Countercyclical Reserve Requirements in a Heterogeneous-Agent and Incomplete Financial Markets Economy*

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Abstract

For a long time reserve requirements fell into disuse as a countercyclical monetary policy tool. Recently, while developed countries struggled to deal the financial crisis, several emerging countries resorted to them as part of the macro-prudential policy toolkit. The apparent success of such non-conventional instruments in mitigating business cycle fluctuations raises the question whether they deserve full credit for that or some merit should be given to conventional instruments, like short-term interest rates. To answer this question, we use a dynamic stochastic general equilibrium model with risk-averse financial intermediaries, heterogeneous agents facing uninsurable idiosyncratic risk and a central bank that implements countercyclical policy using two instruments: short-term rates and reserve requirements. In this environment, in which agents' wealth matters for their consumption and savings decisions, we find that using reserve requirements as a countercyclical tool marginally helps to reduce the consumption volatility and that its effect becomes quantitatively relevant only if banks are sufficiently risk averse. Two factors drive our results: the presence of interest rate risk and the imperfect substitution between bank liabilities.

Keywords: monetary policy, reserve requirements, dynamic general equilibrium.
JEL Codes: C68, E32, E52.

1 Introduction

For much of the twentieth century, reserve requirements (henceforth RRs) were considered one of the main monetary policy instruments of policy makers. In many economies it fell into disuse as the monetary policy framework changed from controlling monetary aggregates to inflation targeting regimes. The occurrence of financial crises, especially in emerging countries, changed this view. These painful experiences led central banks and financial regulatory authorities to explore alternative and unconventional policy measures. For some, to avoid extreme scenarios, such as the above mentioned, abandoning the paradigm of using only one monetary policy instrument (the short-term interest rate) is a necessary condition to achieve macroeconomic and financial stability. This new approach to monetary policy has brought attention for the use of the so called "macro-prudential" tools designed to achieve macroeconomic and financial stability.

RRs are now part of this toolkit and policies aimed to influence the demand as well as the supply of reserves have also been part of this framework. Developed and emerging economies have implemented measures such as remuneration on reserves and changes in reserve requirements under complex frameworks and multiple objectives. For instance, in 2008 the Federal Reserve started to pay interest on reserve balances trying to align the average effective federal funds rate with the target rate. In this fashion, the Fed used the

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interest on reserves to dampen the interbank liquidity generated by its large injections of liquidity into the financial system (see Bech and Klee, 2011).

On the other hand, recently, emerging market economies have used RRs as a countercyclical tool to face upward inflation pressures and contain credit growth. Some of them have also used reserve requirements to deal against large capital inflows and alleviate real appreciations of their currencies. Montoro and Moreno (2011) document how Latin American emerging market economies used RRs as a supplemental countercyclical tool aimed to reduce (increment) the credit supply at the same time price stability was being pursued. This was the case of Brazil, Colombia and Peru which actively used average and marginal reserve requirements in order to complement their interest rate policy. During 2008, these emerging economies experienced the highest inflation rates in the second half of the decade and credit growth levels above 20 percent. However, the presence of the largest capital inflows in the latest five years, made inconvenient to raise interest rates for the central banks of these economies because of the risk of attracting even a higher level of foreign capital. In this context, the central banks used reserve requirements in a countercyclical fashion by raising them prior to the Lehman Brothers bankruptcy, and lowering them after the crisis started. Other countries such as India, Malaysia and Turkey have used RRs as the main instrument to pursue financial stability.

These practices have renewed the interest on studying the macroeconomic effects of RR policies. Glocker and Towbin (2012) propose a general equilibrium model to study the effectiveness of different reserve requirements policies aimed to achieve price and financial stability. Their conclusions indicate that in a frictionless economy with inflation targeting, RR policies have very small effects on economic stability. However, its impact becomes more important as financial frictions appear. Areosa and Coelho (2013) find a similar result by augmenting the model of Gertler and Karadi (2011) to include a compulsory reserve requirement ratio. Their model is a New-Keynesian DSGE model with financial intermediaries facing endogenous balance sheet constraints, which in turn generates imperfect substitutability in the intermediaries' funding structure. After estimating the model for the Brazilian economy, Areosa and Coelho conclude that the effect of a monetary policy shock to the interest rate is much stronger than the one to the reserve requirement ratio despite both shocks yielding similar dynamics in the macroeconomic aggregates.

Cúrdia and Woodford (2011) and Ireland (2012) have also researched on the role of RR policies in a general equilibrium context. Cúrdia and Woodford (2011) propose a model where monetary policy can operate controlling the supply of reserves or the interest paid on them. They are focused in assessing the importance of RR policies and the central bank's balance sheet when monetary policy reaches the zero lower bound. Meanwhile, Ireland (2012) studies the macroeconomic effects of paying interest on reserves and the additional degrees of freedom a monetary authority obtains with this tool. His results point out that a policy of remuneration on reserves has little effect on output and inflation, but that such effect can be larger for less developed financial systems.

Kashyap and Stein (2012) note the importance of RR policies to augment the possibilities of central banks to achieve financial stability while more traditional monetary policy tools can be used to deal with the inflation-output tradeoff. They find that reserve requirements could be considered as a Pigouvian tax used to internalize the externalities generated by high short-term debt exposition of financial intermediaries. Kashyap and Stein also suggest that RR policies, such as contraction in reserves supply, provide a useful tool when facing credit bubbles.

In this paper we study, in a general equilibrium framework, the macroeconomic effects of a countercyclical RR policy in presence of interest rate risk. In particular, we are interested in understanding if the apparent success of countercyclical RR policies implemented by several countries before and after the most recent financial turmoil could be explained by the use of reserve requirements *per se*, or because reserve requirements reinforced the effect of the traditional interest rate policy. In the context of an inflation targeting regime, there are two main factors determining the effectiveness of RRs. The first one is the interest rate risk, i.e. the mismatches between the repo rate and the commercial interest rates. When financial intermediaries try to hedge against this risk, they affect the deposits interest rate and therefore the deposits supply. The other factor is the imperfect substitutability between banks' funding sources. As the costs of getting funds through deposits increase when the RR is raised, the presence of imperfect substitution makes harder for the financial intermediaries to replace these funds with central bank credit. This feature opens a gap where the RR policy can act in order to affect the supply of credit. In absence of imperfect substitution, changes in the RR would have no effect on loans interest rates because banks can fully accommodate their funding structure.

Betancourt and Vargas (2009) find empirical support for this hypothesis for Colombia. Their empirical findings show that increasing the RR generates a more expensive financial intermediation (i.e. an increase in the spread between loans and deposits interest rates) because of the uncertainty about the policy rate. This allows to reduce credit demand and to control inflationary pressures. These results are in line with the analysis in Romer (1985), who concludes that in an OLG model with financial intermediation, changing the RR not necessarily affects inflation directly, but it does so through the adjustment of market interest rates and banks' balance sheets.

Our model extends the Diaz-Gimenez et al. (1992) and Aiyagari (1994)'s general equilibrium models by including financial intermediaries in order to analyze the role of reserve requirements. In our set up, households face both aggregate and uninsurable idiosyncratic shocks in a context of borrowing constraints. We solve the model by using non-linear approximation methods for the stationary equilibrium and the economy dynamics. We find that the presence of interest rate risk and the subsequent imperfect substitutability between financial intermediaries' funding sources allow for the countercyclical RR policy to be employed as a useful complementary instrument to mitigate business cycles fluctuations. Our results also suggest that RRs are not as powerful as interest rates when dealing with macroeconomic volatility.

In this context, and although the works of Glocker and Towbin (2012) and Areosa and Coelho (2013) are closely related to our paper, the model we present accounts for the redistributive effect of interest rates and reserve requirements policies in a context of occasionally binding constraints and interest rate risk. This analysis cannot be carried out using the traditional framework of linearized dynamic stochastic general equilibrium models used by Glocker and Towbin (2012) and Areosa and Coelho (2013). In this way, our paper contribution is to allow for an exploration of other dimensions of the policy problem.

This paper is organized as follows. After this introduction, we present the model of a closed economy in Section 2. In this version of the model, we assume that banks can only obtain funds domestically. We first explain in detail this model in order to isolate and understand what the transmission channel of a countercyclical reserve requirement policy is. With this initial objective in mind, we calibrate the closed economy model in Section 3, and later we present a complete and detailed set of results for it in Section 4. In this section we perform several exercises aiming to gauge the influence of reserve requirements in the financial markets and in the households' decision rules. In addition, and more importantly to the objective of this paper, we assess the effectiveness of different countercyclical monetary policy rules as business cycle stabilizers. These rules include the RR (i) as an independent tool, (ii) as a complement of the interest rate, and (iii) as a last resort instrument. Later, and taking into account that reserve requirements have been uses mainly by emerging market economies with access to foreign debt, in Section 5 we extend the closed economy model to allow for the intermediaries to issue debt on the international financial markets. Using this extended model, we simulate what the effect of different monetary policies considering RRs independently or as a complement of an interest rate policy is. Finally, we make some concluding remarks in Section 6.

2 A closed economy model

We start by considering the case of a closed economy. This allow us to isolate the effect of RRs in the most simple framework given the characteristics of our modeling strategy. The model presented here considers a closed economy with three types of agents: households, financial intermediaries and a central bank. The model is similar to the one of Aiyagari (1994) with some important modifications. The economy experiences aggregate shocks that determine the part of the cycle in which it is, namely, good times or bad times. In addition, households face non-insurable idiosyncratic income shocks. Income shocks generate heterogeneity among households since the conditions with which they begin each period depend on the history of shocks that each household has received.

Households have access to two types of financial assets, loans and deposits. While Aiyagari (1994) considers the existence of a unique asset that can be bought by households for self-insurance and to smooth consumption without any cost, here the financial intermediation is costly. In particular, financial intermediaries require real resources to manage and monitor a given level of loans and deposits. This implies that the financial intermediation process generates a differential between deposits and loans interest rates that does not arise from credit risk (default). We assume that both households and banks fully honor their contracts.

The way financial intermediaries are modeled is based on Diaz-Gimenez et al. (1992) and Betancourt and Vargas (2009). The intermediation of resources between savers and borrowers is carried out by many homogeneous banks operating in a perfectly competitive market. Banks only have access to one type of asset: loans. The funds needed for the acquisition of this asset comes from two sources: households' deposits and central bank resources. Given that we have a closed economy, we rule out the possibility of banks obtaining funds in the international capital markets, although this special case is considered later in Section 5. If intermediaries are funded with deposits, they must satisfy a reserve requirement that is set by the central bank. If they are funded with central bank resources, banks face interest rate risk because the contract with the monetary authority provides that the interests are paid depending on the next period policy rate. Thus, the interest rate risk emerges because commercial banks have a mismatch between the interest rate at which they get additional resources with the central bank and the interest rates for loans and deposits.

The model assumes that the central bank has two instruments to carry out monetary policy: the interest rate at which it lends to commercial banks and an unremunerated reserve requirement. The way in which it sets its policy depends on the state of the economy. For example, when the economy is in good times the central bank has room to increase the intervention rate and/or raise the reserve requirement in order to make resources more expensive to financial intermediaries. In turn, the monetary policy affects the structure of interest rates and the assets allocation of the entire economy, implying a reduction in household spending and aggregate demand. Hence, if the monetary authority is aiming to reduce or stimulate aggregate demand in line with the cyclical conditions of the economy, it could potentially use these two instruments in a countercyclical manner.

This artificial economy allows us to implement quantitative experiments on the impact of these two instruments and, in particular, answer the question that concerns us: how complementary or substitutes are the policy rate and the RR for the conduct of monetary policy? Below we present the detailed structure of the model.

2.1 The state of the economy

The economy faces an aggregated endowment shock at the beginning of each period that affects the decisions of all agents. At each period, the economy is in a state $z_t \in \mathcal{Z} = \{1, 2, \ldots, n_z\}$. This shock follows an exogenous process determined by a first order Markov chain with conditional transition probabilities given by

$$\pi_z(z'|z) = \Pr(z_{t+1} = z'|z_t = z) \tag{1}$$

The economy-wide shock affects positively the income of households, so better realizations of z are reflected in an increased economic activity. As it will be discussed below, the monetary policy responds counter-cyclically to the realizations of z_t.

2.2 Central bank

The central bank counts with two monetary policy instruments: the policy interest rate $r^p(z_{t+1})$, at which it lends to commercial banks, and the reserve requirement $\rho(z_t)$. The monetary authority uses these policy instruments to influence borrowing and saving decisions of households by affecting the cost of resources at with which financial intermediaries fund new loans. The state of the economy fully determines the monetary policy rule followed by the central bank for each one of its instruments. In the case that concerns this paper, the central bank will follow countercyclical rules in both instruments, meaning that the better the aggregated state of the economy is, the higher the policy rate and the reserve requirement will be. Finally, we assume that the monetary authority supplies *repo* loans in a perfectly elastic way.

2.3 Households

There exists a continuum of households indexed by $i \in (0, 1)$. They are infinitely lived, and only derive utility from consumption. Households maximize their expected lifetime utility

$$\max \ \mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_{i,t}) \tag{2}$$

where $\beta \in (0,1)$ is the intertemporal discount factor, $u(\cdot)$ the instantaneous utility function and $c_{i,t}$ the consumption of household i on period t. Households face non-insurable idiosyncratic shocks to their income. Moreover, in each period they can receive one of the $n_s n_z$ different income levels available in the economy. Such income depends on two factors: an idiosyncratic component s_t and the aggregate shock. The idiosyncratic factor belongs to a finite set $\mathcal{S} = \{1, 2, \ldots, n_s\}$. It affects the set of households' consumption opportunities and follows a first order Markov chain with only one ergodic set, non absorbent states, and transition probabilities given by

$$\pi_s(s'|s) = \Pr(s_{t+1} = s'|s_t = s) \tag{3}$$

As described before, the state of the economy also affects households' income. In particular, household i's income on period t is given by $z_t s_{i,t}$. We assume that there are not private insurance markets, so households use the banking sector in order to smooth consumption and eliminate the effect of income fluctuations on their utility. They can accumulate financial assets by saving deposits in the financial sector $d_{i,t}$, or disaccumulate them by taking up loans $l_{i,t}$. Net financial assets at the beginning of period t are given by the difference between deposits and loans, and are denoted by $a_{i,t}$. We also assume that interests on deposits and loans are paid in advance. Given this set up, household i faces the following budget constraint:

$$c_{i,t} + a_{i,t+1} \leq a_{i,t} + z_t s_{i,t} + d_{i,t+1} r_t^d - l_{i,t+1} r_t^l \tag{4}$$

where r_t^d and r_t^l are the interest rates on deposits and loans purchased at t. The net financial assets are defined as:

$$a_{i,t} = d_{i,t} - l_{i,t} \tag{5}$$

Finally, households face a natural borrowing constraint: their debt in each period can not exceed what their lifetime income could repay if they receive the worst income shocks by infinite periods. This is:

$$a_{i,t+1} \geq \phi = -z_1 s_{i,1}/r^l \tag{6}$$

Then, the dynamic programing problem of household i is[1]

$$v(a, s|z, \mu) = \max_{c,a',l'} \; u(c) + \beta \sum_{z',s'} \pi(z', s'|z, s) \, v(a', s'|z', \mu') \tag{7}$$

subject to (4), (5) and (6). In the problem above, $\pi(z', s'|z, s)$ denotes the joint transition probability of moving from state (z, s) to state (z', s'). When solving the households problem we suppose that they do not choose to have deposits and loans simultaneously, hence $a' > 0$ if they make deposits, and $a' < 0$ if they ask for loans. In the previous expression μ refers to the economy-wide net financial assets distribution function. When the bank's problem is presented, it will become clear that the equilibrium interest rates depend on this distribution function.

The optimality conditions for the problem in (7) implies that the Euler equation is

$$\beta \mathrm{E}_t [u'(c_{t+1})] = u'(c_t) \left\{1 + q_t r_{t+1}^d + (1 - q_t) r_{t+1}^l\right\}, \tag{8}$$

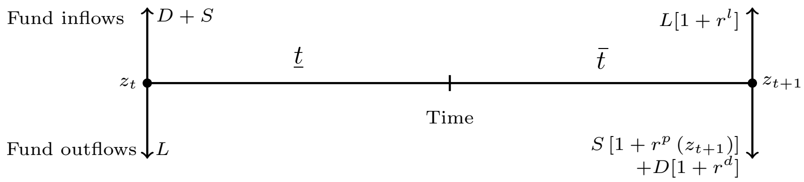
where q_t is a dichotomous variable that is equal to 1 if the household makes deposits, and 0 if it ask for loans. Off course, this optimality condition is only valid when the natural borrowing constraint is not binding. Note that household must form expectations over the interest rates, which means taking into account μ', hence the distribution function becomes a state variable.

2.4 Financial intermediaries

Following Diaz-Gimenez et al. (1992), we suppose the existence of a continuum of banks of unitary mass operating in perfect competition, with free entry and exit and with a constant returns to scale technology in the production of deposits and loans. Each bank intermediates resources between saver households buying D_t, and borrower households acquiring an amount L_t of debt.

[1] As usual in dynamic programing literature, we set $x = x_t$ and $x' = x_{t+1}$.

Figure 1: Commercial bank's flow of funds at t



Besides having deposits as a funding source, banks can access resources S_t through repo operations with the central bank at the interest rate $r^p_{t+1}\left(z_{t+1}\right)$. This rate is unknown when choosing S_t since it depends on the aggregate shock's future realization. In addition to this, they face an unremunerated reserve requirement set by the monetary authority. This means that they must have a fraction of $\rho\left(z_t\right)$ of their deposits as non-interest-bearing reserves R_t. In order to reflect the observed spread between deposit and lending rates, it is assumed that financial intermediation is costly. The costs per unit of deposits and loans are denoted by κ_d and κ_l, respectively.

Following Betancourt and Vargas (2009), we assume that the representative bank's problem in each period can be divided into two sub-periods, $t = \left\{\underline{t}, \bar{t}\right\}$. In $\underline{t}$ the intermediary observes credit demand and deposits supply determined by households when solving their problem. Given this, the bank chooses the amount of repo loans it wants to borrow from the central bank. However, as described before, commercial banks are uncertain about the interest rate that the monetary authority will charge for those loans, since the rate at which they must repay them depends on the future state of the economy at the end of $\bar{t}$. Given that financial intermediaries do not know such rate at $\underline{t}$, they face interest rate risk. Such risk is transferred to active and passive interest rates. At $\bar{t}$, banks repay the *repo* loans at the rate set by the central bank given the new aggregated conditions, $r^p_{t+1}\left(z_{t+1}\right)$. In addition, they pay interests over deposits and receive interests on loans. The bank's flow of funds in each period is summarized in Figure1.

In this context, the representative bank intratemporal problem is to maximize its expected utility derived from its flow of funds w, subject to its balance sheet constraint and to the compulsory reserve requirement. Given the intratemporality of the problem, we can drop the time subscripts. Then, the problem can be written as:

$$\max_{L,D,R,S} \mathrm{E}\left[u_b\left(w\right)\right]$$

subject to

$$L = D + S - R \tag{9}$$

$$R \geq \rho\left(z\right) D \tag{10}$$

We suppose that commercial banks have a CARA utility function that depends on the value of the net flow of funds

$$u_b\left(w\right) = -\exp\left\{-\sigma w\right\} \tag{11}$$

where σ is the absolute risk aversion coefficient. Taking into account the interest rate risk, the expected value of the flow of funds of the financial intermediary is given by

$$\mathrm{E}\left[w|z\right] = \left(D + S - L - R\right) + R + L\left(1 + r^l\right) - D\left(1 + r^d\right) - S\left(1 + \mathrm{E}\left[r^p|z\right]\right) - \kappa\left(D, L\right) \tag{12}$$

and

$$\kappa\left(D, L\right) = \kappa_d D + \kappa_l L$$

where expectations are taken given z because the intermediary has not observed the realization of z' but knows the current state of the economy and its transition probabilities. Since reserves are unremunerated, they generate an opportunity cost for the bank (in terms of resources otherwise lent to households), this ensures that the reserve requirement constraint in (10) holds with equality at the optimum. After substituting (9) and (10), (12) becomes

$$\mathrm{E}\left[w|z\right] = \left(D\left(1 - \rho\right) + S\right) r^l - D r^d - S\mathrm{E}\left[r^p|z\right] - \kappa\left(D, L\right) \tag{13}$$

Now, using the mean-variance representation of the constant absolute risk aversion utility function, the representative bank's problem can be rewritten as:

$$\max_{D,S} \quad \mathrm{E}\left[w|z\right] - \frac{\sigma}{2}\mathrm{Var}\left[w|z\right]$$

subject to (13). Here $\mathrm{E}\left[w|z\right]$ is as in (13) and

$$\mathrm{Var}\left[w|z\right] = S^2\mathrm{Var}\left[r^p|z\right] \tag{14}$$

Since the representative bank is in perfect competition, the solution for the optimal demand of deposits and repo loans takes as given the values of $\mathrm{E}\left[r^p|z\right]$ and $\mathrm{Var}\left[r^p|z\right]$. In addition, banks take as given households' deposits supply and credit demand, which in turn takes into account the financial intermediaries decisions to determine the equilibrium interest rates, reflecting the recursivity of the problem. After solving this problem we derive the following expressions for lending and deposit rates:

$$r^l = \mathrm{E}\left[r^p|z\right] + \sigma S\mathrm{Var}\left[r^p|z\right] + \kappa_l \tag{15}$$

$$r^d = (1-\rho)\left(r^l - \kappa_l\right) - \kappa_d \tag{16}$$

From the optimality conditions of the bank's problem we get that the spread between active and passive interest rates depends on the costs per unit of deposits and loans, and the reserve requirement. The spread may be written as

$$r^l(1-\rho) - r^d = \kappa_l(1-\rho) + \kappa_d \tag{17}$$

The above expression is in line with the literature, which states that the spread reflects the costs of financial intermediation, in our case, the production costs and the opportunity cost of maintaining reserves.

Now, how does the interest rates affect the borrowing constraint faced by commercial banks with the monetary authority? From equation (17) one may conclude at first glance that neither the interbank rate, nor its uncertainty affect the spread. However, these factors do affect the interest rates values, since they reflect the implicit cost of funding that arises when banks request additional funds through repo loans.

In order to close the problem of the financial intermediaries, note that, in equilibrium, banks satisfy their balance sheet constraint, i.e.

$$L^d\left(r^l\right) = (1-\rho)D^s\left(r^d,\rho\right) + S\left(r^d, r^l, \mathrm{E}\left[r^p|z\right],\rho\right) \tag{18}$$

where $L^d\left(r^l\right)$ is the credit demand and $D^s\left(r^d,\rho\right)$ is the deposits supply. Given this, the repo loans demand is

$$S\left(r^d, r^l, \mathrm{E}\left[r^p|z\right],\rho\right) = L^d\left(r^l\right) - (1-\rho)D^s\left(r^d,\rho\right) \tag{19}$$

This expression reflects the channel through which monetary policy operates: changes in the policy rate or in the reserve requirement affect directly the funding scheme of the intermediary with the central bank, which in turn is transmitted to the saving and lending rates of the economy (equations (15) and (16)), affecting households' borrowing and saving decisions.

In this context, the impact of a change in the reserve requirement depends negatively on the degree of substitutability between deposits and repo loans. Here, the financial intermediaries' degree of risk aversion generates the adequate conditions needed by monetary policy. To see this, first note that since there is interest rate risk, the change in repo loans demand in response to changes in the reserve requirement is given by

$$\frac{dS}{d\rho} = -\frac{\left[D^s + (1-\rho)D^s_{r^d}\left(\mathrm{E}\left[r^p|z\right] + \sigma S\mathrm{Var}\left[r^p|z\right]\right)\right]}{\sigma\mathrm{Var}\left[r^p|z\right]\left\{L^d_{r^l} - (1-\rho)^2 D^s_{r^d}\right\} - 1} > 0 \tag{20}$$

Thus, the more risk averse are intermediaries, the less the repo loans demand will increase, i.e. it holds that $d^2S/\left(d\rho d\sigma\right) < 0$. By contrast, in the case of absence of interest rate risk, or if banks were risk-neutral, the intermediaries would seek as much liquidity as they are loosing due to increases in the reserve requirement, that is

$$\frac{dS}{d\rho} = D^s + (1-\rho) D_{r^d} r^p \tag{21}$$

Based on these results, we can say that the change in the demand for repo loans to changes in the reserve requirement will be lower when financial intermediaries are risk averse if it holds that $S < (1-\rho)^2 D_{r^d} \mathrm{E}[r^p|z] - L_{r^l} \mathrm{E}[r^p|z]$.[2] When this happens, changes in the reserve requirement are not fully offset in the interbank market by a central bank following an interest rate rule, guaranteeing that a monetary policy that uses the reserve requirement has an effect on the desired direction.

2.5 Equilibrium

The recursive competitive equilibrium is a value function $v(a,s|,z,\mu)$, individual policy rules for household consumption $c(a,s|z,\mu)$ and and next period net financial assets $a'(a,s|z,\mu)$, a relative price vector $\{r^l(z,\mu), r^d(z,\mu)\}$, a law of motion for the distribution of households over the individual state variable $\mu' = G(\mu,z,z')$ and a vector of aggregates $\{A,D,L,C,S,R\}$ such that, given the central bank policy rules $r^p(z')$ and $\rho(z)$:

1. Aggregated net financial assets, deposits, loans, repo loans, reserves and consumption, are obtained by aggregating over households

$$\begin{aligned} A' &= \sum_{s\in S} \int_{\phi}^{\infty} a'(a,s|z,\mu)\ d\mu & \qquad D &= \sum_{s\in S} \int_{\phi}^{0} a'(a,s|z,\mu)\ d\mu \\ L &= \sum_{s\in S} \int_{0}^{\infty} a'(a,s|z,\mu)\ d\mu & C &= \sum_{s\in S} \int_{\phi}^{\infty} c(a,s|z,\mu)\ d\mu \\ R &= \rho D & S &= L-(1-\rho)D \end{aligned}$$

2. The functions $c(a,s|z,\mu)$ and $a'(a,s|z,\mu)$ are optimal decision rules and solve the household's decision problem in (7).

3. The dynamics of the distribution of the individual state are described by

$$\mu' = G(\mu,z,z')$$

4. The market clears, i.e. $C + A' + \kappa(D,L) = A + \sum_i s_i z$.

5. The active and passive interest rates clear financial markets: equations (16) and (15) hold.

3 Calibration

The parameters are calibrated to match some moments of the Colombian data for the period 1994-2009. We take the case of Colombia because it was one of the emerging economies that have recently used a countercyclical reserve requirement policy. Nevertheless, since the model does not have any particular characteristic of the Colombian economy (aside the RR policy), we believe that this framework can be applied to any other economy using reserve requirements actively. The details of the solution method we use are presented in the Appendix.

We fix the length of a period to be one quarter of a year. We use a CRRA instantaneous utility function for households:

$$u(c) = \frac{c^{1-\theta}}{1-\theta}$$

and we set $\theta = 3$, a common value used in the literature.

[2]This condition is satisfied in the numerical exercises presented below.

The parametrization assumes the existence of 10 individual income states, resulting from five states for the idiosyncratic shock ($n_s = 5$) and two aggregated states ($n_z = 2$): good and bad times. The values for the aggregated shock in good times z_g, and in bad times z_b were taken from the 25 and 75 percentiles of the cyclical component of the quarterly Colombian GDP.[3] Thus, our calibration of this process implies that in good times the income of the economy increases 3.6 percent, while in bad times the income experiences a reduction of 4.76 percent, i.e. $\mathcal{Z} = \{z_g, z_b\} = \{1.0368, 0.9524\}$.

The Markov chain transition matrix for the economy-wide shock, z, is chosen according to Arango et al. (2007). They find that the average Colombian business cycle duration for the period 1980-2007 was 45.6 months, with a probability of 34 percent for the economy to be in recession and 66 percent to be in expansion. Given this, the calibrated transition matrix is

$$\Pi_z = \begin{pmatrix} \pi_{g|g} & \pi_{g|b} \\ \pi_{b|g} & \pi_{b|b} \end{pmatrix} = \begin{pmatrix} 0.9003 & 0.0997 \\ 0.1935 & 0.8065 \end{pmatrix} \tag{22}$$

The values for the idiosyncratic income shock, as well as its transition matrix, are computed using Tauchen (1986)'s methodology in order to approximate the following autoregressive process of order 1 for $\log s_t$:

$$\log s_t = \rho_s \log s_{t-1} + \varepsilon_t, \qquad \varepsilon_t \sim N\left(0, \sigma_s^2\right)$$

We calibrate the parameters of this idiosyncratic process to replicate the average ratios of deposits and outstanding loans to GDP under a reserve requirement equal to 7 percent (mean RR in the same period). More precisely, we target a ratio of deposits to output of 1.021, and a ratio of loans to output of 1.005. The parameters determining the cost of financial intermediation, κ_d and κ_l, are calibrated jointly to generate an average spread between lending and savings rates of 7.34 percent (the average spread for the period 1994-2009). The financial intermediaries' absolute risk aversion coefficient was calibrated to be consistent with the estimations of the relative risk aversion coefficient in emerging market economies. Traditionally, this latter coefficient has been determined to lie between 1 and 5. Using the average ex-post financial sector profits of or model, we calibrate $\sigma = 15$ to generate a relative risk aversion coefficient close 1. Finally, the discount factor β, is set to generate an implicit real interest rate of 2.5 percent. A summary of the parameter values is presented in Table 1.

Table 1: Model parameters

Parameter	Value	Parameter	Value
θ	3.0	κ_l	0.0144
β	0.9938	ρ_s	0.70
σ	15.0	σ_s^2	0.5685
κ_d	0.0022		

4 Results and quantitative analysis

In this section we discuss the quantitative results of the model. First of all, we describe the deposits and credit markets and explain what determines the equilibrium in each one. Then, we present an analysis of how the reserve requirement affects the stationary equilibrium of the economy. Finally, in Subsections 4.3 and 4.4 we examine the effectiveness of different types of monetary policy through simulations used to quantify the reduction in the volatility of consumption and financial assets achieved when (i) the RR is used simultaneously with the interest rate and, (ii) when it is employed as an instrument of last resort.

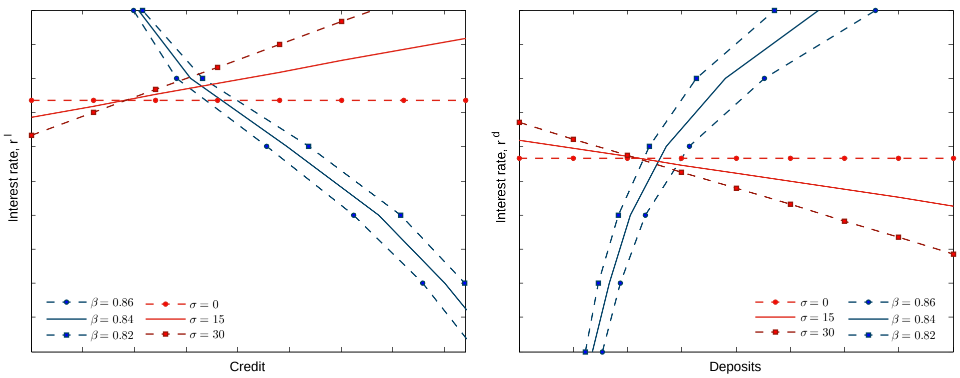
4.1 Financial markets

We start our analysis by describing and illustrating what characteristics from both households and financial intermediaries determine the equilibrium in the credit and deposits markets. Credit demand is made by households and is determined as the result of households solving the dynamic programming problem in (7).

[3] GDP is measured in logarithms, and the cyclical component is extracted with a HP filter.

Figure 2: Financial assets markets

(a) Credit market **(b)** Deposits market



The solution of this problem yields that the higher the lending rate, the lower the credit demand is. The sensitivity of the credit demand against the interest rate is directly related to the households' discount factor, β. The more a household value present consumption, i.e. the lower β, the higher the credit demand will be. However, at the same time the credit demand becomes more sensitive to the interest rate because of the concavity of the utility function.

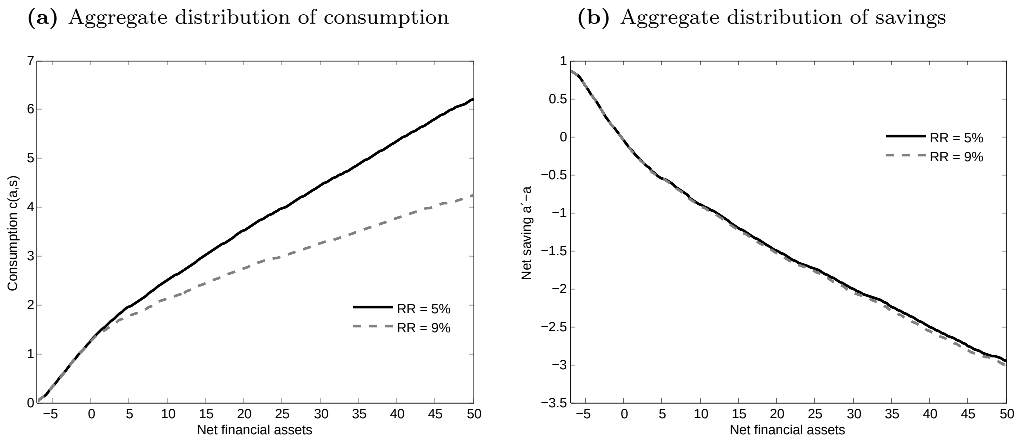
On the other hand, credit supply is affected by the degree of uncertainty faced by financial intermediaries with respect to the interest rate at which they have to repay the repo loans. Thus, the slope of the credit supply (which is obtained for a fixed deposit levels) depends on the variance of the policy rate and the coefficient of absolute risk aversion of bankers, this is $\sigma \mathrm{Var}\left(r^p\right)$. This means that if a bank is more risk averse, it will charge a higher interest rate on loans to compensate the risk it has to face when borrowing resources from the central bank. A risk neutral bank, i.e. $\sigma = 0$, has a horizontal credit supply at $r^l = \mathrm{E}\left[r^p|z\right] + \kappa_l$.

Although not explicitly modeled in this paper, the degree of risk aversion can generate a multiplier effect in the credit market that may enhance the effect of monetary policy. It is well known that in times of economic downturn, commercial banks raise their requirements for new loans. Thus, it is reasonable to think that financial intermediaries are more likely to assume extra risk in booms, which in terms of the model could be translated into a countercyclical risk aversion coefficient. This would imply a steeper credit supply curve in times of recession. To illustrate this effect, the simulations performed in Subsection 4.3 consider different coefficients of absolute risk aversion. Figure 2a shows supply and demand of credit in the stationary equilibrium. The demand curves are computed for a fixed level of deposits and different discount factors. The Figure also shows how credit supply changes for different levels of σ.

Now, in a partial equilibrium context, we can obtain deposits supply by aggregating asset holdings across households with positive wealth for different deposit interest rates. As happens with credit demand, the slope of the deposits supply depends on the intertemporal discount factor: if households value more future consumption relative to present consumption their deposits supply will be higher, and more sensitive to the interest rate. Again this occurs by the curvature of the utility function, and more specifically by the degree of households' risk aversion.

Meanwhile, as occurs with the credit supply, the slope of the deposits demand depends on the degree of uncertainty regarding r^p: the higher the uncertainty about r^p for a fixed credit level, the lower the deposits rate. If uncertainty is not relevant for a commercial bank, that is, if the bank is risk neutral, its deposits demand curve is horizontal. We perform the same exercise that was done previously for the credit market, but now for the deposits market. The results are shown in Figure 2b.

Figure 3: Consumption and savings in the stationary equilibrium



4.2 Effect of reserve requirements on the decision rules

Here we compute the individual household's policy rules in an hypothetical stationary equilibrium where z is set equal to 1 for every period.. This allow us to understand how the reserve requirement affects consumption and saving decisions. In particular, in the exercise presented below we obtain the distribution of consumption and net financial assets for two different levels of RR, namely $\rho = \{0.05, 0.09\}$. As shown in Figure 3a, the reserve requirement affects negatively consumption levels. Such effect is concentrated on households with positive net financial assets. Similarly, a higher RR discourages saving and increases net borrowing particularly on households with higher financial assets. At the same time, the net financial assets distribution function changes and credit demand increases.

To see why this happens, note that reserve requirements directly affect lending and deposit rates (equations 15 and 16). The former is positively affected because when banks are required to have higher reserves they must increase their repo borrowing, which in turn translates into more expensive loans and a lower credit demand. Thus, consumption of households that rely on borrowing to finance it is negatively affected. However, since a higher ρ also reduce deposit rates, saving levels are also lower. Therefore, the mixed effect of this yields that changes on deposit and lending rates generate lower levels of private consumption and thus in higher welfare cost.

4.3 Reserve requirements and interest rate policies to smooth business cycles

We now perform a set of simulations of the economy described before with the idea of determining if interest rates and reserve requirements are complementary or substitutes. We consider four different monetary policy set ups: (i) a scenario in which the central bank controls counter-cyclically both instruments, (ii) a scenario in which the monetary authority only manages the interest rate in a countercyclical manner while the reserve requirement remains fixed, and (iii) another in which the opposite occurs. The first scenario is used to determine the possible complementarities between both instruments, while the other two help to assess their substitutability. In order to have a benchmark, we consider an extra scenario in which the monetary policy does not react to the state of the economy and sets a constant value for both instruments.

We calibrate each policy using results from other studies for Colombia. According to González et al. (2011), for the period 2000-2010, the real 90-day interest rate has fluctuated between 0.53% and 5.24%. These values are used to set the central bank interest rate rule: the central bank sets a reference rate equal to $\overline{r}^p = 1.29\%$ (5.24% annual) in good times and $\underline{r}^p = 0.13\%$ (0.53% annual) in bad times. Similarly, given that the ratio of reserves to liabilities moved between 5% and 9% for the same period, we set $\overline{\rho} = 9\%$ when the economy is in good times, and $\underline{\rho} = 5\%$ if the opposite occurs. Therefore, a set of countercyclical rules in both instruments is given by:

$$r^p = \begin{cases} \overline{r}^p & \text{if } z' = z_g \\ \underline{r}^p & \text{if } z' = z_b \end{cases}, \qquad \rho = \begin{cases} \overline{\rho} & \text{if } z = z_g \\ \underline{\rho} & \text{if } z = z_b \end{cases} \tag{23}$$

In the alternative scenarios in which one particular instrument remains fixed, we use the mid-point of the values stated above.

For each of these scenarios, we simulate the economy for $T = 10,000$ periods. The effectiveness of these countercyclical monetary policy rules will be measured by the volatility of aggregate variables, namely, consumption and net financial assets. In this context, we say that a particular monetary policy is more effective than another if it generates lower volatility on macroeconomic aggregates.

In addition, and in order to reflect the importance of the financial intermediaries' degree of risk aversion in the transmission of monetary policy, the simulation results presented below consider three different values for the absolute risk aversion coefficient, $\sigma = \{0, 15, 30\}$. The variance of consumption and net financial assets for all four scenarios and the three different values of the absolute risk aversion coefficient are presented in Table 2.

The results show that any scenario in which monetary policy is countercyclical is preferably to the one where the central bank does not react to the state of the economy. This is clear from the reduction in the variance of consumption and net financial assets. It is also necessary to stress that the channel through which reserve requirements operate requires banks to be risk averse. If banks are risk neutral ($\sigma = 0$), the interest rate risk is not relevant in the financial intermediaries problem since there is perfect substitutability between deposits and repo loans as funding sources. In other words, as the uncertainty does not affect the demand for repo loans, its cost is not transferred to loans interest rates. It is precisely for this reason that the reduction of consumption and net financial assets volatility is zero when $\sigma = 0$ if we compare a countercyclical policy on the reserve requirement with an inactive monetary policy. For the same reason, as σ increases the RR effect gets larger. Behind this result we have the fact that when risk aversion is higher credit supply and deposits demand are steeper, which implies that the equilibrium interest rates in these markets are more sensitive to changes in the reserve requirement.

Regarding the effectiveness of each policy, the results lead us to one of the major conclusions of this paper: using countercyclical reserve requirements is not as effective as a countercyclical rule for the interest rate. However, reserve requirements can reinforce the effect of the interest rate rule and that contribution gets more significant as the degree of intermediaries' risk aversion increases.

To illustrate this result, Table 2 shows that a RR-only policy (the second less-effective monetary policy) reduces 3.52% and 4.23% the variance of consumption for $\sigma = 15$ and $\sigma = 30$, respectively. Similarly, for the same values of σ, the variance of net financial assets is lowered by 0.16% and 0.24%. Note that the higher σ, the larger the effect of a countercyclical RR policy. Figure 4 summarize graphically this result.

However, while the RR policy achieves to reduce the variance of consumption and net financial assets if $\sigma > 0$, its effect is less powerful when compared to a countercyclical interest rate policy. This policy is more successful in reducing the volatility of the business cycle. Its implementation reduces the variance of consumption and net financial assets by 11.79% and 0.77% when $\sigma = 15$, a result that supports its use as the main monetary policy tool in most countries.

Finally, since the use of reserve requirements helps to reinforce the effect of a countercyclical interest rate, our results indicate that, whatever the structural conditions that affect the financial intermediaries decisions are, the best choice for the central bank is to make use of both policy instruments. In particular, in the scenario in which both instruments are used in a counter-cyclically manner, the volatility of consumption is reduced in 7.61%, 12.63% and 17.03% for $\sigma = \{0, 15, 30\}$, respectively.

4.4 Reserve requirement as last resort instrument

Given that some economies have appealed to reserve requirement policing when dealing with extreme situations, we now perform quantitative exercise to assess the effectiveness of reserve requirements when used as an instrument in extreme situations. More precisely, since the central bank may face a lower limit when setting its intervention rate (known as the zero lower bound), we explore how successful it is to make use of the RR when it is not possible to further reduce the interest rate.

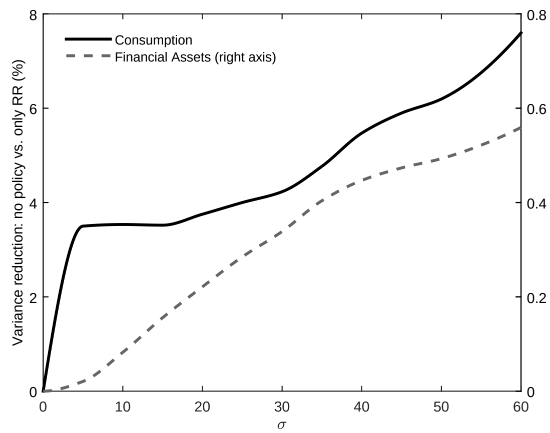
To do so, we consider an additional state of the economy, and we call it "crisis". Taking into account this state, the following experiment considers three states of the economy: good times, bad times, and crisis

Table 2: Consumption and financial assets variance by monetary policy

Policy	**Consumption**			**Net financial assets**		
	$\sigma = 0.0$	$\sigma = 15$	$\sigma = 30$	$\sigma = 0.0$	$\sigma = 15$	$\sigma = 30$
RR and interest rate	0.0859 (7.61%)	0.1065 (12.63%)	0.1315 (17.03%)	0.1255 (0.03%)	0.1259 (0.91%)	0.1265 (2.04%)
Interest rate	0.0859 (7.61%)	0.1075 (11.79%)	0.1329 (16.15%)	0.1255 (0.03%)	0.1260 (0.77%)	0.1267 (1.85%)
RR	0.0930 (0.00%)	0.1176 (3.52%)	0.1518 (4.23%)	0.1255 (0.00%)	0.1268 (0.16%)	0.1287 (0.24%)
No policy	0.0930	0.1219	0.1585	0.1255	0.1270	0.1291

* Percentage reductions with respect to a passive monetary policy (last row) are presented in parenthesis.

Figure 4: Quantitative RR effect and risk aversion



times. In the latter state we assume that households' income experiences an further reduction of 4.72 percent with respect to the bad times income,[4] so $\mathcal{Z} = \{z_g, z_b, z_c\} = \{1.0368, 0.9524, 0.9052\}$. We also modify the transition matrix to include this new possible realization of z:

$$\Pi_z = \begin{pmatrix} \pi_{g|g} & \pi_{g|b} & \pi_{g|c} \\ \pi_{b|g} & \pi_{b|b} & \pi_{b|c} \\ \pi_{c|g} & \pi_{c|b} & \pi_{c|c} \end{pmatrix} = \begin{pmatrix} 0.9003 & 0.0997 & 0.0000 \\ 0.3987 & 0.1012 & 0.5000 \\ 0.0000 & 0.5000 & 0.5000 \end{pmatrix}$$

where the values are calibrated to preserve a 66 percent long-run probability of the economy being in expansion and 34 percent of being in recession (including both bad times and crisis times). The above transition matrix takes into account that it is not possible to go directly from good to crisis times.

Now, we assume that the central bank follows a countercyclical interest rate rule that sets a high rate $\overline{r}^p = 1.28\%$ (5.24% annual) in good times and a low rate $\underline{r}^p = 0.13\%$ (0.53% annual) when the economy is contracting (bad times and crisis). We also assume that the central bank only makes use of reserve requirements in times of crisis by setting a RR equal to $\underline{\rho} = 5\%$ in those moments. In the two remaining states of the economy (good and bad times), the RR remains at $\overline{\rho} = 9\%$. For this RR policy we say that the central bank is using the RR as an instrument of last resort. This fully countercyclical policy is summarized below:

$$r^p = \begin{cases} \overline{r}^p & \text{if } z' = z_g \\ \underline{r}^p & \text{if } z' \in \{z_b, z_c\} \end{cases}, \qquad \rho = \begin{cases} \overline{\rho} & \text{if } z \in \{z_g, z_b\} \\ \underline{\rho} & \text{if } z = z_c \end{cases} \tag{24}$$

We simulate three scenarios: (i) the central banks follows a countercyclical interest rate rule and use the RR as an instrument of last resort, (ii) the central banks only uses the policy rate, and (iii) an inactive monetary policy where the interest rate and the RR remain in their average values. As we did before, the

[4]This value is taken from the 10th percentile of the distribution HP filter cycle of Colombian GDP.

Table 3: Average consumption in crisis times and consumption variance by monetary policy

Policy	Variance			Mean in crisis times		
	$\sigma = 0.0$	$\sigma = 15$	$\sigma = 30$	$\sigma = 0.0$	$\sigma = 15$	$\sigma = 30$
RR and interest rate	0.1475 (6.36%)	0.1866 (10.01%)	0.2353 (13.48%)	0.5447 (−1.38%)	0.5429 (−1.58%)	0.5408 (−1.85%)
Interest rate	0.1475 (6.36%)	0.1870 (9.81%)	0.2360 (13.22%)	0.5447 (−1.38%)	0.5424 (−1.48%)	0.5398 (−1.67%)
No policy	0.1575	0.2073	0.2720	0.5373	0.5344	0.5310

* Percentage reductions with respect to a passive monetary policy (last row) are presented in parenthesis.

effectiveness of each policy is measured by the reduction in the variance of consumption and net financial assets. However, in order to quantify the importance of a monetary policy that uses the RR in times of crisis, we also need to know whether the countercyclical policy prevents a strong contraction of the economic activity in those times. For this reason, we also take into account the mean of consumption in times of crisis to assess the effectiveness of such policy. These results for $\sigma = \{0, 15, 30\}$ are presented in Table 3.

Our results suggest that reserve requirements are an effective monetary policy instrument in this context. For any $\sigma > 0$, lowering the RR when it is no longer possible to modify the interest rate reduces the business cycle volatility. Thus, using the two instruments as described above when $\sigma = 15$ reduces the variance of consumption by 10.01% compared to a scenario where the central bank has a passive monetary policy, whereas if the interest rate is the only instrument used, the consumption volatility drops 9.81%. As in the experiment presented in Section 4.3, here, the effect of a RR policy is widened as the absolute risk aversion coefficient of financial intermediaries increases.

In addition, reserve requirements help to attenuate the effect of the crisis. The mean of consumption in times of crisis is 1.58% and 1.85% higher for $\sigma = \{15, 30\}$ when both instruments are used with respect to a scenario in which the central bank has a passive monetary policy. The implementation of a complementary countercyclical rule for the RR achieves this by reducing the cost of funding of financial intermediaries in crisis times, which in turn eases the access to credit and stimulates consumption. The higher consumption in moments of crisis comes with a cost: the average consumption in good and bad times is lower in presence of the RR policy. Consequently, this result poses a trade-off for policy makers, since they must find the right balance between the benefits derived from a lower volatility, and the costs arising from a lower level of consumption in those periods.

5 The case of a small open economy

Most of the economies that have recently used reserve requirements are emerging market economies (e.g. Brazil, Colombia, India, Peru, and Turkey among others). These economies are characterized for having high output volatility, large swings in current account and surges and sudden stops in capital flows, a set of facts that may be explained by the imperfect international financial integration. Such characteristics pose some risks for the conduct of monetary policy, and in particular may influence the effectiveness of reserve requirements.

When considering the effect of a countercyclical reserve requirement policy in a small open economy we have to opposing forces. On one hand, reserve requirements are used actively in order to change the cost of funding of financial intermediaries, which in turn makes more expensive to produce loans when the economy is booming. On the other hand, fluctuations in the international capital markets may increase or decrease the cost of funding depending of what the behavior of the effective cost of foreign debt is. This latter effect can potentially shape the effect of the RR policy.

The results presented in Section 4.3 are derived from a closed economy model in which financial intermediaries do not have access to any extra source of funding. From the facts described above it becomes relevant to determine if the access to foreign capital markets may affect the outcome of the RR policy. Below we present a similar exercise to the one in the previous section but for the case of a small open economy.

We augment the model of Section 2 by assuming that the economy now faces two aggregate shocks: the aggregate income shock, z_t (that was already present before in the closed economy version of the model), and a foreign interest rate shock, r_t^*. Hence, at each period the economy is in a state of nature e_t, representing the pair of realizations of z_t and r_t^*, this is $e_t = (z_t, r_t^*)$. The state of nature e_t is assumed to follow an exogenous process determined by a first order Markov chain with conditional transition probabilities given by

$$\pi_e(e'|e) = \Pr(e_{t+1} = e'|e_t = e) \tag{25}$$

where $e_t \in \mathcal{E} = \{z_g, z_b\} \times \{\underline{r}^*, \overline{r}^*\}$ and with the upper and lower bars denoting high and low discrete values of the foreign interest.

Economy-wide shocks affect household and banks decisions and therefore good realizations of e are reflected in an increased economic activity. In particular we assume that a good realization correspond to the state $(z_g, \underline{r}^*)$, i.e. a realization with the high income shock and a low foreign interest rate, while a bad realization correspond to the state $(z_b, \overline{r}^*)$. The rest of the states are assumed as "neutral" states for policy purposes. As for the closed economy case, we consider countercyclical policy rules for the central bank. When both instruments are used in a countercyclical manner, the rules are given as follows:

$$r^p = \begin{cases} \overline{r}^p & \text{if } e' = (z_g, \underline{r}^*) \\ \underline{r}^p & \text{if } e' = (z_b, \overline{r}^*) \\ \tilde{r}^p & \text{otherwise} \end{cases}, \qquad \rho = \begin{cases} \overline{\rho} & \text{if } e = (z_g, \underline{r}^*) \\ \underline{\rho} & \text{if } e = (z_b, \overline{r}^*) \\ \tilde{\rho} & \text{otherwise} \end{cases} \tag{26}$$

As in the closed economy model, banks can also fund themselves using households' deposits and repo loans with the central bank, but here we add an additional funding source. We assume that banks can access international financial markets to finance loans. They can issue a non-state contingent one-period zero-coupon bond, B_t^*, and pay the foreign interest rate, r_t^*. Since the economy is small and open, the collective actions of local banks do not influence the foreign interest rate determined in global financial markets. In order to reflect the observed spread between foreign, deposit and lending rates, and to guarantee the stationarity of the foreign debt, it is assumed that financial intermediation is costly. In particular, we include convex portfolio adjustment costs for the foreign debt.

In this set up, the representative bank, after observing credit demand and deposit supply, chooses both the amount to be funded by the central bank and by international financial markets. Therefore, the intratemporal representative bank problem is to maximize its expected utility, derived from its flow of funds w, subject to its balance sheet constraint and to the compulsory reserve requirement. Its problem can be written as:

$$\max_{L,D,R,S,B^*} \mathrm{E}\left[u(w)\right]$$

subject to

$$L = D + S + B^* - R \tag{27}$$

$$R \geq \rho(z) D \tag{28}$$

The flow of funds is give by

$$\tilde{w} = \left[(1-\rho) D + S + B^*\right] r^l - D r^d - S\tilde{r}^p - B^* r^* - \kappa(D, L, B^*) \tag{29}$$

where

$$\kappa(D, L, B^*) = \kappa_d D + \kappa_l L + \frac{\kappa^*}{2}\left(B^* - \overline{B}^*\right)^2 \tag{30}$$

Here, $\overline{B}^*$ denotes a reference value for the adjustment costs of B^* and κ^* is the adjustment costs parameter.

As before, the problem is reduced to one in which the representative bank only needs to choose optimally its demand of deposits and repo loans, with the addition that the demand for foreign funds also appears as a decision variable. The first order conditions for D and S are the same as the ones in 15 and 16. In an interior solution, the optimality condition for B^* is given by

$$r^* = r^l - \kappa_l - \kappa^*\left[B^* - \overline{B}^*\right] \tag{31}$$

This condition pins down a value for B^* such that $B^* > 0$. From equation 31, and since r^* is taken as given by the representative bank, we get the optimal amount of foreign debt to be issued at every period:

$$B^* = \overline{B}^* + \left[\frac{r^l - r^* - \kappa_l}{\kappa^*}\right] = \overline{B}^* + \frac{\mathrm{E}\left[r^p\right] + \sigma S \operatorname{Var}\left[r^p\right] - r^*}{\kappa^*} \tag{32}$$

Hence, the aggregate repo loan demand is:

$$S\left(r^d, r^l, \tilde{r}^p, \rho\right) = L^d\left(r^l\right) - (1-\rho) D^s\left(r^d, \rho\right) - B^*\left(r^l, n\right) \tag{33}$$

where B^* is determined by (32). This conditions reflect that the financial intermediaries' cost of funding now also depends on the cost of issuing foreign debt, and that they are willing to partially substitute domestic funding with the central bank with foreign funds in response to low foreign rates. As a result, the interest rate on loans is affected accordingly: it depends positively on the foreign rate and the cost of adjusting B^*, but that dependence is scaled by the interaction between the uncertainty regarding the repo rate and the risk-aversion of financial intermediaries.

Finally, the presence of external funding implies that the aggregate resource constraint of the economy is now given by $C + A' + \kappa\left(D, L, B^*\right) + TB = A + z\sum_i s_i$ where $TB = (1 + r^*) B^* - B^{*\prime}$ denotes the trade balance.

Calibration of the open economy parameters

Assuming that the processes for z and $r^*$are independent between each other (a reasonable assumption given that both are structural exogenous shocks), we can define the transition matrix of $\mathcal{E}$ as

$$\Pi_{\mathcal{E}} = \Pi_z \otimes \Pi_*$$

where $\otimes$ denotes the Kronecker product, Π_z is the Markov process for $\mathcal{Z}$ defined in equation 22, and Π_* is the transition matrix of an independent Markov process for r^*. In order to calibrate the foreign interest rate process, we suppose that the transition probabilities for r^* are symmetric. We then use the quarterly 3-month T-Bill interest rate and compute its persistence with an AR(1) model. This yields a persistence of 0.7404 that we employ to parametrize the following transition matrix:

$$\Pi_* = \begin{pmatrix} 0.7404 & 0.2596 \\ 0.2596 & 0.7404 \end{pmatrix}$$

The calibration of the transition probabilities matrix for $\mathcal{E}$ guarantees, as in the closed economy calibration, that 66 percent of the time the economy will be in good times, but now half of that time will be characterized by a low foreign interest rate. This is also true for the bad times: 50 percent of that time the economy will experience low foreign rates. As for the values that r^* can take, we take into account that the 3-month T-Bill rate fluctuates between 0.5 and 2 percent most of the time. To these values, we add the average country risk premium for Colombia (from the EMBI Colombia index). This yields $\overline{r}^* = 0.0107$ and $\underline{r}^* = 0.0143$. Finally, the values for $\overline{B}^*$ and κ_* are calibrated jointly to capture the fact that, on average, the foreign debt of the Colombian private sector represented 10.46 percent of GDP for the period 1994-2012.

Results

We perform a 10,000-period simulation for four different sets of monetary policy rules. Table 4 presents the variances for consumption and net financial assets under each policy and for different values of σ. These results are in line with the ones of the closed economy model: reserve requirements by themselves are not very effective in reducing volatility in business cycles, but can help to reinforce the impact of a countercyclical interest rate policy. For the open economy model, we also have that the importance of a RR policy increases as the financial intermediaries become more risk averse.

In our baseline calibration ($\sigma = 15$), a RR-only policy reduces consumption volatility by 1.82%. In contrast, an interest rate-only policy can cut the variance of consumption by much more (8.21%). When both instruments are used jointly in a countercyclical manner, reserve requirements contribute positively, but marginally, to smooth the effect of aggregate shocks.

Table 4: Consumption and financial assets variance by monetary policy in the open economy model

Policy	Consumption			Net financial assets		
	$\sigma = 0.0$	$\sigma = 15$	$\sigma = 30$	$\sigma = 0.0$	$\sigma = 15$	$\sigma = 30$
RR and interest rate	0.0877 (5.77%)	0.1029 (8.59%)	0.1213 (11.03%)	0.1254 (0.07%)	0.1260 (0.48%)	0.1267 (0.98%)
Interest rate	0.0877 (5.77%)	0.1034 (8.21%)	0.1216 (10.76%)	0.1254 (0.07%)	0.1260 (0.44%)	0.1268 (0.94%)
RR	0.0930 (0.00%)	0.1106 (1.82%)	0.1336 (1.97%)	0.1255 (0.00%)	0.1265 (0.10%)	0.1277 (0.20%)
No policy	0.0930	0.1126	0.1363	0.1255	0.1266	0.1280

* Percentage reductions with respect to a passive monetary policy (last row) are presented in parenthesis.

The effect of the RR policy in an open economy context shares the most important characteristics of this policy in the closed economy model. In particular, reserve requirements in both models have a small impact in reducing business cycle volatility when used alone, and there is a complementarity with the interest rate policy that may be exploited by the central bank. However, the importance of monetary policy in the open economy model is dampened by foreign shocks. When financial intermediaries have access to foreign debt, the reduction in consumption volatility reached by a RR-only policy is lower than for the open economy case. This situation is also observed for the other two countercyclical policies. As we discussed before, the presence of an extra source of funding make less effective the influence of monetary policy in modifying the financial intermediaries' cost of funding. Consider the case of the high state of income and low foreign interest rates, i.e. $(z_g, \underline{r}^*)$. The idea of the central bank when increasing the reserve requirement is to make more expensive to borrow from the financial sector. However, since economy is experiencing low foreign rates, it becomes easier to financial intermediaries to substitute repo loans with foreign debt as a source of funding. The net effect of these two opposing forces preserves the effectiveness of the RR policy but reduces its importance. In this manner, our results indicate that the effects of RRs in the closed economy model provide an upper bound upper bound for the effects of changing the required reserve ratio in the simple and stylized model we present.

6 Conclusions

This paper studies the macroeconomic effects of monetary policy when monetary authorities use reserve requirements and the interest rate as part of their countercyclical policy toolkit. We are focused on determining the degree of substitutability or complementarity of these two instruments. To do so, we use a dynamic stochastic general equilibrium model with risk averse financial intermediaries, heterogeneous agents and uninsurable idiosyncratic risk. We initially present a closed economy version of the model, but we also consider an open economy extension where financial intermediaries have access to the foreign credit market. We calibrate the model to the Colombian economy and simulate different monetary policy scenarios.

The results indicate that while the reserve requirement indeed reduces business cycles volatility, its effect is considerably smaller than the one achieved by the short-term interest rate. Even though RRs are not as effective as the interest rate, they can complement an interest-rate-based monetary policy. This complementary effect becomes quantitatively relevant if bankers are sufficiently risk averse. The reduction in consumption and financial assets volatility, and the consequent lower variability in credit markets, also favors financial stability objectives. All these results are maintained in the small open economy version of the model. However, when financial intermediaries can issue foreign debt the effect of monetary policy gets dampened because the access to foreign capital markets limits the strength of its power to affect the cost of funding of commercial banks.

In addition, we show that an increase in RR reduces the level of consumption. This policy operates mainly on households holding larger levels financial assets. The reason is intuitive: in an environment in which agents face idiosyncratic risk and access to only one asset (deposits) to insure against it, reserve requirements act as a tax on wealth, reducing agents' welfare. Despite the cost of increasing reserve requirements, the benefits of mitigating business cycle fluctuations can be much greater than those documented here. This is so because the lower business cycle volatility may help to avoid socially costly events, such as financial crises and bankruptcies, that can potentially strength the economy and guarantee financial stability. Simultaneously, it may favor investment decisions via reduced uncertainty about future economic conditions. These factors, which are not considered in the model presented here, can offset the costs of a countercyclical RR policy and its quantitative effects should be the subject of further research.

We also show that reserve requirements can be successfully used when it is not possible for the central bank to change the interest rate. When this occurs, lowering the RR in times of economic downturn helps to reduce the business cycle volatility. However, the average consumption in non-crisis times is higher when monetary policy is passive. This poses a trade-off for policy makers, in which they must find the right balance between benefits and costs of implement such policy.

Directions for future research include the importance of studying the role of the financial intermediaries risk aversion. For instance, it would be relevant to take into account that the desire of financial intermediaries to take more risk is lower in times of crisis, causing a steepening in the credit supply curve. These results should be considered by the central bank since the channel through which monetary policy operates can change given the credit market conditions and the risk perceptions of financial intermediaries.

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Appendix. Numerical Method

We solve and simulate the model by following a Krusell and Smith (1998) type method. Here, we explain how we compute the recursive competitive equilibrium for the closed economy model developed in Section 2. The algorithms used to solve the model extensions, i.e. the inclusion of the additional crisis state in Subsection 4.4, and the open economy model of Section 5, follow directly from the application of the same method.

The algorithm follows the Krusell and Smith (1998) implementation of Khan and Thomas (2003). We first need to discretize the state space, so we restrict the space of the individual endogenous state variable a to be $\mathcal{A} = \{a_1, a_2, \ldots, a_m\}$. We let $a_1 = -7$ and $a_m = 50$ with $m = 35$ equally spaced grid points. With this in hand, we repeatedly iterate over the household's value function in (7), and the intermediaries' pricing equations in (15) and (16). The value function v is solved by using tensor product splines to interpolate the function values at points different to the ones in the grid. In particular, the splines we use are univariate piece-wise cubic splines on the space $\mathcal{A}$ of the individual state variable a. When joining the spline polynomials at each interior knot point we employ the knot-a-knot condition in order to guarantee that the values of the two contiguous polynomials coincide at every interior knot point and that the functions satisfy to be twice-continuously differentiable. This condition ensure to we have a smooth set of polynomials on the space $\mathcal{A}$.

Solving the household's problem requires finding the law of motion of the distribution μ, this is $G(\mu, z, z')$. However, given that the distribution μ is an infinite-dimensional object, characterizing its law of motion is an impossible task if one takes into account that the function G belongs to a space of a set of functions from an infinite dimensional space into itself. The method proposed by Krusell and Smith (1998) approximates the state space by assuming that individual households forecast the future state of the economy using only a small set of I moments of the aggregate state, $m = (m_1, \ldots, m_I)$. Krusell and Smith (1998) use only the first moment of μ and suppose that agents predict the dynamics of μ by the means of a first order autoregressive process. We apply the same logic and use only one moment but with one caveat.

In the context of the model presented above, the relevant variable for households when forming their expectations about interest rates and deposit is S_t, the repo loans of the financial sector with the central bank. Its value depends on how much the private sector loans exceeds the deposits available to produce loans after taking into account the reserve requirement, i.e. $S_t = L_t - (1-\rho) D_t$. Using the aggregate version of (5), the latter can be rewritten as $S_t = -A_t + \rho D_t$. Thus, for households to be able to "correctly" forecast the aggregate state it is not enough to take into account the aggregate variable A_t, but they should know the moments of at least two of the three following variables: S_t, A_t, and D_t. To solve this issue, we assume that households form their expectations over the proxy variable K_t, defined as $K_t \equiv (1-\rho) A_t$. Using this variable, households are able to forecast with relatively good accuracy the true value of S_{t+1} using the following regression:

$$K_{t+1} = \gamma_{0z} + \gamma_{1z} K_t \tag{A1}$$

where the subscript z on the coefficients denotes that the forecasting rules is conditional on the current state of the economy. We also restrict the values that K_t may take to be on the set $\mathcal{K} \in \{k_1 k_2, \ldots, k_n\}$. We let $k_1 = -3$ and $k_n = 3$ with $n_k = 5$ equally-spaced grid points. Let $\hat{\Gamma}$ be the function that households use to forecast K_{t+1}, so $K' = \hat{\Gamma}\left(z, K|\gamma^l\right)$ is a vector of linear regressions as in A1 with $\gamma_z^l = \left(\gamma_{0z}^l, \gamma_{1z}^l\right)$ for each $z \in \mathcal{Z}$.

A sketch of the algorithm is presented below. It begins with a guess over γ^0 and iterates repeatedly the following steps $l = 1, 2, \ldots$ times until the coefficients in γ^l converge.

Table A1: Forecasting Rules for K' in the Benchmark Closed Economy Model

z	Obs.	γ_0	γ_1	R^2
RR and interest rate				
z_g	6,995	0.004198	0.988365	0.984988
z_b	3,504	0.008654	0.991627	0.970673
Interest rate				
z_g	6,995	-0.008456	0.986804	0.999999
z_b	3,504	0.038877	0.986678	0.999999
RR				
z_g	6,995	0.005372	0.988600	0.985591
z_b	3,504	0.009824	0.992206	0.971827
No policy				
z_g	6,995	-0.006902	0.986837	0.999999
z_b	3,504	0.040398	0.986850	0.999999

*Forecasting rules are conditional on current aggregate shock z_t. Each regression takes the form $K' = \gamma_0 + \gamma_1 K$

Step 1 At each l-th iteration, we replace μ with K and G with $\hat{\Gamma}$. Therefore, households solve for v at each point of the state space $(a, s|z, k)$ by using γ^l to forecast the future value of interest rates r^d and r^l.

Step 2 Simulate the economy for T periods. At each period $t = 1, 2, \ldots, T$, we compute the distribution μ_t on the space $\mathcal{A} \times \mathcal{S}$. To do this, we use linear interpolation on the grid $\mathcal{K}$. To solve the model at each t, from the distribution μ_t we calculate A_t, D_t, L_t and therefore μ_{t+1}. We then use the value of A_t to obtain K. With K in hand, we use $\hat{\Gamma}$ to compute $K' = \hat{\Gamma}\left(z, K|\gamma^l\right)$. On the other hand, using D_t and L_t, and taking as given the monetary policy rules, we can solve the representative banks problem by first calculating S_t and then using equations (15) and (16) to obtain r^d and r^l. Finally, at each t, we store the pair (S_t, S_{t+1}), and the realization of the aggregate shock z_t.

Step 3 Use the resulting time series from the simulation to update the parameters of $\hat{\Gamma}$ by doing a set of least-squares regressions as in (A1). For these regressions we replace K_t and K_{t+1} by the "observed" values of S_t and S_{t+1}. The resulting coefficients of this step are γ^{l+1}.

Step 4 Verify that the parameters of $\hat{\Gamma}$ converge. If so, stop. Otherwise, return to Step 1 and update $\hat{\Gamma}$ with the new parameters γ^{l+1}.

Table A1 presents agents' forecasting rules of our closed economy model under each one of the four monetary policy set ups we consider in Subsection 4.3. Households use these equilibrium forecasting rules to predict S_{t+1} and then r^d and r^l when solving their dynamic programing problem. In the table, we present the values of the coefficients of $\hat{\Gamma}$ and the R^2 of the OLS regressions. All the R^2s are high enough to guarantee that agents can forecast accurately.