Reserve Requirements for Price and Financial Stability: When Are They Effective?*

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Reserve requirements are a prominent policy instrument in many emerging countries. The present study investigates the circumstances under which reserve requirements are an appropriate policy tool for price or financial stability. We consider a small open-economy model with sticky prices, financial frictions, and a banking sector that is subject to legal reserve requirements and compute optimal interest rate and reserve requirement rules. Overall, our results indicate that reserve requirements can support the price stability objective only if financial frictions are important and lead to substantial improvements if there is a financial stability objective. Contrary to a conventional interest rate policy, reserve requirements become more effective when there is foreign currency debt.

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1. Introduction

Reserve requirements are a prominent policy instrument in many emerging countries. China, for example, raised its reserve requirements six times in 2010, while moving interest rates only once (see Kashyap and Stein 2012). The Central Bank of Turkey recently lowered its policy interest rate and increased reserve requirements at the same time. Among policymakers, reserve requirements are under

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discussion both as a financial stability tool—in particular, in order to deal with volatile capital flows—and as an unconventional monetary policy tool for price stability—in particular, when interest rate policy is constrained by the zero lower bound or an exchange rate objective.[1] The main objective of reserve requirements varies substantially across countries and over time, and it is not always easy to identify the main purpose (Gray 2011). The Central Bank of Malaysia recently announced that changes in reserve requirements only serve a financial stability objective, whereas the interest rate is used for price stability (see Central Bank of Malaysia 2011). In Turkey, the central bank considers the interest rate as the main instrument for price stability, with a secondary role for financial stability, and reserve requirements as the main instrument for financial stability, with a secondary role for price stability (Başçi 2010). Until 1993, the Banco Central do Brasil used heterogeneous reserve requirements across regions in order to foster growth in poorer regions by facilitating credit supply there (see Carvalho and Azevedo 2008 and Maia de Oliveira Ribeira and de Holanda Barbosa 2005). Other countries use reserve requirements both for price and financial stability, and the respective weights vary.[2] Using reserve requirements for multiple purposes has both advantages and disadvantages: On the one hand, a setting where reserve requirements respond to price and financial developments can lead to better outcomes as it increases the degrees of freedom; on the other hand, a separation of tasks might increase transparency and facilitate communication.

The main aim of the present paper is to analyze under which circumstances reserve requirements are effective as an additional monetary policy tool to achieve price stability or as a macroprudential tool to achieve financial stability. To that purpose we consider a small open-economy model with sticky prices, financial frictions, and

[1]In addition, reserve requirements serve also as a source of fiscal revenue and as a tool for liquidity management; see Goodfriend and Hargraves (1983) for a description on how the use of reserve requirements in the United States has evolved over time.

[2]Montoro and Moreno (2011) survey the use of reserve requirements in Latin America. Geiger (2008) and Goodfriend and Prasad (2006) discuss monetary policy in China, including the use of reserve requirements. The International Monetary Fund (2010) and Moreno (2011) provide an overview on how reserve requirements are used as a macroprudential tool.

a banking sector that is subject to legal reserve requirements. Apart from the interest rate, the central bank sets reserve requirements and varies them in response to economic conditions.

Our analysis on the effectiveness of reserve requirements focuses on three key dimensions. The first dimension is the financial structure of the economy. We start from an economy without financial frictions and then add a financial accelerator mechanism, first with domestic currency debt and finally with foreign currency debt. The second dimension is the objective of the central bank. We assume that the central bank receives an exogenous mandate from the government in the form of a loss function it has to minimize. In the first setting, the central bank aims to minimize a weighted average of the variability of output and inflation. In the second setting, the variability of loans enters additionally. The additional variable intends to capture an intrinsic motivation of the central bank to contain credit fluctuations, beyond their effect on price stability. The central bank follows log-linear instrument rules and chooses the reaction coefficients that minimize the respective loss function. The third dimension is operational and captures the type of variables that enter the instrument rule. In the most general case, both the interest rate and reserve requirements respond to fluctuations in output, inflation, and credit. We consider more restrictive settings, where the policy instruments respond only to a subset of variables or remain constant, compute the relative losses, and analyze interactions between the two instruments.

We start by showing that the transmission of discretionary changes in reserve requirements depends importantly on other monetary arrangements. In the traditional textbook description, changes in the reserve requirements affect the money multiplier and thereby money supply and, if there are nominal rigidities, real activity. The textbook analysis assumes that the central bank keeps base money constant. But if monetary authorities target interest rates or exchange rates, they accommodate reserve requirement changes automatically through an endogenous expansion of the monetary base. In that case, the main transmission channel builds on the interest rate differential between the interest rates on loans and reserves. If the remuneration of reserves is below the market rate, an increase in reserve requirements acts as a tax on banks and widens the spread between lending and deposit rates. This can lead to a rise in lending rate and a subsequent decline in investment, but also to a decline in the deposit rate. Everything else fixed, the decline in the deposit rate triggers an exchange rate depreciation and capital outflows, but also an increase in consumption. The overall effect on total demand and inflation is therefore ambiguous.

We initially analyze an economy where the central bank only cares about the variability of output and inflation and no financial frictions are present. As supply shocks move output and inflation in opposite directions, an additional instrument in the form of reserve requirements could, in principle, improve the output-inflation tradeoff. In our simulations, however, we find the gains to be negligible. The finding can be related to the mechanism described above: with an interest rate rule, changes in reserve requirements tend to move investment and consumption in opposite directions. If we add a financial accelerator as in Bernanke, Gertler, and Gilchrist (1999), the gains from using reserve requirements are larger. Adapting reserve requirements to economic conditions can alleviate movements in the external finance premium. Reserve requirements are particularly effective if firms borrow in foreign currency. Different from an increase in the policy rate, a raise in reserve requirements generates a depreciation and thereby a decline in firm equity, which amplifies the effect of reserve requirements through balance sheet effects. Gains are even larger if the central bank has an explicit financial stability objective and aims to contain fluctuations in credit in addition to output and prices. Adjusting only the interest rate increases the volatility of the three target variables substantially. Overall our results therefore indicate that reserve requirements can support the price stability objective only if financial frictions are important and lead to substantial improvements if there is a financial stability objective and debt is denominated in foreign currency. Regarding the interaction between the two instruments, a separation of tasks, where the interest rate responds to fluctuations in output and inflation and reserve requirements to fluctuations in loans, appears advantageous, as stabilization losses are small in comparison to a setting where both instruments respond to all variables and the setting is considerably simpler.

Most of the more recent literature that studies the use of reserve requirements as a policy tool dates back to the period between the 1980s and the early 1990s and focuses on advanced economies.

Over the last twenty years, reserve requirements have been losing importance as a monetary policy instrument in advanced economies and there has been little new research on the topic. Fama (1980) and Romer (1985) focus on the microeconomic aspects and analyze the incidence of reserve requirements under different institutional settings. Baltensperger (1982) and Horrigan (1988) employ ISLM-type models to study the effect of reserve requirements on price and output stability. Siegel (1981) analyzes the effect of reserve requirements on price stability in a real model. Since the financial crisis, reserve requirements have received new attention. Kashyap and Stein (2012) analyze how reserve requirements can be used as an additional financial stability tool and act as a Pigouvian tax in a partial equilibrium model, but they do not consider the real economy and the consequences of price stickiness explicitly. Recent papers that study the consequences of reserve remuneration are also relevant (Cúrdia and Woodford 2011, Ireland 2011) but different in focus, as they study unconventional monetary policy at the zero lower bound.

In emerging-market economies, reserve requirements continue to play an important role. Most research on the use of reserve requirements in emerging economies has been empirical and focuses on the impact of reserve requirements on interest spreads and bank profits (see, for instance, Carvalho and Azevedo 2008, Cerda and Larrain 2005, Gomez 2007, Ocampo and Tovar 2003, Souza Rodrigues and Takeda 2004, and Vargas et al. 2010). The general conclusion from these studies is that increases in reserve requirements raise interest spreads and lower bank profits. However, the studies do not allow drawing direct conclusion on the macroeconomic, general equilibrium consequences of reserve requirements. There are also a few theoretical studies on the use of reserve requirements in emerging economies. Reinhart and Reinhart (1999) use a variant of the Dornbusch overshooting model to examine the effects of changes in reserve requirements on the exchange rate. Edwards and Vegh (1997) discuss the use of reserve requirements as a stabilization tool in a stylized open-economy model, but they do not consider its interaction with monetary policy and the gains that derive from using reserve requirements as an additional instrument. Recently, a few central banks that use reserve requirements have built medium-sized dynamic stochastic general equilibrium (DSGE) models of the respective economies that feature reserve requirements (see Prada

Sarmiento 2008 for Colombia and Bokan et al. 2009 for Croatia). In contrast to the present paper, these papers do not provide an explicit evaluation regarding the gains of using reserve requirements as an additional policy instrument and how the gains vary with economic circumstances. The paper is also related to the papers which find that interest rate policy is less effective in stabilizing the economy when there is foreign currency debt (for example, Choi and Cook 2004, Elekdag and Tchakarov 2007, Towbin and Weber 2011). We complement these studies by finding that reserve requirements become more effective with foreign currency debt, in contrast to conventional monetary policy.

More generally, our study also contributes to the recent literature that analyzes the interaction of monetary and macroprudential policies (Bean et al. 2010, Cecchetti and Kohler 2010, Cecchetti and Li 2005, Darracq Pariès, Sørensen, and Rodriguez-Palenzuela 2011, Kannan, Rabanal, and Scott 2009). All of the cited studies are closed-economy models, have a prominent role for the housing sector or bank capital, and focus on advanced economies.

In the remainder, section 2 details model and calibration. Sections 3 and 4 discuss the main results and extensions and section 5 concludes.

2. The Model

The core of the model is a relatively standard small open-economy model with investment, sticky prices, and a financial accelerator mechanism. In addition, household savings have to be intermediated through banks in order to reach firms. Banks make loans to entrepreneurs to finance their capital stock. Banks are subject to reserve requirements set by the government.[3] Households consume a bundle of home and foreign goods and have access to an internationally traded bond.

2.1 The Banking Sector

Banks attract funding from households and lend to entrepreneurs. For ease of exposition, we analyze the tasks of lending and funding

[3]We therefore assume that there are no other means of external finance. Possibilities to circumvent banks would obviously weaken the effects of reserve requirements.

separately and consider lending units and deposit units. Households' savings are remunerated at the deposit rate, while deposit units lend to lending units at the (risk-free) interbank rate. Lending units make risky loans to entrepreneurs.[4]

2.2 Deposit Units

Deposit units operate in perfectly competitive input and output markets. They collect deposits from households and rent a fraction to lending units on the interbank market and keep the rest as reserves with the central bank. Profits accrue to households since they are the owners of the deposit units.

Deposit unit j collects deposits $D_t(j)$ from households and pays a deposit interest rate $i_t^D(j)$. The bank has two possibilities to use the deposits. It allocates a fraction $1 - \varsigma_t(j)$ of deposits to lending in the interbank market and earns a gross return equal to i_t^{IB}. The remaining fraction of funds $Res_t(j) = \varsigma_t(j)D_t(j)$ is put into an account at the central bank, which is remunerated at the reserve rate i_t^R. The bank optimally chooses the composition of its assets, taking into account the minimum reserve requirement ratio ς_t^{MP} imposed by the monetary authority. The balance sheet of the deposit unit reads

$$Res_t(j) + D_t^{IB}(j) = D_t(j), \tag{1}$$

where $D_t^{IB}(j) = (1 - \varsigma_t(j))D_t(j)$ is interbank lending. Deposit units face convex costs in holding reserves $G_t^{\varsigma}(j)$

$$G_t^{\varsigma}(j) = \psi_1\left(\varsigma_t(j) - \varsigma_t^{MP}\right) + \frac{\psi_2}{2}\left(\varsigma_t(j) - \varsigma_t^{MP}\right)^2, \tag{2}$$

where ψ_1 and ψ_2 are cost function parameters. The first linear term determines steady-state deviations from the required reserve ratio. Holding excess reserves may generate some benefits, for example, because it reduces the costs of liquidity management. In addition, the central bank may impose a fee for not fulfilling the reserve requirement. Both motivations would imply $\psi_1 < 0$. The quadratic term

[4] An alternative would be to consider banks that collect savings and lend at the same time. The opportunity cost of attracting an additional unit of deposit would then correspond to the interbank rate.

with $\psi_2 > 0$ guides the dynamics around the steady state. There are several motivations for such convex costs. First, the benefits from holding excess reserves may decline because of decreasing returns to scale. Second, the central bank may punish large negative deviations from its target with a larger penalty rate and phase out the remuneration of excess reserves at the same time.[5]

The profit maximization problem of a bank is

$$\max_{\{\varsigma_t(j), D_t(j)\}} Div_t^S(j) \tag{3}$$

subject to equation (2), and dividends (Div_t^S) are given by

$$Div_t^S(j) = \left[(1 - \varsigma_t(j))i_t^{IB} + \varsigma_t(j)i_t^R - i_t^D(j) - G_t^{\varsigma}(j)\right] \cdot D_t(j). \tag{4}$$

The first-order conditions of the optimization problem are

$$-\left[\left(i_t^{IB} - i_t^R\right) + \psi_1\right] = \psi_2\left(\varsigma_t(j) - \varsigma_t^{MP}\right) \tag{5}$$

$$i_t^D(j) = \left[(1 - \varsigma_t(j))i_t^{IB} + \varsigma_t(j)i_t^R - G_t^{\varsigma}(j)\right]. \tag{6}$$

Equation (5) determines banks' actual reserve ratio. It is decreasing in the spread between the interbank rate and the reserve rate and increasing in the required reserve ratio ς_t^{MP}. Equation (6) shows that the deposit rate is a weighted average of the rates received from lending and reserve holdings, net of operating costs. The interest rate differential $i_t^{IB} - i_t^R \geq 0$ represents the opportunity costs deposit units face by investing part of their assets in reserves. Reserve requirements therefore act as a tax on the banking system. An increase in the monetary authority's target value of reserve requirements increases the opportunity costs. As a consequence, the spread between deposit and interbank rates rises.

2.2.1 Lending Units

Lending units do not interact with households. They are not subject to reserve requirements, as they finance themselves through the

[5]One could also imagine that positive and negative deviations from the target rate are asymmetric: Positive deviations generate small benefits and negative deviations generate large costs. However, in a linearized setting such a specification would be equivalent to ours.

interbank market and do not hold any deposits from households. Lending units operate in perfectly competitive input and output markets. They obtain funds from deposit units (D_t^{IB}) at the cost of the interbank rate and supply loans to entrepreneurs at the lending rate (i_t^L). The amount of interbank lending always equals the stock of loans supplied. The interaction between lending units and entrepreneurs is modeled by means of the financial contract as in Bernanke, Gertler, and Gilchrist (1999).

2.2.2 Equilibrium in the Financial Sector

Equilibrium in the financial sector implies that $\varsigma_t(j) = \varsigma_t$ since, due to equation (5), all deposit units face the same interbank and reserve interest rates as well as the same reserve requirement ratio. Moreover, equation (6) implies that once all banks have chosen the same level of the reserve requirement ratio, they will henceforth all set the same deposit rate: $i_t^D(j) = i_t^D$. Based on these equilibrium conditions, the following consolidated financial sector balance sheet emerges:

$$L_t = (1 - \varsigma_t)D_t. \tag{7}$$

Aggregate nominal reserves $\varsigma_t P_t D_t$ correspond to the monetary base in our model, as households do not hold cash. Taking into account reserve remuneration, real seignorage revenue T_t^S is

$$T_t^S = \varsigma_t D_t - \frac{i_{t-1}^R}{\pi_t} \varsigma_{t-1} D_{t-1}.$$

All seignorage revenue is redistributed as a lump-sum transfer to households.

2.3 The Household Sector

There is a continuum of households. In a given period households derive utility from consumption C_t and disutility from working (h_t). Their instant utility function is $u(C_t, h_t) = \ln C_t - \Psi \frac{h_t^{1+\phi}}{1+\phi}$. Consumption is a Cobb-Douglas bundle of home C_t^H and foreign C_t^F goods: $C_t \propto (C_t^H)^\gamma (C_t^F)^{1-\gamma}$. The resulting price index reads $P_t = (P_t^H)^\gamma (P_t^F)^{1-\gamma}$. Households can invest their savings in real deposits D_t and foreign nominal bonds B_t, evaluated at the nominal exchange S_t. Because of limited capital mobility, acquiring foreign bonds entails a small holding cost $\frac{\psi_B}{2}(\frac{S_t}{P_t}B_t)^2$.[6] By supplying labor, households receive labor income $W_t h_t$. In addition, they receive gross interest payments on their deposits $i^D_{t-1}D_{t-1}$, interest payments on foreign bonds $i^*_{t-1}S_t B_{t-1}$, dividends from deposit units Div^S_t and intermediate goods producers Div^R_t, and lump-sum transfers T_t from the government.

$$P_t C_t + P_t D_t + S_t B_t = i^D_{t-1}P_{t-1}D_{t-1} + i^*_{t-1}S_t B_{t-1} + P_t W_t h_t \\ + P_t \sum_{j\in\{S,R\}} Div^j_t + P_t T_t + \frac{\psi_B}{2}P_t\left(\frac{S_t}{P_t}B_t\right)^2 \tag{8}$$

Households discount instant utility with β. They maximize their expected lifetime utility function subject to the budget constraint, which leads to the familiar optimality conditions:

$$1 = E_t \Lambda_{t,t+1}\frac{i^D_t}{\pi_{t+1}}$$

$$1 - \psi_B \frac{S_t}{P_t}B_t = E_t\left[\Lambda_{t,t+1}\frac{i^*_t}{\pi_{t+1}}\frac{S_{t+1}}{S_t}\right]$$

$$W_t = \Psi h^\phi_t C_t,$$

where the stochastic discount factor is given by $\Lambda_{t,t+k} = \beta^k \frac{C_t}{C_{t+k}}$ and $\pi_t = P_t/P_{t-1}$ is the gross inflation rate.

2.4 Capital Goods Producers

Capital goods producers build the capital stock, which is sold to entrepreneurs. They purchase the previously installed capital stock net of depreciation from enterpreneurs and combine it with investment goods to produce the capital stock for the next period.

[6]The assumption ensures stationarity in small open-economy models (Schmitt-Grohé and Uribe 2003).

Investment goods have the same composition as final consumption goods. Capital is subject to quadratic adjustment costs according to $\frac{\chi}{2}(\frac{I_t}{K_{t-1}} - \delta)^2 K_{t-1}$, where δ is the depreciation rate of capital. The parameter χ captures the sensitivity of changes in the price of capital to fluctuations in the investment to capital ratio.

The market price of capital is denoted by Q_t. The optimization problem is to maximize the present discounted value of dividends by choosing the level of new investment I_t. Since the optimization problem is completely static, it reduces to

$$\max_{I_t} \left[(Q_t - 1) I_t - \frac{\chi}{2} \left(\frac{I_t}{K_{t-1}} - \delta \right)^2 K_{t-1} \right]. \tag{9}$$

The maximization problem yields the following capital supply curve: $Q_t = 1 + \chi(\frac{I_t}{K_{t-1}} - \delta)$. Finally, the aggregate capital stock evolves according to the following law of motion: $K_t = (1 - \delta)K_{t-1} + I_t$.

2.5 Entrepreneurs

Entrepreneurs are the critical link between intermediate goods producers and capital goods producers. They purchase capital from the capital goods producers at the beginning of the period and resell at the end of the period. They rent it to intermediate goods producers at rental rate z_t. The structure of this part of the model is the same as in Bernanke, Gertler, and Gilchrist (1999) and we postpone the details to appendix 1.

Entrepreneurs finance their capital purchases out of their net worth N_t and with bank loans from bank lending units. We consider two cases: in the first case, the loan from the lending unit is denominated in domestic currency $Q_t K_t = N_t + L_t$. In the second case, the loan is denominated in foreign currency $Q_t K_t = N_t + S_t L_t^*$. We interpret the foreign currency case as an approximation for financial dollarization, i.e., an economy where domestic banks (which are subject to reserve requirements) offer only loans in foreign currency.

The interaction between entrepreneurs and bank lending units is characterized by an agency problem: entrepreneurs' projects face idiosyncratic shocks that are not publicly observable and they have an incentive to underreport their earnings. Lenders can verify the idiosyncratic shock at a cost. The optimal financial contract delivers the following key equation that links the spread between the aggregate expected real return on capital $E_t r^K_{t+1}$ and the risk-free lending rate to the entrepreneurs' leverage:

$$Q_t K_t = f\left(\frac{E_t r^K_{t+1}}{i^{IB}_t / E_t \pi_{t+1}}\right) N_t, \text{ with } f'(\cdot) > 0. \tag{10}$$

Equation (10) shows that the external finance premium $\frac{E_t r^K_{t+1}}{i^{IB}_t / E_t \pi_{t+1}}$ increases with the share of debt in total financing. The entrepreneur's real return on capital is given by

$$r^K_t = \frac{z_t + Q_t(1-\delta)}{Q_{t-1}}, \tag{11}$$

where z_t is the real rental cost of capital.[7]

With a probability $1-\nu$, entrepreneurs leave the market and consume their net worth. They are replaced by new entrepreneurs who receive a small transfer $\bar{g}$ from the departing entrepreneurs. Aggregate net worth is given by the following expression:

$$N_t = \nu V_t + (1-\nu)\bar{g}, \tag{12}$$

where V_t denotes the net worth of surviving entrepreneurs. Different from Bernanke, Gertler, and Gilchrist (1999), but in line with Gertler, Gilchrist, and Natalucci (2007), we assume that the lending rate is fixed in nominal terms in the respective currency. In the domestic currency case, the net worth of surviving entrepreneurs is

$$V_t = (1-\tilde{\mu}) r^K_t Q_{t-1} K_{t-1} - i^L_{t-1} \frac{P_{t-1}}{P_t} L_{t-1}, \tag{13}$$

[7]Equation (11) takes into account that in a model with investment adjustment costs and incomplete capital depreciation, one has to differentiate between the entrepreneur's return on capital (r^K_t) and the rental rate on capital (z_t). The return on capital depends on the rental rate as well as on the depreciation rate of capital, adjusted for asset price valuation effects (i.e., variations in Q_t/Q_{t-1}).

where the term $\tilde{\mu}$ reflects the deadweight cost associated with imperfect capital markets (see Bernanke, Gertler, and Gilchrist 1999 for further details) and i_t^L is the state-contingent nominal lending rate specified in the optimal financial contract (see Bernanke, Gertler, and Gilchrist 1999 and appendix 1). Combining equations (12) and (13) yields a dynamic equation for aggregate net worth.

In the scenario where entrepreneurial debt is denominated in foreign currency units, the equation is modified as follows:

$$V_t = (1 - \tilde{\mu}) r_t^K Q_{t-1} K_{t-1} - \left[i_{t-1}^{*L} \frac{S_t}{S_{t-1}} \frac{P_{t-1}}{P_t} \right] \frac{S_{t-1} L_t^*}{P_{t-1}}.$$

In both cases, lending units finance themselves at the domestic interbank rate. Hence, the following no-arbitrage condition between domestic currency and foreign currency lending rates holds:[8] $E_{t-1} i_{t-1}^{*L} \frac{S_t}{S_{t-1}} = i_{t-1}^L$.

Movements in net worth stem from unanticipated changes in returns and borrowing costs. Changes in Q_t are likely to provide the main source of fluctuations in r_t^K, which stresses that changes in asset prices play a key role in the financial accelerator. On the liabilities side, unexpected movements in the price level affect ex post borrowing costs. For instance, unexpected inflation increases entrepreneurs' net worth. If debt is denominated in foreign currency, then an unexpected change in the exchange rate similarly shifts entrepreneurial net worth.

2.6 Intermediate Goods Producers

Intermediate goods producers buy labor input from households and rent capital from entrepreneurs. They produce differentiated intermediate goods and operate in competitive input and monopolistically competitive output markets. The production function of intermediate goods producer $i \in [0, 1]$ is

$$y_t(i) = \xi_t^A K_{t-1}(i)^\alpha h_t(i)^{1-\alpha}. \tag{14}$$

[8] See related derivations in Cespedes, Chang, and Velasco (2004) and Elkedag and Tchakarov (2007).

ξ_t^A is an aggregate technology term and follows an AR(1) process. Cost minimization implies $\frac{h_t(i)W_t}{z_t K_{t-1}(i)} = \frac{1-\alpha}{\alpha}$ and marginal costs are given by

$$mc_t \propto \frac{W_t^{1-\alpha} z_t^{\alpha}}{\xi_t^A}. \tag{15}$$

2.7 Final Goods Producers

Final goods producers buy differentiated intermediate domestic goods from intermediate goods producers and transform them into one unit of final domestic good. They resell these transformed goods to households as consumption goods and to capital goods producers as investment goods. The final good is produced using a constant elasticity of substitution (CES) production function with elasticity of substitution ϵ to aggregate a continuum of intermediate goods indexed by $Y_t = (\int_0^1 y_t(i)^{\frac{\epsilon-1}{\epsilon}} di)^{\frac{\epsilon}{\epsilon-1}}$. Final domestic goods producers operate in competitive output markets and maximize each period the following stream of profits $P_t^H Y_t - \int_0^1 p_t^H(i) y_t(i) di$, where $p_t^H(i)$ is the price of intermediate good i. The demand for each intermediate input good is $y_t(i) = (p_t(i)/Y_t)^{-\epsilon} \cdot Y_t$ and the aggregate price level satisfies $P_t^H = (\int_0^1 p_t^H(i)^{1-\epsilon} di)^{\frac{1}{1-\epsilon}}$.

We assume that Calvo-type price staggering (Calvo 1983) applies to the price-setting behavior of intermediate goods producers. The probability that a firm cannot reoptimize its price for k periods is given by θ^k. Profit maximization by an intermediate goods producer who is allowed to reoptimize his price at time t chooses a target price p_t^* to maximize the following stream of future profits:

$$\max_{\{p_t^*\}_{t\in\mathbb{Z}}} E_t \left[\sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k} Div_{t+k|t}^R(i) \right], \tag{16}$$

where dividends are given by $Div_t^R(i) = \frac{p_t^*}{P_t} \cdot y_t(i) - mc_{t+k|t}(i) y_{t+k|t}(i)$. The first-order condition is

$$E_t \left[\sum_{k=0}^{\infty} \theta^k \Lambda_{t,t+k} y_{t+k|t}(i) \left(\frac{p_t^*}{P_{t+k}} - \frac{\epsilon}{\epsilon - 1} mc_{t+k|t}(i) \right) \right] = 0. \tag{17}$$

Final import goods are provided in competitive markets and the foreign currency price is normalized to one: $P_t^F = S_t$.

2.8 Equilibrium

The economy-wide resource constraint is given by

$$Y_t = \gamma \frac{P_t}{P_t^H}[C_t + I_t + G_t] + \frac{S_t}{P_t^H} X_t + \gamma \frac{P_t}{P_t^H} \Psi_t.$$

Foreigners buy an exogenous amount X_t (expressed in foreign currency) of domestic goods and $\Psi_t = K_{t-1}(\frac{\chi}{2}(\frac{I_t}{K_{t-1}} - \delta)^2 + \tilde{\mu} r_t^K Q_{t-1}) + G_t^{\varsigma}(\cdot) + \frac{\psi_B}{2}(\frac{S_t}{P_t} B_t)^2$ captures adjustment costs.

The balance-of-payments identity is

$$S_t B_t = P_t^H Y_t - P_t[C_t + I_t + G_t] + \left(1 + i_{t-1}^*\right) S_t B_{t-1} + P_t \Psi_t.$$

2.9 The Government Sector

Central bank policy has two dimensions: the central bank's objective and the implementation of the policy.

The central bank's objective is to minimize an exogenously given loss function. We consider two cases. In the first case, the monetary authority's loss function includes only the traditional objectives of output and price stability. The price stability loss function $\mathbb{L}_t^{PS}$ reads

$$\mathbb{L}^{PS} = E\left[\pi_t^2 + \lambda_Y (\hat{Y}_t)^2\right], \tag{18}$$

where $\hat{Y}_t$ is the log-deviation of output from its steady-state value and λ_Y reflects the policymakers' subjective weight of output stability relative to price stability.

In the second case, the central bank cares also about financial stability and, as a consequence, the variability of loans enters the loss function:

$$\mathbb{L}^{FS} = E\left[\pi_t^2 + \lambda_Y (\hat{Y}_t)^2 + \lambda_L (\hat{L}_t)^2\right]. \tag{19}$$

$\hat{L}_t$ is the log-deviation of loans from their steady-state value, and λ_Y and λ_L reflect the policymakers' subjective weight of output stability and loan stability relative to price stability.

An alternative objective for the central bank would be to maximize households' welfare, implied by the utility function, as proposed, for example, in Schmitt-Grohé and Uribe (2007). An advantage of such an approach is that the objective function is derived endogenously from the model and does not require additional judgment on what variables to enter. The welfare evaluation is then consistent with the households' utility function. Our loss function is exogenously given and the central bank does not directly maximize household's welfare.

It is, however, not obvious whether a central bank should or does try to maximize a household's welfare. Most central banks receive a mandate from the general government that they have to fulfill. By using an exogenous loss function, we also acknowledge that our model is only an imperfect description of reality and we may need to use information that comes from outside the model to assess welfare.[9]

By including the variability of loans in the loss function, we intend to approximate the fact that a central bank may want to avoid abrupt fluctuations in credit for some financial stability reason. For example, the government may worry that large swings in credit increase the risk of financial crises and therefore mandate the central bank to control credit fluctuations. Studies from the Bank for International Settlements have pointed out that deviation of credit from its trend can predict financial crisis (Borio and Drehmann 2009, Borio and Lowe 2002).[10] Studying examples where loans enter the loss function allows us to account for this possibility in a "normal times" setting, without explicitly modeling a crisis mechanism. However, since we make use of outside information, containing credit fluctuations may not be optimal from a pure model-based perspective. For instance, Faia and Monacelli (2007) take a model-based

[9]Using a related argument, Blanchard (2009) concludes, "Ad-hoc welfare functions, in terms of deviations of inflation and deviations of output from some smooth path, may be the best we can do given what we know." Svensson (2008) argues that loss functions in policy models should be based on a central bank's mandate rather than model-consistent welfare calculations. Even if not addressed in the present paper, in our view model-consistent welfare evaluation that derives from a sufficiently rich model can nonetheless inform policy about the formulation of a central bank mandate.

[10]Instead of the level of real credit, these studies look at credit over GDP.

welfare criterion and find that the presence of financial frictions constrains investment and leads to an inefficiently small expansion of lending in response to a productivity shock.

The use of an exogenous loss function also means that there is no immediate benchmark to assess the welfare implications of loss function differences. In order to evaluate the importance of loss function differences, we compare the values of our loss function with the corresponding numbers we obtain for the Great Moderation period (1984:Q1 to 2007:Q2) relative to the pre-Great Moderation period (1960:Q1 to 1983:Q4) for the United States.[11]

The implementation of the central bank's policy is characterized by the set of variables the central bank monitors and the instruments it uses. In the most general case, the central bank monitors the deviations of output, inflation, and loans from their long-run values. We will also consider cases where the central bank follows only output and inflation. We consider four main policy rules.

Under the first rule, the central bank only sets the interest rate and keeps reserve requirements constant:

$$\text{Policy I:} \begin{cases} \hat{\imath}_t^{IB} &= \phi_{\pi,i^{IB}}\pi_t + \phi_{Y,i^{IB}}\hat{Y}_t + \phi_{L,i^{IB}}\hat{L}_t \\ \tilde{\varsigma}_t^{MP} &= 0, \end{cases} \tag{20}$$

where $\hat{\imath}_t^{IB}$ and $\tilde{\varsigma}_t^{MP}$ are the percentage and level deviations from their steady-state values. With $\phi_{L,i^{IB}} = 0$, the rule nests the standard interest rate rule where the central bank sets the interest rate as a linear function of output and inflation as a special case. In the more general case, the central bank also responds to fluctuations in loans. A specification where monetary policy responds to financial conditions is, for example, proposed in Faia and Monacelli (2007). Note that the central bank can respond to fluctuations in loans without an explicit financial stability objective. Loans may contain useful information about the state of the economy, and responding to

[11]Of course, such a comparison gives only a relative benchmark, which leaves the absolute welfare gains from economic stabilization open. Estimates on the cost of business-cycle fluctuations that are derived from general equilibrium models vary substantially. Lucas (1987) concludes that the cost of business-cycle fluctuations amounts to only about 0.1 percent of steady-state consumption. Using preferences that are consistent with asset price risk premia, Tallarini (2000) shows that they can exceed 10 percent.

fluctuations therein can facilitate the task of achieving stability in output and prices.[12]

Under the second rule, the central bank pursues a fixed exchange rate regime but lets reserve requirements vary in response to fluctuations in output, inflation, and loans:

$$\text{Policy II:} \begin{cases} \Delta S_t & = & 0 \\ \tilde{\varsigma}_t^{MP} & = & \phi_{\pi,\varsigma^{MP}}\pi_t + \phi_{Y,\varsigma^{MP}}\hat{Y}_t + \phi_{L,\varsigma^{MP}}\hat{L}_t. \end{cases} \tag{21}$$

The policy rule aims to approximate the policy setting in countries with an exchange rate peg and time-varying reserve requirements—for example, China. In order to assess the gains that derive from the use of reserve requirements, we will also report the loss function for a fixed exchange rate regime where reserve requirements are constant.

The third rule is the most general case, where both interest rates and reserve requirements react to fluctuations in inflation, output, and loans:

$$\text{Policy III:} \begin{cases} \hat{i}_t^{IB} & = & \phi_{\pi,i^{IB}}\pi_t + \phi_{Y,i^{IB}}\hat{Y}_t + \phi_{L,i^{IB}}\hat{L}_t \\ \tilde{\varsigma}_t^{MP} & = & \phi_{\pi,\varsigma^{MP}}\pi_t + \phi_{Y,\varsigma^{MP}}\hat{Y}_t + \phi_{L,\varsigma^{MP}}\hat{L}_t. \end{cases} \tag{22}$$

Countries that use both reserve requirements and interest rates as policy tools include Brazil, Colombia, Peru, Turkey, and others.

Under the fourth rule, policy options are slightly more restricted. The interest rate responds to fluctuations in output and inflation, whereas reserve requirements respond only to loans:

$$\text{Policy IV:} \begin{cases} \hat{i}_t^{IB} & = & \phi_{\pi,i^{IB}}\pi_t + \phi_{Y,i^{IB}}\hat{Y}_t \\ \tilde{\varsigma}_t^{MP} & = & \phi_{L,\varsigma^{MP}}\hat{L}_t. \end{cases} \tag{23}$$

[12] As pointed out, for example, by Svensson (1999), in general, monetary policy should respond not only to movements in target variables but also to movements in important determinants of these variables. Giannoni and Woodford (2003) provide a detailed theoretical discussion of the circumstances under which interest rate rules that only respond to target variables are sub-optimal. Intuitively, output and inflation movements are a function of past and present shocks. Contemporaneous output and inflation give only an imperfect representation of the complete history of shocks. Adding loans to the interest rate rule should be helpful, if the different shocks have different relative effects (or at different points in time) on output, inflation, and loans.

We include policy IV in order to assess the costs of a separation of the monetary authority's objectives. Since policy IV is a special case of policy III, the minimal loss under policy IV will be at least as large as under policy III. In practice, however, assigning different targets to different instruments may improve accountability and facilitate communication.

For each policy rule, the central bank then chooses the coefficients that minimize the loss function under study. Tables 3 to 5 (shown later in this paper when they are discussed individually) show the parameter values for the optimal policy projections (ϕ's), which satisfy the following minimization problem:

$$\left.\begin{matrix}\phi_{\pi,x}\\ \phi_{Y,x}\\ \phi_{L,x}\end{matrix}\right\} = \arg \min_{\phi_{\pi,x},\phi_{Y,x},\phi_{L,x}} \mathbb{L}_t^{PS,FS} \quad \forall x \in \{i^{IB}, \varsigma^{MP}\}. \qquad (24)$$

The central bank also sets the rate at which reserves are remunerated. In our specification, we assume that the central bank keeps the spread between the reserve rate and the interbank rate $i_t^{IB} - i_t^R$ constant. As can be seen from equation (5), such a policy implies that the difference between the actual reserve ratio and the target ratio $\varsigma_t^{MP} - \varsigma_t$ remains constant.[13]

The government balances its budget every period. It uses the seignorage revenue net of interest payments to finance government expenditure and lump-sum transfer payments. Government expenditures G_t follow an exogenous AR(1) process and lump-sum transfers T_t adjust as a residual.

$$G_t - T_t = T_t^S$$

2.10 Shocks

Five shocks drive the economy's dynamics: a cost-push shock (ξ_t^{CP}), a technology shock (ξ_t^A), a government spending shock (G_t), a foreign interest rate shock (i_t^*), and a foreign export demand shock

[13] If the central bank lets the spread vary, fluctuations in actual reserves become a function of the parameter ψ_2. The smaller ψ_2 is, the more sensitive actual reserve holdings are to variations in the spread. A policy that keeps the spread constant therefore allows the central bank to control fluctuations in the reserve rate directly, even if the cost for banks to deviate from the target ψ_2 are relatively small.

Table 1. Calibration of the Shocks

ρ	σ^2	Description
0.89	1.13	Technology Shock (ξ_t^A)
0.40	0.14	Cost-Push Shock (ξ_t^{CP})
0.86	4.63	Government Expenditures Shock (G_t)
0.88	0.43	Foreign Interest Rate Shock (i_t^*)
0.80	5.01	Export Demand Shock (X_t)

Notes: All shocks are defined as first-order stochastic difference equations, where ρ denotes the degree of first-order autocorrelation and σ^2 is the variance of the structural innovation of the shock processes.

Table 2. Calibration

Ident.	Value	Description
δ	0.025	Depreciation Rate of Capital
β	0.985	Discount Factor
α	0.33	Capital Share in Production
$\emptyset$	3.00	Inverse of Frish Labor Supply Elasticity
θ	0.75	Degree of Price Stickiness
υ	0.97	Survival Rate of Entrepreneurs
χ	0.25	Capital Adjustment Costs
η	0.05	Elasticity of External Finance Premium to Entrepreneurs' Level of Leverage (from the Financial Accelerator; see appendix 1)
ψ_B	0.02	Adjustment Costs for Net Foreign Assets
γ	0.75	Share of Domestically Produced Goods in Domestic Absorption

(X_t). All shocks follow AR(1) processes. The values attached to the variance of the random shock component as well as the degree of autocorrelation can be found in table 1. The values therein are taken from an estimated DSGE model as described in Christoffel, Coenen, and Warne (2008).

2.11 Calibration and Solution of the Model

Table 2 lists the details for parameters which are standard. Several parameters are not calibrated directly and are specified such that they match model-specific variables to their empirical counterparts.

This applies to the parameters ψ_1 and the steady-state value of ς_t^{MP} in equation (2). These coefficients are calibrated such that they imply an interest rate differential between the interbank rate (i_t^{IB}) and the interest rate on reserves (i_t^R) in the steady state of 150 basis points on quarterly basis and a steady-state share of reserve ratio of 0.10. The steady-state leverage ratio of entrepreneurs is two. We choose the other parameters of the financial contract to generate a steady-state external finance premium of 50 basis points and an elasticity to leverage of $\eta = 0.05$ (Christensen and Dib 2008). Combined with the interbank rate, this pins down the marginal steady-state productivity of capital and the ratio of output to capital. The implied investment share is 0.22. We choose consumption share in output to equal 0.55, which implies a government share of 0.23. We assume that 75 percent of total spending falls on home goods and balanced trade in the long run. This implies that exports over output is 0.25.

Regarding the loss function, we choose for simplicity equal weights and set parameters λ_Y and, where appropriate, λ_L equal to one.

In order to solve the model, we first log-linearize the non-linear equations system around the non-stochastic steady state. The log-linearized equilibrium equations are shown in appendix 2. In general, a hat denotes the percentage deviation from the steady state and a tilde denotes level deviations.

3. Reserve Requirements as an Instrument for Price and Financial Stability

Our analysis on the use of reserve requirements as a policy tool varies along three dimensions. The first dimension is the financial structure of the economy. We consider a first case where no financial frictions are present, apart from the assumption that savings have to be intermediated through banks and the requirement for banks to hold reserves. We then add a financial accelerator mechanism with domestic currency debt in the second case and with foreign currency debt in the third case.[14] The second dimension is the central bank's objective. In the first example, the central bank has the relatively

[14]For the no-financial-accelerator case, we abstract from the role of entrepreneurs, and capital is completely financed by deposits.

standard objective of minimizing a weighted average of inflation and output variability; in the second example, the variability of loans enters additionally. The third dimension is operational: it includes the number of variables the central bank monitors and how it uses its instruments.

The main aim of this section is therefore to analyze to what extent the use of time-varying reserve requirements can improve policy outcomes, as the structure of the economy, the objective of the central bank, and the implementation of policy varies. In section 3.1 we analyze how the effects of discretionary changes in reserve requirements vary with other monetary arrangements and with the financial structure. The analysis of the transmission mechanism prepares the ground for the interpretation of the results in the subsequent sections. Sections 3.2 and 3.3 present the results for the price stability and financial stability objective function.

3.1 The Effects of Discretionary Changes in Reserve Requirements

The present section discusses how the effects of reserve requirement shocks change with monetary policy and the financial structure. To simplify the discussion, we assume that reserve requirements follow an exogenous AR(1) process with autocorrelation 0.7 and we abstract from a systematic component in reserve requirement policy.

We start by analyzing how the effects of changes in reserve requirements on the real economy depend on the use of other monetary policy instruments in an economy without a financial accelerator. Changes in reserve requirements can have two effects: First, they influence the money supply. For a given monetary base, higher reserve requirements imply smaller broad money aggregates and we expect an economic contraction. If the rate of reserve remuneration lies below the market interest rate, a second effect occurs: reserve requirements also act as a tax on the banking sector and drive a wedge between deposit rates and lending rates. In the following we will discuss the relative importance of the two effects under three different monetary policies: a standard interest rate rule for the interbank rate as described by policy I in equation (20), a fixed exchange rate regime as given by policy II (see equation (21)), and, for illustrative purposes, the textbook example of a monetary policy where base money supply is constant and there is no monetary policy rule for the interbank rate (see, for instance, Burda and Wyplosz 2005).[15]

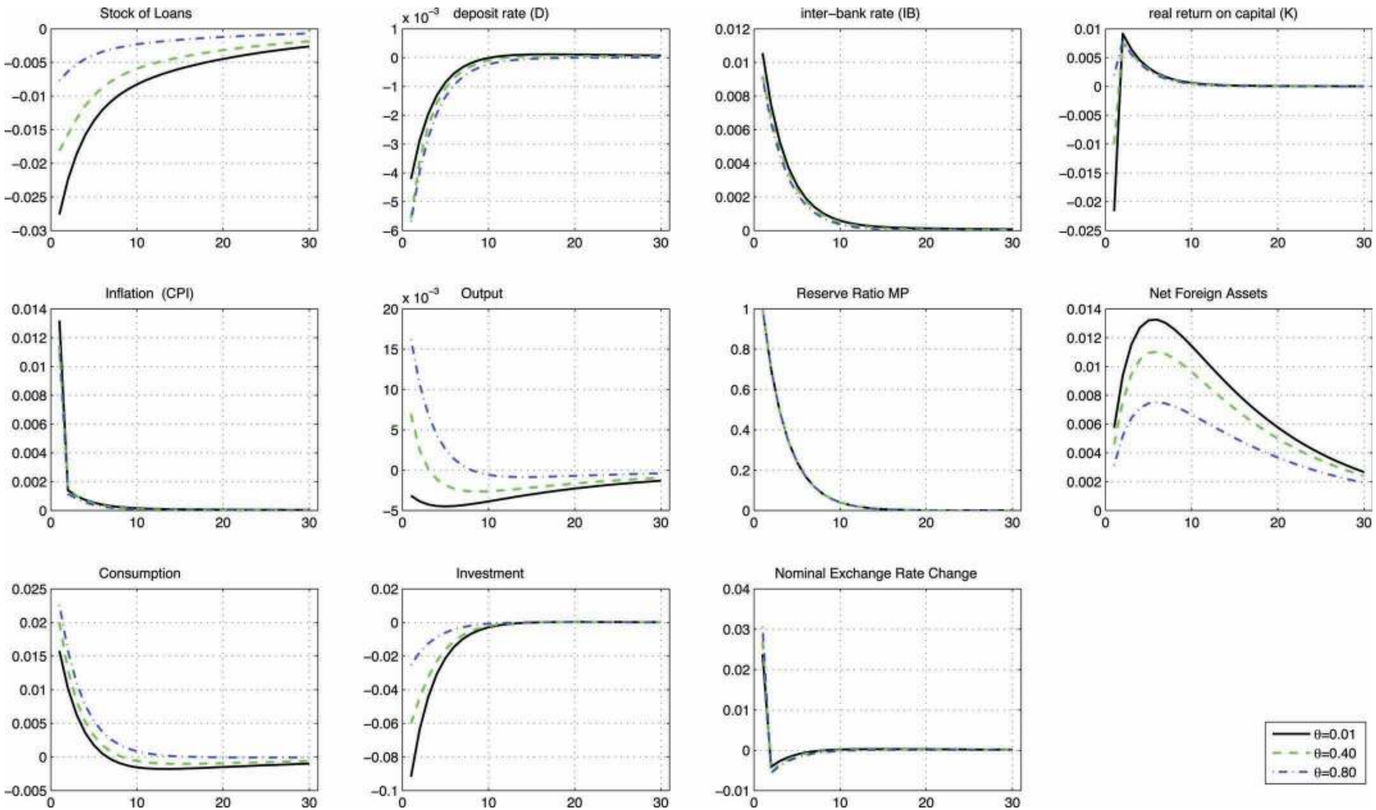
Figures 1, 2, and 3 show the effects of a 1-percentage-point discretionary change of reserve requirements under different monetary policies for various degrees of price stickiness.

Under the interest rate rule, the effect as a tax on the banking sector dominates. If the central bank targets an interest rate, money becomes endogenous and changes in reserve requirements are accommodated. But higher reserve requirements increase the spread between lending and deposit rates. Under the interest rate rule, the deposit rate falls and the lending rate rises. A tightening through an increase in reserve requirements leads therefore to quite different effects than a tightening through an increase in the policy rate, which would raise the level of interest rates in general. The higher spread has two important consequences. The increase in the lending rate implies higher costs of credit for the real sector, which leads to a decline in investment and the capital stock. The fall in investment, however, does not necessarily lead to a decline in output, as there is also an effect on consumption and on exports. A decline in the deposit rate encourages consumption spending, as consumption is linked to the real deposit rate through the Euler equation. Contractionary monetary policy would appreciate the exchange rate. In contrast, an increase in reserve requirements tightens credit conditions and depreciates the exchange rate at the same time. Because of the uncovered interest parity, the decline in the deposit rate also leads to an exchange rate depreciation and a rise in exports. Because of the opposing effects on investment on the one side, and consumption and exports on the other side, the total effect on output is ambiguous. For our calibration, inflation tends to increase, contrary to the popular notion that reserve requirements can be increased to contain inflation. The increase in the tax on banks increases overall production costs, which puts upward pressures on the overall price level.

The effects under a fixed exchange rate are broadly comparable to the ones under an interest rate rule, but with some notable differences. Under a fixed exchange rate and high capital mobility, the

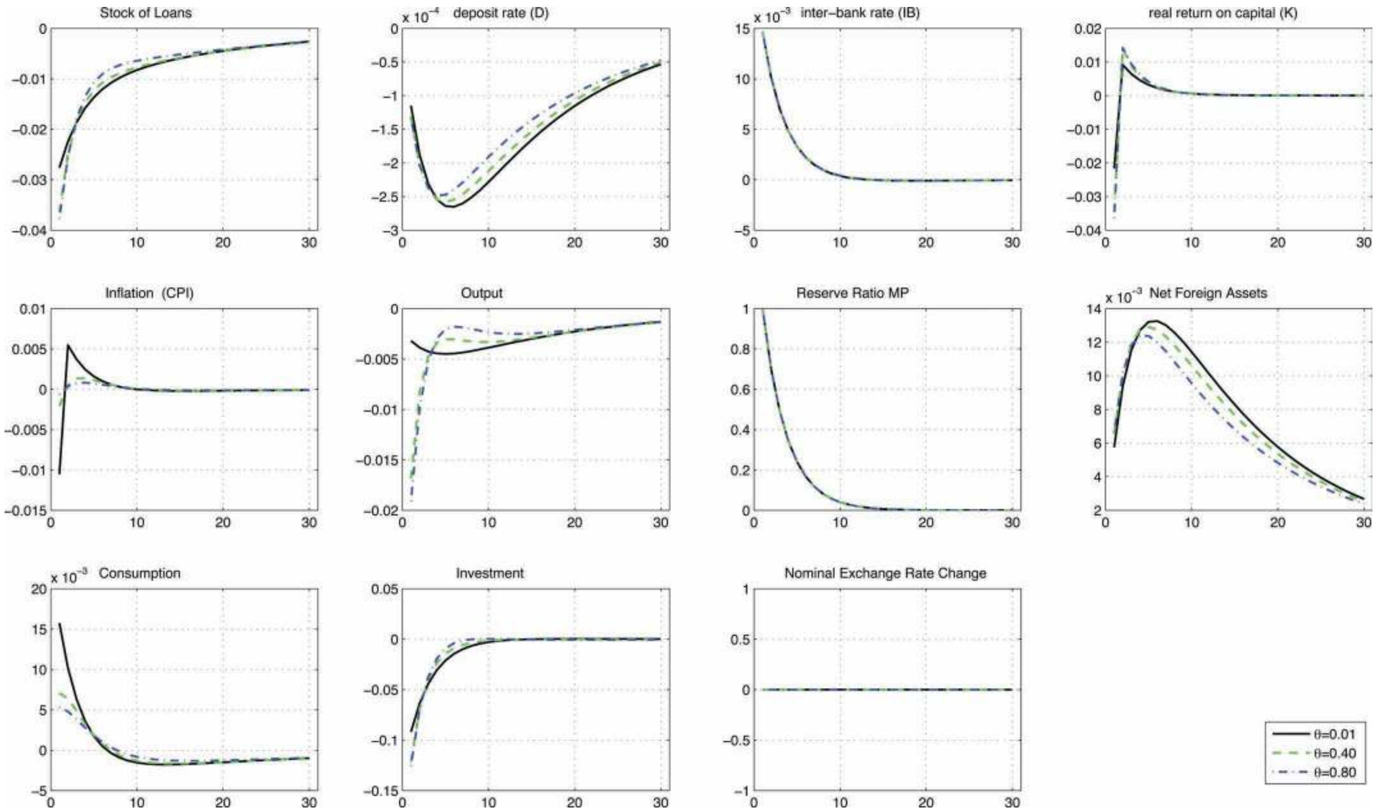
[15]Base money (μ_t) is defined as total bank reserves: $\frac{\mu_t}{P_t} = \varsigma_t D_t$. A constant base money rule is characterized by $\Delta\mu_t = 0$.

Figure 1. Reserve Requirement Shock with an Interest Rate Rule



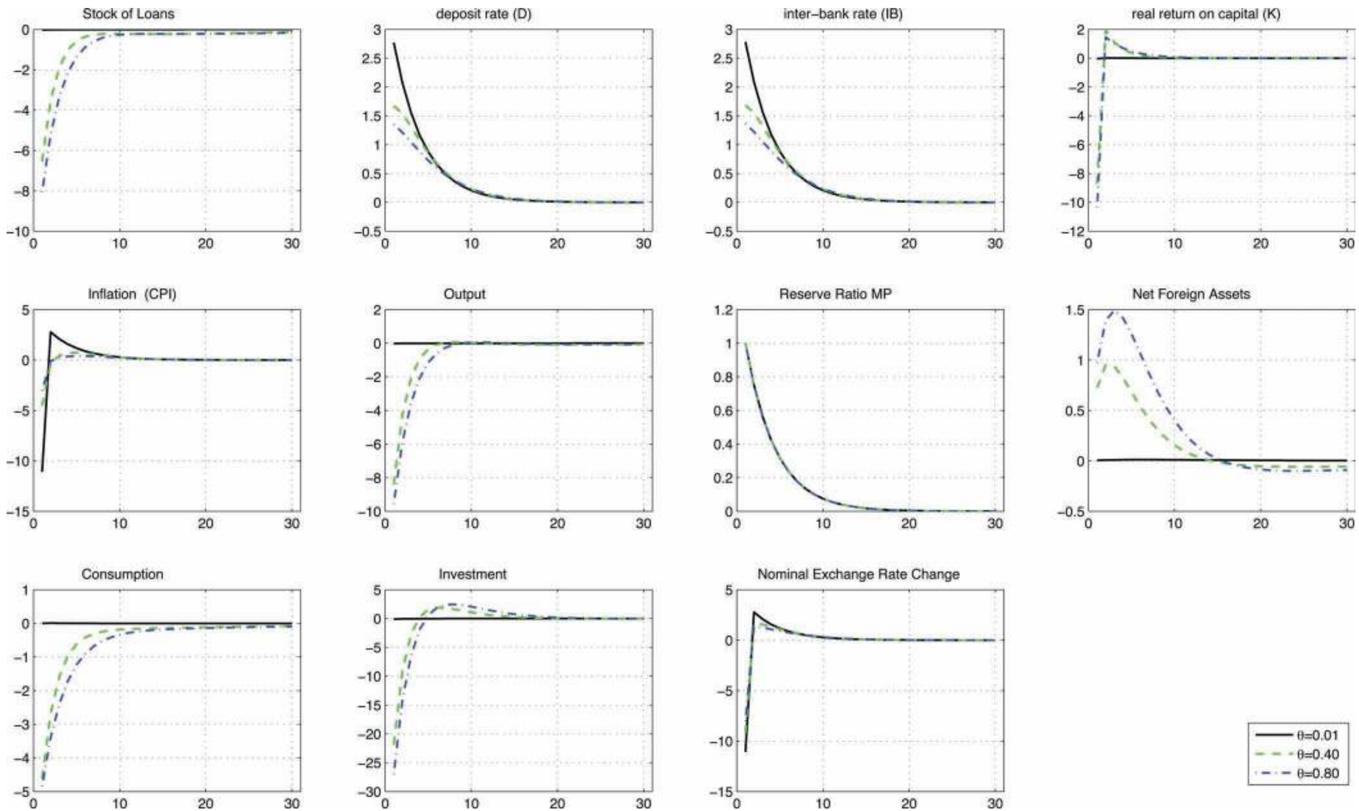
Notes: The figure reports quarterly impulse responses to a 1-percentage-point increase in reserve requirements for different degrees of price stickiness (θ). Monetary policy is specified by an interest rate rule for the interbank interest rate as defined by equation (20) with $\o_{\pi,IB} = 1.5$ and other coefficients equal to zero. Reserve requirements follow an AR(1) process with persistence 0.7. The y-axis denotes the deviation in percent from the steady state. Exceptions are reserve requirements and net foreign assets over steady-state output (absolute deviation). An increase in the exchange rate implies a depreciation of the domestic currency.

Figure 2. Reserve Requirement Shock with Constant Exchange Rate



Notes: The figure reports quarterly impulse responses to a 1-percentage-point increase in reserve requirements for different degrees of price stickiness (θ). Monetary policy is specified by a fixed exchange rate regime. Reserve requirements follow an AR(1) process with persistence 0.7. The y-axis denotes the deviation in percent from the steady state. Exceptions are reserve requirements and net foreign assets over steady-state output (absolute deviation).

Figure 3. Reserve Requirement Shock with Constant Base Money



Notes: The figure reports quarterly impulse responses to a 1-percentage-point increase in reserve requirements for different degrees of price stickiness (θ). Monetary policy is specified by a constant base money rule as specified in the text. Reserve requirements follow an AR(1) process with persistence 0.7. The y-axis denotes the deviation in percent from the steady state. Exceptions are reserve requirements and net foreign assets over steady-state output (absolute deviation). An increase in the exchange rate implies a depreciation of the domestic currency.

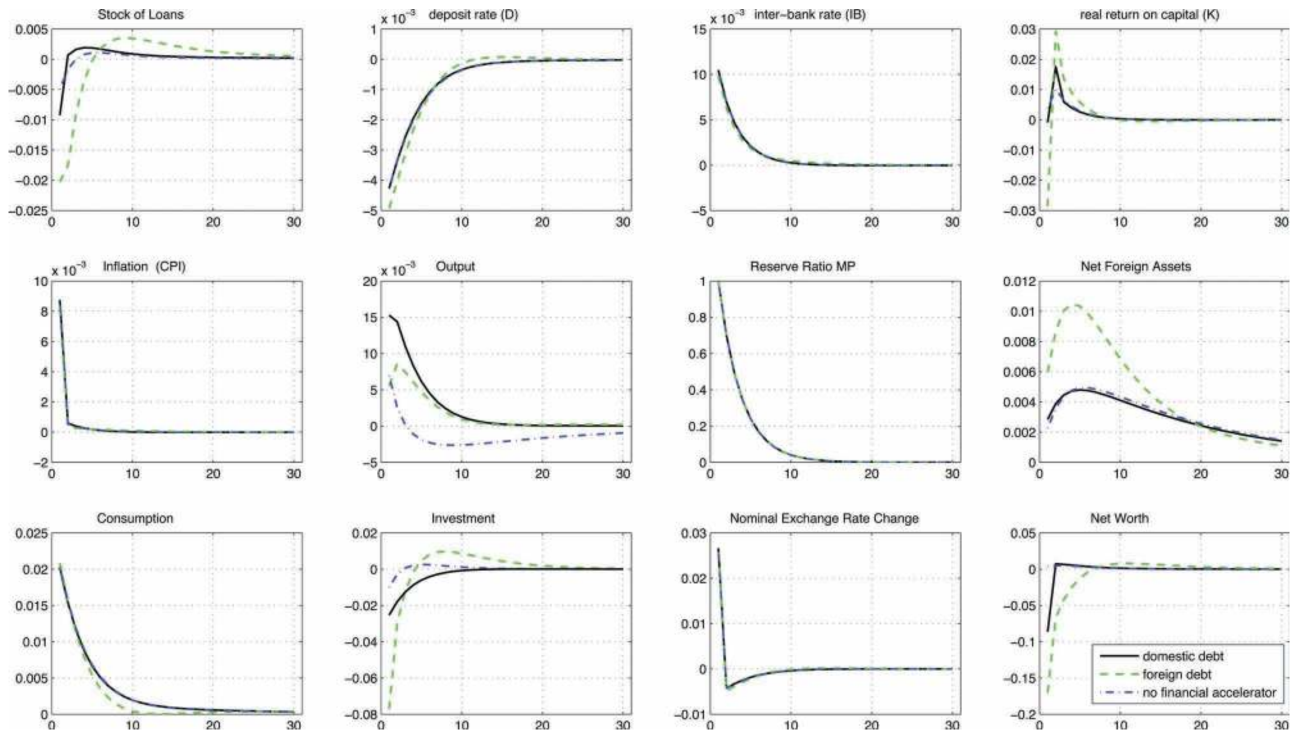
central bank is forced to stabilize the nominal deposit rate almost completely and the increase is absorbed by the lending rate. The increase in consumption, stemming from a decrease in ex ante real interest rates, is more muted and the effect on investment prevails.

Under a constant base money rule, the impulse responses are qualitatively similar to those of a standard contractionary monetary policy interest rate shock. Interest rates rise, whereas output and inflation fall. The increase in reserve requirements increases the demand for deposits by banks. In order to attract more deposits, the deposit rate has to increase. This puts upward pressure on lending rates, as marginal funding costs increase. As in the other cases, investment declines, but now, due to the rise in the deposit rate, consumption declines as well. This leads to an unambiguous decline in prices and output. Compared with the other policies considered, the magnitude of the responses is substantially larger; for example, the decline in investment is about ten times larger. The effect that derives from the contraction in broad money dominates the effects from the tax on banks.[16] However, the money multiplier effect is only important if there are nominal rigidities. The impulse response functions in figures 1, 2, and 3 show each variable's reaction for different degrees of price stickiness. Under the constant base money policy, the effects of reserve requirements are more sensitive to price stickiness than under the other two monetary policies. Without price stickiness, the reaction of the real variables is the same independent of the underlying monetary policy. This can be seen well in figures 1 and 2 by means of the black solid line. In the case of figure 3, the real variables show exactly the same reaction as in figures 1 and 2; however, due to the scaling of the y-axis, this can be hardly distinguished from zero. Intuitively, monetary effects overturn the effects from the tax only if nominal rigidities are important.

We now turn to a discussion on the effects of including a financial accelerator mechanism. Figure 4 compares the effects of a reserve requirement shock with no financial accelerator, with a financial

[16]The different magnitudes under alternative monetary regimes also help to explain the fact that authorities in Brazil and Croatia cut reserve requirements by 10 percentage points and more in the recent financial crisis, while textbook descriptions that treat reserve requirements from a constant base money perspective warn of the potentially large effects that derive from small changes in reserve requirements (see, for instance, Burda and Wyplosz 2005, p. 206).

Figure 4. Reserve Requirement Shock and Financial Frictions



Notes: The figure reports quarterly impulse responses to a 1-percentage-point increase in reserve requirements. Monetary policy is specified by an interest rate rule for the interbank interest rate as defined by equation (20) with $\o_{\pi,IB} = 1.5$ and other coefficients equal to zero. Reserve requirements follow an AR(1) process with persistence 0.7. The adjustment of the economy is shown for different model specifications; in particular, the scenarios represent (i) a model with the financial accelerator based on domestic currency debt, (ii) a model with the financial accelerator based on foreign currency debt, and (iii) a model without the financial accelerator. The y-axis denotes the deviation in percent from the steady state. Exceptions are reserve requirements and net foreign assets over steady-state output (absolute deviation). An increase in the exchange rate implies a depreciation of the domestic currency.

accelerator and domestic currency debt, and with a financial mechanism and foreign currency debt under an interest rate policy. In comparison with the baseline case, introducing a financial accelerator with domestic currency debt strengthens the effect on investment. Because of movements in the external finance premium, investment becomes more sensitive to fluctuations in the interbank rate. Foreign currency debt amplifies the transmission of reserve requirement shocks on investment further. The fall in investment is about four times larger than in the case without a financial accelerator. The decline in the deposit rate depreciates the domestic currency, which increases the domestic currency value of firms' debt, net worth declines, and the external finance premium rises further. Foreign currency debt strengthens therefore the transmission mechanism of reserve requirements—in particular, if the central bank follows an interest rate rule. This is in contrast to policy interest rate increases, where the contractionary effects of interest hikes tend to be weakened because of a currency appreciation and an increase in entrepreneurs' net worth.

3.2 Optimal Reserve Requirement Rules with a Price Stability Objective

In the present section we keep the objective fixed and consider only the price stability loss function defined in equation (18), while we vary the structure of the economy and the operational policy rules.

We start with a situation where the central bank only monitors fluctuations in output and inflation and does not respond to loans (labeled setting A). The results are displayed in table 3. We report the optimized coefficients in the policy rules and the value of the resulting loss function—in particular, its absolute value and the value relative to a policy that keeps the exchange rate and the reserve requirement ratio (ς_t^{MP}) constant.

Consider first the economy without financial frictions. The main result is that the use of reserve requirements adds little in terms of economic stabilization. Under policy A(III), where the central bank sets reserve requirements in addition to interest rates, the loss function is only about 2 percent lower compared with policy A(I), where the reserve requirement ratio is kept constant throughout. By comparison, the corresponding loss function value for the United

Table 3. Optimal Policy Rules under a Price Stability Objective

	Policy A(I)		Policy A(II)		Policy A(III)	
	i_t^{IB}	ς_t^{MP}	i_t^{IB}	ς_t^{MP}	i_t^{IB}	ς_t^{MP}
Without Financial Frictions						
$\tilde{\o}_{Y,j}$	0.2	—	—	10.8	0.1	5.9
$\tilde{\o}_{\pi,j}$	2.1	—	—	28.6	1.9	12.5
$\mathbb{L}^{PS}$	17.2 (0.42)		40.2 (0.98)		16.8 (0.41)	
With Financial Frictions and Domestic Currency Debt						
$\tilde{\o}_{Y,j}$	0.6	—	—	13.2	0.4	11.0
$\tilde{\o}_{\pi,j}$	2.8	—	—	31.9	2.2	17.5
$\mathbb{L}^{PS}$	23.1 (0.48)		45.3 (0.94)		20.7 (0.43)	
With Financial Frictions and Foreign Currency Debt						
$\tilde{\o}_{Y,j}$	0.7	—	—	13.2	0.5	15.3
$\tilde{\o}_{\pi,j}$	3.1	—	—	31.9	2.9	28.9
$\mathbb{L}^{PS}$	26.1 (0.54)		45.3 (0.94)		23.7 (0.49)	

Notes: The table shows the parameter values for policy A(I), policy A(II), and policy A(III) as specified in equations (20)–(22) for the optimal policy projections under the loss function defined in equation (18). The value in parentheses denotes the value relative to fixed exchange rate policy with constant reserve requirements.

States from 1960:Q1 to 1983:Q4 is about 4.3 times higher than from 1984:Q1 to 2007:Q2.[17] Under a fixed exchange rate regime, the value of the loss function is more than twice as large as under an interest rate rule (reported in parentheses) and the gains from using reserve requirements under an exchange rate peg are limited. The loss function is only about 2 percent smaller. Adding financial frictions does not alter the general picture. Not surprisingly, the absolute value of the loss function is higher in each case. In addition, the optimal

[17]Our inflation measure is quarter-to-quarter CPI inflation; output gap and credit gap are the percentage deviation from trend computed with a Hodrick-Prescott filter with smoothing parameter 1,600. Data for real GDP and CPI are from the Federal Reserve Bank of St. Louis database; credit is from the IMF International Financial Statistics (line 22d).

response to output and inflation fluctuations is generally stronger. While we obtain the same ranking of the policy rules, the relative gains of policy A(III) over policy A(I) are slightly larger, improving by about 10 percent with domestic currency debt and with foreign currency debt. Foreign currency debt weakens also the advantage of interest rate rules over exchange rate pegs, as foreign currency debt weakens the effects of interest rate movements on output because of balance sheet effects.[18]

We turn now to situation B, where the central bank also responds to fluctuations in loans but minimizes the same loss function (L_t^{PS}) as before. Note that here the central bank responds to loans because they contain information about the state of the economy, not because the containment of loan fluctuations is an end in itself. The results are reported in table 4. In an economy without financial frictions, the use of reserve requirements brings again little gain, both under an interest rate rule and under a peg. Losses are between 3 and 4 percent smaller. However, reacting to loans leads to lower losses. Compared with setting A, losses are about 10 percent smaller. The result indicates that even in an economy without financial frictions, responding to loans can generate some benefits, as loans contain useful information about the state of the economy.[19]

Introducing a financial accelerator mechanism with domestic currency debt leads to two new important results. First, using reserve requirements as a second policy tool helps to stabilize the economy. The loss function under policy B(III) is 22 percent lower than under policy B(I). Second, separating the targets for interest rates and reserve requirements leads to only minor losses in terms of economic stabilization. Under policy B(IV), where reserve requirements respond only to loans and interest rates to output and inflation, the loss function is only 3 percent higher than under the more general

[18]Results for the reserve requirement rule under a peg are unaffected by foreign currency debt, as the exchange rate is constant.

[19]A shock-specific analysis (using the previously optimized policy rules) indicates that the gains derive mainly from lower loss functions for technology, cost-push, and external demand shocks. For standard calibrations, these shocks induce more relative variation in loans than foreign interest rate and goverment spending shocks. A larger degree of variation in turn may increase the predictive content for inflation and output.

Table 4. Optimal Policy Rules under a Price Stability Objective

	Policy B(I)		Policy B(II)		Policy B(III)		Policy B(IV)	
	i_t^{IB}	ς_t^{MP}	i_t^{IB}	ς_t^{MP}	i_t^{IB}	ς_t^{MP}	i_t^{IB}	ς_t^{MP}
Without Financial Frictions								
$\tilde{\varnothing}_{L,j}$	0.7	—	—	13.3	0.2	5.5	—	13.6
$\tilde{\varnothing}_{Y,j}$	0.3	—	—	8.5	0.1	7.1	0.2	—
$\tilde{\varnothing}_{\pi,j}$	2.4	—	—	35.6	2.1	16.7	2.5	—
$\mathbb{L}^{PS}$	15.6 (0.38)		39.4 (0.96)		15.2 (0.37)		15.5 (0.38)	
With Financial Frictions and Domestic Currency Debt								
$\tilde{\varnothing}_{L,j}$	0.9	—	—	18.7	0.7	15.7	—	19.7
$\tilde{\varnothing}_{Y,j}$	0.4	—	—	10.0	0.3	6.1	0.2	—
$\tilde{\varnothing}_{\pi,j}$	2.8	—	—	39.9	2.7	21.6	2.5	—
$\mathbb{L}^{PS}$	19.8 (0.41)		43.3 (0.91)		15.4 (0.32)		15.9 (0.33)	
With Financial Frictions and Foreign Currency Debt								
$\tilde{\varnothing}_{L,j}$	1.3	—	—	18.7	0.8	23.0	—	25.4
$\tilde{\varnothing}_{Y,j}$	0.5	—	—	10.0	0.4	10.9	0.2	—
$\tilde{\varnothing}_{\pi,j}$	3.3	—	—	39.9	2.4	19.1	2.5	—
$\mathbb{L}^{PS}$	23.2 (0.48)		43.3 (0.91)		16.9 (0.35)		17.0 (0.35)	

Notes: The table shows the parameter values for policy B(I), policy B(II), policy B(III), and policy B(IV) as specified in equations (20)–(23) for the optimal policy projections under the loss function defined in equation (18). The value in parentheses denotes the value relative to fixed exchange rate policy with constant reserve requirements.

policy B(III). We obtain qualitatively similar results when introducing foreign currency debt. Quantitatively, however, the relative gains of policies B(III) and B(IV) over B(I) are even larger: The loss function is about 28 percent smaller. Although the loss under a peg continues to be substantially larger than under the other policy rules, the relative gain of policy B(I) over B(II) shrinks with foreign currency debt, in line with a weakened transmission mechanism for interest rate policy. The relative gains of policies B(III) and B(IV) remain, however, fairly constant, as the weakened effect of interest rate changes is compensated by stronger effects of reserve requirements.

3.3 Optimal Reserve Requirement Rules with a Financial Stability Objective

In this section we consider a case where the central bank explicitly wants to stabilize the fluctuations in loans, as reflected in the loss function L_t^{FS} in equation (19).

The results are displayed in table 5. The optimal policy rules imply four key results: First, the use of reserve requirements as a policy tool leads to substantially lower loss function values, but only if there are financial frictions. Compared with policy C(III), the loss under policy C(I) rises by around 53 percent with domestic currency debt and by even more (89 percent) in the economy with foreign currency debt. For the foreign currency debt, the percentage reduction in the loss function corresponds to roughly 30 percent of the percentage reduction the United States has experienced in the corresponding loss function in the Great Moderation period.[20] The higher loss under policy C(I) can be explained with the example of a technology shock as depicted in figure 5. The expansionary shock triggers a decline in inflation and an increase in loans. A policy aiming to stabilize inflation would favor a decline in the interbank interest rate in order to keep real rates low. The macroprudential policy, however, would favor an increase in the interbank rate which then attenuates credit demand of entrepreneurs. Hence, two goals should be implemented with one policy instrument: the interbank rate should increase and decrease at the same time. The final reaction of the interest rate will be such that it accommodates both policy goals imperfectly.

Second, a separation of tasks, where reserve requirements only respond to loans and interest rates to output and inflation fluctuations leads only to minor stabilization losses. Under policy C(III), both interest rates and reserve requirements react simultaneously to developments in output, inflation, and loans. Such a framework

[20]From 1960:Q1 to 1983:Q4 the loss function value is about 310 percent larger than from 1984:Q1 to 2007:Q2.

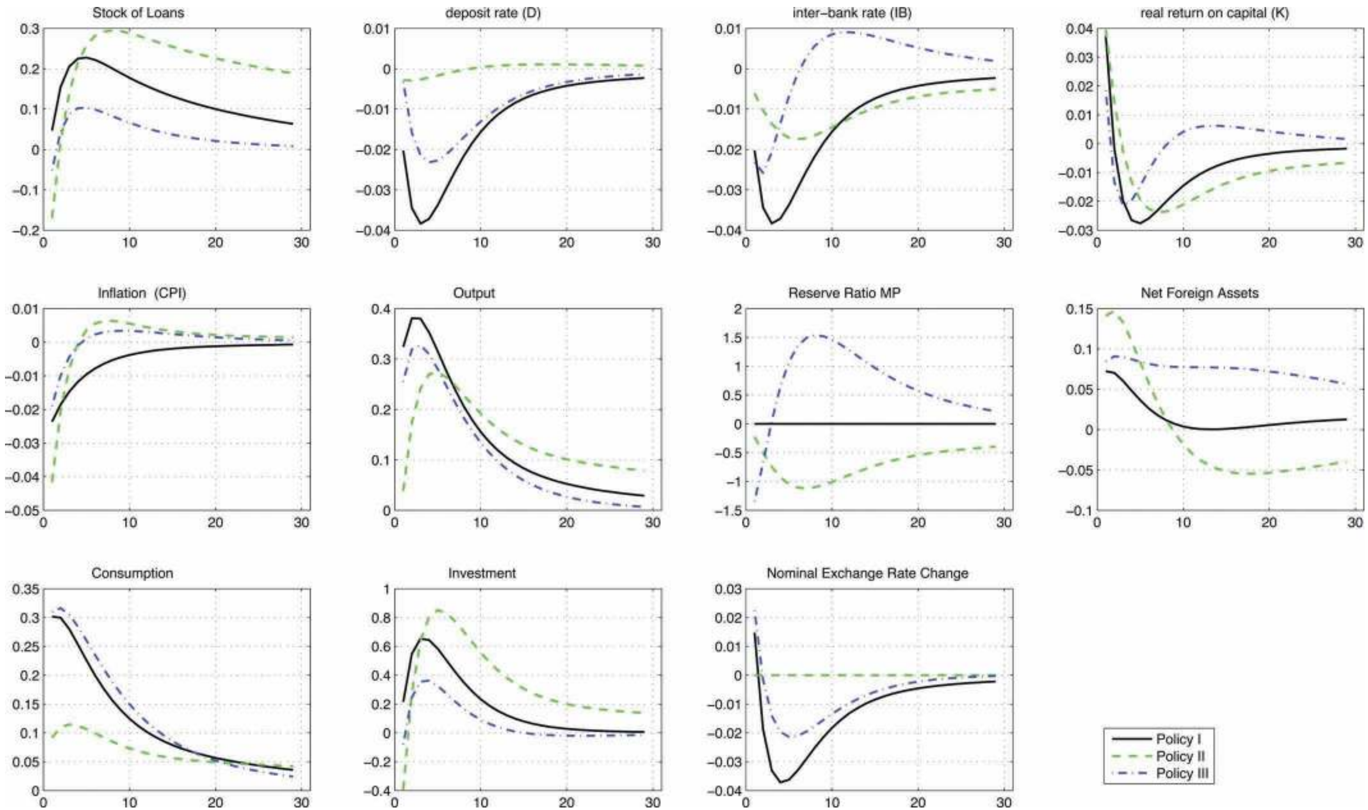
Table 5. Optimal Policy Rules with a Financial Stability Objective

	Policy C(I)		Policy C(II)		Policy C(III)		Policy C(IV)	
	i_t^{IB}	ς_t^{MP}	i_t^{IB}	ς_t^{MP}	i_t^{IB}	ς_t^{MP}	i_t^{IB}	ς_t^{MP}
Without Financial Frictions								
$\tilde{\phi}_{L,j}$	0.9	—	—	21.8	0.6	13.7	—	9.2
$\tilde{\phi}_{Y,j}$	0.1	—	—	9.3	0.1	5.7	0.4	—
$\tilde{\phi}_{\pi,j}$	3.1	—	—	28.9	2.6	21.1	3.4	—
$\mathbb{L}^{FS}$	24.5 (0.52)		46.2 (0.98)		21.7 (0.46)		22.6 (0.48)	
$\mathbb{L}^{PS\|FS}/\mathbb{L}^{PS}$	1.39		1.06		1.25		1.26	
With Financial Frictions and Domestic Currency Debt								
$\tilde{\phi}_{L,j}$	1.2	—	—	31.2	0.8	26.1	—	13.9
$\tilde{\phi}_{Y,j}$	0.1	—	—	13.5	0.1	7.3	0.3	—
$\tilde{\phi}_{\pi,j}$	3.6	—	—	27.2	2.8	16.4	3.3	—
$\mathbb{L}^{FS}$	33.7 (0.57)		53.8 (0.91)		22.1 (0.37)		22.9 (0.37)	
$\mathbb{L}^{PS\|FS}/\mathbb{L}^{PS}$	1.50		1.17		1.24		1.22	
With Financial Frictions and Foreign Currency Debt								
$\tilde{\phi}_{L,j}$	1.2	—	—	31.2	1.1	25.1	—	20.7
$\tilde{\phi}_{Y,j}$	0.2	—	—	13.5	0.1	8.9	0.4	—
$\tilde{\phi}_{\pi,j}$	3.9	—	—	27.2	2.9	13.4	3.4	—
$\mathbb{L}^{FS}$	40.2 (0.68)		53.8 (0.91)		21.2 (0.35)		21.4 (0.36)	
$\mathbb{L}^{PS\|FS}/\mathbb{L}^{PS}$	1.65		1.17		1.05		1.06	

Notes: The table shows the parameter values for policy C(I), policy C(II), policy C(III), and policy C(IV) as specified in equations (20)–(23) for the optimal policy projections under the loss function defined in equation (19). The value in parentheses denotes the value relative to fixed exchange rate policy with constant reserve requirements.

might not be very transparent and therefore difficult to communicate. Under policy C(IV), reserve requirements only respond to fluctuations in loans, whereas interest rates focus on output and inflation. As can be seen from table 5, policy C(IV) implies nearly the same loss function as policy C(III). As discussed in section 3.1, a reserve requirement increase unambiguously lowers aggregate credit

Figure 5. Technology Shock



Notes: The figure reports quarterly impulse responses to an expansionary technology shock. Monetary policy is specified by the three policy regimes outlined in section 3.2 that minimize loss function (24) as reported in table 3. There is no financial accelerator. The y-axis denotes the deviation in percent from the steady state. Exceptions are reserve requirements and net foreign assets over steady-state output (absolute deviation). An increase in the exchange rate implies a depreciation of the domestic currency.

but tends to have small and ambiguous effects on inflation and output. Since reserve requirement policy has small direct effects on output and inflation, a reserve requirement rule that focuses on loans leads only to small losses.

The third key result highlights that under a framework that separates the tasks of price and credit stabilization, financial frictions only affect the optimal reserve requirements rule and not the optimal interest rate rule. Considering policy C(IV) in table 5 for the cases for the three types of financial structure, we can see that the optimal parameter values for the interest rate rule hardly change. There is, however, a substantial increase in the response of reserve requirements to loans when there is a financial accelerator mechanism. The effects of financial frictions on optimal policy are therefore fully absorbed by a change in the reserve requirement policy, leaving the interest rate policy unaffected. In contrast, if the central bank uses the interest rate as the only policy instrument (policy C(I)), financial frictions ask for a substantially stronger response to loan fluctuations. The result can be interpreted as follows: With a financial accelerator mechanism, loan fluctuations become more important for macroeconomic dynamics because they affect risk premia, which warrants a stronger response to loan fluctuations. If a more aggressive reserve requirement policy takes care of financial frictions and can stabilize the risk premium and leverage, optimal monetary policy (conditional on optimal reserve requirement policy) is not affected.

The fourth result relates to the extent by which an additional objective in form of loan stability increases the volatility of the other two components. We compute the price stability loss function that obtains if the central bank pursues a financial stability objective $L^{PS|FS}$. In table 5 we report $L^{PS|FS}/L^{PS}$ as a measure of how much the additional target harms the traditional objective. The increase in the volatility of output and inflation is larger if reserve requirements are constant (policy C(I)) and raises further with financial frictions. In the foreign currency debt setting, the price stability loss function is about 70 percent larger. Under policies C(III) and C(IV), the loss function increases by 26 percent at the most. With foreign currency debt, the increase totals to only about 5 percent. The small increase is in line with the previous argument that foreign currency debt actually increases the effectiveness of reserve requirements. The

Table 6. Optimal Policy Rules with Imperfect Capital Mobility

	No FA		FA with DCD		FA with FCD	
	C(I)	C(IV)	C(I)	C(IV)	C(I)	C(IV)
Low Capital Mobility	28.8	26.4	38.6	34.5	49.9	33.1
High Capital Mobility (compare Table 5)	24.5	22.6	33.7	22.9	40.2	21.4

Notes: The table shows the value of the loss function defined in equation (19) under high and low capital mobility ($\psi_B = 0.02$ and $\psi_B = 0.10$). The policy rules correspond to those outlined in table 5. "No FA" refers to the model without the financial accelerator, "FA with DCD" features the financial accelerator based on domestic currency debt, and "FA with FCD" features it based on foreign currency debt.

result indicates that asking the central bank to control credit can lead to substantially higher fluctuations in output and prices without an additional instrument, but that the use of reserve requirements can contain the resulting losses.

4. Extensions: Limited Capital Mobility and the Role of Specific Shocks

The present section considers two extensions. First, we consider how limited capital mobility affects our results. Second, we analyze the role of specific shocks. In both cases the central bank has a financial stability loss function. To save space, we focus on the policies where only the interest rate moves, C(I), and reserve requirements and interest rates pursue separate tasks, C(IV).

In many emerging countries capital mobility is imperfect, both because of technical impediments and because of capital controls. Capital controls are sometimes under discussion as a substitute for macroprudential policies. To analyze the role of limited capital mobility, we increase the sensitivity of the country risk premium ψ_B from 0.02 to 0.10. The increased sensitivity makes the financing of external imbalances more costly and moves the economy towards financial autarky.[21] Table 6 compares the results for low and high

[21] In the present analysis costs are symmetric for in- and outflows. Considering asymmetries could be an interesting extension.

Table 7. Optimal Policy Rules for Specific Shocks

	No FA		FA with DCD		FA with FCD	
	C(I)	C(IV)	C(I)	C(IV)	C(I)	C(IV)
Technology	1.00	0.96	1.54	1.01	1.94	1.22
Cost Push	1.00	0.92	1.38	1.07	2.07	1.46
Government Expenditures	1.00	0.91	1.05	1.02	1.37	1.18
Foreign Interest Rate	1.00	0.99	1.33	1.26	1.53	1.38
Export Demand	1.00	0.99	1.10	1.07	1.17	1.13

Notes: The table shows the value of the loss function defined in equation (19) if only one type of shock hits the economy. The policy rules considered for the interest rate and reserve requirements correspond to those outlined in table 5. "No FA" refers to the model without the financial accelerator, "FA with DCD" features the financial accelerator based on domestic currency debt, and "FA with FCD" features it based on foreign currency debt.

capital mobility. There are two main findings: First, capital controls increase the loss function values for both type of policy rules, irrespective of the financial structure. Imperfect capital mobility constrains the possibility of the economy to absorb shocks through the current account. Second, capital controls reduce the effectiveness of reserve requirements. The loss of policy C(I) relative to C(IV) drops from 1.5 to 1.1 with domestic currency debt and from 1.9 to 1.5 with foreign currency debt. Limited capital mobility increases the offsetting effects of reserve requirements on consumption, as consumption smoothing possibilities are limited. Furthermore, in the foreign currency debt case, the effects of reserve requirement changes become smaller, as the nominal exchange rate response becomes more muted.

We intend to analyze to what extent our results are affected by the types of shocks that hit the economy. Table 7 considers each of the five shocks separately when the central bank has a financial stability objective (L^{FS}). Different from the previous exercise, the central bank chooses different coefficients for each type of shock. While such a setting is admittedly unrealistic, it allows us to assess whether our results are driven by a specific shock and if the heterogeneity in the optimal responses conditional on some specific shock is important.

The results broadly confirm our previous findings but highlight that the results for specific shocks vary with the financial structure of the economy. If there is no financial accelerator mechanism, the gains of using reserve requirements are limited for all types of shocks, in line with our previous finding. In the model with a financial accelerator and domestic currency debt, the gains from using reserve requirements derive mainly from supply shocks (cost push and technology), whereas they remain small for demand and foreign shocks. A financial accelerator mechanism amplifies both the effects of reserve requirements and of policy rate changes. A reserve requirement rule that responds to loan fluctuations generates substantial benefits only for those shocks that do not move loans, output, and inflation in the same direction. For other shocks, interest rate policy can move all target variables in the desired direction. With foreign currency debt, there are also gains for demand and foreign shocks when applying a reserve requirement rule. Foreign currency debt complicates the task of interest rate policy to stabilize loans for all shocks. While a raise in the policy rate increases risk-free rates, the associated exchange rate appreciation increases entrepreneurs' net worth, which leads to a decline in risk premia and attenuates the contraction in loans. At the same time, foreign currency debt increases the effects of discretionary reserve requirement changes.

5. Conclusion

The present paper aims to provide a framework to analyze if and under which circumstances reserve requirements can be an effective tool. We build a small open-economy model with nominal rigidities, financial frictions, and a banking sector that is subject to reserve requirements. If the central bank pursues mainly a price stability objective and uses the interest rate as its main policy instrument, varying reserve requirements contributes little to economic stability. Higher reserve requirements increase interest rate spreads, which induces upward pressure on consumption due to lower deposit rates, and downward pressure on investment due to higher lending rates. However, if there are financial frictions—in particular, in conjunction with foreign currency debt and an objective to stabilize credit—the gains from adapting reserve requirements to economic conditions are substantial. An increase in reserve requirements allows to generate an exchange rate depreciation and tougher credit conditions at the same time, whereas interest rate policy through interest rates has to forgive one or the other.

We interpret our results as reflecting the Tinbergen rule. As noted by Tinbergen (1952), the policymaker cannot intend to hit targets for more objective variables than the number of instruments available. However, as Tinbergen (1952) emphasizes, the availability of N instruments does not guarantee that as many as N objective targets can be hit. There must be N independent instruments, in the sense that the effects of any one instrument on the objectives are not proportional to those of any other, or of any combination of others. In line with this, we find that in an economy without financial frictions and where the central bank pursues a price stability mandate, the gains from using reserve requirements as an additional instrument are negligible but can improve policy outcomes substantially in an economy where financial frictions are present and the central bank has a financial stability objective.

Appendix 1. Financial Contract between Lending Banks and Entrepreneurs

This appendix refers to section 2.5. The loan contract between entrepreneurs and lending bank units introduces a further friction into the model. This contract's structure is as described in Bernanke, Gertler, and Gilchrist (1999). The financial contract involves two parties: an entrepreneur with net worth and a bank which can raise funds from households. There is a continuum of entrepreneurs indexed by $j \in (0, 1)$ who purchase a capital stock from capital goods producers and rent it to intermediate goods producers. Each entrepreneur finances his end-of-time-t capital holdings with his end-of-time-t net worth and bank loans from the financial intermediary. Let $N_t(j)$ be his net worth, $L_t(j)$ his stock of loans, Q_t the current market price of one unit of capital and $K_t(j)$ its end-of-time-t capital stock, and then this entrepreneur's balance sheet reads

$$Q_t K_t(j) = N_t(j) + L_t(j). \tag{25}$$

Capital is homogeneous and so it does not matter whether capital purchased by the entrepreneur is newly produced within the current period or is old, already depreciated, capital. Having the entrepreneur purchase his total capital stock each period makes sure that leverage restrictions apply to the firm as a whole and not just to marginal investment.

Capital is sensitive to both aggregate and idiosyncratic risk. After the capital purchase, each entrepreneur draws an idiosyncratic productivity shock which changes $K_t(j)$ to $\omega(j)K_t(j)$ at the beginning of period $t+1$. The random variable $\omega(j)$ is i.i.d. across firms and time and satisfies $\ln(\omega(j)) \sim N(\mu_\omega, \sigma_\omega^2)$. Its cumulative distribution is given by $Pr(\omega(j) < x) = F(x)$ and the density function by $f(x) = F'(x)$.

The further parts of the financial contract are based on the assumption of a standard debt contract from the bank. This specifies a loan amount $P_tL_t(j)$ and a gross interest rate i_t^L to be paid if $\omega(j)$ is high enough. Those entrepreneurs who draw $\omega(j)$ below the cutoff level $\bar{\omega}(j)$ cannot repay their loans and go bankrupt as a consequence. They must hand over everything they have to the bank; however, the bank can only recover a fraction $1-\mu$ of the value of such firms. μ is a parameter which captures the degree of monitoring costs or information asymmetry. If μ is set to zero, there will be no financial accelerator effect.

Let $E_tr_{t+1}^K$ denote the expected real gross return on capital at the end of period t. At a point in time when the contract is made, the entrepreneur can only offer it based on $E_tr_{t+1}^K$ and $\bar{\omega}(j)$, which is the cutoff idiosyncratic shock that the entrepreneur is expected to default in period $t+1$ based on information up to and including period t. For a specific value of the expected return on capital, $\bar{\omega}(j)$ is defined such that if $\omega(j) < \bar{\omega}(j)$, the entrepreneur defaults. Hence $\bar{\omega}(j)$ needs to satisfy the following:

$$\bar{\omega}(j)Q_tK_t(j)E_tr_{t+1}^K = i_t^L\frac{P_t}{P_{t+1}}L_t(j). \tag{26}$$

Under the optimal contract, when $\omega(j) > \bar{\omega}$, the entrepreneur repays the lender the promised amount $i_t^L\frac{P_t}{P_{t+1}}L_t(j)$ and keeps the difference, equal to $\omega(j)Q_tK_t(j)E_tr_{t+1}^K - i_t^L\frac{P_t}{P_{t+1}}L_t(j) > 0$. However, if $\omega(j) < \bar{\omega}$, the entrepreneur cannot repay the loan and thus declares bankruptcy. In this situation the financial intermediary pays the auditing costs and gets what is left from the entrepreneur, which equals $(1-\mu)\omega(j)r_{t+1}^KQ_tK_t(j)$. A defaulting entrepreneur earns nothing. Hence the contract maximizes the expected return to the entrepreneur, which can be expressed by

$$E_t\left[\int_{\bar{\omega}(j)}^{\infty}\left(\omega Q_t K_t(j) E_t r_{t+1}^K - i_t^L \frac{P_t}{P_{t+1}} L_t(j)\right) f(\omega) d\omega\right]. \tag{27}$$

The optimal contract must include the participation constraint of the bank as well, which is

$$(1 - F(\bar{\omega}(j)) i_t^L \frac{P_t}{P_{t+1}} L_t(j) + (1-\mu)\int_0^{\bar{\omega}(j)} \omega Q_t K_t(j) E_t r_{t+1}^K f(\omega) d\omega$$
$$= \frac{i_t^{IB}}{E_t \pi_{t+1}} L_t(i). \tag{28}$$

In equation (28), the left-hand side shows that banks' return on the loan has two components: the first is the amount that is paid back including interest rates by the entrepreneur once he does not default. In the case he defaults, the bank receives the firm's remaining assets excluding the monitoring costs. The right-hand side captures the bank's costs for raising funds.

The first-order condition for the optimal purchase of capital is as follows (see Bernanke, Gertler, and Gilchrist 1999 for further details):

$$Q_t K_t(j) = f\left(\frac{E_t r_{t+1}^K}{i_t^{IB}/E_t \pi_{t+1}}\right) N_t(j), \text{ with } f'(\cdot) > 0. \tag{29}$$

Equation (29) shows how much the external finance premium $(E_t r_{t+1}^K/(i_t^{IB}/E_t \pi_{t+1}))$ matters for the relation between a firm's capital stock and its net worth. Capital expenditures are proportional to the net worth of the entrepreneur. A rise in lending banks' financing costs increases the expected default probability. As a consequence, the entrepreneur can take on less debt and hence has to contract the size of his firm. Everything else equal, a reduction in the stock of loans increases the entrepreneur's net worth relative to his stock of loans in the end.

An equivalent way of expressing equation (29) is

$$E_t r_{t+1}^K = h\left(\frac{N_t(j)}{Q_t K_t(j)}\right) \cdot \frac{i_t^{IB}}{E_t \pi_{t+1}}, \text{ with } h'(\cdot) < 0. \tag{30}$$

For an entrepreneur who is not fully self-financed, the expected return to capital has to be equal to the marginal cost of external finance. Equation (30) expresses the equilibrium condition that the ratio $r^K_{t+1}/(i^{IB}_t/E_t\pi_{t+1})$ of the cost of external finance to the safe rate depends on the share of the entrepreneur's new capital purchase that is financed by his own net worth.

Appendix 2. The Log-Linearized Equations

The following equations describe the equilibrium of the model in log-linearized form as referred to in section 2.11. The equations here refer to the model with domestic currency debt. A hat denotes the percentage deviation from the steady state and a tilde denotes level deviations. The variable $\hat{B}_t$ denotes the deviation of net foreign assets from the steady-state level of output.

Households

- Consumption-saving decision:

$$E_t\hat{C}_{t+1} - \hat{C}_t = \hat{\imath}^D_t - E_t\pi_{t+1}$$

- Uncovered interest parity condition:

$$\hat{\imath}^D_t + \psi_B\tilde{B}_t = \hat{\imath}^*_t + E_t\Delta\hat{s}_{t+1}$$

- Labor supply:

$$\hat{w}_t = \phi\hat{h}_t + \hat{C}_t$$

Deposit Banks

- Reserve requirements:

$$\hat{\imath}^{IB}_t = \frac{i^R}{i^{IB}}\hat{\imath}^R_t - \tilde{\psi}_2\left(\tilde{\varsigma}_t - \tilde{\varsigma}^{MP}_t\right)$$

- Deposit rate:

$$\hat{\imath}^D_t = a_1\hat{\imath}^{IB}_t - a_2\tilde{\varsigma}^{MP}_t,$$

where $a_1 = (1-\varsigma)\frac{i^{IB}}{i^D} + \varsigma\frac{i^R}{i^D}$ and $a_2 = \frac{i^{IB}-i^R}{i^D}$.

Entrepreneurs and Lending Banks

- Leverage and external finance premium:

$$E_t\hat{r}^K_{t+1} - \tilde{i}^{IB}_t + E_t\pi_{t+1} = \eta[\hat{Q}_t + \hat{K}_t - \hat{N}_t]$$

- Loan rate (nominal and real):

$$\hat{r}^L_t = \hat{Q}_t + \hat{K}_t + E_t\hat{r}^K_{t+1} - \hat{L}_t$$
$$\hat{i}^L_t = \hat{r}^L_t + E_t\pi_{t+1}$$

Entrepreneurs

- Balance sheet:

$$\hat{Q}_t + \hat{K}_t = \epsilon_L\hat{L}_t + (1-\epsilon_L)\hat{N}_t$$

- Net worth:

$$\hat{N}_t = \nu\hat{N}_{t-1} + (1-\nu)[\hat{Q}_{t-1} + \hat{K}_{t-1}] + \hat{r}^K_t + \nu\frac{\epsilon_L}{1-\epsilon_L}\left[\hat{r}^K_t - \left(\hat{i}^L_{t-1} - \pi_t\right)\right]$$

Intermediate Goods Producers

- Production function:

$$\hat{y}_t = \hat{\xi}^A_t + \alpha\hat{K}_{t-1} + (1-\alpha)\hat{h}_t$$

- Marginal costs:

$$\hat{mc}_t = \alpha\hat{z}_t + (1-\alpha)\hat{W}_t - \hat{\xi}^A_t$$

- Cost minimization:

$$\hat{h}_t + \hat{W}_t = \hat{z}_t + \hat{K}_{t-1}$$

- Price setting:

$$\pi^d_t = \beta E_t\pi^d_{t+1} + \frac{(1-\theta)(1-\theta\beta)}{\theta}\hat{mc}_t + \hat{\xi}^{CP}_t$$

Capital Goods Producers

- Investment demand:

$$\hat{Q}_t = \chi[\hat{I}_t - \hat{K}_{t-1}]$$

- Price of capital:

$$\hat{r}_t^K - \hat{Q}_{t-1} = \frac{MPK}{r^K}\hat{z}_t + \frac{1-\delta}{r^K}\hat{Q}_t,$$

where MPK is the marginal product of capital.

- Capital dynamics:

$$\hat{K}_t = (1-\delta)\hat{K}_{t-1} + \delta\hat{I}_t$$

Monetary and Macroprudential Policy

See section 2.9 and section 3.2 for the details.

Market Clearing

- Goods market:

$$\hat{Y}_t = \gamma[c_y\hat{C}_t + i_y\hat{I}_t + g_y\hat{G}_t + (1-\gamma)\hat{\epsilon}_t] + (1-\gamma)[\hat{\epsilon}_t + \hat{X}_t]$$

- Balance of payments:

$$\tilde{B}_t = \hat{Y}_t - [c_y\hat{C}_t + i_y\hat{I}_t + g_y\hat{G}_t + (1-\gamma)\hat{\epsilon}_t] + i^*\tilde{B}_{t-1}$$

- Real exchange rate:

$$\hat{\epsilon}_t - \hat{\epsilon}_{t-1} = \Delta\hat{s}_t - \pi_t^d$$

- CPI—inflation rate:

$$\pi_t = \gamma\pi_t^d + (1-\gamma)\Delta\hat{s}_t$$

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