Assessing the role of reserve requirements under financial frictions *

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Abstract

The global financial crisis has proven that central banks must give financial stability a more prominent role. This requires providing central banks with new instruments and understanding their general equilibrium implications. This paper extends an otherwise standard New-Keynesian model to include (i) a banking sector and an interbank market subject to financial frictions in the form of collateral and liquidity contraints in a spirit similar to Kiyotaki and Moore (2008); (ii) multiperiod credit contracts a-là Benes and Lees (2010); and (iii) reserve requirements on deposits as a policy instrument that complements the interest rate. The first two components generate an endogenous credit spread and a credit intermediation that is subject to maturity mismatches. In this setting we evaluate the role of reserve requirements for financial stability and business cycle dynamics. A key finding is that reserve requirements can complement monetary policy in stabilizing the business cycle when the economy is subject to demand shocks, but not under supply shocks.

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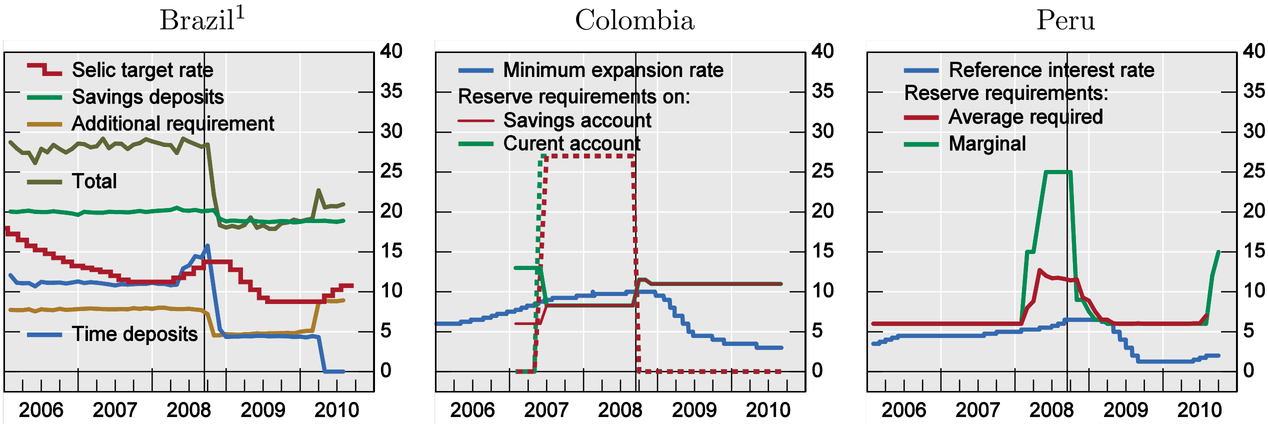
1 Introduction

The international financial crisis has made evident that a single policy objective -low and stable inflation- and a single policy instrument -the interest rate- do not suffice to guarantee the stability of the financial system. Central bank policy objectives and the tools required to achieve financial stability are being re-examined. However, the well-known "Tinbergen principle" states that at least as many instruments are required as objectives are in place. Therefore greater emphasis on financial stability objectives will require central banks to complement its main monetary policy instrument, the interest rate, with additional tools.

An instrument that has increasingly been employed in emerging market economies (EMEs) is the reserve requirements on bank deposits. In Latin America, the central banks of Brazil, Colombia, and Peru used them as a mechanism to contain credit in boom episodes and to ease liquidity conditions in local markets in times of stress (Graph 1.1). Thus over the past few years, reserves requirements on bank deposits allowed central banks to "lean-against-the wind" during the upswing part of the cycle and buffer the abrupt changes in financial conditions during the downswing. Furthermore, they helped maintain monetary policy focused on its inflationary goals in the expansionary phase of the cycle.

Graph 1.1
Policy rates and reserve requirements



The vertical line marks 15 September 2008, the date on which Lehman Brothers filed for Chapter 11 bankruptcy protection.

[1] Effective reserve requirements rates.

Sources: Bloomberg; CEIC; Central Bank of Brazil; Central Bank of Peru.

This paper re-examines the role of reserve requirements as a macroprudential tool in a dynamic stochastic general equilibrium (DSGE) model. The paper makes important contributions in capturing the macroeconomic and financial linkages of the economy by introducing a banking sector, an interbank market, multi-period loan contracts, and financial frictions in the form of collateral and liquidity constraints. By doing so the model captures relevant financial features of financial markets: retail and wholesale bank funding, financial maturity transformation, and endogenous time varying credit spreads. Intuitively, the novel aspect is that investment is carried out by entrepreneurs that borrow long-term from banks. To satisfy this credit demand, banks fund themselves either from household deposits or short-term in the interbank market. Thus, in this setting bank intermediation involves maturity transformation risk. An additional key element is that banks´ access to interbank funds is subject to financial frictions in the form of collateral and liquidity constraints. These frictions give rise to an endogenous time varying credit spread. This alters significantly the credit channel and the transmission mechanism of monetary policy, and therefore the business cycle.

From a policy perspective, the contribution of this paper is to highlight that the role of reserve requirements on bank deposits can act as a macroprudential tool that acts as a buffer to smooth out the procyclicality of the financial system. Because of this, they have the potential to complement the interest rate as a monetary policy tool. Simulation results show that this is particularly the case for demand shocks but not for supply side shocks.

These two contributions must also be examined in perspective. First, over the past couple of decades the use of reserve requirements declined rapidly across the world as central banks were increasingly managing its monetary policy through interest rates. Thus, from a theoretical perspective its analysis, which was framed as a tax on financial intermediation, gradually lost interest. By contrast, in our paper the emphasis is on reserve requirements as a macroprudential tool to smooth out the procyclicality of the financial system rather than as a monetary policy tool to achieve an inflation objective. Second, modern macroeconomic models (Dynamic Stochastic General Equilibrium or DSGE models) neglected the role of financial markets and the banking sector[1]. Only recently, with the international crisis, have researchers begun to examine the role of financial markets and its linkages with the real economy. Our paper brings a stylised perspective that that complements the existing literature examining the role of financial factors, such as the financial accelerator or the literature on collateral constraints (See Bernanke, Gertler, and Gilchrist, 1999, Iiacovello, 2005 or Christiano et al, 2007a) Specifically, our paper adds to this literature not just in capturing credit or market risk, but more importantly in understanding the role of liquidity risk. Furthermore, our paper also contributes to the recent literature that examines the role of financial markets and how they matter for the conduct of monetary policy (See Curdia and Woodford, 2008).

The paper is structured as follows. The next section presents a brief discussion of the role of reserve requirements as a macroprudential tool. It also reviews the Latin American experience with reserve requirements. Next, the DSGE model is presented. This is followed by a brief section that analyses the role of financial frictions in the model. Then, we present the calibration and simulate the model's response to monetary policy shocks and examine the role of reserve requirements. This is followed by a robustness analysis to understand the response of the model to three type of shocks. A shock on monetary policy, to understand the credit channel and transmission mechanism in the model. And a demand side and a supply side shock. In analyzing these shocks we also explore the role of financial frictions in the model. A final section concludes.

[1] For an overview of the state of DSGE literature see Tovar (2009).

2 Reserve requirements on bank deposits in emerging economies

The use of reserve requirements on bank deposits as a monetary policy instrument declined across the world over the past twenty years. This was particularly evident in advanced countries conducting monetary policy through interest rates. In some cases, reserve requirements were eliminated all together (e.g. Canada or New Zealand). The declining reliance on reserve requirements had to do to a large extent with changes in the manner in which central banks conduct monetary policy operations (i.e. through open market operation), but also due to financial innovation, and the inefficiencies of taxing the banking sector vis-à-vis other financial intermediaries, which put the banking sector in a clear competitive disadvantage. The role of reserve requirements was also vilified as they became to be considered a defining element of financially repressed economies (McKinnon, 1973).

In recent years the perception of this policy tool changed, especially as central banks begun to focus their attention on systemic risk. However, a greater emphasis on systemic risk requires a careful examination of the policy toolkit. Possibly new policy instruments will have to be introduced or existing ones modified to smooth out the financial cycle i.e. reduce the procyclicality of the financial system. In this respect, reserve requirements on bank deposits have features that make them suitable as a macroprudential tool (IMF (2010) and CGFS (2010)). This is not surprising as they were originally introduced as a financial stability instrument to manage liquidity risk, in a similar fashion to deposit insurance.

Reserve requirements may act as a macroprudential tool for at least three reasons (see IMF, 2010). First, in the upswing part of the business cycle they can help contain credit growth, effectively acting as a speed limit. Second, during the upswing they build up a cushion of reserves that can be deployed during the downturn. In this manner, they can smooth out financial liquidity pressures in the financial system during bad times, thus acting as a liquidity buffer. Finally, they can be an effective complement to monetary policy when the credit cycle conflicts with its own goals. This is best illustrated in episodes of capital surges. In such context raising interest rates to contain aggregate demand pressures can be self-defeating, as this may induce more capital inflows. Of course, under such circumstances raising reserve requirements may be effective, not only to contain aggregate demand, but also credit growth.

Certainly, these benefits must be weighted against its costs. Reserve requirements are a blunt instrument and are a tax on bank intermediation. Thus their use may be more appropriate when other traditional and less costly instruments (e.g. monetary policy) are insufficient to achieve financial or price stability (Vargas et al (2010)).

The central banks of Brazil, Colombia and Peru have actively used reserve requirements over the past few years. The use of this instrument as a macroprudential tool in the context of capital surges is illustrated by the case of Colombia and Peru (Graph 1, IMF (2010) and Jara, Moreno and Tovar (2010)). Prior to the global crisis (2007-2008) the central banks of Colombia and Peru managed reserve requirements as a prudential tool to contain pressures on credit growth amanating from large capital inflows. In this context both central banks raised marginal reserve requirements during this period. In the case of Peru, marginal reserve requirements were also imposed on foreign currency deposits. As global financial conditions deteriorated towards the end of 2008 both central banks lowered marginal reserve requirements as a mechanism to ease liquidity conditions in the economy. The Central Bank of Brazil also used average reserve requirements as a mechanism to prevent disruptions in the interbank market following Lehman Brothers' episode in September 2008. Specifically, average reserve requirements were lowered to large and liquid banks if they extended credit to small and illiquid banks. More recently, as capital inflows to emerging markets surged, the Central Bank of Peru has actively raised marginal reserve requirements again.

From a policy perspective several questions arise. First, under liquidity pressures how effective are reserve requirements vis-à-vis interest rates? Second, how do reserve requirements affect the credit channel and the business cycle? These are the main questions that we aim to address with the model. Given the complex nature of the model, we leave for future research the extension to an open economy.

3 The model

The model in this section introduces three key features: retail and wholesale bank funding, financial maturity transformation, and endogenous time-varying credit spreads. Specifically, the banking sector in the model intermediates short-term funds from the interbank market or from household deposits to entrepreneurs that borrow long-term to finance investment. However, bank intermediation faces two key financial frictions: liquidity and collateral constraints. This is relevant because they generate an endogenous credit spread.

The model departs from recent attempts to model financial markets and financial Frictions in the DSGE literature. Indeed, a common approach is to model financial frictions following the financial accelerator framework (Bernanke and Gertler,1999). This framework relies on an optimal debt contract problem with costly state verification. As a result information asymmetries between borrowers and lenders endogenously amplify credit market developments and generate an external finance premium that depends inversely on the debt to net worth ratio. The model also departs from recent efforts at modeling the banking sector, in the sense that in our model banks fund themselves in the retail and wholesale market. Furthermore, we introduce long-term loan contracts a-la Benes and Lees (2010), so that banks activity is characterized by a maturity transformation problem. This implies that the credit channel takes into account expectations about future real interest rate payments, which generates a maturity risk and endogenously a wedge between lending rates and the interbank rate. Linking interest rates with long-interest rates also smoothes out fluctuations of interest rates. This generates a degree of interest rate persistence that has so far been modeled through a monopolistic competitive banking sector with interest rate adjustment costs (e.g. Gerali et al, 2009).

In our model financial frictions also play an important role. Specifically, bank intermediation faces collateral and liquidity constraints. The use of collateral constraints to amplify the credit cycle is now commonly employed (Iacovello, 2005). However, rather than relying of a durable good asset (e.g. a durable good), our collateral is the banks financial assets. In that sense our problem takes into account financial institutions leverage positions. Our framework follows the recent contributions by Kiyotaki and Moore (2008) and Del Negro et al (2010). This framework generates a demand for liquid assets. However, we depart from these approaches by applying this problem to the financial sector rather than to a financing problem for entrepreneurs. A key aspect is that we are able to consider the role of core funding in the model and generate endogenous credit spreads that arise from the bank intermediation process.

By making the credit channel more realistic, the role of reserve requirements becomes less trivial. The reason is that changing reserve requirements eases the constraints imposed by the financial frictions, which in turn creates a more complex interaction with the real economy. In this respect, the paper also adds to the literature that examines how credit spreads between borrowers and lenders affect the credit channel and the monetary transmission mechanism (Curdia and Woodford, 2008).

Overall, aside of these complexities associate to the financial market, the economy corresponds to the standard New Keynesian model with capital, as in Woodford (2003).

3.1 Households

We assume the following utility function on consumption (C_t^h) and labour (H_t) of the representative household

$$U_t = E_t \sum_{s=0}^{\infty} \beta^s \left[\frac{\left(C_{t+s}^h\right)^{1-\sigma}}{1-\sigma} - \frac{H_{t+s}^{1+v}}{1+v} \right], \tag{3.1}$$

where σ represents the coefficient of risk aversion and v captures the inverse of the elasticity of labour supply. The optimiser consumer takes decisions subject to a standard budget constraint which is given by

$$C_t^h = \frac{W_t H_t}{P_t} + \frac{B_{t-1}}{P_t} + R_{t-1}^D \frac{D_{t-1}}{P_t} - \frac{1}{R_t}\frac{B_t}{P_t} - \frac{D_t}{P_t} + \frac{\Gamma_t}{P_t} + \frac{T_t}{P_t}, \tag{3.2}$$

where W_t is the nominal wage, P_t is the price of the consumption good, B_t is the end of period nominal bond holdings, D_t is the end of period stock of deposits in the bank system, R_t is the riskless nominal gross interest rate paid by the bonds, R_{t-1}^D is nominal interest rate paid by the deposits made in $t-1$, Γ_t is the share of the representative household on total nominal profits, and T_t are net transfers from the government. The first order conditions for the optimising consumer's problem are:

$$1 = \beta E_t \left[R_t \left(\frac{P_t}{P_{t+1}}\right) \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \right] = \beta E_t \left[R_t^D \left(\frac{P_t}{P_{t+1}}\right) \left(\frac{C_{t+1}}{C_t}\right)^{-\sigma} \right], \tag{3.3}$$

$$\frac{W_t}{P_t} = \left(C_t^h\right)^{\sigma} H_t^v. \tag{3.4}$$

Equation (3.3) is the standard Euler equation for both bonds and deposits that determines the optimal path of consumption . At the optimum the representative consumer is indifferent between consuming today or tomorrow, and consumers are indifferent between bonds and bank deposits if $R_t^D = R_t$. Equation (3.4) describes the optimal labour supply decision. We assume that labour markets are competitive and also that individuals work in each sector $z \in [0,1]$. Therefore, H_t corresponds to the aggregate labour supply:

$$H_t = \int_0^1 H_t(z)dz. \tag{3.5}$$

3.2 Firms

3.2.1 Final good producers

There is a continuum of final good producers of mass one, indexed by $f \in [0,1]$ that operate in an environment of perfect competition. They use intermediate goods as inputs, indexed by $z \in [0,1]$ to produce final consumption goods using the following technology:

$$Y_t^f = \left[\int_0^1 Y_t(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{3.6}$$

where ε is the elasticity of substitution between intermediate goods. The demand function of each type of differentiated good is obtained by aggregating the input demand of final good producers:

$$Y_t(z) = \left(\frac{P_t\,(z)}{P_t} \right)^{-\varepsilon} Y_t, \tag{3.7}$$

where the price level is equal to the marginal cost of the final good producers and is given by:

$$P_t = \left[\int_0^1 P_t\,(z)^{1-\varepsilon}\, dz \right]^{\frac{1}{1-\varepsilon}}. \tag{3.8}$$

and Y_t represents the aggregate level of output.

$$Y_t = \int_0^1 Y_t^f df. \tag{3.9}$$

3.2.2 Intermediate goods producers

There is a continuum of intermediate good producers indexed by $z \in [0,1]$. Each firm z produces an intermediate good using capital and labour. These firms operate under monopolistic competition in the intermediate goods market and demand production factors in competitive markets. They use the following Cobb-Douglas production function:

$$Y_t(z) = A_t \left[K_{t-1}(z) \right]^{\alpha} \left[H_t(z) \right]^{1-\alpha}, \tag{3.10}$$

These firms take as given the real wage, W_t/P_t , and the rental rate of capital, R_t^K. They allocate the optimal level of capital and labour minimising costs given the technology. The demands for both production factos are given by:

$$H_t^d(z) = (1-\alpha) \frac{MC_t}{W_t/P_t} Y_t(z). \tag{3.11}$$

$$K_{t-1}^d(z) = \alpha \frac{MC_t}{R_t^K} Y_t(z). \tag{3.12}$$

After replacing the demand for each factor, we can obtain an expression for the real marginal cost:

$$MC_t(z) = \frac{1}{A_t} \left(\frac{R_t^K}{\alpha} \right)^{\alpha} \left(\frac{W_t/P_t}{1-\alpha} \right)^{1-\alpha}, \tag{3.13}$$

where $MC_t(z)$ represents the real marginal cost for each intermediate firm. Notice that marginal costs are the same for all intermediate firms, since technology has constant returns to scale and factor markets are competitive, *ie* $MC_t(z) = MC_t$.

Intermediate producers set prices following a staggered pricing mechanism *a la Calvo*. Each firm faces an exogenous probability of changing prices given by $(1-\xi)$. A firm that changes its price in period t chooses its new price $P_t(z)$ to maximise:

$$E_t \sum_{s=0}^{\infty} \xi^s \zeta_{t,t+s} \Gamma\left(P_t(z), P_{t+s}, MC_{t+s}, Y_{t+s}\right),$$

where $\zeta_{t,t+s} = \beta^s \left(\frac{C_{t+s}}{C_t}\right)^{-\sigma} \frac{P_t}{P_{t+s}}$ is the stochastic discount factor. The function: $\Gamma^{int}\left(P_t(z), P_t, MC_t, Y_t\right) \equiv \left[P_t(z) - P_t\, MC_t\right] \left(\frac{P_t(z)}{P_t}\right)^{-\varepsilon} Y_t$ is nominal profits of the supplier of good z with price $P_t(z)$, where the aggregate demand and aggregate marginal costs are equal to Y_t and MC_t, respectively. The optimal price that solves the firm's problem is given by

$$\left(\frac{P_t^*(z)}{P_t}\right) = \frac{\mu E_t \left[\sum\limits_{s=0}^{\infty} \theta^s \zeta_{t,t+s} MC_{t,t+s} F_{t+s}^{\varepsilon+1} Y_{t+s}\right]}{E_t \left[\sum\limits_{s=0}^{\infty} \theta^s \zeta_{t,t+s} F_{t+s}^{\varepsilon} Y_{t+s}\right]}, \tag{3.14}$$

where $\mu \equiv \frac{\varepsilon}{\varepsilon-1}$ is the price markup, $P_t^*(z)$ is the optimal price level chosen by the firm and $F_{t+s} = \frac{P_{t+s}}{P_t}$ the cumulative level of inflation. The optimal price solves equation (3.14) and is determined by the average of expected future marginal costs as follows:

$$\left(\frac{P_t^*(z)}{P_t}\right) = \mu E_t \left[\sum_{s=0}^{\infty} \varphi_{t,t+s} MC_{t,t+s}\right], \tag{3.15}$$

where $\varphi_{t,t+s} \equiv \frac{\xi^s \zeta_{t,t+s} F_{t+s}^{\varepsilon+1} Y_{t+s}}{E_t \left[\sum\limits_{s=0}^{\infty} \xi^s \zeta_{t,t+s} F_{t+s}^{\varepsilon} Y_{t+s}\right]}$.

Since only a fraction $(1-\xi)$ of firms changes prices every period and the remaining one keeps its price fixed, the aggregate price level, defined as the price of the final good that minimise the cost of the final goods producers, is given by the following equation:

$$P_t^{1-\varepsilon} = \xi P_{t-1}^{1-\varepsilon} + (1-\xi)\left(P_t^*(z)\right)^{1-\varepsilon}. \tag{3.16}$$

Following Benigno and Woodford (2005), equations (3.14) and (3.16) can be written recursively introducing the auxiliary variables NN_t and DD_t :

$$\xi\left(\Pi_t\right)^{\varepsilon-1} = 1 - (1-\xi)\left(\frac{NN_t}{DD_t}\right)^{1-\varepsilon}, \tag{3.17}$$

$$DD_t = Y_t\left(C_t\right)^{-\sigma} + \xi\beta E_t\left[\left(\Pi_{t+1}\right)^{\varepsilon-1} DD_{t+1}\right], \tag{3.18}$$

$$NN_t = \mu Y_t\left(C_t\right)^{-\sigma} MC_t + \xi\beta E_t\left[\left(\Pi_{t+1}\right)^{\varepsilon} NN_{t+1}\right], \tag{3.19}$$

where $\Pi_t = P_t/P_{t-1}$ is the gross inflation rate. Equation (3.17) comes from the aggregation of individual firms prices. The ratio NN_t/DD_t represents the optimal relative price $P_t^*(z)/P_t$. These three last equations summarise the recursive representation of the non linear Phillips curve.

3.2.3 Capital goods producers

Capital producers transform consumption goods into capital goods and operate in perfect competition. The capital produced is sold to the entrepreneurs at price Q_t in terms of units of consumption. The cost function is given by the following equation:

$$I_t \left[1 + \Psi\left(\frac{I_t}{\overline{I}}\right)\right] \tag{3.20}$$

Capital producers also need to consider that entrepreneurs' demand for investment is constrained by the amount of credit they can receive from banks, as explained below.

3.3 Entrepreneurs

Entrepreneurs buy investment goods from the capital producers (at price Q_t) and accumulate capital.

$$K_t = I_t + (1-\delta) K_{t-1} \tag{3.21}$$

They rent capital to intermediate goods producers at rate R_t^K. The rate of return of the entrepreneurs is given by:

$$R_t^Q = \frac{1}{Q_{t-1}} \left[R_t^K + (1-\delta) Q_t\right] \tag{3.22}$$

which is given by the rental rate of capital and the price of capital net of the depreciation rate, all divided by the initial price of capital, Q_{t-1}.

Entrepreneurs finance enterely its investment from the banks. The value of investment each period is equal to the flow of credit from the banks:

$$Q_t I_t = \frac{CR_t}{P_t} \tag{3.23}$$

where CR_t is the nominal amount of of credit of each period.

We assume that entrerpreneurs take credit in a multiperiod contract with fixed repayments as in Bennes and Lees (2010). A credit CR_t taken at time t is paid back in repayments proportional to the amount borrowed and decay at a fixed rate $\lambda \in (0,1)$. This implies the following repayment schedule: $Q_t^{cr} CR_t$, $\lambda Q_t^{cr} CR_t$, ..., $\lambda^{k-1} Q_t^{cr} CR_t$, ... for repayments due at $t+1, t+2, ..., t+k$, respectively. Where Q_t^{cr} is a shadow price associated to the credit. This form of multiperiod contract allows us to draw out the implications of long-term debt and maturity mismatch in an analytically tractable framework.

Accordingly, the sum of all repayments due at t associated with all past loans is:

$$J_{t-1} = \sum_{k=1}^{\infty} \lambda^{k-1} Q_{t-k}^{cr} CR_{t-k} \tag{3.24}$$

Also, J_t can be written recursively as:

$$J_t = \lambda J_{t-1} + Q_t^{cr} CR_t \tag{3.25}$$

The stock of loans, estimated as the present value of repayments, is equal to:

$$L_t = \Omega_t J_t \tag{3.26}$$

where $\Omega_t = E_t \left[\frac{1}{R_t} + \lambda \frac{1}{R_t R_{t+1}} + ... + \lambda^{k-1} \frac{1}{R_t ... R_{t+k-1}} + ... \right]$, which can be written recursively as:

$$\Omega_t = E_t \left[\frac{1}{R_t} \left(1 + \lambda \Omega_{t+1}\right) \right] \tag{3.27}$$

Considering equation (3.25), the evolution of the stock of loans can be written as:

$$L_t = \lambda \frac{\Omega_t}{\Omega_{t-1}} L_{t-1} + \Omega_t Q_t^{cr} CR_t. \tag{3.28}$$

The optimal condition for the entrepreneurs equalise the expected return of capital with the real value of the repayments, given by:

$$E_t \left(R_{t+1}^Q \right) = E_t Q_t^{cr} \left(\frac{1 + \frac{\lambda}{Q_{t+1}^{cr}}}{\Pi_{t+1}} \right). \tag{3.29}$$

See appendix $A.2$ for details on the derivation of equation (3.29).

3.4 The interbank market

To model the interbank bank market we assume that the economy is populated by a continuum of banks $b \in (0, 1)$, whose objective is given by

$$\max E_t \sum_{s=0}^{\infty} \beta_b^s \ln \left[C_{t+s} (b) \right] \tag{3.30}$$

where $C_t(b)$ is the bankers consumption. Each period commercial banks have a random lending opportunity. Specifically, this implies that the stock of loans $(L_t(b))$ supplied by each bank evolves according to:

$$L_t(b) = \begin{cases} \lambda \frac{\Omega_t}{\Omega_{t-1}} L_{t-1}(b) + \Omega_t Q_t^{cr} CR_t(b) & \text{with probability } \chi \\ \frac{\Omega_t}{\Omega_{t-1}} \lambda L_{t-1}(b) & \text{with probability } 1 - \chi \end{cases} \tag{3.31}$$

where λ is the rate that loan repayments decay, as explained above. $CR_t(b)$ is the the amount of new credit extended by each bank. We also assume that $\beta_b > \lambda$. Lending opportunities are i.i.d. across time and banks. Banks lend to entrepreneurs with multiperiod contracts with fixed repayments as explained above. The main problem these agents face is that they may not have enough resources to take advantage of the lending opportunity. This forces them to seek funding in the interbank market to take advantage of it.

Table 3.1: Banks' balance sheet

Assets	Liabilities
Loans, $L_t(b)$	Interbank borrowing, $Z_t^B(b)$
Interbank lending, $Z_t^L(b)$	Deposits , $D_t(b)$
Reserves, $RR_t(b)$	net worth, $Z_t(b) - D_t(b) + RR_t(b) + B_t(b)$

Access to the interbank market is going to be subject to a number of financial imperfections, which are modelled, similarly as in Del Negro et al (2010), as constraints on the evolution of the banks' balance sheets. The banks liabilities consist of the interbank borrowing, $Z_t^B(b)$, and the deposits received from households, $D_t(b)$.Assets consist of the claims on its own loans, $L_t(b)$,and on loans extended in the interbank market, $Z_t^L(b)$.In addition, banks must hold some unremunerated reserves at the central bank, $RR_t(b)$. We assume that there is a minimum amount of reserves that must be held at the central bank without any remuneration. However the central bank may also decide to offer banks the possibility of holding reserves at a discount over the rate fixed by the central bank. The bank balance sheet is then summarised in Table 3.1, where $Z_t(b) = \left[Z_t^L(b) + L_t(b) - Z_t^B(b)\right]$.

The constraints on the evolution of the banks balance sheet are a *collateral contraint* (CC) and a *leverage constraint* (LC) . The CC implies that banks can only fund in the interbank market a fraction θ_t of the amount of credit extended, $CR_t(b)$. The LC implies that in any given period a bank can only borrow from the interbank market a fraction ϕ_t of its claims on its own loans, $L_t(b)$.

These two constraints taken together imply that the evolution of interbank borrowing is subject to the following innequality:

$$Z_t^B(b) \leq \underbrace{\phi_t L_{t-1}(b)}_{LC} + \underbrace{\theta_t CR_t(b)}_{CC} \tag{3.32}$$

Note that LC and CC are similar in spirit, the former is a constraint on existing loans, while the later applies to new loans.

The inter-temporal budget constraint of the banks can then be summarised by:

$$P_t C_t(b) + CR_t(b) + \left[Z_t^L(b) - Z_t^B(b)\right] \leq J_{t-1} + X_t + R_{t-1}^{ib}\left[Z_{t-1}^L(b) - Z_{t-1}^B(b)\right] \tag{3.33}$$

In the first line we have the use of funds of the banks, which can be for consumption to give new credit or for interbank lending. In the second line we have the sources of funds, which can be from their return on loans claims, J_{t-1}, and, the flow of deposits from the consumers net of the flow of reserve requirements, X_t, and from repayments of the interbank loans considering the gross interes rate R_t^{ib}. We define X_t as:

$$X_t = D_t(b) - R_{t-1}D_{t-1}(b) - \left[RR_t(b) - RR_{t-1}(b)\right] \tag{3.34}$$

From equation (3.34) we can see that reserve requirements affect the quantity of disposable resources that banks have to finance entrepreneurs.

3.5 Monetary policy

The central bank sets the risk-free interest rate, which in turn is the same paid by the banks for the deposits because of the arbitrage condition of the households. We assume the central bank follow a simple Taylor rule that depends on current inflation:

$$R_t = \overline{R}\left(\frac{\Pi_t}{\Pi}\right)^{\psi_\pi}. \tag{3.35}$$

Also, the central bank sets the reserve requirement rate, as a fraction of the deposits received from the households, that is:

$$RR_t = \tau_t D_t. \tag{3.36}$$

To make a comparative analysis, we assume the central bank can follow the next rules:

$$\tau_t = \begin{cases} \overline{\tau} \\ \overline{\tau} + \psi_{cr}\left(\frac{CR_t}{\overline{CR}}\right) \end{cases} \tag{3.37}$$

It can maintain fixed at some level ($\overline{\tau}$) or can either adjust it with respect to deviations of credit with respect to its steady state value. .

Moreover, the central bank balance sheet is given by:

$$(RR_t - RR_{t-1}) - (N_t - N_{t-1}) = 0, \tag{3.38}$$

Reserve requirements correspond to a liability to the central bank, changes in the reserve requirements need to be matched with the change in the net worth (N_t) of the central bank[2].

3.6 Market clearing

In equilibrium labour, intermediate and final goods markets clear. The economy-wide resource constraint is given by

$$Y_t = C_t + I_t. \tag{3.39}$$

The labour market clearing condition is given by:

$$H_t = H_t^d, \tag{3.40}$$

where the demand for labour comes from the aggregation of individual intermediate producers in the same way as for the labour supply:

$$\begin{aligned} H_t^d &= \int_0^1 H_t^d(z)dz = (1-\alpha)\frac{MC_t}{W_t/P_t}\int_0^1 Y_t(z)dz \\ &= (1-\alpha)\frac{MC_t}{W_t/P_t}Y_t\Delta_t, \end{aligned} \tag{3.41}$$

[2] We are not modelling explicitely the monetary base, therefore any analysis of the balance sheet of the central bank can be done only partially. A natural extension of this model will be to include the monetary base in the analysis.

where $\Delta_t = \int_0^1 \left(\frac{P_t(z)}{P_t}\right)^{-\varepsilon} dz$ is a measure of price dispersion.

Similarly, aggregate capital demand equals:

$$K_{t-1}^d = \alpha \frac{MC_t}{R_t^K} Y_t \Delta_t \tag{3.42}$$

Also, aggregate credit is equal to the proportion of banks that give credit times individual credit:

$$CR_t = \chi CR_t(b) \tag{3.43}$$

Total consumption is equal to:

$$C_t = C_t^h + C_t^b \tag{3.44}$$

where $C_t^b = \int_b C_t(b)$. In equilibrium, the demand for bonds equals zero ($B_t = 0$) and interbank borrowing equals its corresponding lending ($Z_t^L = Z_t^B$).

4 Financial frictions in the interbank market

The interest rate adjusted by reserve requirements is defined by:

$$R_t^\tau = \frac{R_t - \tau_t}{1 - \tau_t} > R_t, \tag{4.1}$$

where R_t^τ includes the intermediation mark-up generated by reserve requirements. Reserve requirements act as a tax on the banking system increasing the intermediation cost. Moreover, the first order conditions for the banks determine that the interest rate paid by interbank lending equals the reserve requirement adjusted-interest rate, that is $R_t^{ib} = R_t^\tau$, which is higher than the risk-free rate. Furthermore, the first order conditions for the bank with a lending opportunity determines the shadow price associated to the credit paid in multiperiod contracts:

$$\begin{aligned} \varphi_t\left(b^L\right)(1-\theta_t) \quad = \quad & E_t \beta \sum_{s=0}^{\infty} \left(\lambda^s \overline{\varphi}_{t+s+1} \frac{P_{t+s}}{P_{t+s+1}}\right) Q_t^{cr} - E_t \beta \left(\overline{\varphi}_{t+1} \frac{P_t}{P_{t+1}}\right) R_t^{ib} \theta_t \\ & + \chi \beta E_t \sum_{s=0}^{\infty} \left[(\chi\lambda)^s \varphi_{t+s+1}\left(b^L\right) \frac{P_{t+s}}{P_{t+s+1}} \left(\phi_{t+s+1} \Omega_{t+s}\right)\right] Q_t^{cr} \end{aligned} \tag{4.2}$$

where $\varphi_t\left(b^j\right)$ for $j = \{L, NL\}$ is the Lagrange multiplier of the budget constraint for a bank with and without a lending opportunity, respectively, and $\overline{\varphi}_{t+1} = \chi \varphi_{t+1}\left(b^L\right) + (1-\chi)\varphi_{t+1}\left(b^{NL}\right)$ is the average Lagrange multiplier. The term on the LHS is the marginal cost of the use of funds in terms of consumption, which equals the marginal benefit for having more income in the future because of larger loan stock net of the cost for interest payments plus the expected benefit of being able to borrow more in the interbank market because of larger loan stock, respectively. According this condition, if situations in the interbank market are tighter, that is lower ϕ_{t+1} or θ_t, Q_t^{cr} needs to increase to maintain the equality in this condition. Also, if the probability of having a lending oportunity (χ) is smaller, the expected benefit of being able to borrow in the interbank market next period is smaller, and Q_t^{cr} needs to be higher. This implies a larger premium on the interest rate paid by the entrepreneurs.

After considering other optimality conditions, equation (4.2) can be simplified to:

$$Q_t^{cr} = \frac{R_t^{\tau}}{\Omega_t^{\tau} + \Omega_t^{\chi}} \tag{4.3}$$

where $\Omega_t^{\tau} \equiv E_t\left[\frac{1}{R_t^{\tau}}\left(1 + \lambda\Omega_{t+1}^{\tau}\right)\right]$ and $\Omega_t^{\chi} \equiv E_t\left[\frac{\chi}{R_t^{\tau}}\left(\phi_{t+1}\Omega_t + \lambda\Omega_{t+1}^{\chi}\right)\right]$ are recursive representations of the present values terms in equation (4.2). Note that from this condition, if $\tau_t = 0$, Q_t^{cr}can be lower than the risk-free rate because of the multiperiod contract. Also, the parameter asociated to the colateral constraint θ_t does not affect the risk premium. The risk premium of the interest rate paid by the entrepreneurs depends on the tightening conditions of the interbank market. When the leverage constraint are tighter, that is ϕ is lower, the spread between the interest rate paid by the entrepreneurs and the risk free rate becomes higher.

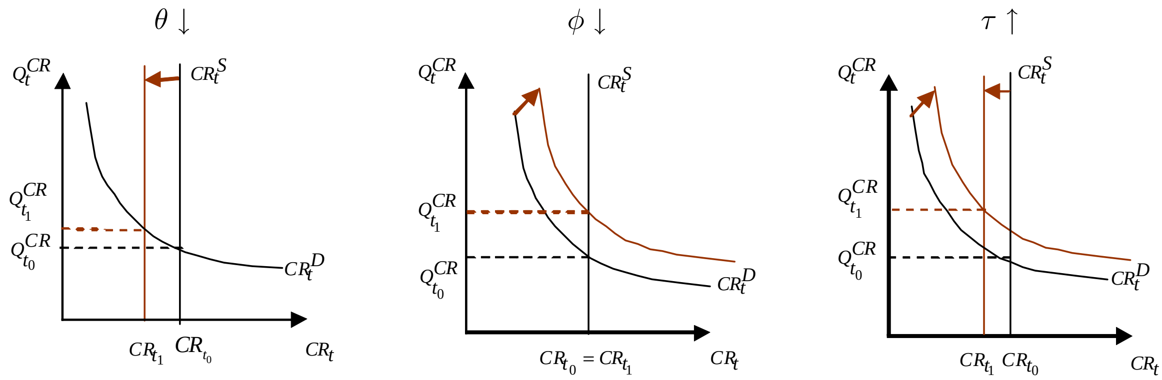
Moreover, the supply of credit comes from the budget constraint of the banks with a lending opportunity, after considering the solution for banks' consumption. The supply of credit give by the banks is the following:

$$CR_t = \frac{\beta_b}{(1-\theta_t)}\chi\left\{\left(\frac{1}{\Omega_{t-1}} + \phi_t\right)L_{t-1} - \left(R_{t-1} - \tau_{t-1}\right)D_{t-1}\right\} + (1-\tau_t)\,D_t, \tag{4.4}$$

where reserve requirements affect the resources available for credit. They affect directly the amount of credit supplied by the banks and it can be an additional channel that monetary policy can work. Also, the colateral constraint affects directly the supply of credit.

The equilibrium in the credit market is given by the intersection of the credit supply (equation 4.4) and the credit demand (equation 3.29 after replacing in it equations 4.3, 3.12, 3.21 and 3.23). Credit supply is perfectly inelastic with respect the shadow price of credit (Q_t^{cr}) while the credit demand is downward slopping with respect to Q_t^{cr}. Graph 4.1 shows the effects in the model of changes in the financial frictions and the reserve requirement rate. A more restricted collateral constraint (lower θ) reduces the supply of credit, because banks can finance a lower proportion of credit, leaving the demand of credit unchanged (Graph 4.1 (a)). On the other hand, with a more restricted leverage constraint (lower ϕ) banks can borrow a lower fraction of its assets, leaving the supply of loans unchanged, but increasing the cost of credit moving upwards the demand for credit (Graph 4.1 (b)). Moreover, an increase in the reserve requirement rate (higher τ) reduces the credit supply, because of the lower flow of funds available to banks, and increases the interest rate paid by the entrepreneurs, moving upwards the demand for credit (Graphs 4.1 (c)). Notice that both a reduction in ϕ or an increase in τ move upwards the credit demand in the same way a tax increases the price of goods.

Graph 4.1
Credit market equilibrium: comparative statics



(a) Collateral constraint | (b) Leverage constraint | (c) Reserve requirement rate

5 Simulation results

To simulate the model we first calibrate the parameters such that generate reasonable values of the steady state (Table 5.1). The discount factor for households (β) is calibrated such that the annualised risk-free rate is 4%. In the calibration is important to consider a low parameter for the discount factor of bankers (β_b), for having a positive steady state level of deposits (see appendix for more details). The probability of a bank having a lending opportunity is calibrated at 0.5. The parameters associated to the leverage constraint (ϕ) and the colateral constraint (θ) are set in 0.9 and 0.8, respectively, which are equivalent to a leverage ratio of 10 and a loan-to-value ratio of 0.8. The elasticity of substitution between goods (ε) is calibrated such that the mark-up of the intermediate goods producers is 15%. Moreover, we assume that investment depreciate in 10 years, which generates a quarterly depreciation rate of 2.5%. The deacay rate of the credit repayments is calibrated at 0.8, which imply a Macaulay's duration of 1.5 years. The reserve requirement rate is calibrated at 20%, a median value of the reserve requirements in the Latin American region.

Table 5.1
Baseline calibration

$\beta = 0.99$	$\mu = 1.15$	$\delta = 0.25$
$\beta_b = 0.8$	$\alpha = 0.5$	$\lambda = 0.8$
$\chi = 0.5$	$\sigma = 1$	$\theta = 0.8$
$\phi = 0.9$	$v = 1$	$\overline{\tau} = 0.2$

According our benchmark calibration, the ratio credit over GDP in steady state (Table 5.2) is 9.5%, which is small because of the effects of financial frictions and reserve requirements in the model. If both the collateral and the leverage constraint were absent together with the reserve requirement, under the same calibration the credit over GDP ratio would be around 20%. The financial constraints and the reserve requirement make the return of capital (R^Q), which is 1.090 in steady state, higher than the risk-free real interest rate R. Then, the stock of capital (together with investment and credit) is smaller to generate a higher return in steady state.

Table 5.2
Steady state - baseline calibration

$\frac{CR/P}{Y}$	$= 0.095$	$\frac{L/P}{Y}$	$= 0.654$
$\frac{I}{Y}$	$= 0.095$	Q^{cr}	$= 0.290$
$\frac{C}{Y}$	$= 0.905$	R	$= 1.010$
$\frac{D/P}{Y}$	$= 0.361$	R^Q	$= 1.090$

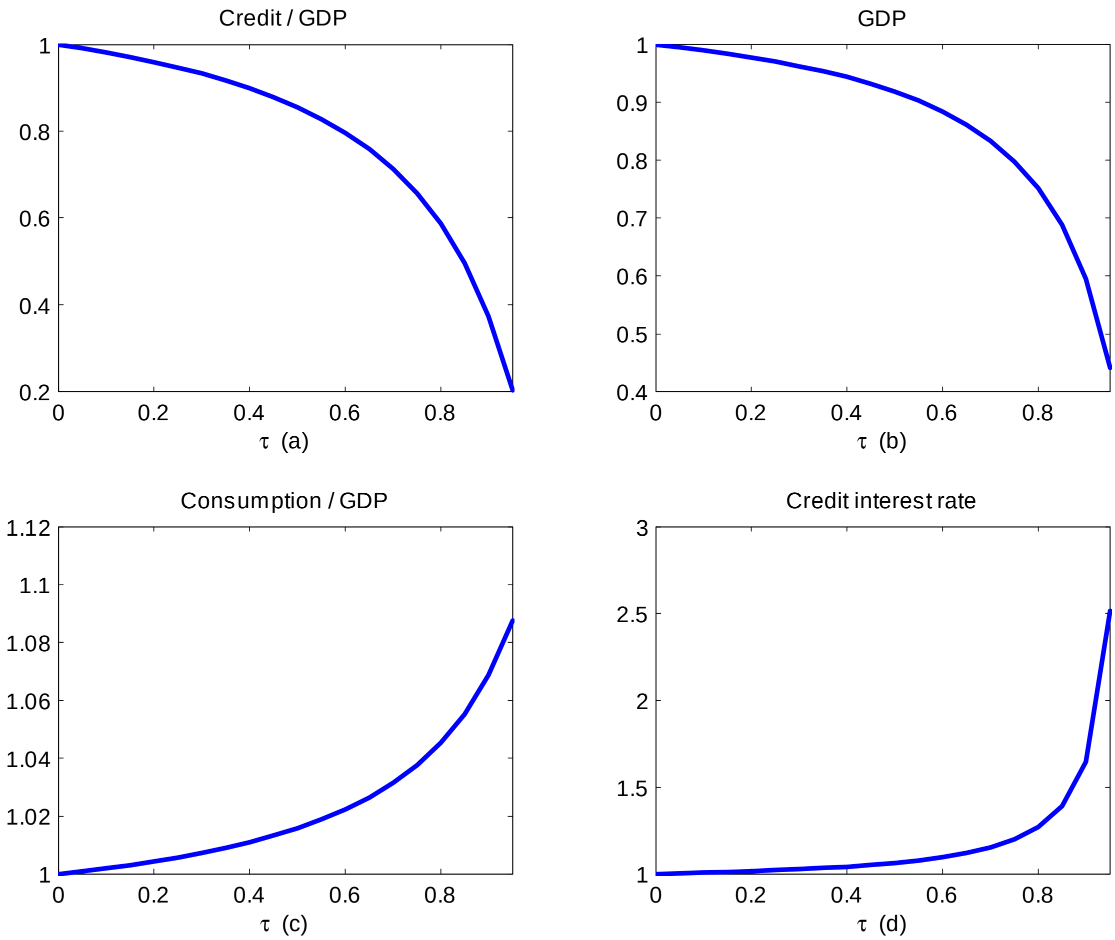
5.1 Reserve requirements and the steady state

Reserve requirements generate a distortion in steady state, because it increases the cost of credit (equation 4.3) as a tax in the banking system. However, in this model reserve requirements do not affect the supply of credit in steady state (equation 4.4) because it doesn't affect the flow of funds of banks (X) in steady state. Since the steady state is an stationary equilibrium, deposits in real terms are constant and so there is no change in the level of reserve requirements in steady state[3].

Graph 5.1 shows the effects in the steady state of the model of considering different values of the reserve requirement rate. The red line corresponds to the baseline calibration. A higher reserve requirement increases exponentially the interest rate paid by credit (panel d), which reduces the level of GDP (panel b). Moreover, it also changes the composition of GDP, reducing investment (and credit) while consumption increases. That is, the higher cost of financing crowds-out investment.

[3]However, these result will change if we consider growth in the model. Reserve requirement will bring another distortion through the credit supply.

Graph 5.1
Steady state of the model[1]



[1]Steady state values normalised to the case of zero reserve requirements (eg value$=1$ when $\tau = 0$)

5.2 Effects of reserve requirements as a monetary policy instrument

The central bank can use actively reserve requirements as a monetary policy instrument in addition to the interest rate. When doing this, it affects the transmission mechanism of the interest rate and the macroeconomic response to different shocks.

Monetary policy transmision mechanism:

To analyse how the transmission mechanism of monetary policy changes, we analyse first how is the response of an exogenous change in the monetary policy interest rate. *Graph 5.2* shows the impulse responses to an iid shock to the Taylor rule (equation 3.35) when the reserve requirement rate is maintained fixed. Under the baseline calibration (red line), an increase in the interest rate has the traditional effects: it contracts household consumption and increases the interest rate paid by credit. Moreover, it reduces both investment and credit with a lag.

There is also a small increase in investment and credit in the first period, generated by the initial reduction in the price of investment.

The duration of the multiperiod credit contract has also implications for the transmission mechanism of monetary policy. A higher λ parameter implies a slower decay of the repayments and a higher duration of the loan. When increasing λ from 0.8 to 0.95 (the blue line), the impact of an interest rate shock on both investment and credit is reduced. This is because an incraese in the interest rate reduces the loans stock (as the present value of the payments gets smaller), reducing also the supply of credit because of the leverage constraint. As the duration of the loans gets higher, the effect of a transitory increase of the interest rate today is smaller, and reduces less the supply of credit. Then, monetary policy looses power.

On the other hand, a tighter leverage constraint in steady state increases the impact on both investment and credit. A reduction in ϕ from 0.9 to 0.3 (the green line), makes the effect of the interest rate on the supply of credit more important. However, also note that the effect (pass-through) on the credit interest rate is unchanged.

Reserve requirement transmission mechanism:

In graph 5.3 we analyse the effect of an exogenous increase in the reserve requirement rate of 10% with some persistence (red line). This increases the credit interest rate, which reduces credit and investment. Moreover, the reduction in GDP also decreases household consumption. As inflation decreases, the interest rate also falls. However, after one period there is some recovery in investment and GDP generated by the decrease in the price of investment. Furthermore, a tighter leverage constraint (blue line) reduces the impact of reserves requirements on credit. This effect is opposite to the one on the interest rate shock.

How is affected the transmission mechanism of monetary policy is affected when we use reserve requirements?

We compare the different responses to shocks maintaining fixed the reserve requirement rate with those where the reserve requirement rate follows a feedback rule. Since an objective of macropudential policy is to moderate the financial cycle, in order to limit the likelihood of financial stress, we consider a policy rule for the reserve requirements rate that responds to deviations of credit from its steady state (equation 3.37).

Graphs 5.4 shows the impulse responses to a shock in the aggregate demand equation (3.39). Given the size and persistence calibrated for this shock, it implies a implies a maximum increase in the reserve requirement rate of 15%. Also, the increase in credit is around 1/3 than in the counterfactual case without the use of reserve requirement. Moreover, the transmission mechanism of the interest rate is improved. The interest rate has to increase a half than in the counterfactual case and inflation is controlled better.

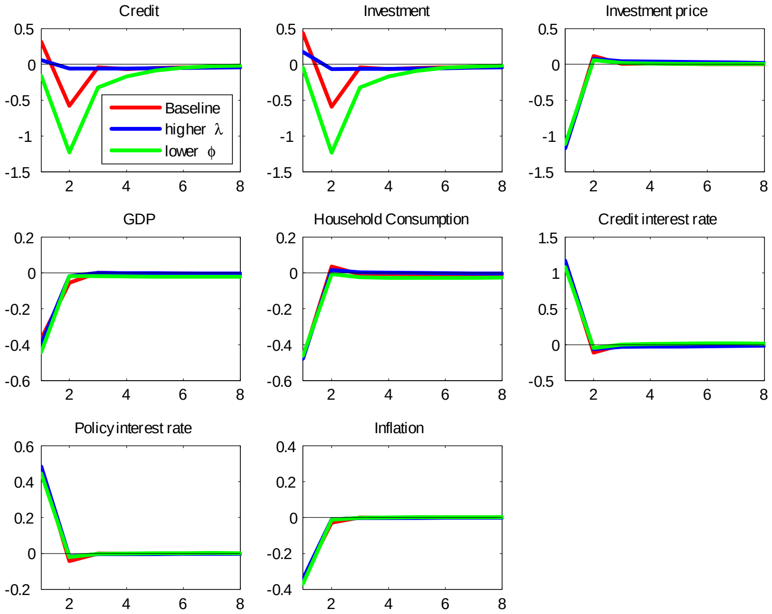
However, it is not necessarily the case that using a feedback rule for the reserve requirement rate always improves the power of the interest rate. It will depend on the source of the shock. For instance, graph 5.5 shows the impulse responses to a productivity shock. In this case both credit and investment increases, and inflation decreases. A reserve requirement rule on credit moderates credit growth, however since this generates a negative output gap (aggregate demand grow less than aggregate supply), inflation decreases more and the interest rate should have a higher response to control.

How about the response to shocks that affect the financial constraints?

Our framework allows also analysing what happens when the financial conditions change. For example, in the case of a financial crisis financial conditions get tighter, which in our setup will imply an increase in the risk premium paid by credit. In our model we have two types of financial constraints, the leverage constraint and the collateral constraint. As shown in *graph 5.6*, an exogenous reduction in the fraction ϕ_t that a bank can borrow from its own loans imply an increase in the cost of investment, reducing both credit and GDP. The endogenous response of the interest rate partially offset this effect, however even when the credit interest rate is is reduced, it takes time for credit to recover. On the other hand, an endogenous reduction of 15% in the reserve requirement rate (blue line) complements the response of the interest rate, making credit and other macroeconomic variables more stable. Moreover, the outcome of using a reserve requirement rate feedback rule is similar in the case of an exogenous reduction in the fraction θ_t that banks can fund from the credit (*graph 5.7*).

Graph 5.2

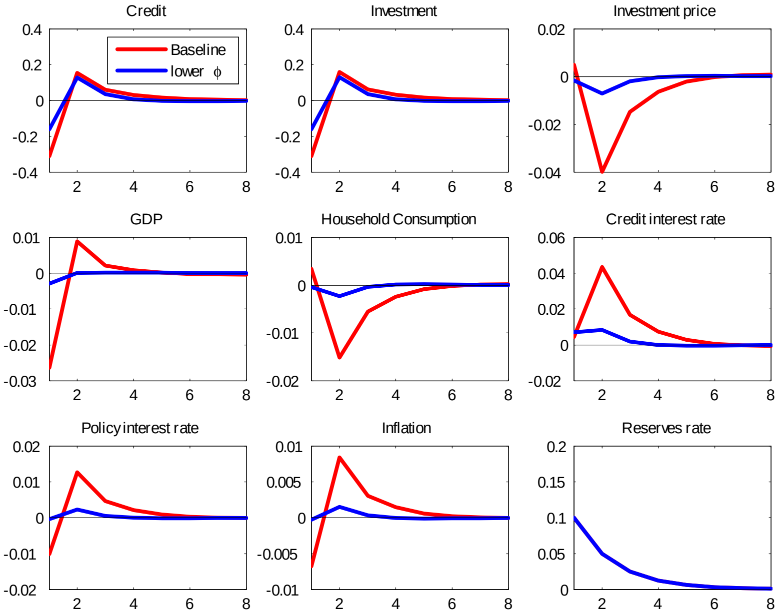
Impulse responses to a monetary policy shock[1]



[1]Shock iid with 1% standard deviation. Sensitivity analysis with λ=0.95 and ϕ=0.3.

Graph 5.3

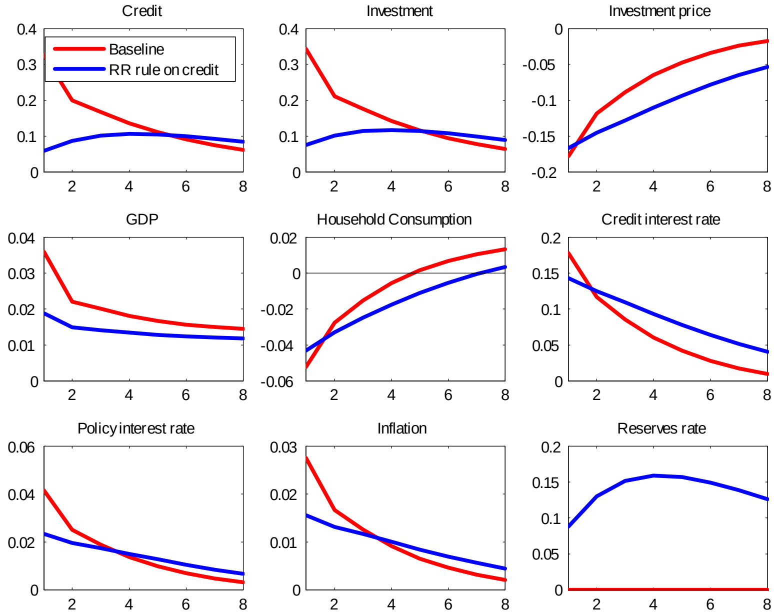
Impulse responses to an increase in the reserves rate[1]



[1]Shock with autocorrelation coefficient of 0.5 and standard deviation of 0.1. Sensitivity analysis with ϕ=0.3.

Graph 5.4

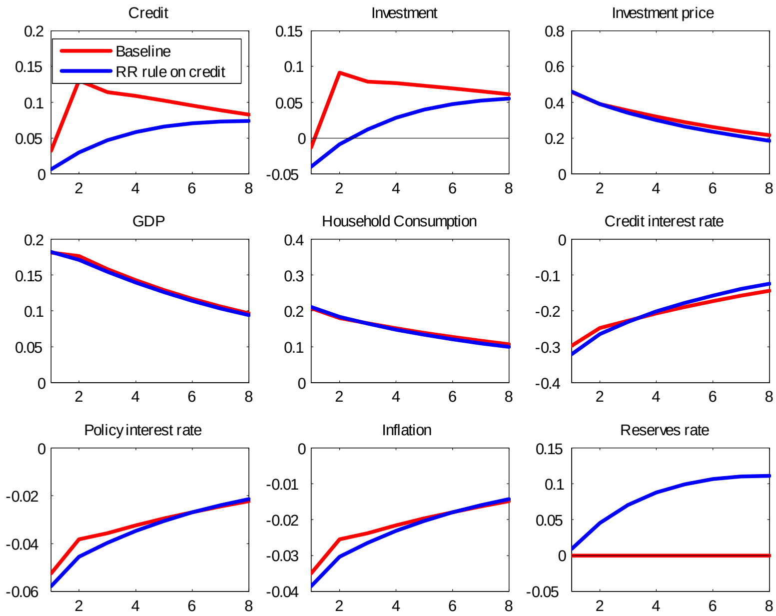
Impulse responses to a demand shock[1]



[1]Shock with autocorrelation coefficient of 0.8 and standard deviation of 0.05.

Graph 5.5

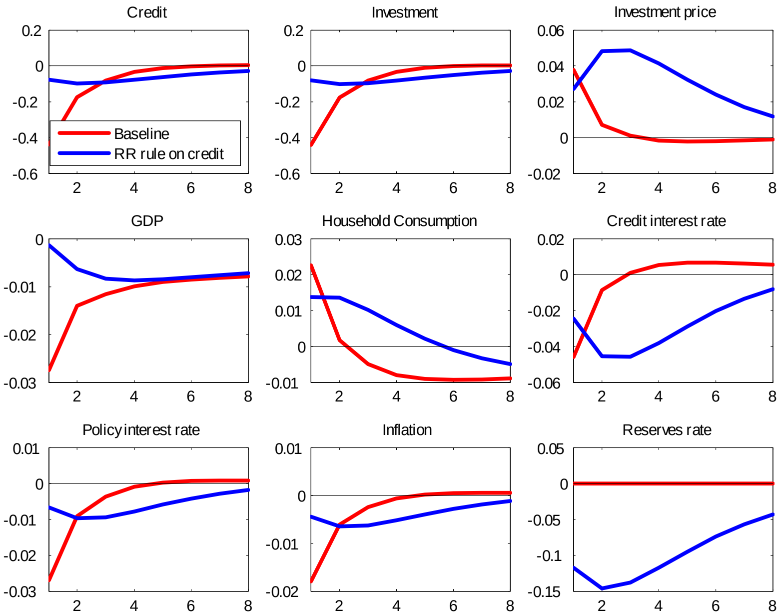
Impulse reponses to a productivity shock[1]



[1]Shock with autocorrelation coefficient of 0.9 and standard deviation of 0.2.

Graph 5.6

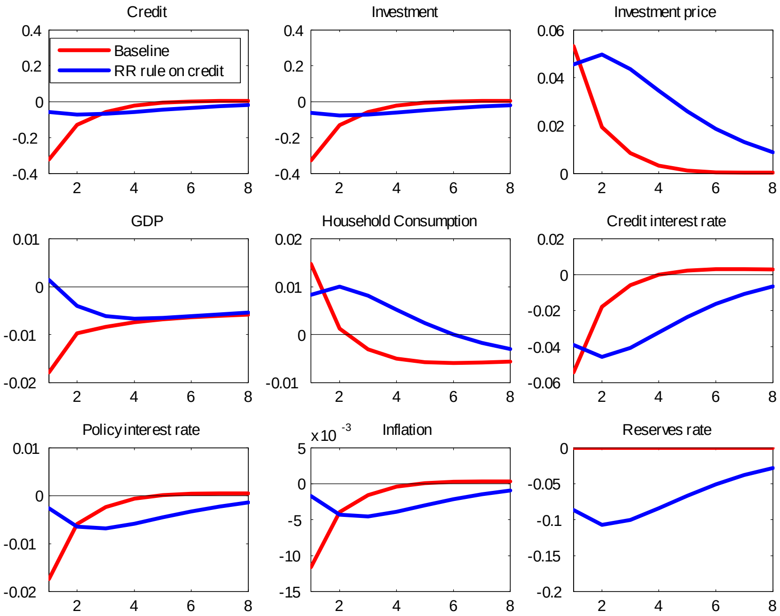
Impulse responses to a shock to the LC (ϕ)[1]



[1] Shock with autocorrelation coefficient of 0.5 and standard deviation of 0.1.

Graph 5.7

Impulse responses to a shock to the colateral constraint (θ)[1]



[1] Shock with autocorrelation coefficient of 0.5 and standard deviation of 0.25.

6 Conclusions

This paper has presented a DSGE model with a banking sector, an interbank market, multi-period loan contracts and financial firctions in the form of collateral and liquidity contraints. As a results banks become engaged in a maturity transfomation activity in which they are able to fund themselves from retail deposits or the wholesale market and lend long-term to entrepreneurs. Collateral and liquidity constraints introduce accelerator type features that generate procyclical credit cycles and introduce a source of liquidity shortages in the economy.

In this setting we examine the role of reserve requiremnts, not as a monetary policy tool but as a macroprudential tool to handle liquidity problems in the economy. In this setting we examine how the credit channel and the monetary transmission mechanism change. A key finding is that reserve requirements can complement monetary policy in stabilizing the business cycle when the economy is subject to demand shocks, but not under supply shocks.

References

[1] Benes, Jaromir and Kirdan Lees (2010), "Multi-period fixed-rate loans, housing and monetary policy in small open economies", forthcoming International Journal of Central Banking.

[2] Bernanke, B, M Gertler and S Gilchrist (1999). "The Financial Accelerator in a Quantitative Business Cycle Framework" in J Taylor and M Woodford (eds) Handbook of

[3] Macroeconomics. Volume 1C, North Holland.

[4] Betancourt, Y, N Rodríguez, C Varela and H Vargas (2010): "Effects of reserve requirements in an inflation targeting regime: the case of Colombia", mimeo, Bank of the Republic (Colombia).

[5] Christiano, L., Eichenbaum, M. and Evans, C. (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," Journal of Political Economy 113,pp. 1-45.

[6] Chrisitiano, L, R Motto and M Rostagno (2007a). "Financial Factors in Business Cycles", Mimeo, European Central Bank.

[7] Curdia, Vasco and Michael Woodford (2008). "Credit frictions and optimal monetary policy", mimeo Columbia University.

[8] Del Negro, M., G. Eggertsson, A. Ferrero and N. Kiyotaki (2009), "The Great Escape? A Quantitative Evaluation of the Fed's Non-Standard Policies", mimeo.

[9] Gerali, A, Stefano Neri, Luca Sessa, and Federico Signoretti (2009), "Credit and banking in a DSGE model", mimeo Bank of Italy.

[10] Iacovello, M (2005). "House Prices, Borrowing Constraints and Monetary Policy in the Business Cycle", American Economic Review, vol 95, pp 739–764.

[11] International Monetary Fund (2010): *Regional Economic Outlook: Cool in the North, Warming in the South.* Western Hemisphere Department.

[12] Jara, A and C Tovar (2008): "Monetary and financial stability implications of capital flows in Latin America and the Caribbean", BIS Papers, no 48. Moreno, R (2006): "The changing nature of risks facing banks", BIS Papers, no 28, pp 67-98.

[13] Kiyotaki, N. and J. Moore (2008), "Liquidity, Business Cycles, and Monetary Policy", mimeo.

[14] Smets, F and R Wouters (2003). "An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area", Journal of the European Economic Association, vol 1, no 5, pp 1123–1175.ia).

[15] Tovar, Camilo E. (2009). DSGE Models and Central Banks. Economics: The Open-Access, Open-Assessment E-Journal, Vol. 3, 2009-16. doi:10.5018/economics-ejournal.ja.2009-16, http://dx.doi.org/10.5018/economics-ejournal.ja.2009-16

A Appendix: Some important derivations

A.1 The entrepreneurs problem

A.1.1 The multiperiod credit contract problem

Entrepreneurs take credit in a multiperiod contract with fixed repayments as in Bennes and Lees (2010). A credit CR_t in nominal values taken at time t is paid back in repayments proportional to the amount borrowed and decay at a fixed rate i $\lambda \in (0,1)$. This implies the following repayment schedule: $Q_t^{cr}CR_t$, $\lambda Q_t^{cr}CR_t$, ..., $\lambda^{k-1}Q_t^{cr}CR_t$, ... for repayments due at $t+1, t+2, ..., t+k, ...$ respectively. Where Q_t^{cr} is a shadow price associated to the credit. This form of multiperiod contract allows us to draw out the implications of long-term debt and maturity mismatch in an analytically tractable framework.

Accordingly, the sum of all repayments due at t associated with all past loans is:

$$\begin{aligned} J_{t-1} &= Q_{t-1}^{cr}CR_{t-1} + \lambda Q_{t-2}^{cr}CR_{t-2} + ... + \lambda^{k-1}Q_{t-k}^{cr}CR_{t-k} + ... \\ &= \sum_{k=1}^{\infty} \lambda^{k-1} Q_{t-k}^{cr} CR_{t-k} \end{aligned} \quad \text{(A-1)}$$

Also, J_t can be written recursively as:

$$\begin{aligned} J_t &= Q_t^{cr}CR_t + \lambda Q_{t-1}^{cr}CR_{t-1} + ... + \lambda^{k}Q_{t-k}^{cr}CR_{t-k} + ... \\ &= Q_t^{cr}CR_t + \lambda \left(Q_{t-1}^{cr}CR_{t-1} + ... + \lambda^{k-1}Q_{t-k}^{cr}CR_{t-k} + ... \right) \\ &= Q_t^{cr}CR_t + \lambda J_{t-1} \end{aligned} \quad \text{(A-2)}$$

which is equal to equation (3.25) in the main text. The stock of loans, estimated as the present value of repayments due at $t+1, t+2, ...$is equal to:

$$\begin{aligned} L_t = \; & E_t\left(\frac{1}{R_{t+1}}\right)\left(Q_t^{cr}CR_t + \lambda Q_{t-1}^{cr}CR_{t-1} + ... + \lambda^{k}Q_{t-k}^{cr}CR_{t-k} + ...\right) \\ & +\lambda E_t\left(\frac{1}{R_{t+1}R_{t+2}}\right)\left(Q_t^{cr}CR_t + \lambda Q_{t-1}^{cr}CR_{t-1} + ... + \lambda^{k}Q_{t-k}^{cr}CR_{t-k} + ...\right) \\ & +\lambda^2 E_t\left(\frac{1}{R_{t+1}R_{t+2}R_{t+3}}\right)\left(Q_t^{cr}CR_t + \lambda Q_{t-1}^{cr}CR_{t-1} + ... + \lambda^{k}Q_{t-k}^{cr}CR_{t-k} + ...\right) \\ & + ... \end{aligned}$$

This can be rewritten as:

$$L_t = \Omega_t \left(Q_t^{cr}CR_t + \lambda Q_{t-1}^{cr}CR_{t-1} + ... + \lambda^{k}Q_{t-k}^{cr}CR_{t-k} + ...\right)$$

where

$$\begin{aligned} \Omega_t &= E_t\left(\frac{1}{R_{t+1}} + \lambda\frac{1}{R_{t+1}R_{t+2}} + \lambda^2\frac{1}{R_{t+1}R_{t+2}R_{t+3}} + ...\right) \\ &= E_t\left\{\frac{1}{R_{t+1}}\left[1 + \lambda\left(\frac{1}{R_{t+2}} + \lambda\frac{1}{R_{t+2}R_{t+3}} + ...\right)\right]\right\} \end{aligned}$$

which after using the definition $\Omega_{t+1}$and the law for iterated expectations, is equal to:

$$\Omega_t = E_t \left\{ \frac{1}{R_{t+1}} \left[1 + \lambda \Omega_{t+1} \right] \right\} \tag{A-3}$$

Ω_t is a discount factor that depends on future interest rates!!

Also, after using the definition for J_t, the stock of loans can be written as:

$$L_t = \Omega_t J_t \tag{A-4}$$

Replacing $J_t = L_t/\Omega_t$ from this equation in the recursive representation of J_t, the evolution of loans can be written as:

$$\begin{aligned} \frac{L_t}{\Omega_t} &= Q_t^{cr} CR_t + \lambda \frac{L_{t-1}}{\Omega_{t-1}} \\ L_t &= \Omega_t Q_t^{cr} CR_t + \lambda \frac{\Omega_t}{\Omega_{t-1}} L_{t-1} \end{aligned} \tag{A-5}$$

A.1.2 The optimal condition of the entrepreneurs

The entrepreneurs' profits are given by:

$$\Gamma_t^{ent} = P_t \left(R_t^K K_{t-1} - Q_t I_t \right) + CR_t - J_{t-1} \tag{A-6}$$

where $J_t = Q_t^{cr} CR_t + \lambda J_{t-1}$. From this, solving for CR_t :

$$CR_t = \frac{(1 - \lambda L)}{Q_t^{cr}} J_t$$

where L is the lag operator. Then, profits become:

$$\Gamma_t^{ent} = P_t \left(R_t^K K_{t-1} - Q_t I_t \right) + \frac{(1 - \lambda L)}{Q_t^{cr}} J_t - J_{t-1} \tag{A-7}$$

we calculate the present disconted value of the profits considering $\frac{(1-\lambda L)}{Q_t^{cr}}$ as the discount factor:

$$\begin{aligned} & \Gamma_t^{ent} + \frac{(1 - \lambda L)}{Q_t^{cr}} \Gamma_{t+1}^{ent} + \frac{(1 - \lambda L)^2}{Q_t^{cr} Q_{t+1}^{cr}} \Gamma_{t+2}^{ent} + ... \\ = \; & P_t \left(R_t^K K_{t-1} - Q_t I_t \right) + \frac{(1 - \lambda L)}{Q_t^{cr}} P_{t+1} \left(R_{t+1}^K K_t - Q_{t+1} I_{t+1} \right) \\ & + \frac{(1 - \lambda L)^2}{Q_t^{cr} Q_{t+1}^{cr}} P_{t+2} \left(R_{t+2}^K K_{t+1} - Q_{t+2} I_{t+2} \right) + ... - J_{t-1} \end{aligned}$$

The problem for this entrepreneur can be written recursively as

$$V \left(K_{t-1} \right) = \max_{K_t, I_t} P_t \left(R_t^K K_{t-1} - Q_t I_t \right) + \frac{(1 - \lambda L)}{Q_t^{cr}} E_t V \left(K_t \right) \tag{A-8}$$

which equals:

$$\left(1+\frac{\lambda}{Q_t^{cr}}\right)V\left(K_{t-1}\right) = \max_{K_t,I_t} P_t\left(R_t^K K_{t-1}-Q_t I_t\right)+\frac{1}{Q_t^{cr}}E_t V\left(K_t\right),$$

$$V\left(K_{t-1}\right) = \max_{K_t,I_t} \frac{1}{1+\frac{\lambda}{Q_t^{cr}}}P_t\left(R_t^K K_{t-1}-Q_t I_t\right)+\frac{1/Q_t^{cr}}{1+\frac{\lambda}{Q_t^{cr}}}E_t V\left(K_t\right),$$

or

$$V\left(K_{t-1}\right)=\max_{I_t}\frac{1}{1+\frac{\lambda}{Q_t^{cr}}}P_t\left(R_t^K K_{t-1}-Q_t I_t\right)+\frac{1/Q_t^{cr}}{1+\frac{\lambda}{Q_t^{cr}}}E_t V\left[I_t+\left(1-\delta\right)K_{t-1}\right]. \tag{A-9}$$

The first order condition of the Bellman equation (A-9) with respect to I_t is:

$$-\frac{1}{1+\frac{\lambda}{Q_t^{cr}}}P_t Q_t+\frac{1/Q_t^{cr}}{1+\frac{\lambda}{Q_t^{cr}}}E_t V'\left(K_t\right)=0. \tag{A-10}$$

To calculate $E_t V'\left(K_t\right)$ in (A-10) we need to calculate first $V'\left(K_{t-1}\right)$ in (A-9) using the envelope theorem:

$$V'\left(K_{t-1}\right)=\frac{1}{1+\frac{\lambda}{Q_t^{cr}}}P_t R_t^K+\left(1-\delta\right)\frac{1/Q_t^{cr}}{1+\frac{\lambda}{Q_t^{cr}}}E_t V'\left(K_t\right). \tag{A-11}$$

We also use the first order condition (A-10) to simplify equation (A-11):

$$V'\left(K_{t-1}\right)=\frac{1}{1+\frac{\lambda}{Q_t^{cr}}}P_t R_t^K+\left(1-\delta\right)\frac{1}{1+\frac{\lambda}{Q_t^{cr}}}P_t Q_t, \tag{A-12}$$

then we evaluate equation (A-12) in t+1 and take expectations:

$$E_t V'\left(K_t\right)=E_t\left[\frac{1}{1+\frac{\lambda}{Q_{t+1}^{cr}}}P_{t+1}R_{t+1}^K+\left(1-\delta\right)\frac{1}{1+\frac{\lambda}{Q_{t+1}^{cr}}}P_{t+1}Q_{t+1}\right], \tag{A-13}$$

and replace this in the first order condition (A-10):

$$E_t Q_t^{cr}\left(\frac{1+\frac{\lambda}{Q_{t+1}^{cr}}}{\Pi_{t+1}}\right)=E_t\left[\frac{R_{t+1}^K+\left(1-\delta\right)Q_{t+1}}{Q_t}\right]. \tag{A-14}$$

This condition (3.29) in the main text.

A.2 Solving for the banks problem:

The budget constraint of the bank is:

$$P_tC_t(b) + CR_t(b) + \left[Z_t^L(b) - Z_t^B(b)\right] \leq J_{t-1}(b) + X_t(b) + R_{t-1}^{ib}\left[Z_{t-1}^L(b) - Z_{t-1}^B(b)\right] \quad \text{(A-15)}$$

$$J_t(b) = \frac{1}{\Omega_t}L_t(b) \quad \text{(A-16)}$$

$$L_t(b) = \lambda\frac{\Omega_t}{\Omega_{t-1}}L_{t-1}(b) + \Omega_t Q_t^{cr}CR_t(b) \quad \text{(A-17)}$$

After considering these three equations, the budget constraint in t and in $t+1$ becomes:

$$\begin{aligned} & P_tC_t(b) + CR_t(b) + \left[Z_t^L(b) - Z_t^B(b)\right] \\ \leq\ & \frac{1}{\Omega_{t-1}}L_{t-1}(b) + X_t(b) + R_{t-1}^{ib}\left[Z_{t-1}^L(b) - Z_{t-1}^B(b)\right] \end{aligned} \quad \text{(A-18)}$$

where $L_{t-1}(b) = \lambda\frac{\Omega_{t-1}}{\Omega_{t-2}}L_{t-2}(b) + \Omega_{t-1}Q_{t-1}^{cr}CR_{t-1}(b)$. We claim that a bank with a lending oportunity, the constraint (3.32) binds, and for the others not (see proof).

The budget constraint for a bank with lending opportunity, after replacing $Z_t^B(b) = \phi_t L_{t-1}(b) + \theta_t CR_t(b)$, becomes:

$$\begin{aligned} & P_tC_t\left(b^L\right) + (1-\theta_t)CR_t\left(b^L\right) - \phi_t L_{t-1}(b) \\ \leq\ & \frac{1}{\Omega_{t-1}}L_{t-1}(b) + X_t\left(b^L\right) + R_{t-1}^{ib}\left[Z_{t-1}^L(b) - Z_{t-1}^B(b)\right] \end{aligned} \quad \text{(A-19)}$$

Similarly, **the budget constraint for a bank without lending opportunity (that is $CR_t(b) = 0$):**

$$P_tC_t\left(b^{NL}\right) + Z_t^L\left(b^{NL}\right) \leq \frac{1}{\Omega_{t-1}}L_{t-1}(b) + X_t\left(b^{NL}\right) + R_{t-1}^{ib}\left[Z_{t-1}^L(b) - Z_{t-1}^B(b)\right]$$

where $X_t(b) = (1-\tau_t)D_t(b) - (R_{t-1} - \tau_{t-1})D_{t-1}(b)$.

Considering the above, the **Lagrangian for a lending bank is:**

$$\begin{aligned} \mathcal{L} =\ & \ln\left(C_t\left(b^L\right)\right) - \varphi_t\left(b^L\right)BC_t\left(b^L\right) + \chi\beta E_t\left[\ln\left(C_{t+1}\left(b^L\right)\right) - \varphi_{t+1}\left(b^L\right)BC_{t+1}\left(b^L|b_t^L\right)\right] \\ & + (1-\chi)\beta E_t\left[\ln\left(C_{t+1}\left(b^{NL}\right)\right) - \varphi_{t+1}\left(b^{NL}\right)BC_{t+1}\left(b^{NL}|b_t^L\right)\right] + \ldots \end{aligned} \quad \text{(A-20)}$$

Similarly, the **Lagrangian for a non-lending bank:**

$$\begin{aligned} \mathcal{L} =\ & \ln\left(C_t\left(b^{NL}\right)\right) - \varphi_t\left(b^{NL}\right)BC_t\left(b^{NL}\right) + \chi\beta E_t\left[\ln\left(C_{t+1}\left(b^L\right)\right) - \varphi_{t+1}\left(b^L\right)BC_{t+1}\left(b^L|b_t^{NL}\right)\right] \\ & + (1-\chi)\beta E_t\left[\ln\left(C_{t+1}\left(b^{NL}\right)\right) - \varphi_{t+1}\left(b^{NL}\right)BC_{t+1}\left(b^{NL}|b_t^{NL}\right)\right] + \ldots \end{aligned} \quad \text{(A-21)}$$

where we have defined the following notation for the budget constraints in real terms as:

$$
\begin{aligned}
BC_t\left(b^L\right) &\equiv \left\{\begin{array}{c} P_tC_t\left(b^L\right)+\left(1-\theta_t\right)CR_t\left(b^L\right)-\phi_tL_{t-1}\left(b\right)-\frac{1}{\Omega_{t-1}}L_{t-1}\left(b\right)-X_t\left(b^L\right) \\ -R^{ib}_{t-1}\left[Z^L_{t-1}\left(b^L\right)-Z^B_{t-1}\left(b^L\right)\right]\end{array}\right\}\frac{1}{P_t} \\
BC_{t+1}\left(b^L|b^L_t\right) &\equiv \left\{\begin{array}{c} P_{t+1}C_{t+1}\left(b^L\right)+\left(1-\theta_{t+1}\right)CR_{t+1}\left(b^L\right)-\phi_{t+1}\left[\lambda\frac{\Omega_t}{\Omega_{t-1}}L_{t-1}\left(b\right)+\Omega_tQ^{cr}_tCR_t\left(b^L\right)\right] \\ -\frac{1}{\Omega_t}\left[\lambda\frac{\Omega_t}{\Omega_{t-1}}L_{t-1}\left(b\right)+\Omega_tQ^{cr}_tCR_t\left(b^L\right)\right]-X_{t+1}+R^{ib}_t\left[\phi^B_tL_{t-1}\left(b\right)+\theta_tCR_t\left(b^L\right)\right]\end{array}\right\}\frac{1}{P_{t}} \\
BC_{t+1}\left(b^{NL}|b^L_t\right) &\equiv \left\{\begin{array}{c} P_{t+1}C_{t+1}\left(b^{NL}\right)+Z^L_{t+1}\left(b^{NL}\right)-\frac{1}{\Omega_t}\left[\lambda\frac{\Omega_t}{\Omega_{t-1}}L_{t-1}\left(b\right)+\Omega_tQ^{cr}_tCR_t\left(b^L\right)\right] \\ -X_{t+1}\left(b^{NL}\right)+R^{ib}_t\left[\phi^B_tL_{t-1}\left(b\right)+\theta_tCR_t\left(b^L\right)\right]\end{array}\right\}\frac{1}{P_{t+1}}
\end{aligned}
$$

and

$$
\begin{aligned}
BC_t\left(b^{NL}\right) &\equiv \left\{P_tC_t\left(b^{NL}\right)+Z^L_t\left(b^{NL}\right)-\frac{1}{\Omega_{t-1}}L_{t-1}\left(b\right)-X_t\left(b^{NL}\right)-R^{ib}_{t-1}\left[Z^L_{t-1}\left(b\right)-Z^B_{t-1}\left(b\right)\right]\right\}\frac{1}{P_t} \\
BC_{t+1}\left(b^L|b^{NL}_t\right) &\equiv \left\{\begin{array}{c} P_{t+1}C_{t+1}\left(b^L\right)+\left(1-\theta_{t+1}\right)CR_{t+1}\left(b^L\right)-\phi^B_{t+1}\left[\lambda\frac{\Omega_t}{\Omega_{t-1}}L_{t-1}\left(b\right)\right] \\ -\frac{1}{\Omega_t}\left[\lambda\frac{\Omega_t}{\Omega_{t-1}}L_{t-1}\left(b\right)\right]-X_{t+1}\left(b^L\right)-R^{ib}_t\left[Z^L_t\left(b^L\right)\right]\end{array}\right\}\frac{1}{P_{t+1}} \\
BC_{t+1}\left(b^{NL}|b^{NL}_t\right) &\equiv \left\{\begin{array}{c} P_{t+1}C_{t+1}\left(b^{NL}\right)+Z^L_{t+1}\left(b^{NL}\right)-\frac{1}{\Omega_t}\left[\lambda\frac{\Omega_t}{\Omega_{t-1}}L_{t-1}\left(b\right)\right] \\ -X_{t+1}\left(b^{NL}\right)-R^{ib}_t\left[Z^L_t\left(b^{NL}\right)\right]\end{array}\right\}\frac{1}{P_{t+1}}
\end{aligned}
$$

The **first order conditions for the lending bank** are**:**

$$C_t\left(b^L\right) \quad : \quad \frac{1}{C_t\left(b^L\right)}=\varphi_t\left(b^L\right) \tag{A-22}$$

$$
\begin{aligned}
CR_t\left(b^L\right) \quad &: \quad \varphi_t\left(b^L\right)\left(1-\theta_t\right)=E_t\beta\sum_{s=0}^{\infty}\left(\lambda^s\overline{\varphi}_{t+s+1}\frac{P_{t+s}}{P_{t+s+1}}\right)Q^{cr}_t-E_t\beta\left(\overline{\varphi}_{t+1}\frac{P_t}{P_{t+1}}\right)R^{ib}_t\theta_t \\
&\quad +\chi\beta E_t\sum_{s=0}^{\infty}\left[\left(\chi\lambda\right)^s\varphi_{t+s+1}\left(b^L\right)\frac{P_{t+s}}{P_{t+s+1}}\left(\phi_{t+s+1}\Omega_{t+s}\right)\right]Q^{cr}_t
\end{aligned} \tag{A-23}
$$

$$D_t\left(b^L\right) \quad : \quad \varphi_t\left(b^L\right)\left(1-\tau_t\right)\frac{1}{P_t}=E_t\beta\left(R_t-\tau_t\right)\left[\frac{\chi\varphi_{t+1}\left(b^L\right)+\left(1-\chi\right)\varphi_{t+1}\left(b^{NL}\right)}{P_{t+1}}\right] \tag{A-24}$$

$$
\begin{aligned}
\varphi_t\left(b^L\right)\left(1-\theta_t\right) &= E_t\beta\sum_{s=0}^{\infty}\left(\lambda^s\overline{\varphi}_{t+s+1}\frac{P_{t+s}}{P_{t+s+1}}\right)Q^{cr}_t-E_t\beta\left(\overline{\varphi}_{t+1}\frac{P_t}{P_{t+1}}\right)R^{ib}_t\theta_t \\
&\quad +\chi\beta E_t\sum_{s=0}^{\infty}\left[\left(\chi\lambda\right)^s\varphi_{t+s+1}\left(b^L\right)\frac{P_{t+s}}{P_{t+s+1}}\left(\phi_{t+s+1}\Omega_{t+s}\right)\right]Q^{cr}_t
\end{aligned} \tag{A-25}
$$

Similarly, the **first order conditions for the non-lending bank** are:

$$C_t\left(b^{NL}\right) \quad : \quad \frac{1}{C_t\left(b^{NL}\right)} = \varphi_t\left(b^{NL}\right) \tag{A-26}$$

$$Z_t^L\left(b^{NL}\right) \quad : \quad \varphi_t\left(b^{NL}\right) = \chi\beta E_t\varphi_{t+1}\left(b^L\right)\left[\frac{R_t^{ib}}{P_{t+1}}\right] + (1-\chi)\beta E_t\varphi_{t+1}\left(b^{NL}\right)\left[\frac{R_t^{ib}}{P_{t+1}}\right] \tag{A-27}$$

$$D_t\left(b^{NL}\right) \quad : \quad \varphi_t\left(b^{NL}\right)(1-\tau_t)\frac{1}{P_t} = E_t\beta\left(R_t-\tau_t\right)\left[\frac{\chi\varphi_{t+1}\left(b^L\right)+(1-\chi)\varphi_{t+1}\left(b^{NL}\right)}{P_{t+1}}\right] \tag{A-28}$$

From (A-27) and (A-28), we have:

$$R_t^{ib} = \frac{R_t-\tau_t}{1-\tau_t} > R_t, \tag{A-29}$$

the interest rate charged by interbank loans is higher than the risk free rate that pay for the deposits. The reserve requirement rate generates a mark-up on that rate (it works as a tax).

Condition (A-23) determines the shadow price associated to the credit paid in multiperiod contracts. Using condition (A-24) and (A-29) to simplify (A-23), and representing recursively the infinite sum terms, we get:

$$Q_t^{cr} = \frac{R_t^{\tau}}{\Omega_t^{\tau}+\Omega_t^{\chi}} \tag{A-30}$$

where $\Omega_t^{\tau} \equiv E_t\left[\frac{1}{R_t^{\tau}}\left(1+\lambda\Omega_{t+1}^{\tau}\right)\right]$ and $\Omega_t^{\chi} \equiv E_t\left[\frac{\chi}{R_t^{\tau}}\left(\phi_{t+1}\Omega_t+\lambda\Omega_{t+1}^{\chi}\right)\right]$ are recursive representations of the present values terms in equation (A-23).

Also, note from conditions (A-24) and (A-28) that $\varphi_t\left(b^L\right) = \varphi_t\left(b^{NL}\right)$, which imply that $C_t\left(b^L\right) = C_t\left(b^{NL}\right)$ from conditions (A-22) and (A-26). There is perfect risk sharing between bankers, the demand for deposits will equalise the consumption for both type of banks

The budget constraints for the banks with and without lending opportunity, are respectively:

$$P_tC_t\left(b^L\right) + (1-\theta_t)CR_t\left(b^L\right) = \left(\frac{1}{\Omega_{t-1}}+\phi_t^B\right)L_{t-1}(b) + X_t(b) + R_{t-1}^{ib}\left[Z_{t-1}^L(b)-Z_{t-1}^B(b)\right] \tag{A-31}$$

$$P_tC_t\left(b^{NL}\right) + Z_t^L\left(b^{NL}\right) = \frac{1}{\Omega_{t-1}}L_{t-1}(b) + X_t(b) + R_{t-1}^{ib}\left[Z_{t-1}^L(b)-Z_{t-1}^B(b)\right] \tag{A-32}$$

Because of the assumption on logarithmic utility, total consumption of banks is given

$$P_tC_t\left(b^L\right) = (1-\beta_b)\left\{\left(\frac{1}{\Omega_{t-1}}+\phi_t^B\right)L_{t-1}(b) - \left(R_{t-1}-\tau_{t-1}\right)D_{t-1}(b) + R_{t-1}^{ib}\left[Z_{t-1}^L(b)-Z_{t-1}^B(b)\right]\right\} \tag{A-33}$$

$$P_tC_t\left(b^{NL}\right) = (1-\beta_b)\left\{\frac{1}{\Omega_{t-1}}L_{t-1}(b) - \left(R_{t-1}-\tau_{t-1}\right)D_{t-1}(b) + R_{t-1}^{ib}\left[Z_{t-1}^L(b)-Z_{t-1}^B(b)\right]\right\} \tag{A-34}$$

Then, credit is defined from the budget constraint of those that lend:

$$CR_t\left(b^L\right)(1-\theta_t) = \beta_b\left[\left(\frac{1}{\Omega_{t-1}}+\phi_t\right)L_{t-1}-\left(R_{t-1}-\tau_{t-1}\right)D_{t-1}(b)\right]+(1-\tau_t)\,D_t \quad \text{(A-35)}$$

A.3 Aggregation

The Household's budget constraint:

$$P_tC_t^h = W_tH_t + R_{t-1}D_{t-1} - D_t + \Gamma_t + T_t \tag{A-36}$$

Intermediate producer's profits:

$$\Gamma_t^{int} = P_t\left(Y_t - R_t^K K_{t-1} - \frac{W_tH_t}{P_t}\right) \tag{A-37}$$

Capital producer‘s profits:

$$\Gamma_t^{cap} = P_t\left(Q_t - 1\right)I_t \tag{A-38}$$

Entrepreneur‘s profits:

$$\Gamma_t^{ent} = P_t\left(R_t^K K_{t-1} - Q_tI_t\right) + CR_t - J_{t-1} \tag{A-39}$$

Total profits are:

$$\begin{aligned}\Gamma_t &= \Gamma_t^{int} + \Gamma_t^{cap} + \Gamma_t^{ent} \\ &= P_tY_t - W_tH_t - P_tI_t + CR_t - J_{t-1}\end{aligned} \tag{A-40}$$

After replacing total profits in the household‘s budget constraint, we obtain:

$$P_tC_t^h = P_tY_t - P_tI_t + CR_t - J_{t-1} + R_{t-1}D_{t-1} - D_t + T_t \tag{A-41}$$

The banker's budget constraint is:

$$P_tC_t^b + CR_t = J_{t-1} + D_t - R_{t-1}D_{t-1} - RR_t + RR_{t-1} \tag{A-42}$$

The central bank's budget constraint is:

$$T_t = -\left(T_t - T_{t-1}\right) = RR_t - RR_{t-1} \tag{A-43}$$

Summing up this three constraints, we have:

$$Y_t = C_t^h + C_t^b + I_t \tag{A-44}$$

which equation (3.39) in the main text.

B Appendix: The set of equations

B.1 The non-linear set of equations

B.1.1 Aggregate demand

Total demand [Y_t]:

$$Y_t = C_t + I_t. \tag{B.1-1}$$

Total Consumption [C_t]:

$$C_t = C_t^h + C_t^b. \tag{B.1-2}$$

Consumption of households [C_t^h]:

$$1 = \beta E_t \left[R_t \left(\frac{1}{\Pi_{t+1}} \right) \left(\frac{C_{t+1}^h}{C_t^h} \right)^{-\sigma} \right]. \tag{B.1-3}$$

Consumption of bankers [C_t^b]:

$$C_t^b = (1 - \beta_b) \left[\left(\frac{1}{\Omega_{t-1}} + \chi \phi_t \right) \frac{L_{t-1}}{P_{t-1}} - \left(R_{t-1} - \tau_{t-1} \right) \frac{D_{t-1}}{P_{t-1}} \right] \frac{1}{\Pi_t}, \tag{B.1-4}$$

where X_t/P_t is defined below.

Investment [I_t] :

$$Q_t I_t = \frac{CR_t}{P_t}. \tag{B.1-5}$$

B.1.2 Aggregate supply

Phillips curve [Π_t] :

$$\begin{aligned} \theta \left(\Pi_t \right)^{\varepsilon - 1} &= 1 - (1 - \theta) \left(\frac{N_t}{D_t} \right)^{1 - \varepsilon}, \\ D_t &= Y_t \left(C_t \right)^{-\sigma} + \theta \beta E_t \left[\left(\Pi_{t+1} \right)^{\varepsilon - 1} D_{t+1} \right], \\ N_t &= \mu Y_t \left(C_t \right)^{-\sigma} MC_t + \theta \beta E_t \left[\left(\Pi_{t+1} \right)^{\varepsilon} N_{t+1} \right]. \end{aligned} \tag{B.1-6}$$

Marginal costs [MC_t]

$$MC_t = \frac{1}{A_t} \left(\frac{R_t^K}{\alpha} \right)^{\alpha} \left(\frac{W_t/P_t}{1 - \alpha} \right)^{1 - \alpha}. \tag{B.1-7}$$

B.1.3 Labour market

Labour demand [H_t]:

$$H_t = \left(\frac{1}{1 - \alpha} \frac{W_t/P_t}{MC_t} \right)^{-1} Y_t \Delta_t. \tag{B.1-8}$$

Labour supply [$\frac{W_t}{P_t}$]:

$$\frac{W_t}{P_t} = \left(C_t^h \right)^{\sigma} H_t^v. \tag{B.1-9}$$

B.1.4 Capital market

Capital demand $[R_t^K]$

$$K_{t-1} = \left(\frac{1}{\alpha}\frac{R_t^K}{MC_t}\right)^{-1} Y_t\Delta_t. \tag{B.1-10}$$

Capital supply $[K_t]$:

$$K_t = I_t + (1-\delta) K_{t-1}. \tag{B.1-11}$$

Return of capital $[R_t^Q]$:

$$R_t^Q = \frac{1}{Q_{t-1}}\left[R_t^K + (1-\delta) Q_t\right]. \tag{B.1-12}$$

Arbitrage condition for capital $[Q_t]$:

$$E_t\left(R_{t+1}^Q\right) = E_t Q_t^{cr}\left(\frac{1+\frac{\lambda}{Q_{t+1}^{cr}}}{\Pi_{t+1}}\right). \tag{B.1-13}$$

B.1.5 Interbank market

Arbitrage condition between $CR_t\left(b^L\right)$ and $D_t\left(b^L\right)$: $[Q_t^{cr}]$

$$1 = Q_t^{cr}\left(\Omega_t^\tau + \Omega_t^\chi\right). \tag{B.1-14}$$

Evolution (supply) of Loans $[\frac{L_t}{P_t}]$:

$$\frac{L_t}{P_t} = \Omega_t Q_t^{cr}\frac{CR_t}{P_t} + \lambda\frac{\Omega_t}{\Omega_{t-1}}\frac{L_{t-1}}{P_{t-1}}\frac{1}{\Pi_t}. \tag{B.1-15}$$

Supply of credit (from balance of banks) $[\frac{CR_t}{P_t}]$:

$$\frac{CR_t}{P_t}(1-\theta_t) = \chi\left\{\beta_b\left[\frac{1}{\Omega_{t-1}}\frac{L_{t-1}}{P_{t-1}} - \left(R_{t-1}-\tau_{t-1}\right)\frac{D_{t-1}}{P_{t-1}}\right]\frac{1}{\Pi_t} + (1-\tau_t)\frac{D_t}{P_t}\right\}. \tag{B.1-16}$$

Flow of deposits net of the flow of reserves $[\frac{X_t}{P_t}]$

$$\frac{X_t}{P_t} = \frac{D_t}{P_t} - R_{t-1}\frac{D_{t-1}}{P_{t-1}}\frac{1}{\Pi_t} - \left(\frac{RR_t}{P_t} - \frac{RR_{t-1}}{P_{t-1}}\frac{1}{\Pi_t}\right). \tag{B.1-17}$$

Deposits supply $[\frac{D_t}{P_t}]$, from the budget constraint of the households

$$C_t^h = \frac{W_t H_t}{P_t} + R_{t-1}\frac{D_{t-1}}{P_{t-1}}\frac{1}{\Pi_t} - \frac{D_t}{P_t} + \frac{\Gamma_t}{P_t}. \tag{B.1-18}$$

B.1.6 Monetary policy

Taylor rule

$$R_t = \overline{R}\left(\frac{\Pi_t}{\Pi}\right)^{\psi_\pi}. \tag{B.1-19}$$

Reserve requirements rule

$$RR_t = \tau_t D_t. \tag{B.1-20}$$

and

$$\tau_t = \begin{cases} \overline{\tau} \\ \overline{\tau}\left[\frac{Q_t^{cr}}{R_t}/\frac{\overline{Q}^{cr}}{\overline{R}}\right]^{-\psi_1} \\ \overline{\tau}\left(\frac{\Pi_t}{\Pi}\right)^{\psi_2} \end{cases} \tag{B.1-21}$$

B.1.7 Other equations

$$\Omega_t = E_t\left[\frac{1}{R_t}\left(1+\lambda\Omega_{t+1}\right)\right]. \tag{B.1-22}$$

$$\Omega_t^\tau = E_t\left[\frac{1}{R_t^\tau}\left(1+\lambda\Omega_{t+1}^\tau\right)\right] \tag{B.1-23}$$

$$\Omega_t^\chi = E_t\left[\frac{\chi}{R_t^\tau}\left(\phi_{t+1}+\lambda\Omega_{t+1}^\chi\right)\right] \tag{B.1-24}$$

$$R_t^\tau = \frac{R_t-\tau_t}{1-\tau_t} \tag{B.1-25}$$

$$\frac{\Gamma_t}{P_t} = \left(Y_t - \frac{W_t}{P_t}H_t - I_t + \frac{CR_t}{P_t} - \frac{1}{\Omega_{t-1}}\frac{L_{t-1}}{P_{t-1}}\frac{1}{\Pi_t}\right), \tag{B.1-26}$$