Reserves, Required and Excess Reserves



There is however little academic literature on the role of interest on reserves as a credit liquidity regulation tool and particularly as a welfare enhancing monetary policy tool. Hall (2002) shows that interest on reserves can help monetary policy control the price level. Ireland (2014) shows that interest on reserves provide the monetary authority with an additional degree of freedom that can be used to target the supply of reserves to the banking system, independently from the short-term market rate. Support of this is also suggested in Goodfriend (2002, 2011), Curdia and Woodford (2011), Dutkowskya and VanHoose (2011), Kashyap and Stein (2012) and Cochrane (2014). Some papers also examine the role of interest on reserves as part of an 'exit strategy' at the lower zero bound, (Bech and Klee 2011, Goodfriend, 2011). Dressler and Kersting (2015) focus on the real effects that interest on reserves can have through the accumulation of excess reserves. This literature, however, does not examine the role of interest on reserves as a welfare-enhancing macroprudential policy tool following financial or real shocks, or compare the performance of the interest on reserves with that of its more traditional policy counterpart, the required reserve ratio. Historically, the required reserve ratio

[4]In the ECB the interest on reserves reached 0.25% in 2008. However, as credit and liquidity markets remained very tight and deflation was becoming a concern in the Eurozone, the ECB decided to reduce the interest rate on the deposit facility to zero in 11 July 2012, followed by a negative rate, -0.10%, in June 11, 2014 (along with a reduction of the refinance rate, by 10 basis points, to 0.15%).

has attracted more attention than the interest on reserves, in both policy and academic research, particularly for developing economies. Recent studies that examine the required reserve ratio as a macroprudential tool include, Montoro and Moreno (2011), Glocker and Towbin (2012), Mimir, Sunel and Taşkın (2013), Agénor and Pereira da Silva (2014), and Mora (2014). Glocker and Towbin (2012) use the Bernanke, Gertler and Gilchrist (1999) framework to show that when the loss function of the central bank incorporates a financial stability objective, the use of reserve requirements can lead to non-negligible welfare improvements. Their policy analysis focuses mainly on the effects of the required reserve ratio, while the interest on reserves is assumed to be constant. Conversely, Ireland (2014) focuses his analysis mainly on the effects that the interest on reserves has on the short-term interest rate.

The main goal of this paper is to study the transmission mechanism of the interest on reserves and the required reserve ratio and analyze which of these two is the most welfare-enhancing liquidity regulation tool to facilitate monetary policy following financial and real shocks. To capture the effects of all potential channels at work, I employ a dynamic stochastic general equilibrium (DSGE) model of financial intermediation that has both nominal frictions (sticky prices) and financial frictions (risky loans to firms), a *cost channel* effect, (Ravenna and Walsh, 2006), which here is driven by a loan rate that accounts endogenously for risk (based on Agénor, Bratsiotis and Pfajfar, 2014) and a *balance sheet* effect with bank capital requirements. In terms of monetary policy all three policy rules considered, augmented Taylor rules, the interest on reserves and the required reserve ratio, are allowed to respond to both credit and credit spreads. Welfare is measured based on a second order approximation of the household's utility function (Ravenna and Walsh, 2006), that is used to determine the optimal weights in the policy rules considered.

Within this rich framework it is shown that both the interest on reserves and the required reserve ratio can facilitate control over short term interest rates, a result that is consistent with earlier findings, for example, Glocker and Towbin (2012), for the required reserve ratio and Ireland (2014), for the interest on reserves. However, it is also shown that these two policy tools have different transmission effects and therefore different implications for monetary policy and welfare. Two main channels of transmission are identified: the *deposit rate channel* and the *balance sheet channel*. The deposit rate channel is mainly the focus in both Glocker and Towbin (2012) and Ireland (2014).[5]

[5]Note that Ireland (2014) does not incorporate credit frictions or equity costs, but focuses on the effects that the interest on reserves has on the monetary base and the short-term interest rate.

However, in comparing the two credit regulation tools the *balance sheet channel* is also important, particularly when credit frictions play a significant role. It is shown that the required reserve ratio implies conflicting effects through the *deposit rate* and the *balance sheet channels* which mitigate its monetary policy effectiveness. Conversely, the interest on reserves affects both the *deposit rate* and the *balance sheet* channels in a complementary way, so that both these channels work together in reducing the size of the *cost channel*, the output gap and inflation. This means that the use of interest on reserves requires a lower degree of policy rate intervention than a required reserve ratio policy and so as a macroprudential tool, interest on reserves can produce smoother policy rate responses and better welfare outcomes than the required reserve ratio.

The results also show that augmented Taylor rules that respond to credit or credit spreads, achieve higher welfare than the standard Taylor rule, but appear to have no welfare-enhancing role over an optimal Taylor rule. In general, the results show that the use of the interest on reserves in combination with an optimal Taylor rule, is a more welfare-enhancing policy than either the use of an optimal Taylor rule, or an optimal Taylor rule combined with the required reserve ratio, or a credit-augmented Taylor rule. The only case examined where the required reserve ratio and the interest on reserves can deliver similar welfare results, is when the shock is due to a direct increase in risk (credit spread), and both credit regulation tools can respond directly to credit spreads. Even in this case however, it is shown that a stronger intervention is required through the required reserve ratio than the interest on reserves for the same level of welfare.

The rest of the paper is organized as follows. Section 2 develops the main model and introduces the two credit regulation tools in focus. Section 3 describes the equilibrium properties of the model. Section 4 details the steady state and the parameterization of the model. Section 5 examines the transmission effects of the required reserve ratio and the interest on reserves. Section 6 examines the optimal policy rules that minimize a micro-founded welfare loss function following financial and supply shocks and section 7 concludes.

2 The Model

Consider a closed economy financial intermediation model with a representative household, a continuum of intermediate goods firms producing differentiated goods, a competitive final good firm, a competitive banking sector with a deposit and a lending bank, and a central bank that decides on monetary policy, the required reserve ratio and the interest on reserves. Each intermediate goods firm borrows from the lending bank to fund wage payments to households. Its production is subject to an idiosyncratic shock, which makes the loan repayment risky, requiring firms to pledge a fraction of their output as collateral in case of default. The deposit bank is offered an interest on its total reserves, but its deposits are also subject to a required reserve ratio, (as in Glocker and Towbin, 2012). The lending bank's funds are made of deposits, bank capital and central bank liquidity. Bank capital offers a higher rate of return because of the bank's exposure to firms' risk. The supply of equity is determined by regulatory requirements (as set by the Basel Accords). The loan rate is derived by the bank as a finance premium over the cost of borrowing and based on the distribution of the idiosyncratic risk of the firm. Taking the loan rate as given, each intermediate goods firm decides on the level of employment, prices and loans. The final good firm combines all intermediate goods to produce a homogeneous final good used only for consumption purposes. There is a full transmission of risk from firms to the lending bank, with bank equity holders absorbing the cost of default.

2.1 Households

The representative household maximizes,

$$U_t = \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left(\frac{c_t^{1-\sigma}}{1-\sigma} - \frac{h_t^{1+\eta}}{1+\eta} \right), \tag{1}$$

where $\sigma > 0$ is the intertemporal elasticity of substitution in consumption, η is the inverse of the Frisch elasticity of labour supply, $\mathbb{E}_t$ the expectations operator and $\beta \in (0,1)$ is the discount factor. Households enter period t with cash holdings of m_t. They receive wage income, $w_t h_t$, where w_t is the real wage and h is employment hours. They supply deposits, d_t, to the deposit bank and invest in bank capital (equity), e_t, both defined in real terms. The household's remaining income is spent on a basket of consumption goods c_t. At the end of the period the household receives gross interest payments on deposits, R_t^d, bank capital holdings, $(1-\Phi_t^B)R_t^e$, and aggregate real profits from intermediaries and firms, J_t. The term Φ_t^B denotes the probability of bank default (derived below). If the bank collapses, then equity holders must absorb any incurred financial losses. The real value of cash carried over to period $t+1$ is,

$$m_{t+1}\frac{p_{t+1}}{p_t} = m_t + w_t h_t - d_t - e_t - c_t + R_t^d d_t + (1-\Phi_t^B)R_t^e e_t + J_t, \tag{2}$$

where p_t denotes the price of the final good and $\pi_t \equiv \frac{p_t}{p_{t-1}}$ is the gross inflation rate. With a positive deposit rate, ($R_t^d > 1$), and taking wages and prices as given, the first order conditions with respect to c_t, d_t and e_t result in,

$$c_t^{-\sigma} = \beta \mathbb{E}_t R_t^d \frac{p_t}{p_{t+1}} c_{t+1}^{-\sigma}, \tag{3}$$

$$w_t = h_t^\eta c_t^\sigma, \tag{4}$$

$$R_t^e = \frac{R_t^d}{(1-\Phi_t^B)}. \tag{5}$$

Equation (3) is the Euler equation, describing consumption behavior. Equation (3) determines the optimal labour supply, while equation (5) is the arbitrage-free condition between the return on bank capital and the risk free deposit rate. The return on bank capital is shown to be higher than the deposit rate due to the probability of bank default, which is equal to the firm's credit risk, as explained below.

2.2 Final Goods Firm

The competitive final good firm assembles all intermediate goods, $y_{j,t}$, $j \in (0,1)$, to produce a final output, y_t, which then sells at the price p_t. This is produced using a CES technology with Dixit-Stiglitz (1977) preferences, $y_t = \left(\int_0^1 y_{j,t}^{\frac{\lambda_p-1}{\lambda_p}} dj\right)^{\frac{\lambda_p}{\lambda_p-1}}$, where $\lambda_p > 1$, is the elasticity of substitution between the differentiated intermediate goods. The demand for each intermediate good j is, $y_{j,t} = y_t\left(\frac{p_{j,t}}{p_t}\right)^{-\lambda_p}$, where $p_{j,t}$, is the price set by intermediate firm j and $p_t = \left(\int_0^1 p_{j,t}^{1-\lambda_p} dj\right)^{\frac{1}{1-\lambda_p}}$ is the average price index.

2.3 Intermediate Goods Firms

The production of each firm j is,

$$y_{j,t} = z_{j,t} h_t, \tag{6}$$

where $z_{j,t}$ captures the total productivity innovation experienced by each firm j. The latter is subject to both an economy-wide supply shock, a_t, and an idiosyncratic shock,

$\varepsilon_{j,t}$,

$$z_{j,t} = a_t \varepsilon_{j,t}. \tag{7}$$

The economy-wide supply shock, a_t, follows an $AR(1)$ process, $\log a_t = \rho_a \log a_{t-1} + \epsilon_t^a$, where ϵ_t^a is an iid shock, and its mean is $a = 1$. The idiosyncratic shock, $\varepsilon_{j,t}$, is uniformly distributed over the interval $(\underline{\varepsilon}, \bar{\varepsilon})$, with a constant variance and a mean value of unity.[6] At the symmetric aggregate equilibrium level, $z_t = a_t$. Each firm borrows loans to cover its working capital, so in real terms loans are[7],

$$l_{j,t} = w_t h_t. \tag{8}$$

In a good state the firm repays the lending bank the full borrowing cost, $R_t^l l_{j,t} = R_t^l w_t h_t$, where R_t^l is the gross loan rate, as set in the financial contract between the bank and the firm (derived below). As production is risky, borrowing requires some collateral that the firm can pledge in the event of default. It is assumed that in the latter case the lender seizes a fraction χ_t of the firm's output as collateral, as in Agénor, Bratsiotis and Pfajfar (2014). In this model this fraction can vary by allowing χ_t to vary according to an $AR(1)$ process, $\log \chi_t = \rho_\chi \log \chi_{t-1} + \epsilon_t^\chi$, where ϵ_t^χ is an iid shock, and its mean is χ. This shock directly affects the value of collateral, hence the firm's credit risk and thus the credit spread. Default occurs when the real value of collateral is less than the amount that needs to be repaid, $\chi_t y_{j,t} < R_t^l l_{j,t}$. Using equations (6) and (8), the maximum *cut-off* value below which the firm defaults is,

$$\varepsilon_{j,t}^m = \frac{R_t^l w_t}{\chi_t a_t}. \tag{9}$$

The cut-off value is shown to be a function of the cost of labour, w_t, the cost of borrowing, R_t^l, the aggregate productivity shock, a_t, and the credit shock χ_t.

Price setting is based on Calvo-type contracts, where a portion ω_p of firms keep their prices fixed, while the rest, $(1 - \omega_p)$ of firms adjust prices optimally by taking the loan rate (derived below) as given. From the firm's cost minimization problem, real marginal cost is,

$$mc_t = \frac{R_t^l w_t}{z_t}, \tag{10}$$

and from the firm's maximization problem we derive the new Keynesian Phillips curve

[6] The assumption of the idiosyncratic shock $\varepsilon_{j,t}$ following a uniform distribution is to facilitate a tractable probability of default with no loss in generality.

[7] Thus all firms' funding is external. This is mainly for simplicity, but also because we are interested in economies with substantial credit frictions.

equation, in log-linear terms,

$$\widehat{\pi}_t = \beta \mathbb{E}_t \widehat{\pi}_{t+1} + k_p \widehat{mc}_t, \tag{11}$$

where $k_p \equiv (1-\omega_p)(1-\omega_p\beta)/\omega_p$.

2.4 The Banking Sector

The banking sector consists of a representative competitive bank with two branch banks, a deposit bank and a lending bank.

2.4.1 The Deposit Bank

The deposit bank receives deposits from all households. It keeps a fraction of its deposits as total reserves, $\widetilde{r}_t$, at the central bank for which it receives a gross interest on reserves, R_t^{ior}, and makes the rest of its deposits, $(1-\widetilde{r}_t)d_t$, available to the lending bank at the gross interbank rate R_t. The interbank rate, R_t, which is the same as the policy rate here, the required reserve ratio, $\widetilde{rr}_t$, and the interest rate on required and excess reserves, R_t^{ior}, are set by the central bank. The deposit bank's maximization problem is,

$$\begin{aligned} \max_{d_t, \widetilde{r}_t} \Pi_t^{dep} &= R_t^{ior}\widetilde{r}_t d_t + R_t(1-\widetilde{r}_t)d_t - R_t^d d_t - G_t^{\widetilde{r}}(\cdot), \qquad (12) \\ s.t. \qquad G_t^{\widetilde{r}} &= \left[\psi_1(\widetilde{r}_t - \widetilde{rr}_t) + \frac{\psi_2}{2}(\widetilde{r}_t - \widetilde{rr}_t)^2\right] d_t, \end{aligned}$$

where the cost and benefit of holding reserves is captured by a convex function, $G_t^{\widetilde{r}}(\cdot)$, $\psi_1 < 0$ and $\psi_2 > 0$, as in Glocker and Towbin (2012). The first term $\psi_1(\cdot)$ captures the benefits of holding reserves, whereas the quadratic term, $\psi_2(\cdot)$, captures the fact that benefits of excess reserves start decreasing after some level because of decreasing returns to scale. From its maximization problem, (12), the deposit bank sets the optimal levels of the deposit rate,

$$R_t^d = R_t - \widetilde{r}_t(R_t - R_t^{ior}) - \left[\psi_1(\widetilde{r}_t - \widetilde{rr}_t) + \frac{\psi_2}{2}(\widetilde{r}_t - \widetilde{rr}_t)^2\right], \tag{13}$$

and excess reserves,

$$\widetilde{r}_t - \widetilde{rr}_t = -\frac{\psi_1}{\psi_2} - \frac{(R_t - R_t^{ior})}{\psi_2}, \tag{14}$$

where the spread between the refinance rate and the interest on reserves is assumed to be positive, $R_t - R_t^{ior} > 0$. Without policy for reserves, $(R_t^{ior} = \widetilde{rr}_t = \widetilde{r}_t = 0)$, and with no operating costs, the deposit rate equals the refinance rate, $R_t^d = R_t$. Equation (14) determines the bank's total reserves and its excess reserves. The latter is shown to decrease the higher is the spread between the refinance rate and the interest on reserves. In general, from the maximization problem of the deposit bank, (12-14), it is shown that the required reserve ratio acts as a *banking-sector tax*, because it obligates banks to lock a lump-sum of their funds as reserves, (see also Glocker and Towbin, 2012), Conversely, the interest on reserves acts as a *banking-sector subsidy*, because banks receive an interest payment on any reserves they hold, (see also Güntner, 2015). We examine the transmission effects of these two policy tools in more detail in section 5.

2.4.2 The Lending Bank

The representative lending bank raises $(1 - \widetilde{r}_t)d_t$ funds via the deposit bank at the inter-bank gross rate, R_t, and also issues regulatory bank capital, e_t, at the gross rate R_t^e.[8] The lending bank also receives an extra liquidity x_t from the central bank which is remunerated also at the policy rate, R_t.[9] All funds are used to finance the working capital needs of the firms and thus are liabilities of the bank to households, the deposit bank and the central bank, respectively. The bank's balance sheet in real terms is,

$$l_t = (1 - \widetilde{r}_t)d_t + e_t + x_t. \tag{15}$$

The lending rate is set at the beginning of the period, before firms engage in their production activity and prior to their labour demand and pricing decisions. Given a competitive environment it is assumed that, on average, the bank breaks even such that the expected income from lending to firms is equal to the total costs of borrowing these funds (deposits, bank equity and liquidity from the central bank).[10] The bank's expected intra-period zero profit condition from lending to firm j is,

$$\int_{\varepsilon_{j,t}^m}^{\bar{\varepsilon}} R_t^l l_{j,t} f(\varepsilon_{j,t}) d\varepsilon_{j,t} + \int_{\underline{\varepsilon}}^{\varepsilon_{j,t}^m} \chi_t y_{j,t} f(\varepsilon_{j,t}) d\varepsilon_{j,t} = \left[(1 - \widetilde{r}_t)d_t + x_t\right] R_t + e_t R_t^e, \tag{16}$$

[8] Since raising funds through equity is more costly for the bank ($R_t^e > R_t$), equity is issued merely to satisfy regulatory bank capital requirements in this model.

[9] Introducing a liquidity injection, x_t, is simply to allow the markets to clear, as in Ravenna and Walsh (2006), (see Section 3).

[10] This condition is employed purely for simplicity and clarity. Adding monopolistic banks would introduce a further mark-up on the loan rate, on top of the risk premium shown here. However, since the latter drives the results in this model, we ignore monopolistic mark ups.

where $f(\varepsilon_{j,t})$ is the probability density function of $\varepsilon_{j,t}$. The first part of the left hand side is the expected repayment to the bank in the non-default state, while the second part is the expected return to the bank in the default state, including the legal collateral commitment, $\chi_t y_{j,t}$, which forms part of the financial contract (see also Agénor, Bratsiotis and Pfajfar, 2014). The right hand side is the total cost of funds. To derive the lending rate, substitute the production function, equations (6) and (7) into (16), together with $R_t^l l_{j,t} = \chi_t a_t \varepsilon_{j,t}^m h_t$ (from equation 9), and $(1-\widetilde{r}_t)d_t + x_t = l_t - e_t$, (from the balance sheet equation 15), to obtain,

$$R_t^l l_{j,t} = (l_t - e_t)R_t + e_t R_t^e + \int_{\underline{\varepsilon}}^{\varepsilon_{j,t}^m} (\varepsilon_{j,t}^m - \varepsilon_{j,t})\chi_t a_t h_t f(\varepsilon_{j,t}) d\varepsilon_{j,t}$$

To find an explicit expression for the probability of default, we can use the distribution properties of the idiosyncratic shock. Since, $\varepsilon_{j,t}$ is follows a uniform distribution over the interval $(\underline{\varepsilon}, \bar{\varepsilon})$, its probability density is $1/(\bar{\varepsilon} - \underline{\varepsilon})$ and its mean $\mu_\varepsilon = (\bar{\varepsilon} + \underline{\varepsilon})/2$. Using this information and the definition $\gamma_t = e_t/l_t$, where γ_t is the bank capital-to-loan ratio, the loan rate is,[11]

$$R_t^l = (1-\gamma_t)R_t + \gamma_t R_t^e + \chi_t \frac{y_t}{l_t}\left(\frac{\bar{\varepsilon} - \underline{\varepsilon}}{2}\right)\Phi_t^2, \tag{17}$$

where $y_t = a_t h_t$ and $\Phi_t = \int_{\underline{\varepsilon}}^{\varepsilon_t^m} f(\varepsilon_t) d\varepsilon_t = \frac{\varepsilon_t^m - \underline{\varepsilon}}{\bar{\varepsilon} - \underline{\varepsilon}}$, is the probability of default. From equation (17), the loan rate is shown to be set as a finance premium (last term in 17) over the total cost of borrowing, that is from deposits and central bank liquidity at the cost of R_t, and from bank capital at R_t^e, weighted by the bank capital-to-loan ratio γ_t. With no bank capital requirements, $\gamma_t = 0$, the loan rate spread is driven mainly by the finance premium, $R_t^l - R_t = \chi_t \frac{y_t}{l_t}\left(\frac{\bar{\varepsilon} - \underline{\varepsilon}}{2}\right)\Phi_t^2$ and thus by the probability of default, Φ_t , the fraction of collateral, χ_t, and the output-to-loan ratio, y_t/l_t. The interest on reserves and the required reserve ratio affect the loan rate through two channels: (a) through their effect on the *deposit rate*, (13), which in turn affects the equity rate, R_t^e (see 5) and (b) through the *balance sheet* because they affect total reserves which determine the credit, (loans l_t), available in the economy (see 14 and 15).

The default risk of the firm is fully transmitted to the bank in this model. As the bank's total funds are provided to identical firms and the loan rate has been derived from a break even condition, it is implied that at equilibrium when the firm's default condition is satisfied the bank would also no longer break even (see also 16). Hence, for

[11] Note that the cut-off value, $\varepsilon_{j,t}^m$, depends on the state of the economy and hence it is identical across all firms. Similarly, real wages and the labour employed by each firm are identical and therefore the loan rate applies to all firms and so in what follows the subscript j is dropped.

simplicity the bank's default probability is approximated to the firm's default probability, i.e. $\Phi_t^B \approx \Phi_t$.[12]

2.5 Monetary and Macroprudential Liquidity Policy

The monetary policy rate R_t, which is also the refinance rate in this model, is set according to the following credit-augmented Taylor rules[13],

$$R_t = R^{(1-\phi)} R_{t-1}^{\phi} \left[\left(\frac{\pi_t}{\pi} \right)^{\phi_\pi} \left(\frac{y_t}{y} \right)^{\phi_y} \left(\frac{l_t}{l} \right)^{\phi_l} \right]^{(1-\phi)}, \tag{18}$$

and

$$R_t = R^{(1-\phi)} R_{t-1}^{\phi} \left[\left(\frac{\pi_t}{\pi} \right)^{\phi_\pi} \left(\frac{y_t}{y} \right)^{\phi_y} \left(\frac{R_t^l / R_t}{R^l / R} \right)^{-\phi_s} \right]^{(1-\phi)}, \tag{19}$$

where the term $\phi \in (0,1)$ is the degree of interest rate smoothing and $\phi_y, \phi_\pi > 0$, are policy coefficients. The policy rate is also allowed to respond to deviations of credit liquidity (loans), (18), or the credit spread, (19), from their respective steady states.[14] In (18) the policy rate responds positively to the loan cycle to capture the fact that credit expansions are driven by increased economic activity when credit risk and spreads are low, (see Cúrdia and Woodford 2010, Glocker, and Towbin, 2012, Kannan, Rabanal and Scott, 2012, Rubio and Carrasco-Gallego, 2014, Angelini, Neri, and Panetta, 2014, Benes and Kumhof, 2015). Similarly, in (19), the policy rate responds negatively to credit spreads, (with $\phi_s > 0$), to capture the idea that monetary policy must be relaxed in times of high spreads, because tightening monetary policy, (with no imminent inflationary pressure), would result in further increases in the spreads, (Taylor, 2008, Cúrdia and Woodford, 2010). Thus a 'leaning against the cycle' policy is applied here in both augmented Taylor rules.

As the aftermath of the Great Recession showed central banks may require more than just conventional, or augmented policy rate rules, if they are to be successful in achieving financial stability. In this model the monetary policy rules described above are facilitated by a credit liquidity regulation tool, either a required reserve ratio, or an interest on reserves policy rule. Some recent studies show that required reserve ratio rules

[12] This assumption is made for simplicity and it does not change the robustness of the results in this paper.

[13] Scenarios of extreme liquidity shortages, or lower zero bound interest rate policy, are not the focus of this paper so we assume that the interbank rate follows closely the policy rate.

[14] Steady state values are denoted by the respective variable without its time time subscript (i.e. $X_t = X$)

that respond in a countercyclical fashion to financial variables, such as credit or credit spreads, can help promote financial and macro stability, (Gray, 2011, Glocker and Towbin, 2012, Chadha and Corrado, 2012, and Mimir, Sunel and Taşkın, 2013). Accordingly, the following rules are examined for the required reserve ratio,

$$\widetilde{rr}_t = \widetilde{rr}_{t-1}^{\rho_{\widetilde{rr}}} (\widetilde{rr})^{(1-\rho_{\widetilde{rr}})} \left(\frac{l_t}{l}\right)^{(1-\rho_{\widetilde{rr}})\mu^l_{\widetilde{rr}}}, \tag{20}$$

and

$$\widetilde{rr}_t = \widetilde{rr}_{t-1}^{\rho_{\widetilde{rr}}} (\widetilde{rr})^{(1-\rho_{\widetilde{rr}})} \left(\frac{R^l_t/R_t}{R^l/R}\right)^{(1-\rho_{\widetilde{rr}})\mu^s_{\widetilde{rr}}}, \tag{21}$$

where $\rho_{\widetilde{rr}} \in (0,1)$ is a persistence parameter and the elasticities $\mu^l_{\widetilde{rr}}$ and $\mu^s_{\widetilde{rr}}$ measure the responsiveness of the required reserve ratio to loans and the credit spread respectively.

The motivation for examining the interest rate on reserves as a credit regulation tool, comes from the fact that this tool has been used by a number of central banks recently (including the US Fed and the ECB) and has attracted more research attention in the aftermath of the Great Recession, (Cúrdia and Woodford, 2011, Dutkowsky and VanHoose, 2011, and Kashyap and Stein, 2012). In the same spirit, the following two rules for the interest on reserves are examined,

$$R^{ior}_t = \left(R^{ior}_{t-1}\right)^{\rho_{R^{ior}}} \left(R^{ior}\right)^{(1-\rho_{R^{ior}})} \left(\frac{l_t}{l}\right)^{(1-\rho_{R^{ior}})\mu^l_{ior}}, \tag{22}$$

and

$$R^{ior}_t = \left(R^{ior}_{t-1}\right)^{\rho_{R^{ior}}} \left(R^{ior}\right)^{(1-\rho_{R^{ior}})} \left(\frac{R^l_t/R_t}{R^l/R}\right)^{(1-\rho_{R^{ior}})\mu^s_{ior}}, \tag{23}$$

where $\rho_{R^{ior}} \in (0,1)$ is a persistence parameter, and μ^l_{ior} and μ^s_{ior} measure the the responsiveness of the interest on reserves to loans and the credit spread respectively. Finally, for the purpose of this paper, it is assumed that the bank capital requirement constraint remains fixed, so that $\gamma_t = \gamma = (\theta + \Phi)$, where $\theta = 0.08$, represents the fixed bank capital to loan ratio, as set by the Basel Accords and $\Phi \approx 0.03$ (derived below) is the steady state risk of default by borrowers. This partly mimics a Basel II type regulation, where borrowers' credit risk is taken into account in the determination of the overall bank capital ratio.

3 Aggregate Equilibrium and the Log-linearized Model

At the aggregate equilibrium where the final goods market clears, $y_t = c_t$. Thus, with no fixed capital investment, or government intervention, aggregate demand is determined by aggregate consumption, c_t, as explained by the household's Euler equation (3). From the production side equilibrium also requires that $\int_0^1 \left(\frac{p_{j,t}}{p_t}\right)^{-\lambda_p} y_t = \int_0^1 \varepsilon_{j,t} a_t h_t$.[15] Using the distribution properties of the idiosyncratic shocks (that has an average mean of unity and at the symmetric equilibrium, $\int_0^1 \varepsilon_{j,t} = 1$), aggregate equilibrium becomes $y_t = a_t h_t / \Delta_t$, where $\Delta_t \equiv \int_0^1 \left(\frac{p_{j,t}}{p_t}\right)^{-\lambda_p}$ is the price dispersion index. Also, at the aggregate equilibrium we assume that $x_t = m_{t+1}\frac{p_{t+1}}{p_t} - m_t$, and $w_t h_t = (1 - \widetilde{r}_t) d_t + e_t + x_t = l_t$ and also that the financial markets clear.

The model is log-linearized around its non-stochastic, zero inflation, flexible price steady state. The flexible price level of output is, $y_t^f = \left(\frac{z_t^{1+\eta}}{\vartheta_p R_t^{l,f}}\right)^{\frac{1}{\eta+\sigma}}$, where ϑ_p is the price mark-up and $R_t^{l,f}$ is the loan rate under flexible prices. The efficient level of output, free of both financial frictions and nominal rigidities, is $y_t^* = \left(\frac{z_t^{1+\eta}}{\vartheta_p}\right)^{\frac{1}{\eta+\sigma}} > y_t^f$, such that in log-linear form, $\widehat{y}_t^* - \widehat{y}_t^f = (\eta + \sigma)^{-1} \widehat{R}_t^{l,f}$. The log-linearized versions of (3), (4), (5), (11) (13), (14), (15) and (17), can then be used to express the model in terms of the (efficient) output gap, $\widehat{y}_t^g = \widehat{y}_t - \widehat{y}_t^*$, inflation ($\widehat{\pi}_t$), the equity rate ($\widehat{R}_t^e$), the deposit rate ($\widehat{R}_t^d$), excess reserves ($\widehat{\widetilde{rr}}_t - \widetilde{rr}\widehat{\widetilde{rr}}_t$), loans ($\widehat{l}_t$), the loan rate ($\widehat{R}_t^l$) and the default risk ($\widehat{\Phi}_t$),

$$\widehat{y}_t^g = \mathbb{E}_t \widehat{y}_{t+1}^g - \sigma^{-1}\left(\widehat{R}_t^d - \mathbb{E}_t \widehat{\pi}_{t+1}\right) + \widehat{u}_t, \tag{24}$$

where $\widehat{u}_t \equiv ((1+\eta)/(\sigma+\eta))\left(\mathbb{E}_t \widehat{z}_{t+1} - \widehat{z}_t\right)$,

$$\widehat{\pi}_t = \beta \mathbb{E}_t \widehat{\pi}_{t+1} + k_p (\eta + \sigma) \widehat{y}_t^g + k_p \widehat{R}_t^l, \tag{25}$$

$$\widehat{R}_t^e = \widehat{R}_t^d + \left(\frac{\Phi}{1-\Phi}\right)\widehat{\Phi}_t, \tag{26}$$

$$\begin{aligned} \widehat{R}_t^d \quad = \quad & (1-\widetilde{r})\frac{R}{R^d}\widehat{R}_t + \widetilde{r}\frac{R^{ior}}{R^d}\widehat{R}_t^{ior} - \frac{(R - R^{ior})}{R^d}\widehat{\widetilde{rr}}_t \\ & - \frac{[\psi_1 + \psi_2(\widetilde{r} - \widetilde{rr})]\left(\widehat{\widetilde{rr}}_t - \widetilde{rr}\widehat{\widetilde{rr}}_t\right)}{R^d}, \end{aligned} \tag{27}$$

$$\widehat{\widetilde{rr}}_t - \widetilde{rr}\widehat{\widetilde{rr}}_t = -\frac{1}{\psi_2}(R\widehat{R}_t - R^{ior}\widehat{R}_t^{ior}), \tag{28}$$

[15] This follows from the demand for each intermediate good, $y_{j,t} = y_t \left(\frac{p_{j,t}}{p_t}\right)^{-\lambda_p}$, and its production by firm j, eq (6).

$$\widehat{l}_t = \widehat{w}_t + \widehat{h}_t = (\eta + \sigma)\,\widehat{y}_t^g + \widehat{y}_t, \tag{29}$$

$$R^l \widehat{R}_t^l = v\left[(1-\gamma)R\widehat{R}_t + \gamma R^e \widehat{R}_t^e + \left(\frac{\bar{\varepsilon} - \underline{\varepsilon}}{2}\right)\frac{R^l \Phi^2}{\varepsilon^m}\left(2\widehat{\Phi}_t - \widehat{\varepsilon}_t^m\right)\right], \tag{30}$$

$$\widehat{\Phi}_t = \left(\frac{\varepsilon^m}{\varepsilon^m - \underline{\varepsilon}}\right)\left(\widehat{R}_t^l + (\eta + \sigma)\,\widehat{y}_t^g - \widehat{\chi}_t\right), \tag{31}$$

where $\hat{R}_t$, $\widehat{\widetilde{rr}}_t$ and $\hat{R}_t^{ior}$ are determined by the log-linear representations of the policy rules, (18)-(23). The steady state values and the parameterization of the model are discussed next.

4 Steady State and Parameterization

The key steady state equations are, $R = 1/\beta$, $R^e = \frac{R^d}{(1-\Phi)}$, $R^l = (1-\gamma)R + \gamma R^e + \chi \frac{y}{l}\left(\frac{\bar{\varepsilon}-\underline{\varepsilon}}{2}\right)\Phi^2$, $\Phi = \frac{\varepsilon^m - \underline{\varepsilon}}{\bar{\varepsilon} - \underline{\varepsilon}}$, where $\varepsilon^m = \frac{\mu_\varepsilon}{\chi \vartheta_p}$, $\widetilde{r} = \widetilde{rr} - \frac{\psi_1}{\psi_2} - \frac{(R - R^{ior})}{\psi_2}$, and $R^d = R - \widetilde{r}(R - R^{ior}) - \left[\psi_1(\widetilde{r} - \widetilde{rr}) + \frac{\psi_2}{2}(\widetilde{r} - \widetilde{rr})^2\right]$. Table 1 shows the baseline parameter values of the model. Most of the parameter values follow largely the existing literature, whereas other parameter values are chosen so that the steady state values match observed ratios for advanced economies. The idiosyncratic productivity shock's range is set to $\underline{\varepsilon} = 0.85$ and $\bar{\varepsilon} = 1.15$, so that $\mu_\varepsilon = (\bar{\varepsilon} + \underline{\varepsilon})/2 = 1$ and the steady state fraction of collateral received by the bank is set to $\chi = 97\%$.[16] These values, together with a price mark-up of 20%, generate a steady state credit risk of 3.04% and a loan rate of 5.48% (in annual terms). The required reserve ratio at the steady state is $\widetilde{rr}$ =2%, which is the average ratio (usually between 1-3%) in OECD countries.[17] The initial steady state spread between the policy rate and interest on reserves is set to $R - R^{ior} = 1\%$ (see also Glocker and Towbin, 2012), and the values of ψ_1 and ψ_2 are chosen so that total reserves are $\widetilde{r} = 0.04$. Some of the key steady state values (in annual terms) resulting from the above parameterization are as follows: $\Phi = 0.0304$, $R^d = 1.0404$, $R = 1.0408$, $R^{ior} = 1.0008$, $R^l = 1.0548$ and $l/y = 0.8221$. These estimates are consistent with values supported for advanced economies. For the baseline case, before examining optimal policy rules, standard Taylor rule parameters are assumed, ($\phi = 0.7, \phi_\pi = 1.5, \phi_y = 0.1$ with $\phi_s = \phi_l = 0$). The degree of persistence in the required reserve ratio ($\rho_{\widetilde{r}}$) and and the interest on reserves ($\rho_{R^{ior}}$), are set to zero, as positive values for these variables obscure the analysis and increase welfare losses.[18]

[16] The value of $\chi = 0.97$ is justified in Agénor, Bratsiotis and Pfajfar, (2014).

[17] A 2% required reserve ratio also reflects the ratio recently proposed for the Euro Zone countries.

[18] Note that positive persistence in the policy rules of the required reserve ratio and the interest on reserves do not affect the qualitative results of the model.

Table 1: Baseline Parameterization

Parameter	Value	Description
β	0.99	Discount Factor
σ	1.00	Intertemporal Substitution in Consumption
η	1.00	Inverse of the Frisch Elasticity of Labour Supply
λ_p	6.00	Elasticity of Demand - Intermediate Goods
ω_p	0.65	Degree of Price Stickiness
a	1.00	Average Productivity Parameter
$\underline{\varepsilon}$	0.85	Idiosyncratic Risk: Lower Range
$\bar{\varepsilon}$	1.15	Idiosyncratic Risk: Upper Range
χ	0.97	Proportion of Output seized in case of Default
θ	0.08	Bank Capital Adequacy Ratio
$\widetilde{rr}$	0.02	Steady State Required Reserve Ratio
ψ_1	-0.02	Linear cost function parameter
ψ_2	0.50	Quadratic cost function parameter
ϕ	0.70	Persistence in Taylor Rule
ϕ_π	1.50	Response of Policy Rate to Inflation Deviations
ϕ_y	0.10	Response of Policy Rate to Output Deviations
ϕ_s, ϕ_l	0.00	Response of Policy Rate to Credit Spread or Loans
$\mu^s_{\widetilde{rr}}, \mu^l_{\widetilde{rr}}$	0.00	Response of the Required Reserve Ratio to Credit Spread or Loans
μ^s_{ior}, μ^l_{ior}	0.00	Response of Interest on Reserves to Credit Spread or Loans

Finally, the persistence parameters and the standard deviations associated with financial shocks and supply shocks are calibrated in line with Benes and Kumhof (2015). Specifically, $\rho_\chi = 0.87$ and $s.d(\chi_t) = 0.11$, while $\rho_a = 0.92$ and $s.d(a_t) = 0.024$.

5 Transmission Effects: Required Reserve Ratio and Interest on Reserves

From (13) and (14) the required reserve ratio, $\widetilde{rr}_t$, and the interest on reserves, R^{ior}_t, are shown to affect both the deposit rate and total reserves, though not in the same way. Both liquidity regulation tools have a positive effect on total reserves, $\partial\widetilde{r}_t/\partial\widetilde{rr}_t = 1 > 0$, and $\partial\widetilde{r}_t/\partial R^{ior}_t = 1/\psi_2 > 0$, ($\psi_2 > 0$) respectively. Thus a higher required reserve ratio, or a higher interest on reserves, increases total reserves. This is a *balance sheet effect*, as it restricts the amount of credit liquidity available in the economy by reducing the volume of loans (see 15). However, the effect that these two liquidity regulation tools have on the deposit rate is shown to be opposite: a *negative* for the required reserve ratio and a *positive* for the interest on reserves.

In particular, for $R_t > R_t^{ior} > 0$, and any reasonable parameter values (see below), it is shown that $\partial R_t^d / \partial \widetilde{rr}_t = (\widetilde{r}_t - \widetilde{rr}_t)\psi_2 + \psi_1 - (R_t - R_t^{ior}) < 0$, (where $\psi_1 < 0$ and $\psi_2 > 0$), hence a decrease in the required reserve ratio raises the deposit rate, an effect that is also consistent with Glocker and Towbin, (2012). I will refer to this as the *deposit rate channel*. In this model a higher deposit rate reduces consumption (via an intertemporal substitution effect) and the output gap, which in return reduces inflationary pressures. As bank capital is also considered here, a higher deposit rate also raises the equity rate and thus the loan rate and the cost channel (see 5 and 17).[19] As it is shown below, the effect of the *deposit rate channel* on consumption and the output gap is stronger than its effect through the *equity channel*, so overall a higher deposit rate curbs inflationary pressures.[20] However, from (14), a decrease in the required reserve ratio also decreases total reserves, since $\partial \widetilde{r}_t / \partial \widetilde{rr}_t > 0$, and this encourages some credit expansion through the *balance sheet channel* (15), which eventually increases the output gap and inflation through the loan rate and the *cost channel*, (10-11). Therefore, by freeing up some deposits and increasing borrowing the *balance sheet channel* mitigates the decrease in the output gap and inflation achieved through the *deposit rate channel*.

In contrast, the effects of the interest on reserves on the deposit rate and total reserves are both positive. From (13), and for $R_t > R_t^{ior} > 0$, $\partial R_t^d / \partial R_t^{ior} = \widetilde{r}_t - \psi_1/\psi_2 - (R_t - R_t^{ior})/\psi_2 > 0$, ($\psi_1 < 0$ and $\psi_2 > 0$) and thus a higher interest on reserves puts upward pressure on the deposit rate, a result that is also consistent with the findings in Ireland (2014). In addition here, from (14), $\partial \widetilde{r}_t / \partial R_t^{ior} > 0$, and so an increase in the interest on reserves, also increases total reserves, thus simultaneously reducing the amount of credit liquidity available to banks. This implies that both the *deposit rate channel* and the *balance sheet channel* work in a complementary way in reducing the size of borrowing, (and *cost channel*), the output gap and inflation. The result, as shown below, is that a higher interest on reserves implies a further reduction in loans through the *balance sheet channel*, thus reducing both the size of borrowing and the output gap, and hence inflation, more effectively than the required reserve ratio.

Technically speaking the effects of the required reserve ratio and the interest on re-

[19] Due to the higher costs of raising equity compared to deposits (due to credit risk), higher equity costs magnify the movements in both financial and real variables compared to the case where banks are not subject to any bank capital requirements.

[20] Although, as expected, the presence of a cost channel amplifies the required intervention required through the policy rate.

serves on the deposit rate can be verified as follows. $\partial R_t^d/\partial \widetilde{rr}_t > 0$, is satisfied for any parameter value of ψ_2 that satisfies, $0 < \psi_2 < \frac{(R_t - R_t^{ior}) - \psi_1}{(\widetilde{r}_t - \widetilde{rr}_t)}$. Similarly, $\partial R_t^d/\partial R_t^{ior} > 0$ is satisfied for any value $0 < \psi_2 < \frac{(R_t - R_t^{ior}) + \psi_1}{\widetilde{r}_t} < \frac{(R_t - R_t^{ior}) - \psi_1}{(\widetilde{r}_t - \widetilde{rr}_t)}$. This implies that both conditions, $\partial R_t^d/\partial \widetilde{rr}_t > 0$, and $\partial R_t^d/\partial R_t^{ior} > 0$, are satisfied for any values $0 < \psi_2 < \frac{(R - R^{ior}) - \psi_1}{(\widetilde{r} - \widetilde{rr})}$ and therefore for any reasonable parameterization of the model.

6 Optimal Simple Policy Rules and Welfare

This section provides a numerical welfare analysis of the optimal policy weights in the policy rules outlined above following financial and supply shocks. The central bank's objective function is given by a second order approximation around the efficient steady state of the household's expected utility function (1) written in welfare gap form,[21]

$$\sum_{t=0}^{\infty} \beta^t U_t \approx U - \frac{1}{2} U_c c \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\lambda_p}{k_p} var\left(\widehat{\pi}_t\right) + (\eta + \sigma)\, var(\widehat{y}_t^{gap}) \right], \tag{32}$$

where $\widehat{y}_t^{gap} = \widehat{y}_t - \widehat{y}_t^*$ is the welfare relevant output gap and $\widehat{y}_t^*$ is the log deviation of the efficient output from its steady-state. Based on (32), Table 2, summarizes the optimal weights in the augmented Taylor Rule (18), the required reserve ratio (20), and the interest on reserves (22), when monetary policy responds to deviations of *credit* from its steady state. The policy regimes examined are as follows. 'Baseline (STR)': standard Taylor rule, setting exogenously $\phi_\pi = 1.5$, $\phi_y = 0.1$ and $\phi_l = 0$ in (18) and keeping the required reserve ratio, $(\widetilde{rr}_t)$, and the interest on reserves, (R_t^{ior}), constant. 'OTR': optimal response to inflation in the Taylor rule, (solving for ϕ_π only, keeping $\widetilde{rr}_t$ and R_t^{ior}constant). 'OTR+L': optimal response to inflation and loans in the augmented Taylor rule, (solving for ϕ_π and ϕ_l, keeping $\widetilde{rr}_t$ and R_t^{ior}constant). 'OTR+RRR': optimal augmented Taylor rule and optimal required reserve ratio, (solving for ϕ_π, ϕ_l and $\mu_{\widetilde{rr}}^l$, keeping R_t^{ior} constant). 'OTR+IOR', optimal augmented-Taylor rule and optimal interest on reserves, (solving for ϕ_π, ϕ_l and μ_{ior}^l, keeping $\widetilde{rr}_t$ constant). For the welfare analysis the persistence in the required reserve ratio and the interest on reserves policy rules is set to zero, $\rho_{R^{ior}} = \rho_{\widetilde{rr}} = 0$. The persistence in the Taylor rule is set at $\phi = 0.7$, as it is used widely in the literature. The optimal parameters that minimize the welfare loss function are grid-searched (with step of 0.1) within the following ranges: $\phi_\pi = [1, 3]$, $\phi_l = [0, 10]$,

[21]The derivation of the welfare loss function follows strictly Ravenna and Walsh (2006), who also incorporate the monetary policy cost channel. In the efficient steady state, price markups and financial distortions are eliminated through appropriate subsidies. The detailed derivation of the loss function is available upon request.

and $\mu^l_{\widetilde{rr}}, \mu^l_{ior} = [-10, 10]$. In Table 3, the above tests are also examined using the same assumptions, with the augmented Taylor rule (19), the required reserve ratio (21), and the interest on reserves (23), responding to deviations of *credit spreads* from their steady state. The comparison among the alternative policies are performed in terms of a consumption equivalent measure, in percentage terms,

$$\Lambda = \left\{1 - \exp\left[(1-\beta)\left(\mathbb{W}^O_t - \mathbb{W}^B_t\right)\right]\right\} \times 100,$$

where $\mathbb{W}^O_t = \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t U_t\left(c^O_t, h^O_t\right)$, is welfare under the optimal policy rule and $\mathbb{W}^B_t = \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t U_t\left(c^B_t, h^B_t\right)$, is the welfare under the baseline policy. A higher positive Λ implies a larger welfare gain and hence indicates that the policy is more desirable from a welfare point of view.

6.1 Optimal Policy Rules Responding to Credit (Loans)

Table 2 shows the baseline and optimal weights under policy rules, (18), (20) and (22), and their welfare gain (as a deviation from the baseline policy), in units of steady state consumption, following an adverse credit risk shock, ($s.d(\chi) = 0.11$) and a negative supply shock, ($s.d(a) = 0.024$). It also reports the standard deviations of the variables determining the loss function, as well as the loan rate ($\hat{R}^l_t$) and the deposit rate ($\hat{R}^d_t$). The simulations of these shocks, under each policy regime, are shown in Figures 1 and 2. In Figure 1, in the baseline policy (STR, blue line), an adverse financial shock is shown to reduce output and increase the risk of default, the equity rate (since banks are subject to bank capital requirements) and the loan rate, all of which lead to a rise in marginal cost and inflation. This raises the refinance rate which raises the deposit rate and places further upward pressure to the equity and loan rates causing, loans, production and the output gap to fall.

The optimal weights in policies OTR (red line) and OTR+L (red line - identical to OTR) prescribe a relatively stronger response to inflation, in relation to the baseline policy, and no reaction to deviations of credit from its steady state in the augmented Taylor rule. Note that the optimal Taylor rule (OTR) performs equally well as the credit-augmented Taylor rule (OTR+L), implying that extending the former policy rule to account for responses to credit fluctuations results in no further improvements in welfare.

Table 2: Optimal Policy Rules: Responses to Credit (Loans)

Policy	Financial Shock		Supply Shock	
Baseline (STR)	ϕ_π= 1.50	$s.d\,(\widehat{\pi}_t) = 0.0081$	ϕ_π= 1.50	$s.d\,(\widehat{\pi}_t) = 0.0087$
	ϕ_l= $-$	$s.d(\widehat{y}_t^g)$= 0.0411	ϕ_l= $-$	$s.d(\widehat{y}_t^g)$= 0.0046
	$\mu^l_{\widetilde{rr}}$= $-$	$s.d(\hat{R}^l_t)$= 0.0948	$\mu^l_{\widetilde{rr}}$= $-$	$s.d(\hat{R}^l_t)$= 0.0138
	μ^l_{ior}=$-$	$s.d(\hat{R}^d_t)$= 0.0083	μ^l_{ior}=$-$	$s.d(\hat{R}^d_t)$= 0.0099
		$\Lambda = -$		$\Lambda = -$
OTR	ϕ_π= 3.00	$s.d\,(\widehat{\pi}_t) = 0.0032$	ϕ_π= 3.00	$s.d\,(\widehat{\pi}_t) = 0.0029$
	ϕ_l= $-$	$s.d(\widehat{y}_t^g)$= 0.0423	ϕ_l= $-$	$s.d(\widehat{y}_t^g)$= 0.0029
	$\mu^l_{\widetilde{rr}}$= $-$	$s.d(\hat{R}^l_t)$= 0.0900	$\mu^l_{\widetilde{rr}}$= $-$	$s.d(\hat{R}^l_t)$= 0.0079
	μ^l_{ior}=$-$	$s.d(\hat{R}^d_t)$= 0.0064	μ^l_{ior}=$-$	$s.d(\hat{R}^d_t)$= 0.0065
		$\Lambda = 0.0749$		$\Lambda = 0.1060$
OTR+L	ϕ_π= 3.00	$s.d\,(\widehat{\pi}_t) = 0.0032$	ϕ_π= 3.00	$s.d\,(\widehat{\pi}_t) = 0.0029$
	ϕ_l= 0.00	$s.d(\widehat{y}_t^g)$= 0.0423	ϕ_l= 0.00	$s.d(\widehat{y}_t^g)$= 0.0029
	$\mu^l_{\widetilde{rr}}$= $-$	$s.d(\hat{R}^l_t)$= 0.0900	$\mu^l_{\widetilde{rr}}$= $-$	$s.d(\hat{R}^l_t)$= 0.0079
	μ^l_{ior}=$-$	$s.d(\hat{R}^d_t)$= 0.0064	μ^l_{ior}=$-$	$s.d(\hat{R}^d_t)$= 0.0065
		$\Lambda = 0.0749$		$\Lambda = 0.1060$
OTR+RRR	ϕ_π= 3.00	$s.d\,(\widehat{\pi}_t) = 0.0030$	ϕ_π= 3.00	$s.d\,(\widehat{\pi}_t) = 0.0028$
	ϕ_l= 0.00	$s.d(\widehat{y}_t^g)$= 0.0422	ϕ_l= 0.00	$s.d(\widehat{y}_t^g)$= 0.0028
	$\mu^l_{\widetilde{rr}}$= 10	$s.d(\hat{R}^l_t)$= 0.0896	$\mu^l_{\widetilde{rr}}$= 10	$s.d(\hat{R}^l_t)$= 0.0077
	μ^l_{ior}=$-$	$s.d(\hat{R}^d_t)$= 0.0063	μ^l_{ior}=$-$	$s.d(\hat{R}^d_t)$= 0.0064
		$\Lambda = 0.0750$		$\Lambda = 0.1067$
OTR+IOR	ϕ_π= 3.00	$s.d\,(\widehat{\pi}_t) = 0.0010$	ϕ_π= 3.00	$s.d\,(\widehat{\pi}_t) = 0.0002$
	ϕ_l= 0.0	$s.d(\widehat{y}_t^g)$= 0.0406	ϕ_l= 0.00	$s.d(\widehat{y}_t^g)$= 0.0005
	$\mu^l_{\widetilde{rr}}$= $-$	$s.d(\hat{R}^l_t)$= 0.0795	$\mu^l_{\widetilde{rr}}$= $-$	$s.d(\hat{R}^l_t)$= 0.0011
	μ^l_{ior}= -1.39	$s.d(\hat{R}^d_t)$= 0.0050	μ^l_{ior}= -2.01	$s.d(\hat{R}^d_t)$= 0.0051
		$\Lambda = 0.1049$		$\Lambda = 0.1198$

Note: Λ is a measure of welfare gain in units of steady-state consumption

Figure 1. Adverse Financial Shock with Optimal Policy Rules: Responses To Credit

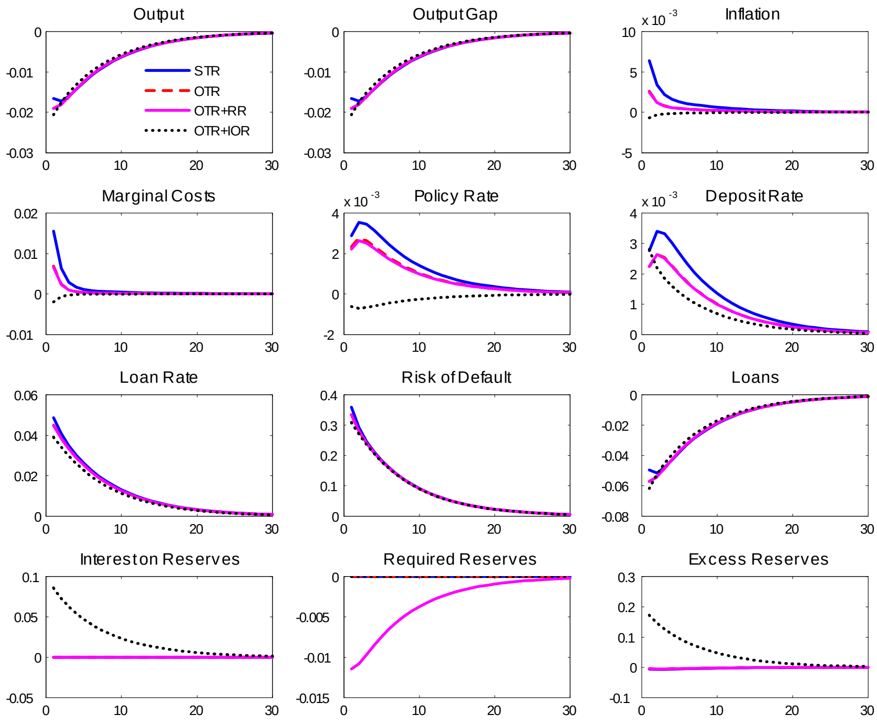
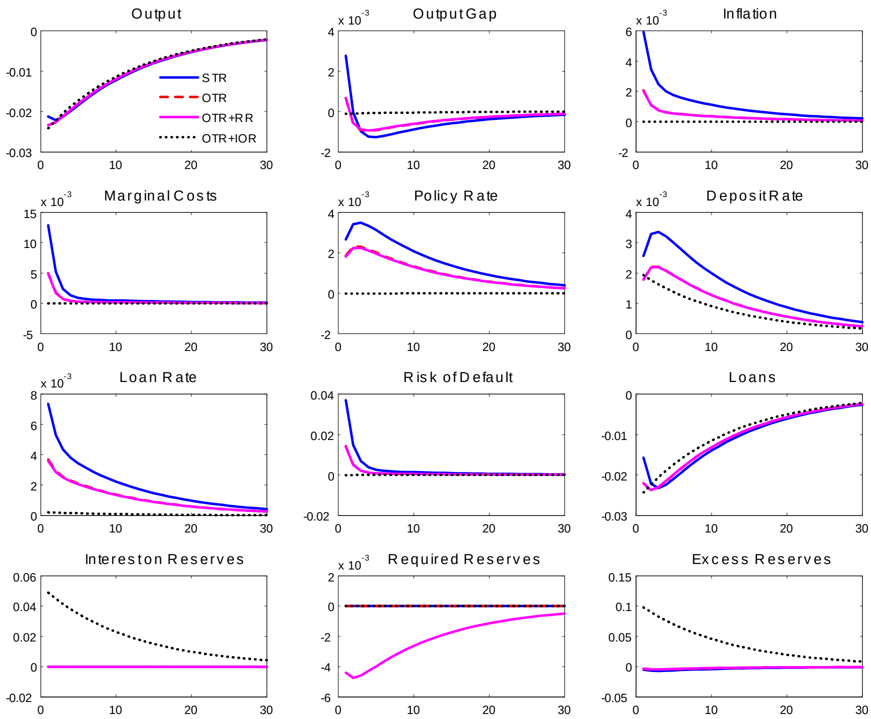


Figure 2. Adverse Supply Shock with Optimal Policy Rule: Responses To Credit



Policy rule OTR+RR shows that, in terms of welfare, the use of a required reserve ratio policy reacting to credit fluctuations improves upon the baseline policy, though this welfare improvement is similar to those achieved under the credit-augmented Taylor Rule (OTR+L) and the simple optimal Taylor rule (OTR).

In general, the welfare results show that policy OTR+IOR, that combines a relatively strong response to inflation in the Taylor rule together with a higher interest on reserves, (a response of $\mu^{l}_{ior}= -1.39$ to falling loans), produces the best welfare policy outcome under both shocks. This is due to the positive effect that interest on reserves have on both the deposit rate and loans, (discussed in section 5). As the *deposit rate* and the *balance sheet channels* work in the same direction, Figure 1 shows that the rise in the interest on reserves raises the deposit rate, while at the same time reduces loans, further than the required reserve ratio, or the other policy rules considered here. These effects help reduce further the size of total borrowing (hence the cost channel), and the output gap and inflation, which result in a lower refinance rate. The latter eases pressure on the loan rate, marginal cost and the cost channel, which in turn feed back into a smoother policy rate. In our example here the policy rate is shown to adjust from below, allowing for even a reduction in the refinance rate. Overall, interest rates are shown to be much smoother when monetary policy is combined with interest on reserves, than the required reserve ratio, because the latter is shown to require a higher intervention from the policy rate.

These results are also reaffirmed in the case of an adverse supply shock, (Table 2 and Figure 2). The main difference here is that the interest on reserves requires a stronger policy response than in the case of the financial shock, because an adverse supply shock increases both inflation and the output gap. Note also that in the case of an adverse supply shock the combination of a relatively strong response to inflation in the Taylor rule, together with a higher interest on reserves (OTR+IOR), is the most effective policy in stabilizing the inflation rate and the output gap while keeping the policy rate around its steady state, which is also reflected on the risk of default and the loan rate.

6.2 Optimal Policy Rules Responding to Credit Spreads

In this section we repeat the welfare analysis in section 6.1, but allow monetary policy to respond to credit spreads (see equations 19, 21, 20). Table 3 summarizes the welfare results and Figures 3 and 4, show the simulations of these shocks under each monetary policy rule.

Table 3: Optimal Simple Policy Rules: Responses to Credit Spreads

Policy	Financial Shock		Supply Shock	
Baseline (STR)	$\phi_\pi = 1.50$	$s.d.\,(\widehat{\pi}_t) = 0.0081$	$\phi_\pi = 1.50$	$s.d.\,(\widehat{\pi}_t) = 0.0087$
	$\phi_s = -$	$s.d.(\widehat{y}^g_t) = 0.0411$	$\phi_s = -$	$s.d.(\widehat{y}^g_t) = 0.0046$
	$\mu^s_{\widetilde{rr}} = -$	$s.d.(\hat{R}^l_t) = 0.0948$	$\mu^s_{\widetilde{rr}} = -$	$s.d.(\hat{R}^l_t) = 0.0138$
	$\mu^s_{ior} = -$	$s.d.(\hat{R}^d_t) = 0.0083$	$\mu^s_{ior} = -$	$s.d.(\hat{R}^d_t) = 0.0099$
		$\Lambda = -$		$\Lambda = -$
OTR	$\phi_\pi = 3.00$	$s.d.\,(\widehat{\pi}_t) = 0.0032$	$\phi_\pi = 3.00$	$s.d.\,(\widehat{\pi}_t) = 0.0029$
	$\phi_s = -$	$s.d.(\widehat{y}^g_t) = 0.0423$	$\phi_s = -$	$s.d.(\widehat{y}^g_t) = 0.0029$
	$\mu^s_{\widetilde{rr}} = -$	$s.d.(\hat{R}^l_t) = 0.0900$	$\mu^s_{\widetilde{rr}} = -$	$s.d.(\hat{R}^l_t) = 0.0079$
	$\mu^s_{ior} = -$	$s.d.(\hat{R}^d_t) = 0.0064$	$\mu^s_{ior} = -$	$s.d.(\hat{R}^d_t) = 0.0065$
		$\Lambda = 0.0749$		$\Lambda = 0.1060$
OTR+S	$\phi_\pi = 3.00$	$s.d.\,(\widehat{\pi}_t) = 0.0032$	$\phi_\pi = 3.00$	$s.d.\,(\widehat{\pi}_t) = 0.0029$
	$\phi_s = 0.00$	$s.d.(\widehat{y}^g_t) = 0.0423$	$\phi_s = 0.00$	$s.d.(\widehat{y}^g_t) = 0.0029$
	$\mu^s_{\widetilde{rr}} = -$	$s.d.(\hat{R}^l_t) = 0.0900$	$\mu^s_{\widetilde{rr}} = -$	$s.d.(\hat{R}^l_t) = 0.0079$
	$\mu^s_{ior} = -$	$s.d.(\hat{R}^d_t) = 0.0064$	$\mu^s_{ior} = -$	$s.d.(\hat{R}^d_t) = 0.0065$
		$\Lambda = 0.0749$		$\Lambda = 0.1060$
OTR+RR	$\phi_\pi = 3.00$	$s.d.\,(\widehat{\pi}_t) = 0.0010$	$\phi_\pi = 3.00$	$s.d.\,(\widehat{\pi}_t) = 0.0026$
	$\phi_s = 0.00$	$s.d.(\widehat{y}^g_t) = 0.0406$	$\phi_s = 0.00$	$s.d.(\widehat{y}^g_t) = 0.0027$
	$\mu^s_{\widetilde{rr}} = -1.52$	$s.d.(\hat{R}^l_t) = 0.0795$	$\mu^s_{\widetilde{rr}} = -10$	$s.d.(\hat{R}^l_t) = 0.0072$
	$\mu^s_{ior} = -$	$s.d.(\hat{R}^d_t) = 0.0050$	$\mu^s_{ior} = -$	$s.d.(\hat{R}^d_t) = 0.0065$
		$\Lambda = 0.1049$		$\Lambda = 0.1190$
OTR+IOR	$\phi_\pi = 3.00$	$s.d.\,(\widehat{\pi}_t) = 0.0010$	$\phi_\pi = 3.00$	$s.d.\,(\widehat{\pi}_t) = 0.0002$
	$\phi_s = 0.0$	$s.d.(\widehat{y}^g_t) = 0.0406$	$\phi_s = 0.00$	$s.d.(\widehat{y}^g_t) = 0.0005$
	$\mu^s_{\widetilde{rr}} = -$	$s.d.(\hat{R}^l_t) = 0.0795$	$\mu^s_{\widetilde{rr}} = -$	$s.d.(\hat{R}^l_t) = 0.0011$
	$\mu^s_{ior} = 0.0076$	$s.d.(\hat{R}^d_t) = 0.0050$	$\mu^s_{ior} = 0.7298$	$s.d.(\hat{R}^d_t) = 0.0051$
		$\Lambda = 0.1049$		$\Lambda = 0.1198$

Note: Λ is a measure of welfare gain in units of steady-state consumption

Figure 3 Adverse Financial Shock with Optimal Policy Rules: Responses to Credit Spreads

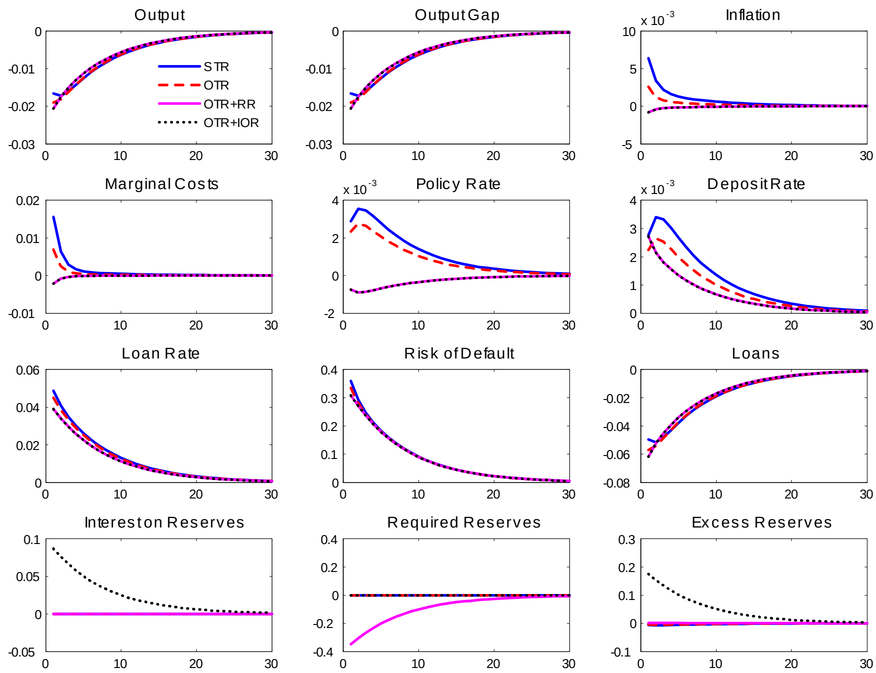
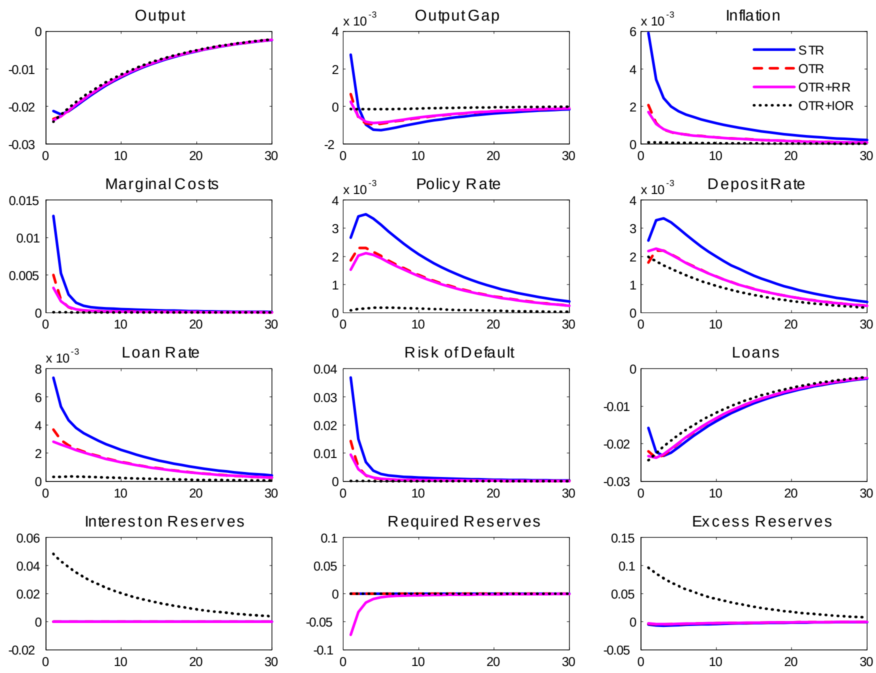


Figure 4 Adverse Supply Shock with Optimal Policy Rules: Responses to Credit Spreads



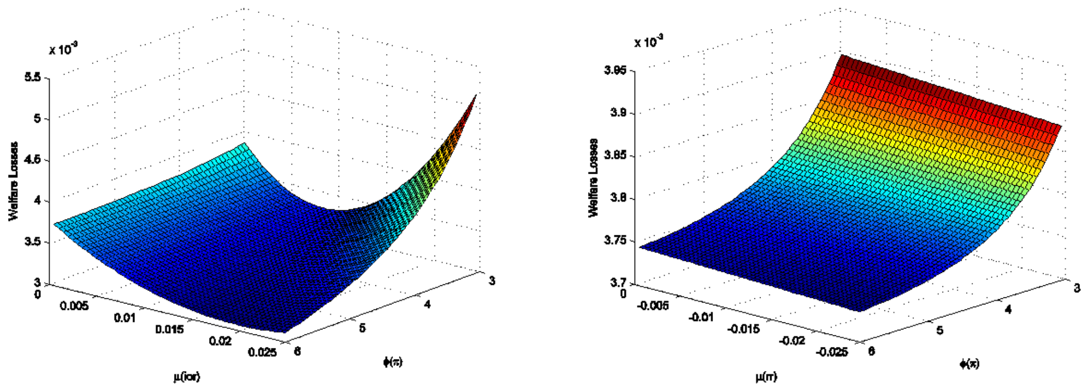
The baseline policy for an adverse financial shock is described in section 6.1. Policies OTR and OTR+S, in Table 3, are again shown to prescribe a relatively strong response to inflation fluctuations and no reaction to deviations of credit spreads from their steady state in the credit spread-augmented Taylor rule. Thus, as with the optimal credit-augmented Taylor rule earlier, optimal credit spread-augmented policy rules increase welfare in relation to the standard Taylor rule, but perform just as well as the simple optimal rule in this model (OTR).

Table 3 also shows that when the economy is affected by financial shocks and the central bank's liquidity policy tools respond directly to credit spreads, then the required reserve ratio and the interest on reserves can attain similar welfare improvements. This is because an adverse financial shock in this model, (a lower χ_t) causes a direct rise in the credit spread. If the liquidity credit policy tools can also respond directly to credit spreads then they can stabilize the credit spread shock with a much smaller response than they would require if they responded to the level of credit. As a result the trade-off between the effects of the *deposit rate channel* and the *balance sheet channel* in the case of the required reserve ratio is insignificant here, as it is shown in Figure 3. As Table 3 shows, $\phi_\pi= 3.00$, combined with either $\mu^s_{\widetilde{rr}}= -1.52$, or a mild response of $\mu^s_{ior}= 0.0076$, can attain the same welfare improvement under both liquidity tools.

However, this is no longer the case when we examine supply shocks that require a stronger response of the monetary and credit liquidity policies to stabilize inflation, because of the positive output gap they generate along with higher inflation. Unlike the credit spread shock that initially impacts on financial variables, a supply shock affects both real variables (production and the output gap) and financial variables (through the risk of default). As a result, the positive output gap requires a stronger policy stance, as it is indicated by the optimal policy parameters $\mu^s_{\widetilde{rr}}$ and μ^s_{ior} in Table 3. Following supply shocks, the interest on reserves is again shown to stabilize the output gap and inflation more effectively than the required reserve ratio, or any of the other policy rules considered, resulting in a smoother refinance rate and a higher welfare gain.

Finally note that for the above welfare results the liquidity regulation policy parameters have been allowed to range widely, $\mu^s_{\widetilde{rr}}$,$\mu^s_{ior} = [-10, 10]$. Within a smaller parameter range the interest on reserves is shown to produce an even larger welfare improvement over the use of the required reserve ratio, whose optimal value in all cases, (other than financial shocks with responses to credit spreads), is its absolute bound of $|\mu^s_{\widetilde{rr}}| = 10$. Conversely, when we examine the case where all optimal policy parameter values are completely unrestricted, the required reserve ratio can eventually match the welfare reached by the interest on reserves, but this is achieved at some very strong policy responses for the former, (i.e. $\mu^{s}_{\widetilde{rr}} = -145.99$ in Table 3, in the case of adverse supply shocks). Overall, a number of parametrization experiments carried out show that gains in welfare levels are more responsive to changes in the interest on reserves, rather than the required reserve ratio. Figure 5, demonstrates this even in the case of financial shocks when policy responds to credit spreads.[22]

Figure 5. Monetary Policy and Liquidity Regulation Responses to Credit Spreads: Financial Shocks



7 Concluding Remarks

This paper is motivated by the recent policy emphasis placed by the US FED and other central banks on the interest on reserves as a credit liquidity regulation tool. The role of the interest on reserves and the required reserve ratio is examined in a model that can account for frictions in both the financial and goods sectors and features a number of key channels (i.e. *balance sheet (credit) channel*, *deposit rate channel*, *cost channel* and *equity channel*). The results show that as a macroprudential tool of credit liquidity regulation, the interest on reserves produces better welfare outcomes than its traditional counterpart, the required reserve ratio, but also other credit, or credit spread-augmented Taylor rules. This result is shown to be due to the complementary effect that the interest on reserves has on the economy through the *balance sheet channel* and the *deposit rate channel*. It is shown that although the interest on reserves has a positive effect on both the *balance sheet channel* and the *deposit rate channel*, the required reserve ratio has opposite transmission effects through these two channels; a positive on the *balance sheet*

[22]That is the only case for which our wide policy parameter range above, shows the required reserve ratio to produce similar welfare gains to those achieved by the interest on reserves.

channel and a negative on the *deposit rate channel*. This mitigates the effectiveness of the required reserve ratio as a credit liquidity policy tool, because it is shown to require a higher intervention through the policy rate. Overall, the results show that a central bank can achieve smoother policy rates and higher welfare gains by choosing the interest on reserves as its credit liquidity regulation tool to facilitate its monetary policy.

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