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Topics

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Required reserves as a credit policy tool

Abstract: This paper quantitatively investigates the role of reserve requirements as a credit policy tool. We build a monetary dynamic stochastic general equilibrium (DSGE) model with a banking sector in which an agency problem between households and banks leads to endogenous capital constraints for the latter. In this setup, a countercyclical required reserves ratio (RRR) rule that responds to expected credit growth is found to countervail the negative effects of the financial accelerator mechanism triggered by productivity and bank capital shocks. Furthermore, it reduces the procyclicality of the financial system compared to a fixed RRR policy regime. The credit policy is most effective when the economy is hit by a financial shock. A time-varying RRR policy reduces the intertemporal distortions created by the fluctuations in credit spreads at the expense of generating higher inflation volatility, indicating an interesting trade-off between price stability and financial stability.

Keywords: banking sector; time-varying reserve requirements; macroeconomic; financial shocks.

JEL Classification: E44; E51; G21; G28.

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1 Introduction

Policymakers in both advanced and emerging countries have been exercising a variety of measures to mitigate the transmission of financial disruptions to the real sector. To that end, frictions in the financial sector and macroprudential policy instruments have been the focal point of the recent literature on macroeconomic dynamics and policy. Among many policy tools, reserve requirements have recently been used extensively as a macroprudential policy tool in several countries. Among others, China, Brazil, Malaysia, Peru, Colombia, and Turkey are some of the countries that have used this policy tool mainly to curb excessive credit growth in upturns and to ease financial constraints in downturns, along with other reasons.[1] The main objective of these countries is to employ reserve requirements either as a monetary policy tool to achieve price stability or as a macroprudential policy tool to foster financial stability, or sometimes both. In this paper, we explicitly focus on the second objective: financial stability.

As Montoro and Moreno (2011) note, central banks use reserve requirements to achieve financial stability in the following manner. They can raise reserve requirements to contain credit growth in the boom part of the business cycle in order to counteract financial imbalances in the economy. In an economic downturn, they can lower reserve requirements to utilize reserve buffers accumulated during the boom part, having the banking sector extend more credit to nonfinancial businesses. Therefore, reserve requirements can be used as a countercyclical policy instrument to ease credit fluctuations in the financial sector and, hence, to stabilize the real economy.

The goal of this study is to investigate the effectiveness of reserve requirements that respond to expected credit growth in moderating the real and financial cycles of an economy. We do so in a model in which real and financial fluctuations are amplified by a financial accelerator mechanism. Specifically, we explore the stabilizing role of reserve requirements as a credit policy tool in the transmission of productivity and financial shocks. The results suggest that a time-varying reserve requirement policy mitigates the fluctuations in key macroeconomic variables in response to macroeconomic and financial shocks and improves welfare vis-á-vis a fixed reserve requirement policy.

We build a monetary dynamic stochastic general equilibrium (DSGE) model in which the financial intermediation between depositors and nonfinancial firms is explicitly described, as in Gertler and Karadi (2011). In this model, the amplification of total factor productivity (TFP) shocks is larger due to the so-called financial accelerator mechanism built in endogenous capital constraints faced by financial intermediaries. Endogenous capital constraints emerge from an agency problem assumption, which posits that banks might divert a fraction of assets that they have expanded to nonfinancial firms. When this action is realized by depositors, a bank run is initiated, causing the bank to liquidate. Therefore, the contracting problem between depositors and banks requires an incentive compatibility condition to hold (i.e., the liquidation value of banks must be larger than or equal to the amount of diverted funds). As expected, in this environment, depositors abstain from providing as much funds as they would have provided in the absence of this agency problem.

We modify the basic financial intermediation framework to one in which "money" is modeled via a cash-in-advance constraint. Consequently, the central

1 See Gray (2011), Lim et al. (2011), Montoro (2011), Montoro and Moreno (2011), Glocker and Towbin (2012) for a discussion of country experiences.

bank meets the summation of cash demand of workers and the "nominal" reserves demand of bankers by supplying the monetary base. The resulting money market clearing condition creates room for fluctuations in the inflation rate, induced by movements in reserve requirements, which then feed back into the cash-in-advance constraint of workers, with real effects. Therefore, the time-varying required reserves policy renders inflation much more volatile compared to a fixed reserves policy.[2] This finding suggests that in this setup, there is a trade-off between price stability and financial stability.

We abstract from nominal rigidities and use a simplistic monetary policy setup to focus solely on the "financial stability" considerations of the central bank, as highlighted by the Central Bank of the Republic of Turkey (to be discussed in greater detail in Section 2) and other monetary policy authorities around the globe. Therefore, we do not resort to a discussion of inflation targeting (indeed, nominal interest rates are endogenous) or the Friedman rule, since monetary policy is summarized by a constant monetary base growth that is calibrated to the historical data. Nevertheless, the recent global financial turmoil has established that financial stability is warranted for the *effective transmission* of monetary policy, and the coordination of macroprudential and monetary policies has been at the center of policy debates [for examples, see Angelini, Neri, and Panetta (2012); Beau, Clerc, and Mojon (2012)]. Indeed, macroprudential and macroeconomic policies might not always reinforce each other, depending on the sources of shocks to the economy [Angelini, Neri, and Panetta (2012), Kannan, Rabanal, and Scott (2012)].

We calibrate the model to the Turkish economy, which has been exemplifying the use of reserve requirements as a credit policy tool since the end of 2010 (see Figure 1). In particular, the Central Bank of the Republic of Turkey (henceforth, CBRT) has increased the weighted average of the required reserves ratio (henceforth, RRR) from 5% to 13% between October 2010 and April 2011, in a stepwise manner. This period also coincides with the aftermath of the second phase of quantitative easing implemented by monetary authorities in a number of advanced economies. Evidently, this period is characterized by an increase in the risk appetite of global investors and excessive credit growth in economies such as Turkey. On the other hand, the same measure of the RRR was reduced to about 10% around November 2011 by the CBRT following the debt crisis of the Euro area to ease the domestic credit markets.

Our quantitative exercise involves comparing a *fixed* RRR economy in which the RRR is calibrated to its long-run value preceding the interventions of the

2 Endogenously determined short-term nominal interest rates will also be more volatile compared to a Taylor rule setup.

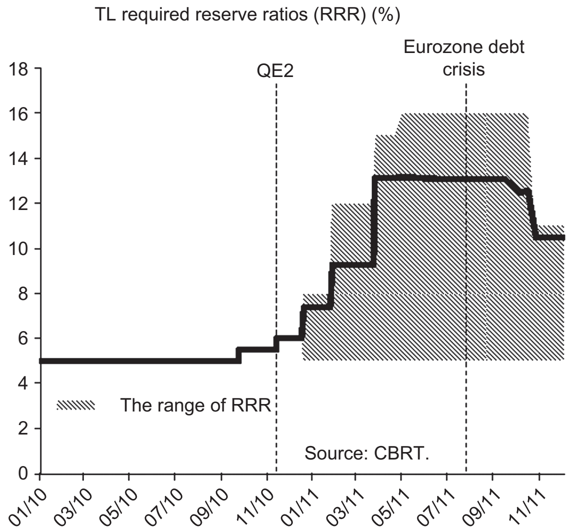

Figure 1 Evolution of required reserve ratios in Turkey.

CBRT and the *time-varying* RRR economy in which the RRR is countercyclical with respect to expected credit growth.[3] We also simulate the model under moderate and aggressive required reserves policies in order to understand the strength of the credit policy tool. Moreover, we consider required reserves policies that respond to asset price growth and output growth rather than credit growth to assess the effectiveness of alternative policies in stabilizing the real and financial cycles of the economy. We then compute optimal credit policy intensity by using an exogenous loss function, which includes the variabilities of credit, output and the required reserves ratio as its arguments. Finally, we conduct sensitivity analysis by changing key parameters of the benchmark model regarding the financial sector in order to evaluate the effectiveness of reserve requirements as a credit policy tool in different economic structures.

The paper has three main results. First, a countercyclical required reserves policy mitigates the negative effects of the financial accelerator mechanism triggered by adverse TFP and bank capital shocks on key macroeconomic and financial variables in comparison with a fixed reserves policy. As a result, we conclude that RRRs might be used as a credit policy tool in an economy that exhibits financial frictions. Second, a time-varying reserve requirement policy is

3 We also conduct an analysis of a model economy with a zero required reserves policy. However, since the dynamics of this case strongly resemble those of the fixed RRR economy, we do not include it in the paper in order to save space.

always welfare superior to a fixed reserve requirement policy under both shocks. Furthermore, loss function comparisons indicate that the central bank should optimally take a more aggressive stance in varying the RRR when the economy is hit by both TFP and financial shocks than the case in which it is solely hit by the former. Finally, the effectiveness of the policy increases as financial frictions become more severe. Thus, the effect of a time-varying required reserves policy is bigger in a high-risk economy with a less efficient financial system where loan-deposit spreads are higher and the leverage of the banking sector is lower.

We acknowledge that canceling reserve requirements altogether might improve the aggregate welfare of the economy. Mostly for precautionary reasons, however, positive reserve requirements do exist in practice, although this still does not necessarily prove that they are optimal. Therefore, since it is beyond the scope of this paper, we do not bring any microfoundation to this institutional framework.[4] Indeed, from another perspective, our optimal policy results imply that the distortion created by reserve requirements might be reduced if they are implemented in a time-varying manner.

The workings of the model might be elaborated in greater detail as follows. An adverse TFP shock reduces the demand of financial intermediaries for equity and drives down its price. The collapse in asset prices feeds back into the endogenous capital constraints of intermediaries and causes banks' net worth to decline, eroding banks' funding resources. Accordingly, the shortage in loanable funds, which manifests itself as a rise in credit spreads, combined with the collapse in asset prices, causes investment to decline substantially. When the RRR is fixed, the dynamics of reserves resemble those of deposits.

When the countercyclical RRR policy is in place, the fall in bank credit led by the adverse TFP shock calls for a reduction in the RRR. This induces banks to substitute loans for reserves on the assets side of the balance sheet, because the cost of raising external finance is lower with a smaller RRR. Accordingly, the larger supply of funds extended by banks mitigates the collapse in investment and asset prices, countervailing the financial accelerator mechanism. This also limits the rise in credit spreads, which is an intertemporal distortion created by financial frictions in the consumption-savings margin of workers. The downward response of RRR reduces the demand for monetary base and shoots up inflation on impact. Therefore, the credit policy mitigates the financial accelerator at the expense of higher inflation. However, since this immediate surge is transitory and driven by the reserves policy, the model implies an undershooting of inflation

4 Christensen, Meh, and Moran (2011) and Angelini, Neri, and Panetta (2012) follow a similar route when analyzing countercyclical capital requirements for macroprudential purposes.

in the following periods. This implies a substitution of consumption for leisure, which is a credit good in this model on the part of forward-looking households and labor supply increases, in contrast with the fixed RRR economy. Increased labor supply, combined with a stronger trajectory for capital, significantly mitigates the collapse in output.

We also consider an adverse financial shock in the form of an exogenous decline in the net worth of financial intermediaries as in Hancock, Laing, and Wilcox (1995), Brunnermeier and Pedersen (2009), Cúrdia and Woodford (2010), Iacoviello (2010), Meh and Moran (2010), Mendoza and Quadrini (2010) and Mimir (2013). This shock crudely captures loan losses, asset write-downs, or asset revaluations that we observe in the recent financial crisis.

Although the initial decline in banks' net worth led by the financial shock is exogenous, second-round effects will amplify the collapse in the internal finance of banks. This creates a shortage of bank credit and drives a drop in both investment and the price of capital. Banks then increase their demand for external financing (i.e., increase their deposit demand) to compensate for the decline in bank net worth. This causes reserves to increase and drives down inflation, pointing out a difference from the case of TFP shocks on part of the nominal dynamics. Yet, since the shock is transitory, inflation overshoots in the period following the shock, and workers' expectations regarding the hike in future inflation cause hours to decline substantially on impact. Therefore, output collapses together with investment.

Credit policy in response to financial shock calls for a reduction in the RRR and is again inflationary in the sense that the reduction in inflation on impact becomes substantially lower. Accordingly, overshooting in inflation becomes less as well, limiting the collapse in hours. In this manner, the analysis shows that the countercyclical RRR policy has a stabilizing effect in response to financial shocks in addition to TFP shocks and might be used by the central bank as a macroprudential policy tool.

1.1 Related literature

The financial friction ingredients of our analytical framework do not lead to a concept of *systemic risk* but rather to a scheme of imperfect financial intermediation between borrowers and savers. Nevertheless, abstracting from systemic risk is unfortunately a caveat suffered by a set of numerous contributions in the recently growing macro-finance literature, as pointed out by Angelini, Neri, and Panetta (2012). Furthermore, the number of studies that tend to provide a comprehensive analysis of the systemic risk gets even smaller when conventional macroeconomic policy tools are introduced alongside macroprudential policy measures.[5] On the other hand, it is arguably very difficult to identify through what channels the macroprudential policy actions taken by policymakers in real life succeed in reducing the systemic risk of an economy. Consequently, throughout the theoretical and quantitative analysis, we abstain from labeling our reserve requirements policy design as a *macroprudential* policy measure, but rather call it a *credit* policy measure, the goal of which is to maintain financial stability. Indeed, it is not misleading to think that financial stability is perceived as a prior in containing systemic risk by policymakers who implement liquidity, capital, and credit measures [as documented by Lim et al. (2011)] for that matter.[6]

Our work is mostly related to the studies of Montoro (2011) and Glocker and Towbin (2012), who analyze the role of reserve requirements as a macroprudential policy tool. Montoro (2011) introduces countercyclical RRR policy tools in an otherwise standard New Keynesian setting, which is extended with collateral and liquidity constraints as in Kiyotaki and Moore (2008) and maturity mismatch frictions as in Beneš and Lees (2010). He finds that RRRs contain the procyclicality of the financial system in response to demand shocks, but not under supply shocks.

Glocker and Towbin (2012) augment required reserves as an additional policy instrument, and variations in loans as an additional target, into a New Keynesian open economy model with financial frictions that are modeled in the spirit of Bernanke, Gertler, and Gilchrist (1999). Their results imply that reserve requirements favor the price stability objective only if financial frictions are nontrivial, and they are more effective if there is a financial stability objective and debt is denominated in foreign currency. The main differences between our work and these papers are that we model financial frictions à-la Gertler and Karadi (2011), who introduce an agency problem between depositors and bankers, and involve the equity financing of nonfinancial firms.[7] Deviating from the study of Montoro (2011) we find RRRs to be partly stabilizing even under supply shocks. An important deviation from the work of Glocker and Towbin (2012) is that we also explore the role of RRRs in response to financial shocks.

Other than the two mostly related studies mentioned above, this paper is naturally related to the recently growing macro-finance literature that analyzes alternative macroprudential policy tools. Among these, Angeloni and Faia (2009) introduce capital requirements alongside responses to asset prices or leverage in

5 For examples, see Benigno et al. (2010), Jeanne and Korinek (2010), Mendoza and Quadrini (2010), Benigno et al. (2011), Brunnermeier and Sannikov (2011) and Christensen, Meh, and Moran (2011), among others.

6 Gilchrist and Zakrajšek (2012) illustrate that monetary policy response to credit spreads, as a means to maintain financial stability, countervails the adverse impact of financial disruptions on macroeconomic variables.

7 This study analyzes the role of public intermediation of funds in times of financial repression.

the short-term interest rule, using a DSGE model that involves banks modeled as in Diamond and Rajan (2001). They find that monetary policy should respond to asset prices or leverage, and capital requirements should be mildly countercyclical. Christensen, Meh, and Moran (2011) explore the role of countercyclical bank capital regulations in an environment where systemic risk is exogenously introduced via a positive relationship between the aggregate banking sector loans-to-GDP ratio and the likelihood of banking sector default. Within this setup, they find that time-varying bank capital regulations reduce the volatilities of real variables and bank lending, as opposed to time-invariant regulation. Angelini, Neri, and Panetta (2012) analyze the interaction of capital requirements with conventional monetary policy within the setup of Gerali et al. (2010), which extends the combination of the models studied by Christiano, Eichenbaum, and Evans (2005) and Iacoviello (2005) to one that includes a stylized banking sector. As in Glocker and Towbin (2012), they study cases in which macroprudential policy is augmented with monetary policy, and they consider macroprudential modifications to loss functions of the central bank by adding the volatility of loans-to-GDP ratio to it. They find that lack of cooperation among the two policymakers leads to suboptimal results and that macroprudential policy might have asymmetric welfare implications across borrowers/savers/entrepreneurs. Kannan, Rabanal, and Scott (2012) introduce exogenous loan-deposit spreads to the framework of Iacoviello (2005) and analyze the impact of macroprudential policy that has a first-order impact on these spreads alongside conventional monetary policy. They find that the effectiveness of macroprudential policies crucially depends on the sources of (whether financial or supply side) disturbances to the economy.

Our study differs from these classes of papers, first, by the microfoundations that it brings to the modeling of banks and, second, by its abstraction from monetary policy to focus on the role of reserve requirements in maintaining financial stability. Additionally, different from the studies that analyze capital requirements, credit policy in the form of countercyclical reserve requirements focuses on the *composition of the assets side* of the balance sheet rather than its *size*. A noteworthy similarity, on the other hand, is that financial stability policies are most effective when financial shocks are nontrivial. However, our results conflict with the finding that macroprudential policies might even lead to undesirable outcomes when only conventional shocks are considered [as in Angelini, Neri, and Panetta (2012) and Kannan, Rabanal, and Scott (2012)]. We find that, although its impact gets smaller, a countercyclical reserve requirement policy still reduces the volatility of real and financial variables, and the procyclicality of the financial system in response to TFP shocks in isolation.

Our work also has linkages to the frameworks studied in Cúrdia and Woodford (2010) and Kashyap and Stein (2012) in which the remuneration of reserves has been studied. Yet, it is obvious that the reserves policy studied in these papers is more related to the central bank balance sheet considerations of the Federal Reserve at the onset of the subprime financial crisis and does not focus on containing excessive credit growth, in contrast with the focus of our work. From another perspective, the descriptive work of Gray (2011) on recent reserve requirement policy experiences also relates to the current paper.

The rest of the paper is organized as follows. In Section 2, the Turkish experience of the implementation of macroprudential policies is briefly discussed. Section 3 describes the model economy and characterizes the equilibrium. In Section 4, quantitative analysis regarding the dynamics introduced by macroeconomic and financial shocks is undertaken. Section 5 analyzes the impact of the countercyclical reserve requirements policy on model dynamics and welfare. Section 6 conducts a sensitivity analysis on key parameters of the model, and finally, Section 7 concludes.

2 Turkish experience of the implementation of macroprudential policies

As listed in the cross-country study of Lim et al. (2011), Turkey is among the group of countries that exemplify the use of macroprudential policies in the midst and the aftermath of the recent financial crisis. Due to the sharp reversal in global capital flows during the downturn, the focus of these policies has been directed to the provision of foreign currency denominated liquidity. Specifically, Lim et al. (2011) document (i) relaxing the currency mismatch regulations (i.e., enabling domestic currency earning borrowers to borrow in foreign currency), (ii) easing financial institutions' ability to meet liquidity ratios, and (iii) limitations on the distribution of financial firms' profits, among the policy responses of Turkish authorities during 2008–2009. Following these actions, in order to institutionalize the awareness of the need for financial stability, the Financial Stability Committee (FSC) was constituted in 2011, under the leadership of the Banking Regulation and Supervision Agency (BRSA) with members from the Undersecretariat of Treasury, the CBRT, the Capital Markets Board of Turkey, and the Savings Deposit Insurance Fund. The FSC maintained better communication among policymakers with a different focus, yet each authority reserved the discretion to implement its own policy measures without the necessity of seeking broad consensus among the members of the committee.[8]

The current paper is more focused on the macroprudential measures taken by Turkish authorities in the *aftermath* of the financial crisis. The CBRT governor, Erdem Başçı, lists financial stability among the pillars of economic growth, along with price stability and productivity growth [see Başçı (2012)]. Financial stability considerations for emerging economies are especially highlighted following the effort of advanced economies to cope with the financial turmoil, which has induced a substantial rise in the risk appetite of international investors and accordingly has rendered global capital flows excessively volatile. In that respect, the CBRT has implemented a policy mix to curb excessive credit growth and exchange rate volatility in response to the strong capital inflows in the last quarter of 2010. At that point, it started using required reserves as a macroprudential tool, and the first action was to stop paying interest to the required reserves. Following the omission of the reserves remuneration, the weighted average of the required reserves ratio gradually increased from 5% to 13.3% during the period 2010:Q4–2011:Q1, mainly to slow down the accelerated credit growth CBRT (2012–2014). Moreover, the reserve requirement ratios have been changed asymmetrically with respect to the maturity and currency composition of deposits, specifically to (i) extend the deposit maturities and (ii) induce a substitution from foreign currency to Turkish lira denominated deposits in the banking system CBRT (2012–2014). In order to facilitate the liquidity management of banks, the CBRT also introduced an option for the banks to keep a portion of their Turkish lira liability reserves in foreign currency [Başçı (2012); CBRT (2012–2014)].

The CBRT extended the set of its policy tools by using the interest rate corridor (the lending/borrowing rate window in the overnight market) in addition to the standard interest rate policy (one-week repo rate). This policy was enacted to affect short-term interest rates in a flexible framework and to take timely actions in response to changes in the global risk appetite. In particular, following quantitative easing in advanced economies, the corridor has been widened downward to keep short-term market rates more volatile [CBRT (2011-IV); Başçı (2012)]. In

8 Beau, Clerc, and Mojon (2012) provide a section in which the institutional frameworks adopted by the US, the UK, and the European Union are discussed in terms of the implementation of macroprudential policies. Arguably, the governance of macroprudential policies in Turkey is similar to that in the European Union in that the European Systemic Risk Board is independent from the European Central Bank (as the BRSA is independent from the CBRT in Turkey), but does not possess ultimate control over all macroprudential policy measures (the CBRT being in full charge of, for example, currency/maturity composition and the level of reserve requirements).

this sense, as mentioned by Lim et al. (2011), this policy served as a means of capital controls, since it slowed down inflows. It also served for macroprudential purposes, because excessive capital inflows translate to excessive domestic credit growth in an economy such as Turkey's. On the other hand, reflecting a time-varying nature, the interest rate corridor has been shifted upward following the Eurozone debt crisis [Başçı (2012), CBRT (2012a) and CBRT (2012b-IV)], which has driven a reduction in the global risk appetite. In this case, the higher level and the lower volatility of short-term market rates have been maintained in order to mitigate the impact of capital flow reversals.[9]

Finally, the BRSA has complemented the macroprudential (credit and liquidity) measures taken by the CBRT by bringing additional regulations to the banking sector regarding leverage as well as credit. In the first and second quarters of 2011, the BRSA increased the risk weight of certain types of loans so that banks would reduce these types of credit in order to match the capital adequacy ratio set by the BRSA (minimum 8%).[10] Moreover, the loan-loss provisions were increased for banks that extend more than a certain level of high loan-to-value ratio credit. These regulatory steps have boosted the impact of the CBRT measures, and the year-on-year credit growth has slowed from about 40% in 2011:Q3 to 15% by 2012:Q3 [see Başçı (2012)].[11]

In this paper, among the macroprudential tools used by Turkish authorities, we are interested in focusing on the role of reserve requirements in maintaining financial stability in response to conventional TFP shocks, as well as financial shocks that tend to capture exogenous disturbances faced by the financial system (such as reversals in the investors' risk appetite). Accordingly, we proceed to the next section in which a monetary DSGE model of banking is constructed.

9 Increasing reserve requirements prior to this regime change was essential because by doing so, the CBRT rendered itself the net lender in the overnight market. This way, when it decides to carry out a traditional auction (instead of a quantity auction) in the overnight funding market, it could raise the average cost of central bank funding, way above the benchmark policy rate, which can be adjusted only once a month.

10 The Turkish banking system has been considerably conservative in complying with the regulations enacted by the BRSA since the aftermath of the domestic financial turmoil of 2001. Indeed, the actual risk weighted capital adequacy ratio of the Turkish banking system is currently around 16%, which is much higher than the regulatory minimum.

11 The introduction of a wide overnight interest corridor by the CBRT has illustrated that the effectiveness of reserve requirement hikes on increasing the cost of extending credit for banks is dampened, if the rate at which the central bank provides as much liquidity as the banking system demands is close to the policy rate. See BRSA (2011) for the details of the collective policy measures taken by the BRSA and the CBRT during the excessive capital inflows era and the developments thereafter.

3 The model

The model economy is inhabited by households, banks, final goods producers, capital producers, and a government. Time is discrete. Two financial frictions characterize the economy. First, market segmentation ensures that households that are the ultimate savers in the economy cannot directly lend to nonfinancial firms. This assumption makes the banking sector essential for transferring funds from savers (households) to borrowers (final goods producers). Second, the banking sector is characterized by credit frictions that are modeled à la Gertler and Karadi (2011). Households face a cash-in-advance constraint, which makes them hold real balances, leading to the existence of monetary equilibria. Finally, banks are subject to time-varying reserve requirements imposed by the central bank, which react countercyclically to expected credit expansion in the economy. Below is a detailed description of the economic agents that reside in this model economy.

3.1 Households

The population consists of a continuum of infinitely lived identical households. We assume that each household is composed of a worker and a banker who perfectly insure each other. Workers supply labor to the final goods producers and deposit their savings in the banks owned by the banker member of *other* households.[12]

A representative household maximizes the discounted lifetime utility earned from consumption, c_t, and leisure, l_t,

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t), \tag{1}$$

where $0<\beta<1$ is the subjective discount factor and E is the expectation operator. Households face the real flow budget constraint,

$$c_t + b_{t+1} + \frac{M_{t+1}}{P_t} = w_t(1-l_t) + R_t b_t + \frac{M_t}{P_t} + \Pi_t + \frac{T_t}{P_t}, \tag{2}$$

where b_t is the beginning of period t balance of deposits held at commercial banks, P_t is the general price level, w_t is the real wage earned per labor hour, R_t

12 This assumption is useful in making the agency problem that we introduce in Section 3.2 more realistic.

is the gross risk-free deposits rate, Π_t is the profits remitted from the ownership of banks and capital producers, and T_t is a lump-sum transfer remitted by the government.

Households face a cash-in-advance constraint that reflects the timing assumption that asset markets open first as in Cooley and Hansen (1989):

$$c_t \leq \frac{M_t}{P_t} + \frac{T_t}{P_t} + R_t b_t - b_{t+1}. \tag{3}$$

The solution of the utility maximization problem of households leads to the optimality conditions below:

$$u_c(t) = \beta E_t \{R_{t+1} u_c(t+1)\} \tag{4}$$

$$\frac{u_l(t)}{P_t w_t} = \beta E_t \left\{ \frac{u_c(t+1)}{P_{t+1}} \right\}. \tag{5}$$

Condition (4) is a standard consumption-savings optimality condition, which equates the marginal benefit of consumption to the expected discounted benefit of saving in deposits. Equation (5), on the other hand, is a nonstandard consumption-leisure optimality condition, due to the existence of the cash-in-advance friction, which transforms the trade-off between the two into an intertemporal one. Specifically, increasing leisure demand by one unit reduces savings in cash by $\frac{P}{P'} = \frac{1}{1+\pi'}$ future units because the yield of cash balances is deflated by inflation. Therefore, the utility cost of leisure is measured only in terms of future utility forgone by facing a tighter cash-in-advance constraint in the next period.

3.2 Banks

The modeling of the financial sector closely follows that in Gertler and Karadi (2011) except for the shocks to bank net worth. The key ingredients are as follows. At the beginning of period *t*, before banks collect deposits, an aggregate net worth shock hits the balance sheet of banks. Let ω_t represent the financial soundness of the banking sector. Innovations to ω_t, then, shall be shocks to bank net worth. Consequently, $\omega_t \tilde{n}_{jt}$ becomes the effective net worth of the financial intermediary. For notational convenience, hereafter, we denote $\omega_t \tilde{n}_{jt}$ by n_{jt}. Hence, n_{jt} is the net worth of bank *j* at the beginning of period *t* after the net worth shock hits. We denote the period *t* balance sheet of bank *j* as

$$q_t s_{jt} = (1 - rr_t) b_{jt+1} + n_{jt}. \tag{6}$$

The right-hand side of the balance sheet denotes the resources of bank j, namely, net worth, n_{jt}, and deposits, b_{jt+1}, needed to finance its credit extension to nonfinancial firms, $q_t s_{jt}$. The loans to firms serve as state-contingent claims s_{jt} toward the ownership of firms' physical capital demand and are traded at the market price q_0. Note that the bank can only loan $(1-rr_t)$ fraction of deposits to the firms, where rr_t is the required reserves ratio (RRR) set by the central bank as we describe below. Next period's net worth, n_{jt+1}, will be determined by the return earned on assets and the cost of liabilities. Therefore,

$$n_{jt+1}=R_{kt+1}q_t s_{jt}-R_{t+1}b_{jt+1}+rr_t b_{jt+1}, \tag{7}$$

where R_{kt+1} is the gross real return earned from purchased firm equity, and R_{t+1} is the risk-free cost of borrowing from worker $i\neq j$. Since required reserves do not pay any real return, reserve balances are multiplied by one.[13] Solving for b_{jt+1} in equation (7) and substituting it in the balance sheet of banker j [i.e., equation (6)], we obtain the net worth evolution of a financial intermediary as

$$n_{jt+1}=\left[R_{kt+1}-\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)\right]q_t s_{jt}+\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)n_{jt}. \tag{8}$$

Bankers have a finite life and survive to the next period with probability $0<\theta<1$.[14] At the end of each period, $1-\theta$ measure of new bankers are born and are remitted $\frac{\varepsilon}{1-\theta}$ fraction of the net worth owned by exiting bankers. Given this framework, the bankers' objective is to maximize the present discounted value of the terminal net worth of their financial firm, V_{jt}, by choosing the amount of claims toward the ownership of nonfinancial firms' physical capital demand, s_{jt}. That is,

$$V_{jt}=\max_{s_{jt}} E_t\sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^{i+1}\Lambda_{t,t+1+i}\left\{\left[R_{kt+1+i}-\left(\frac{R_{t+1+i}-rr_{t+i}}{1-rr_{t+i}}\right)\right]q_{t+i}s_{jt+i}+\left(\frac{R_{t+1+i}-rr_{t+i}}{1-rr_{t+i}}\right)n_{jt+i}\right\}, \tag{9}$$

13 The zero real return earned from required reserves actually implies that the central bank is remunerating reserves with a nominal rate equal to the rate of inflation. This is indeed consistent with the experience of commercial banks in Turkey, since their local currency denominated reserves have been remunerated with a nominal return in line with the rate of inflation in the period 2002:1–2010:3. For the remuneration rates, see www.tcmb.gov.tr/yeni/bgm/dim/TLzorunlukarsilikfaizorani.html.

14 This assumption ensures that bankers never accumulate enough net worth to finance all their equity purchases of nonfinancial firms via internal funds so that they always have to borrow from households in the form of deposits.

where $\beta^{i+1}\Lambda_{t,t+1+i}=\beta^{i+1}\frac{u_c(t+1+i)}{u_c(t)}$ is the 1+i periods ahead stochastic discount factor of households.

The key feature of the financial sector unfolds around a moral hazard problem between banks and households. In this model of banking, households believe that banks might divert λ fraction of their total assets for their own benefit. This might be thought of as investing part of $q_t s_{jt}$ in excessively risky projects that go bankrupt eventually and not paying back the corresponding liability to the depositor. In this case, the depositors shall initiate a bank run that leads to the liquidation of the bank altogether. Therefore, the bankers' optimal plan regarding the choice of s_{jt} at any date t should satisfy an incentive compatibility constraint,

$$V_{jt}\geq\lambda q_t s_{jt}, \tag{10}$$

to prevent liquidation by bank runs. This inequality suggests that the liquidation cost of bankers, V_{jt}, from diverting funds should be greater than or equal to the diverted portion of the assets, $\lambda q_t s_{jt}$. By using an envelope condition and algebraic manipulation, one can write the optimal value of banks as

$$V^{*}_{jt}=\nu_t q_t s^{*}_{jt}+\eta_t n^{*}_{jt} \tag{11}$$

and obtain the recursive objects,

$$\nu_t=E_t\left\{(1-\theta)\beta\Lambda_{t,t+1}\left[R_{kt+1}-\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)\right]+\theta\beta\Lambda_{t,t+1}\chi_t\nu_{t+1}\right\} \tag{12}$$

and

$$\eta_t=E_t\left\{(1-\theta)\beta\Lambda_{t,t+1}\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)+\theta\beta\Lambda_{t,t+1}\rho_t\eta_{t+1}\right\}, \tag{13}$$

where $\chi_t=\frac{q_{t+1}s_{jt+1}}{q_t s_{jt}}$, and $\rho_t=\frac{n_{jt+1}}{n_{jt}}$ represent growth rates of bank loans and net worth, respectively.[15] Accordingly, equations (12) and (13) represent the marginal values of making new loans and accumulating net worth for the banks, in order. As the spread between R_k and R gets larger, the marginal value of making loans to nonfinancial firms increases. On the other hand, since the risk-free deposit rate is the opportunity cost of raising funds by borrowing from households, as R gets larger, the marginal benefit of accumulating net worth increases. The ratio

15 Derivations of equations (11), (12) and (13) are available in the technical Appendix.

of required reserves, rr, decreases the marginal benefit of making loans, since it reduces the returns to making new loans, $\left[R_{kt+1}-\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)\right]$, and increases the marginal value of accumulating net worth, since it increases the return to accumulating net worth, $\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)$, *ceteris paribus*.

One can obtain the following by combining equations (10) and (11):

$$\nu_t q_t s_{jt}+\eta_t n_{jt}\geq\lambda q_t s_{jt} \tag{14}$$

Our methodological approach is to linearly approximate the stochastic equilibrium around the deterministic steady state. Therefore, we are interested in cases in which equation (14), an equilibrium condition of the model, is always binding. Given that $\eta_t n_{jt}$ is strictly greater than zero, $\nu_t\geq\lambda$ would imply a strict inequality in (14). Therefore, $\nu_t\geq\lambda$ should hold for (14) to be an equality. This would be the case in which banks have made enough loans until the marginal value of increasing loans falls short of the fraction of these assets that they are willing to divert. Consequently, $\nu_t\geq\lambda$ corresponds to a case in which the amount of loans made is small enough that the marginal benefit of making new loans is greater than the fraction of diverted assets.

The existence of a well-behaved equilibrium also necessitates that ν_t be greater than zero for the banks to extend loans to nonfinancial firms at any date t. Therefore, we make sure that under reasonable values of parameters, $0<\nu_t<\lambda$ always holds in our model. This modifies equation (14) into an endogenous capital constraint for banks as follows:

$$q_t s_{jt}=\frac{\eta_t}{\lambda-\nu_t}n_{jt}=\kappa_t n_{jt}. \tag{15}$$

This is the case in which the loss of bankers in the event of liquidation is just equal to the amount of loans that they can divert. This endogenous constraint, which emerges from the costly enforcement problem described above, ensures that banks' leverage shall always be equal to $\frac{\eta_t}{\lambda-\nu_t}$ and is decreasing with the fraction of funds (λ) that depositors believe that banks will divert. We confine our interest to equilibria in which all households behave symmetrically so that we can aggregate equation (15) over j and obtain the following aggregate relationship:

$$q_t s_t=\kappa_t n_t, \tag{16}$$

where $q_t s_t$ and n_t represent aggregate levels of banks' assets and net worth, respectively. Equation (16) shows that aggregate credit in this economy can only be up to an endogenous multiple of aggregate bank capital. Also, fluctuations in asset prices (q_t) will feed back into fluctuations in bank capital via this relationship. This will be the source of the financial accelerator mechanism in our model.

The evolution of aggregate net worth depends on that of the surviving bankers (n_{et+1}) and the start-up funds of the new entrants (n_{nt+1}):

$$n_{t+1}=n_{et+1}+n_{nt+1} \tag{17}$$

The start-up funds for new entrants are equal to $\frac{\varepsilon}{1-\theta}$ fraction of exiting banks' net worth, $(1-\theta)n_t$. Therefore,

$$n_{nt+1}=\varepsilon n_t. \tag{18}$$

Bankers' net worth evolution, (8), the capital constraint, (16), and the fact that θ fraction of bankers survive to the next period yield a net worth evolution condition for surviving bankers as follows:

$$n_{et+1}=\theta\left\{\left[R_{kt+1}-\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)\right]\kappa_t+\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)\right\}n_t. \tag{19}$$

Finally, equations (18) and (19) can be summed up to obtain the evolution of net worth for the entire banking system:

$$n_{t+1}=\left\{\theta\left(\left[R_{kt+1}-\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)\right]\kappa_t+\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)\right)+\varepsilon\right\}n_t. \tag{20}$$

Dividing both sides of equation (20) by n_t implies that the growth of aggregate net worth depends positively on loan-deposit spreads, endogenous bank leverage, risk-free deposits rate, survival probability, and the fraction of start-up funds. On the other hand, the impact of RRR on net worth accumulation depends on the two opposing effects discussed above: a higher rr_t *decreases* returns to making loans to nonfinancial firms and *increases* returns to accumulating net worth, *ceteris paribus*. However, since bank leverage is greater than one (i.e., $\kappa>1$), any change in the former is amplified as equation (20) suggests. Consequently, an increase in rr_t decreases the aggregate net worth growth of the banking system.

3.3 Firms

Firms produce the consumption good by using physical capital and labor as production factors. They operate with a constant returns to scale technology $F(k, h)$ that is subject to total factor productivity shocks, z_t,

$$y_t = \exp(z_t)F(k_t, h_t), \tag{21}$$

where

$$z_{t+1} = \rho_z z_t + \varepsilon_{zt+1} \tag{22}$$

with zero mean and constant variance innovations, ϵ_{zt+1}.

Firms finance capital at date t by issuing claims s_t to financial intermediaries at the price of capital and acquire capital k_{t+1} from capital producers. Therefore,

$$q_t s_t = q_t k_{t+1} \tag{23}$$

where q_t is the market price of the firms' equity and capital.

The banks' claim against the ownership of the firm pays out its dividend via the marginal product of capital in the next period. Hence, the cost of credit to the firm is state contingent. Indeed, the cost of credit to the firm must satisfy

$$R_{kt} = \frac{z_t F_k(k_t, h_t) + q_t(1-\delta)}{q_{t-1}}. \tag{24}$$

Finally, the optimal labor demand of the firm must satisfy the usual static condition,

$$w_t = \exp(z_t)F_h(k_t, h_t), \tag{25}$$

which equates the marginal product of labor to its marginal cost.

3.4 Capital producers

Capital producers are introduced in order to obtain variation in the price of capital, which is necessary for the financial accelerator mechanism to operate. To that end, capital producers provide physical capital to the firms, repair the depreciated capital, and incur the cost of investment. Consequently, the optimization problem of capital producers is,

$$\max_{i_t} q_t k_{t+1} - q_t(1-\delta)k_t - i_t \tag{26}$$

subject to the capital accumulation technology,

$$k_{t+1} = (1-\delta)k_t + \Phi\left(\frac{i_t}{k_t}\right)k_t, \tag{27}$$

where the function $\Phi(\cdot)$ represents the capital adjustment cost. The optimality condition that emerges from the solution to this problem is the well-known q relation that pins down the price of capital,

$$q_t = \left[\Phi'\left(\frac{i_t}{k_t} \right) \right]^{-1}. \tag{28}$$

3.5 Government

The government is responsible for (i) meeting workers' and bankers' cash-in-advance and required reserves demands, respectively, and (ii) setting the credit policy rule. For the former, it controls the supply of monetary base M_{0t+1}, and for the latter, it determines the required reserves ratio rr_t.

The monetary base grows at the constant rate μ, that is,

$$M_{0t+1} = \exp(\mu) M_{0t}. \tag{29}$$

The growth of the monetary base is remitted to households in the form of lump-sum transfers, T_t.[16] Therefore, $T_t = (\exp(\mu) - 1) M_{0t}$.[17]

In order to contain the financial accelerator mechanism, the government uses required reserves as a credit policy rule. Specifically, the required reserves ratio is assumed to follow a trajectory that reacts to the expected growth rate of bank credit at date $t+1$, compared to its level in the current period, that is,

$$rr_t = \overline{rr} + \phi E_t [\log(q_{t+1} s_{t+1}) - \log(q_t s_t)], \tag{30}$$

where $\overline{rr}$ is the steady-state value of the required reserves ratio and $\phi > 0$. Consequently, as discussed in Section 3.2, the central bank increases the effective profit from extending new loans (i.e., reduces rr_t when credit in the aggregate economy is expected to shrink and vice versa). Stabilizing the stock of credit is expected to smooth fluctuations in credit spreads that emerge due to the existence of financial frictions. Since credit spreads are a measure of intertemporal distortions in this model, the overall economy's welfare level is expected to be higher when this credit policy rule is in place as opposed to fixing $rr_t = \overline{rr}$.

Money market clearing necessitates that

$$M_{0t+1} = M_{t+1} + P_t rr_t b_{t+1}, \tag{31}$$

16 We model monetary policy in a simplistic manner in order to isolate the impact of required reserves policy described below. We also abstain from modeling disturbances to money growth because they produce implausible inflation dynamics in a cash-in-advance model of a flexible price environment.

17 Perfect insurance within family members of households ensures that the increase in real balances and reserves demand is lumped into T_t, which does not alter the optimality conditions of the utility maximization problem.

where P_t is the general price level of the consumption good. Since the left-hand side of equation (31) is exogenously determined by the central bank, equilibrium in the money market might call for adjustments in the price level in response to fluctuations in reserves. The dynamics of inflation driven by these fluctuations shall then feed back into the intertemporal consumption leisure margin and have real effects via the cash-in-advance constraint shown by equation (3).

3.6 Competitive equilibrium

Notice that the nominal monetary base and prices grow constantly in this model, which renders the equations listed above nonstationary. Therefore, following Cooley and Hansen (1989), we make the model stationary by applying the following normalizations: $\widehat{P}_t = P_t / M_{0t+1}$ and $\hat{m}_t = M_{t+1} / (\widehat{P}_t M_{0t+1})$, and then solve the model locally around a deterministic steady state.

A competitive equilibrium of this model economy is defined by sequences of allocations $\{c_t, k_{t+1}, i_t, l_t, h_t, s_t, n_t, n_{et}, b_{t+1}, \Lambda_{t,t+1}, \nu_t, \eta_t, \kappa_t, \rho_{t,t+1}, \chi_{t,t+1}, \hat{m}_{t+1}, \pi_t\}_{t=0}^{\infty}$, prices $\{q_t, R_{kt+1}, R_{t+1}, w_t, \widehat{P}_t\}_{t=0}^{\infty}$, the shock process $\{z_t\}_{t=0}^{\infty}$, and the government policy $\{rr_t\}_{t=0}^{\infty}$ that satisfy the optimality conditions of utility maximization of workers, net worth maximization of bankers, profit maximization of firms and capital producers, and the market clearing for the consumption good and money. A complete set of these conditions may be found in Appendix B.

4 Quantitative analysis

The benchmark model is calibrated to Turkish economy, which is representative of using reserve requirements as a credit policy instrument since the last quarter of 2010. This reduces to fixing the long-run value of RRR to its value preceding the credit policy intervention of the CBRT and calibrating the response parameter in the credit policy rule, equation (30), in order to match the volatility of RRR following the intervention. In order to investigate the dynamics of the model, we apply perturbation methods in approximating equilibrium conditions linearly by using the software DYNARE.[18]

18 Loss function analysis in Section 5.4 uses second-order approximation of equilibrium conditions.

With the parameterized economy, we first investigate the impact of the RRR on the long-run values of key real and financial variables to see how it affects banks' incentives and financing decisions. Second, we illustrate the role of the financial accelerator driven by credit frictions in the banking sector. Third, we study the dynamics of the model led by productivity and bank capital shocks. In the next section, we focus on the impact of credit policy, designed as a countercyclical RRR rule on model variable volatilities and the procyclicality of the financial system. To that end, we investigate changes in the policy aggressiveness and targets. After exploring optimal policy intensities for alternative specifications, we conduct sensitivity analysis by changing the key parameters of the benchmark model regarding the financial sector in order to evaluate the effectiveness of reserve requirements as a credit policy tool.

4.1 Calibration of the benchmark model

The parameter values used in the quantitative analysis are reported in Table 1. Some of the preference and production parameters are standard in the business cycle literature. The share of capital in the production function is set to 0.4. The capital adjustment cost parameter is taken to be 6.76 to match the annual elasticity of price of capital with respect to an investment-capital ratio of 1, as in Bernanke, Gertler, and Gilchrist (1999). We use a standard value of 2 for relative risk aversion, γ, as in Angeloni and Faia (2009). The relatively nonstandard value of 3 for inverse of the Frisch elasticity of labor, ν, is used as in Glocker and Towbin (2012) to compare our findings with this mostly related study. We take the quarterly discount factor, β, as 0.9885 to match the 2006–2011 average annualized real deposit rate, 4.73%, in Turkey. We pick the relative utility weight of labor, ψ, to fix hours worked in steady state, $\bar{h}$, at one-third of the available time. The quarterly depreciation rate of capital is set to 3.7% to match the 1987–2011 average annual investment to capital ratio of 14.8% in Turkey (Source: CBRT).

Parameters related to the financial sector are calibrated to match the financial statistics of the Turkish economy in the period 2006–2011. We set ε to 0.0005 so that the proportional transfer to newly entering bankers is 1.3% of the aggregate net worth. We pick the fraction of diverted funds, λ, and the survival probability, θ, simultaneously to match the following two targets: an average interest rate spread of 48 basis points, which is the historical average of the difference between the quarterly commercial and industrial loan rates, and the quarterly deposit rate from 2006:Q1 to 2011:Q4, and an average capital adequacy ratio of 16%, which is the historical average of Turkish commercial banks' capital adequacy ratio for

Table 1 Parameter values in the Benchmark model.

Description	Value	Target
Preferences		
Quarterly discount factor (β)	0.9885	Annualized real deposit rate (4.73%)
Relative risk aversion (γ)	2	Angeloni and Faia (2009)
Inverse of the Frisch elasticity (ν)	3	Glocker and Towbin (2012)
Relative utility weight of leisure (ψ)	46.16	Hours worked (0.33)
Production technology		
Share of capital in output (α)	0.4	Labor share of output (0.64)
Capital adjustment cost parameter (ϕ)	6.76	Elasticity of price of capital w.r.t. investment-capital ratio of 0.25
Depreciation rate of capital (δ)	0.037	Average annual ratio of investment to capital (14.8%)
Government		
Steady-state value of RRR ($\overline{rr}$)	0.05	Pre-macroprudential policy period
Adjustment parameter in the RRR rule (ϕ)	3.28	Standard deviation of RRR for 2010:Q4–2012:Q2 (2.33%)
Growth rate of monetary base (μ)	0.0446	Time series average for 2006:Q1–2011:Q4
Financial intermediaries		
Fraction of diverted loans (λ)	0.514	Annual commercial & industrial loan spread (1.96%)
Prop. transfer to the entering bankers (ε)	0.0005	1.33% of aggregate net worth
Survival probability of the bankers (θ)	0.9625	Capital adequacy ratio of 16% for commercial banks
Shock processes		
Persistence of TFP process (ρ_z)	0.9821	Estimated persistence from detrended $\log TFP_t = \rho_z \log TFP_{t-1} + \epsilon_{zt}$
Std. deviation of productivity shocks (σ_z)	0.0183	Estimated standard deviation from detrended $\log TFP_t = \rho_z \log TFP_{t-1} + \epsilon_{zt}$
Std. deviation of financial shocks (σ_ω)	0.0531	Relative volatility of bank capital w.r.t. output for 2003:Q1–2011:Q4 (1.24)

the same period.[19] The resulting values for λ and θ are 0.514 and 0.9625, respectively. The benchmark model involves a credit policy rule illustrated in equation (30), which does not alter the steady state of the model but affects the dynamics around it. The level of weighted RRR preceding the macroprudential intervention by the CBRT is 5% (see Figure 1). Therefore, we calibrate the long-run value of RRR to 0.05 in the baseline model. The value of the response parameter of the credit policy rule, ϕ, is calibrated to 3.28 in order to match the standard deviation of RRR of 2.33% for the Turkish economy in the period 2010:Q4–2012:Q2.[20] The time series average of the growth rate of monetary base for the period 2006:Q1–2011:Q4 is 4.46% (Source: CBRT). Therefore, we set $\mu = 0.0446$.

Regarding the shock processes, we follow the standard Solow residuals approach to construct the productivity shocks. Using the production function, we obtain

$$z_t = \frac{y_t}{K_t^{\alpha} H_t^{1-\alpha}}. \tag{32}$$

Using the empirical series for output, y_t, capital, K_t, and labor, H_t, we use equation (32) to obtain the z_t series. Then we construct the log-deviation of the TFP series by linearly detrending the log of the z_t series over the period 1988:Q2–2011:Q2. Similar to the construction of productivity shocks, the ω_t series are constructed from the law of motion for bank net worth, which is given by

$$\omega_t = \frac{1}{\theta[(R_{kt+1} - R_{t+1})\frac{\eta_t}{\lambda - \nu_t} + R_{t+1}] + \epsilon} \frac{\tilde{n}_{t+1}}{\tilde{n}_t}. \tag{33}$$

Using the empirical series for net worth, n_t, credit spreads, $R_{kt+1} - R_{t+1}$, leverage, $\frac{\eta_t}{\lambda - \nu_t}$, and gross deposit rate, R_{t+1}, we use equation (33) to obtain the ω_t series.[21] Then we construct the log-deviation of the ω_t series by linearly detrending the log of these series over the period 2006:Q1–2012:Q2. The innovations to ω_t are net worth shocks.

After constructing the z_t and ω_t series, we estimate two independent AR(1) processes for both series:

19 The legal target of the risk-weighted capital adequacy ratio set by the BRSA in Turkey is 8%, however, in practice, commercial banks in Turkey maintain 16% for this ratio.

20 This is the period in which the CBRT changed the RRR for macroprudential purposes.

21 We do not input the series of reserve requirement ratios into this empirical equation because the observed credit spreads and deposit rates would endogenously reflect the impact of reserves.

$$\log(z_{t+1}) = \rho_z \log(z_t) + \epsilon^z_{t+1} \tag{34}$$

$$\log(\omega_{t+1}) = \rho_\omega \log(\omega_t) + \epsilon^\omega_{t+1}, \tag{35}$$

where $\epsilon_{z,\, t+1}$ and $\epsilon_{\omega,\, t+1}$ are i.i.d. with standard deviations σ_z and σ_ω, respectively. We found ρ_ω to be statistically insignificant at a 5% significance level. Therefore, the resulting parameters are ρ_z=0.9821, σ_z=0.0183, ρ_ω=0, and σ_ω=0.0531. Consequently, net worth shocks might be thought as financial disturbances due to *transitory* conditions such as sharp reversals in the risk appetite of investors, unexpected loan losses, or balance sheet shocks that bankers face.[22] Notice that although the shock process is white noise, its effects on bank capital would be persistent due to the propagation via capital constraints that feed back into the law of motion for bank net worth.

4.2 Functional forms

Preferences: We use a standard utility function that is constant relative risk aversion (CRRA) in consumption and separable in leisure:

$$u(c_t, l_t) = \frac{c_t^{1-\gamma}}{1-\gamma} - \psi \frac{(1-l_t)^{1+\nu}}{1+\nu}, \tag{36}$$

where $\gamma > 1, \psi, \nu > 0$.

Production: Firms produce according to a constant returns to scale Cobb-Douglas production function:

$$\exp(z_t) F(k_t, h_t) = \exp(z_t) k_t^\alpha h_t^{1-\alpha}, \tag{37}$$

where $0 < \alpha < 1$.

Capital Producers: Capital producers are subject to a convex adjustment cost function:

$$\Phi\left(\frac{i_t}{k_t}\right) = \frac{i_t}{k_t} - \frac{\varphi}{2}\left[\frac{i_t}{k_t} - \delta\right]^2. \tag{38}$$

22 On bank capital shocks, see Hancock, Laing, and Wilcox (1995), Brunnermeier and Pedersen (2009), Cúrdia and Woodford (2010), Iacoviello (2010), Meh and Moran (2010), Mendoza and Quadrini (2010), and Mimir (2013).

4.3 Impact of reserve requirements on banks' incentives

Figure 2 plots the key real and financial variables' steady-state values as a function of different long-run values of RRR and shows how it affects bankers' financing decisions. First, as illustrated in Section 3.2, RRR reduces the growth of aggregate net worth. Furthermore, an increase in rr_t would potentially induce banks to demand more deposits in order to make up for the required reserves, which do not pay any real return. These two effects will induce bankers to substitute external financing, b_{t+1}, for internal financing, n_t, when RRR is higher, resulting in a higher leverage ratio as evidenced by the bottom left panel of Figure 2. A higher leverage ratio $\left(\text{i.e.,} \frac{b_{t+1}}{n_t}\right)$ for the banking system would then increase its exposure to external financing and cause financial frictions to become more severe, potentially resulting in higher loan-deposit spreads, as can be seen from the bottom middle panel of Figure 2.

The bottom right panel of Figure 2 indicates that on the assets side of the balance sheet, an increase in RRR induces banks to substitute required reserves for bank loans for these reasons: (i) they are obliged to increase reserves, and (ii) the return to making new loans to nonfinancial firms gets smaller. This would result in a reduction in investment (see the top right panel of Figure 2), since the intermediated funds to the real sector shrink (see the top middle panel of Figure 2).

The steady-state analysis is helpful to gain insight on how reserve requirements might affect the workings of financial frictions in the model. In the following section, we explore the impact of the financial accelerator on key real variables and study the impact of the long-run level of RRR on the amplification of TFP shocks.

4.4 Amplifying effect of financial frictions

In this section, we compare the dynamics of key real variables (output, investment, asset prices) and credit spreads in response to adverse technology shocks under (i) the benchmark economy, (ii) an economy that involves financial frictions but no required reserves, and (iii) the standard cash-in-advance model with no financial frictions.[23] Although the comparison of (ii) and (iii) isolates the impact of financial frictions, the comparison of (i) and (ii) is focused on understanding the impact of the steady-state required reserves level on model dynamics. In

23 Financial shocks cannot be studied in this experiment because when financial frictions are absent, banks become a veil and bank capital is not defined.

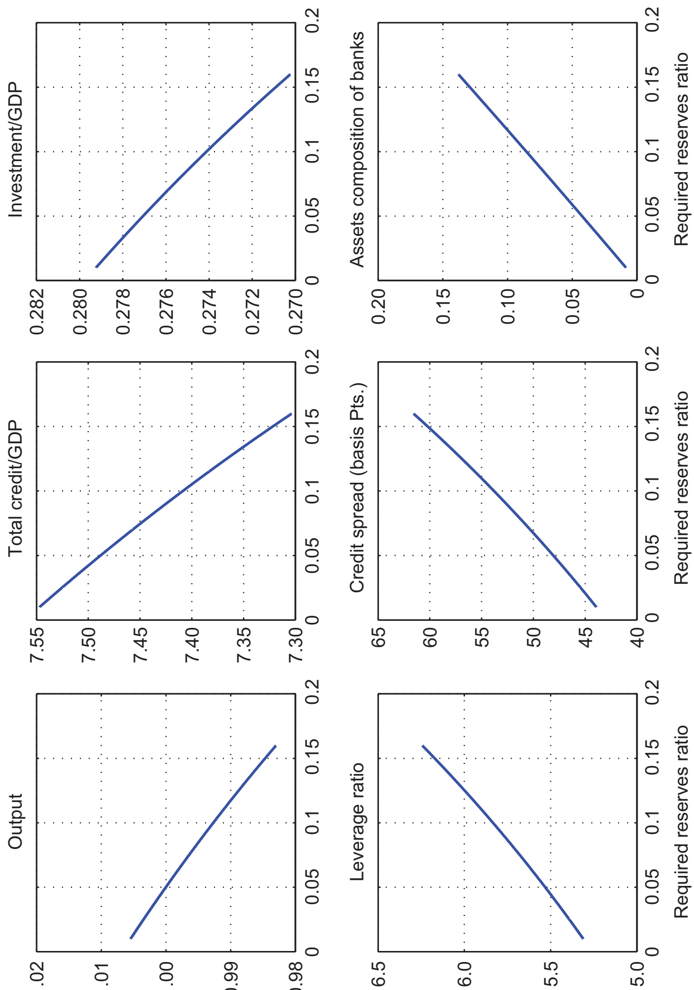

Figure 2 Steady-state implications of reserve requirement ratio.

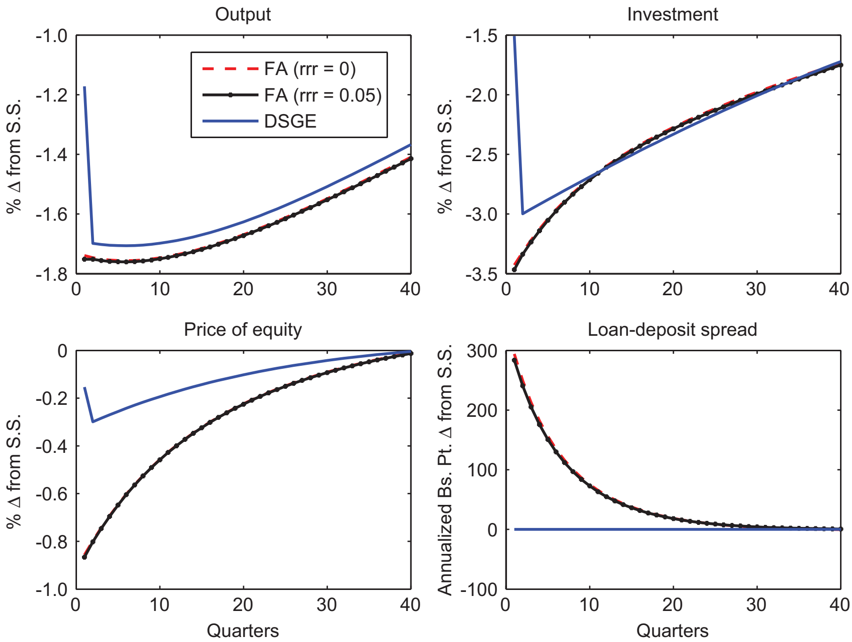

Figure 3 1-σ Negative productivity shock.

Figure 3, the three economies are represented by the dotted straight, dashed, and straight plots, respectively.

A comparison of the dashed (which essentially coincides with the dotted straight plots) and straight plots shows that the collapse in output, investment, price of capital, and loan-deposit spreads in response to a one-standard-deviation negative TFP shock is amplified when financial frictions are in place. We especially want to highlight the more than doubling in the reduction of investment, quadrupling in the decline in asset prices, and 300 basis points of increase in the credit spreads in annualized terms. The last increase is even more striking because in the economy with no financial frictions, there is no arbitrage between the return to capital and the return to deposits. The evident amplification is due to the banks' reduced demand for deposits in case of lower productivity. This stems from the decline in the return to state-contingent equity issued by firms when productivity is lower. As a result, the price of equity issued by firms is depressed, which results in a collapse in the value of funds provided to them. Consequently, firms acquire less capital and investment declines more. On the other hand, the long-run level of the RRR does not seem to have any significant impact on the

Table 2 Variance decomposition of model variables.

Variable	TFP shocks	Financial shocks
Real variables		
Output	78.32	21.68
Consumption	94.38	5.62
Investment	53.13	46.87
Hours	1.11	98.89
Financial variables		
Credit	56.20	43.80
Deposits	22.80	77.20
Net worth	18.19	81.81
Leverage	15.89	84.11
Credit spread	32.47	67.53
Asset prices	52.84	47.16
Monetary variables		
Inflation	3.92	96.08

dynamics of the model, since the dashed and dotted straight plots coincide with each other.[24]

In the next section, we additionally introduce financial shocks over the business cycle and disentangle their relative importance via variance decomposition analysis.

4.5 Variance decomposition

We report the variance decomposition of key model variables under the existence of both shocks in Table 2.[25] As expected, financial shocks are found to derive much of the variation in deposits, net worth, bank leverage, and credit spreads. On the other hand, their less emphasized role in driving the variation in asset prices and bank credit (which is strongly affected by the price of capital) is due to the well-known transmission of productivity shocks via return to capital, which shifts the demand for capital and distorts its price.

It is striking to see that despite TFP shocks having a first-order effect on output, financial shocks still explain one-fifth of the variation in this variable.

24 Notice that the fluctuations in these two cases are around different steady states because the long-run value of RRR is different across economies.

25 RRR is assumed to be positive but fixed in order not to obscure the variance decomposition analysis.

Additionally, the financial accelerator mechanism that operates via bank capital constraints renders the explanatory power of financial shocks for the variation in investment as nontrivial (about 47%). Another important finding is that financial shocks explain almost all of the variation in inflation (which feeds back into the labor-leisure decision via the cash-in-advance constraint). This is mostly due to the insignificance of TFP shocks on the monetary variables in a flexible price environment and the highlighted role of financial shocks in driving the variation in deposits, which directly determine the reserves demand with a constant RRR. In the following sections, we analyze model dynamics driven by TFP and net worth shocks in greater detail and explore how alternative reserve requirement policy rules affect these dynamics.

5 Credit policy

We now analyze the implications of the RRR policy on the dynamics of real, financial, and monetary variables. In Figures 4 and 5, we compare the dynamics of these variables in response to one-standard-deviation negative TFP and net worth shocks, respectively. In the figures, the dashed plots correspond to the benchmark economy with the countercyclical RRR rule, and the straight plots correspond to an economy with a fixed RRR. The dynamics of the economy with no reserves closely resemble those with a fixed RRR. Therefore, for space considerations, we do not discuss them here and only present the comparison of the fixed RRR economy with the benchmark economy that displays a countercyclical RRR.[26] Unless stated otherwise, the numbers in the *y*-axes correspond to percentage deviations of variables from their long-run values. For the case of inflation and RRR, we plot percentage *point changes* and for the case of credit spreads we plot *basis point changes* in annualized terms.

5.1 Impulse response experiments

5.1.1 TFP shocks

The general observation that emerges from Figure 4 is that the time-varying RRR policy dampens the impact of the financial accelerator on key macroeconomic real and financial variables at the expense of higher inflation in response to TFP shocks.

26 The dynamics of the economy with no reserves are available upon request.

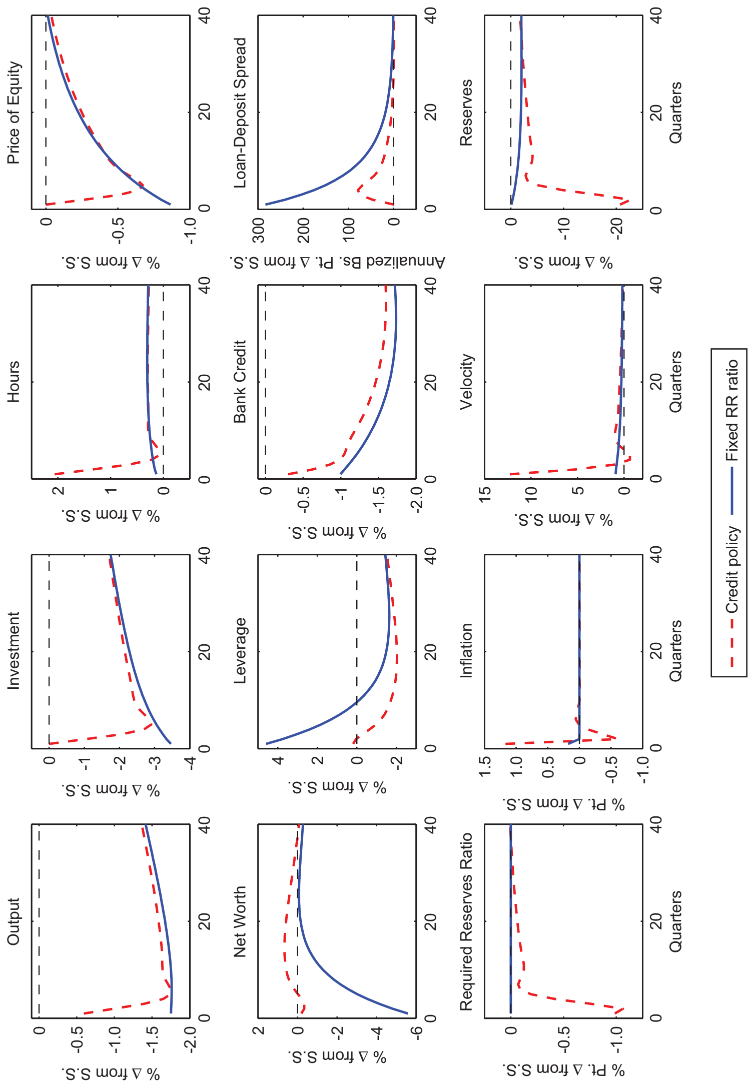

Figure 4 Impulse responses led by a 1-σ adverse TFP shock.

In the economy with fixed RRR, as expected, households reduce their demand for consumption and supply of deposits in response to the adverse TFP shock, since output and the profits that accrue from the ownership of banks and capital producers are lower. On the banks' side, the reduced TFP highlights the reduction in the profitability of equity loans to firms, inducing them to reduce their demand for deposits.

Under the fixed RRR economy, as Figure 4 shows, the net worth of banks collapses about 5.75%, reflecting the feedback effect of a 0.8% decline in asset prices through the endogenous capital constraint of banks, represented by equation (16). The decline in net worth, in accordance with the decline in deposits, downsizes the total financing for nonfinancial firms (see Figure 4). However, since the decline in bank capital is larger than that of the value of bank assets, the model implies a countercyclical bank leverage, which increases by 5%. On the other hand, the scarcity of funds for firms shoots up loan-deposits spreads by about 300 basis points in annualized terms (see the middle right panel of Figure 4). The reduction in the quantity of equities traded and the collapse in asset prices trigger a downsizing in bank credit of about 1%. As a combined outcome of these dynamics, investment falls by 3.5% and output declines by about 1.75%.

The nominal price level increases (the bottom panel of Figure 4) because the economy is now less productive in generating output. Hence, inflation increases by 0.2% points, causing the real balances demand to decline and the consumption velocity of the monetary base to increase by about 1%.

Now, we explain how the credit policy defined by a countercyclical RRR rule mitigates the impact of the financial accelerator on key macroeconomic real and financial variables (see the dashed plots in Figure 4). Since bank credit declines in response to the adverse TFP shock, the policy rule implies a reduction in the RRR by about 1% point, which can be seen in the bottom left panel of the figure. This reduces the cost of extending credit for banks and induces a substitution from reserves balances to loans on the assets side of their balance sheets. Consequently, the stronger demand for firm equity stabilizes its price on impact, and the peak of decline in the equity price becomes about 0.2% less than that in the fixed RRR economy. The substitution in the balance sheets of banks, combined with the better outlook of asset prices, reduces the collapse in bank credit from 1% to 0.3%. Accordingly, the trough points of output and investment are 1.6% and 0.5% above their level in the fixed RRR economy, respectively.

The support of the central bank via lower reserve requirements causes credit spreads to rise by about 225 basis points less compared to the fixed RRR economy over five quarters. We emphasize this finding because credit spreads introduce an intertemporal wedge into the savings decision of the aggregate economy and are created by financial frictions. The relatively muted response of spreads stems from the reduced decline in return to firm equity. The stronger outlook of the economy is also reflected by the balance sheets of banks, and bank capital declines by 5% less compared to the fixed RRR economy. It even stays above its long-run level for about 20 quarters, since RRR is lower than its long-run value for about 30 quarters. The immediate implication of the stronger trajectory of net worth is a rise of virtually zero in bank leverage on impact (against a 5% hike with fixed RRR), even implying a decline of up to 2% caused by the increase in bank capital.

The substantial collapse in reserves demand (about 20%) reduces the demand for total monetary base, and since money supply is exogenously determined by the central bank, the price of money declines to restore equilibrium in the money market [see equation (31)]. This amplifies the upward response of inflation obtained in the fixed RRR economy (see the bottom panel of Figure 4). However, since this immediate surge is transitory and driven by the reserves policy, the model implies an undershooting of inflation in the coming seven quarters. This implies a substitution of consumption for leisure on the part of forward-looking households, and labor supply increases by 2% more in comparison to the fixed RRR economy (see the top panel of Figure 4). Hence, we obtain the stabilizing impact of the countercyclical RRR rule on the dynamics of output displayed in the top left panel of Figure 4. Consistent with these findings, demand for real balances collapses on impact but outweighs its steady-state level along the transition, and consumption velocity increases by 12% more than the fixed RRR economy.

To sum up, the countercyclical RRR policy mitigates the impact of the financial accelerator triggered by TFP shocks on real and financial variables at the expense of higher inflation. In a nutshell, this is due to the increased incentives of bankers to make more loans, as well as the role that reserves play in the monetary base.

5.1.2 Financial shocks

In this section, we explore how countercyclical reserve requirements perform in response to financial disturbances in the form of net worth shocks as described in Section 4.1. When they are adverse, these shocks are intended to capture loan losses, asset write-downs, or asset revaluations that we observe in financially repressed periods. As stated in Section 1, they might also be thought of as a sharp reversal in the risk appetite of investors, which is an exogenous factor that threatens the financial stability of a country such as Turkey.

Although the initial decline in banks' net worth driven by these shocks is exogenous, second round effects endogenously trigger an adverse financial accelerator mechanism. The initial fall in the net worth reduces the amount of bank credit that can be extended to nonfinancial firms, since banks are not able to compensate the decline in their internal financing with households' deposits. Since nonfinancial firms finance their capital expenditures via bank credit, there will be a drop in investment and, hence, in the price of capital. The value of intermediary capital depends on asset prices. The endogenous decline in asset prices leads to a further deterioration in banks' net worth, creating an adverse feedback loop of falling aggregate demand, declining asset prices, and deteriorating intermediary balance sheets. We analyze the effects of this shock in the model economy with fixed RRR policy and then illustrate the mitigating effects of time-varying RRR policy on real, financial, and monetary variables in Figure 5.

In the economy with fixed RRR, the negative net worth shock immediately reduces bank capital by 12% on impact (see the middle left panel of Figure 5). Although deposits rise due to banks' increased demand for deposits to compensate for the decline in their internal financing, the deterioration of bank capital causes total financing by financial intermediaries to shrink. This translates into a reduction in bank credit in the form of equity purchases to firms by 1.25% on impact. As the demand for firms' shares is lower, the price of equity falls by 1%. This amplifies the exogenous impact of the financial shock via the endogenous capital constraint of banks and explains the substantial decline of 12% in the net worth. The decline in bank capital raises their leverage by 10%. Induced by the shortage in credit and the collapse in asset prices, credit spreads rise by 500 basis points in annualized terms. This in turn causes firms to severely cut back their investment (by about 4.2%) due to lower bank credit and the higher cost of financing.

The increase in bank deposits driven by banks' effort to compensate for the net worth loss increases reserves balances by 1% in the fixed RRR economy. This creates an excess demand for the monetary base, and inflation declines on impact by 0.6% points (see the bottom panel of Figure 5). However, since the shock is transitory, inflation overshoots by 0.7% points in the period that follows the shock, and workers' expectations regarding the hike in future inflation cause hours to decline by 2.2% on impact. Therefore, output shrinks by 1.25% as shown in the top left panel of the figure. The dynamics of real balances demand and the consumption velocity of the monetary base resemble the expected implication of the dynamics of inflation.

In the model economy with credit policy, the time-varying rule induces a fall in the RRR of about 0.6% points, since bank credit declines in response to the negative financial shock. Reserves immediately drop by 11% and almost completely eliminate the collapse in inflation. Most importantly, the dynamics of reserves move inflation in such a way as to induce hours and, accordingly, output to increase on impact (see the bottom and top panels of Figure 5).

Following the reduced cost of making equity loans to firms, banks substitute away their assets from reserves to firm equity; therefore, the initial decline in bank credit is 1% smaller. As the demand for firm equity is higher in the model with credit

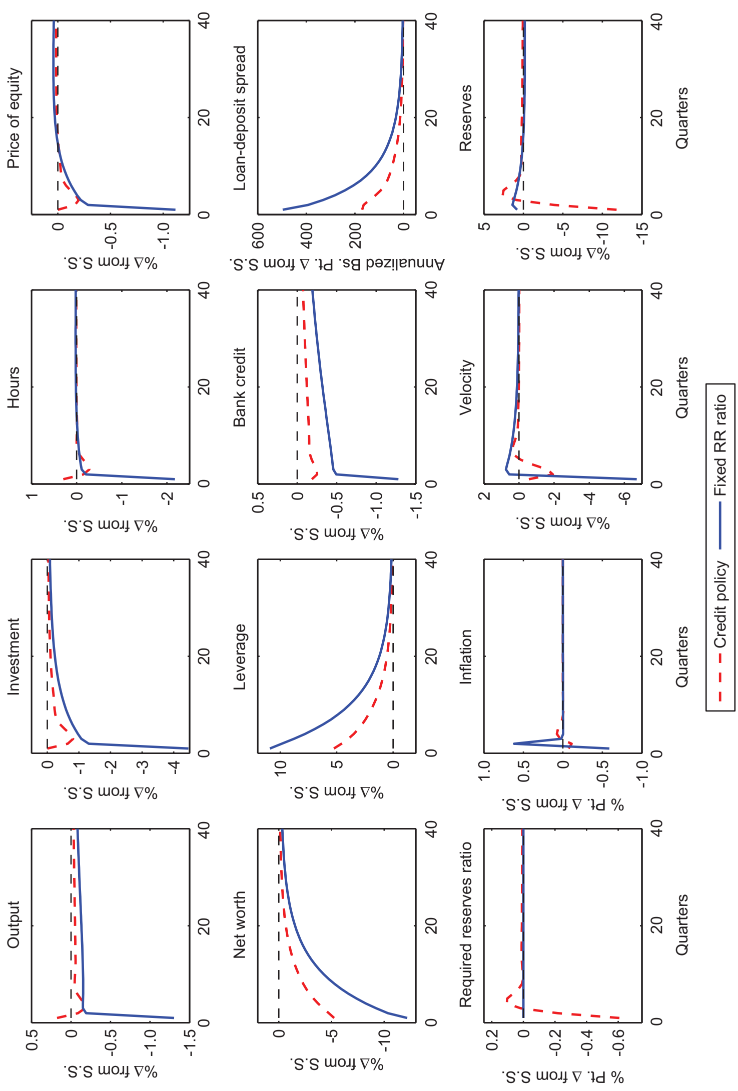

Figure 5 Impulse responses led by a 1-σ adverse financial shock.

policy, the 1% reduction in the price of equity in the economy with fixed a RRR policy is almost totally eliminated. This reinforces the intermediary capital via the leverage constraint and reduces the collapse in bank net worth by 7%. We emphasize this finding that the credit policy reduces the amplified impact of the financial shock on bank capital by more than 50%. Accordingly, the rise in credit spreads is 300 basis points lower in annualized terms, and bank leverage increases by 5% instead of 10%. As another favorable outcome, investment falls by 3% less than the decline in the fixed RRR economy over five quarters. To sum up, we obtain the result that a countercyclical reserve requirements policy that has a first-order impact on the balance sheets of financial intermediaries proves effective in response to financially repressed periods in which balance sheets of banks deteriorate.

In the next section, we analyze the operational role of credit policy by changing the response intensity of RRR to the aggregate credit growth.

5.2 Credit policy intensity, volatilities, and procyclicality of financial system

We assess the role of credit policy intensity by changing the response parameter ϕ in the RRR rule, equation (30). We call a credit policy regime that generates a standard deviation of the policy variable, RRR, of 3.50% (1.17%), which is 50% larger (smaller) than that in the benchmark economy, 2.33%, as *aggressive* (*moderate*). Naturally, ϕ is recalibrated in each case to generate those volatilities for the policy variable.[27] In both experiments, both TFP and financial shocks are in place.

The first column of Table 3 gives a list of key real, financial, and monetary variables and correlations of loan-deposit spreads growth and credit growth with output growth. Columns 2–5 report the standard deviations of these variables and values of correlation coefficients under (i) fixed RRR ($\phi=0$), (ii) moderate credit policy regime ($\phi=1.45$), (iii) benchmark credit policy regime ($\phi=3.28$), and (iv) aggressive credit policy regime ($\phi=4.79$). The success of credit policy is assessed by its ability in (i) reducing volatilities of model variables and (ii) reducing the procyclicality of the financial system. The latter goal is actually paving the way to the first goal because policymakers have reached a broad consensus that a procyclical financial system amplifies the impact of various shocks that the economy faces, as mentioned by Lim et al. (2011).

27 Standard deviations of model variables are computed over sufficiently long simulations of the approximated decision rules. When simulations are sufficiently long, the moments of the simulated data converge to their theoretical counterparts.

Table 3 Impact of credit policy on volatilities and financial system procyclicality.

Variable	Fixed reserves $\phi=0$ $\sigma_{rr}=0$[b]	Moderate[a] $\phi=1.45$ $\sigma_{rr}=1.17\%$	Benchmark $\phi=3.28$ $\sigma_{rr}=2.33\%$	Aggressive[a] $\phi=4.79$ $\sigma_{rr}=3.50\%$
Volatilities				
Real variables				
Output	2.51	1.92	1.70	1.60
Consumption	1.38	1.36	1.27	1.23
Investment	6.15	3.83	3.36	3.14
Hours	2.13	2.23	2.32	2.38
Financial variables				
Credit	1.81	1.15	1.03	0.97
Deposits	1.88	1.36	1.65	1.94
Net worth	17.19	6.91	6.96	6.98
Leverage	15.71	6.56	6.67	6.73
Credit spread	0.58	0.29	0.27	0.26
Asset prices	1.56	0.97	0.85	0.79
Monetary variables				
Inflation	0.20	0.24	0.30	0.35
Cyclicality of financial system				
$\rho(\Delta_{spread}, \Delta_{GDP})$[c]	−0.86	−0.08	−0.02	0.04
$\rho(\Delta_{credit}, \Delta_{GDP})$[c]	0.96	0.67	0.79	0.80

[a]Column 3 (5) is obtained by recalibrating ϕ to reduce (increase) the volatility of the reserve requirement rule by 50% compared to the benchmark model.
[b]σ_{rr} stands for the standard deviation of required reserves ratio over simulated series.
[c]$\rho(\Delta_{spread}, \Delta_{GDP})$ and $\rho(\Delta_{credit}, \Delta_{GDP})$ represents the correlation coefficient of loan-deposit spreads (credit) growth and output growth.

Consistent with the impulse response analysis of the previous section, even the moderate policy regime is considerably successful in reducing volatilities of key model variables at the expense of higher inflation volatility. We emphasize the more than 50% decline in the volatilities of net worth, bank leverage, and credit spreads and the more than 30% decline in the volatilities of investment, bank credit, and asset prices. The comparison of columns 3–5 indicates that as the credit policy gets more aggressive, the volatility of output, investment, bank credit, loan-deposit spreads, and asset prices gets even smaller. Notice that since reserve requirements have a strong impact on banks' deposits demand and monetary base, the volatility of deposits and inflation increases as credit policy gets more aggressive. Considering the money market equilibrium condition represented by equation (31), higher volatility in reserves, led by the credit policy rule, induces higher volatility in inflation to restore equilibrium in the money market.[28] Simultaneously, hours become more volatile, since inflation feeds back into the intertemporal consumption-leisure optimality condition, equation (5). Finally, although negligibly small, bank net worth becomes more volatile, because of the increased effort of banks' rebalancing between internal and external finance in response to the change in the reserve requirements.

The last two rows of Table 3 report the business cycle statistics regarding the cyclicality of the financial system. A quick glance at the last two rows in the second column suggests that the financial system is strongly *procyclical* under the fixed RRR regime; that is, in bad times, the borrowing terms for nonfinancial firms deteriorate substantially (implied by the strong negative correlation between loan-deposit spreads growth and output growth of –86%), and the magnitude of intermediated funds diminishes (implied by the strong positive correlation between bank credit growth and output growth of 96%). Comparing these numbers to the last two rows of columns 3–5 shows that countercyclical RRR policy essentially renders credit spreads almost *acyclical* (i.e., correlation reduces to negative 2% for the benchmark regime) and reduces the procyclicality of bank credit substantially (i.e., correlation reduces to 79% for the benchmark regime).

To summarize, a countercyclical reserve requirements policy that is designed to stabilize credit is operational in mitigating the adverse impact of the financial accelerator. In particular, the credit policy mitigates the amplified responses to TFP and net worth shocks under the existence of financial frictions, and reduces the procyclicality of the financial system that helps to fuel this mechanism.

5.3 Alternative reserve requirement policies

As we discuss in the Introduction, stabilizing credit growth does not necessarily have a systemic risk-reducing role in this model because systemic risk is not modeled in the first place. Yet, there is a strong case for studying this kind of reserve requirement policy because (i) numerous policymakers in Turkey and others have used time-varying reserve requirements among other measures to countervail excessive credit growth [for a comprehensive list of macroprudential policy practices across countries, see Lim et al. (2011)], and (ii) countercyclical reserve requirements that stabilize credit are also found to stabilize loan-deposit spreads, a wedge in the consumption-savings margin of this economy.[29]

28 It is straightforward to predict that the volatility of nominal interest rates (which are not set by a monetary policy authority, but rather are determined endogenously) increases in this case as well.
29 Indeed, stabilizing credit spreads in this way is analogous to stabilizing distortionary consumption taxes in the usual Ramsey framework.

Table 4 Impact of alternative policy rules on volatilities and financial system procyclicality.

Variable	No reserves	Fixed reserves	Credit policy	Output policy[a]	Asset prices policy[a]
	$rr=0$ $\phi=0$	$\overline{rr}=0.05$ $\phi=0$	$\overline{rr}=0.05$ $\phi=3.28$	$\overline{rr}=0.05$ $\phi=1.84$[b]	$\overline{rr}=0.05$ $\phi=4.98$[b]
Volatilities					
Real variables					
Output	2.65	2.51	1.70	1.93	1.64
Consumption	1.39	1.38	1.27	1.28	1.22
Investment	6.66	6.15	3.36	4.63	3.28
Hours	2.58	2.13	2.32	3.42	2.42
Financial variables					
Credit	1.95	1.81	1.03	1.36	1.02
Deposits	1.99	1.88	1.65	1.93	1.70
Net worth	18.39	17.19	6.96	8.26	7.03
Leverage	16.78	15.71	6.67	7.71	6.75
Credit spread	0.68	0.58	0.27	0.33	0.27
Asset prices	1.69	1.56	0.85	1.17	0.83
Monetary variables					
Inflation	0.23	0.20	0.30	0.39	0.32
Cyclicality of financial system					
$\rho(\Delta_{spread}, \Delta_{GDP})$	−0.85	−0.86	−0.02	−0.39	0.03
$\rho(\Delta_{credit}, \Delta_{GDP})$	0.97	0.96	0.79	0.83	0.70

[a]Columns 5 and 6 are obtained by solving the model by replacing equation (30) by $rr_t=\overline{rr}+\phi E_t[\log(y_{t+1})-\log(y_t)]$, and $rr_t=\overline{rr}+\phi E_t[\log(q_{t+1})-\log(q_t)]$, respectively.
[b]Under each reserves policy regime, ϕ is recalibrated to match the standard deviation of RRR (2.33%) during the intervention period.

In this section, for completeness, we make an extension and consider alternative macroeconomic target variables for the reserve requirement policy rule. We then compare the performance of these alternative regimes with the benchmark policy. To that end, Table 4 is constructed to include no required reserves (column 2) and alternative policy rules that aim to stabilize output (column 5) and asset prices (column 6), in addition to the benchmark policy that aims to stabilize credit (column 4). In each policy regime (other than the no-reserves case), the policy response parameter ϕ is recalibrated to match the volatility of the RRR observed during which the CBRT has intervened (2010:Q4–2012:Q2).[30] We assess the performance of each policy regime again by focusing on the volatilities of key model variables and the procyclicality of the financial system vis-á-vis the economy with fixed RRR (column 3).

30 Accordingly, equation (30) is modified to be $rr_t=\overline{rr}+\phi E_t[\log(y_{t+1})-\log(y_t)]$, and $rr_t=\overline{rr}+\phi E_t[\log(q_{t+1})-\log(q_t)]$, respectively.

The main message of Table 4 is clear: a countercyclical reserve requirement policy that aims to stabilize either output or asset prices reduces the volatility of key real and financial variables at the expense of higher inflation volatility along the mechanism that we lay out in Section 5.1. Specifically, credit stabilization outperforms output stabilization because volatilities are reduced more at the expense of less volatile inflation (see columns 4 and 5). Asset price stabilization, on the other hand, outperforms credit stabilization but at a negligible level (see columns 4 and 6). Another observation is that the economy with a positive and time-invariant RRR displays at most slightly lower volatilities than the economy with no required reserves (see columns 2 and 3). Lastly, credit and asset prices stabilization are more effective in reducing the procyclicality of the financial system than output stabilization (see the last two rows of Table 4). This result resembles the findings of Faia and Monacelli (2007), Gilchrist and Saito (2008), and Angeloni and Faia (2009), who find that monetary policy authority should respond to asset prices when financial frictions are relevant. When reserve requirements countercyclically respond to asset prices, the adverse feedback effects of the financial accelerator that operate via endogenous bank capital constraints are mitigated.[31]

One other avenue to explore is to understand the relative impact of shocks on the performance of alternative reserve requirements policy rules in reducing the volatilities in model variables and the procyclicality of the financial system. To that end, we replicate Table 4 by shutting down financial shocks to shed light on the importance of this shock. The findings are reported in Table 5. The findings are striking in the sense that not only are the volatilities of model variables lower, but also the effectiveness of alternative countercyclical required reserves policies in reducing these volatilities diminishes substantially.[32] Most notably, the capability of alternative policies in reducing the countercyclicality of loan-deposit spreads is hindered significantly when there are no financial shocks. Focusing on the *credit policy*, one observes that the success of the reserve requirements policy in reducing the procyclicality of credit is severely hampered. Consequently, we argue that financial shocks, in the form of balance sheet disturbances faced by banks, make a good case for introducing countercyclical reserves policies regardless of the choice of target variable among bank credit, output, or asset prices.

31 Indeed, responding to credit partly resembles responding to asset prices because credit is defined as the market value of capital claims issued by production firms that are traded at the asset price of capital.

32 Consistent with the variance decomposition results reported in Table 2, the volatility of inflation under time-invariant reserves policy economies is reduced sharply when there are no financial shocks.

Table 5 Alternative policy rules on volatilities and financial system procyclicality without financial shocks.

Variable	No reserves $\bar{rr}=0$ $\phi=0$	Fixed reserves $\bar{rr}=0.05$ $\phi=0$	Credit policy $\bar{rr}=0.05$ $\phi=3.5$[a]	Output policy $\bar{rr}=0.05$ $\phi=1.895$[a]	Asset prices policy $\bar{rr}=0.05$ $\phi=5.35$[a]
Volatilities					
Real variables					
Output	2.13	2.14	1.65	1.87	1.58
Consumption	1.37	1.38	1.27	1.30	1.22
Investment	4.16	4.19	3.04	4.25	2.96
Hours	0.21	0.20	2.30	3.39	2.44
Financial variables					
Credit	1.24	1.24	0.92	1.24	0.91
Deposits	0.84	0.85	1.60	1.78	1.61
Net worth	6.74	6.82	0.92	2.63	0.88
Leverage	5.77	5.84	1.41	2.59	1.39
Credit spread	0.34	0.31	0.11	0.15	0.12
Asset prices	1.05	1.06	0.77	1.08	0.74
Monetary variables					
Inflation	0.05	0.04	0.31	0.39	0.32
Cyclicality of financial system					
$\rho(\Delta_{spread}, \Delta_{GDP})$	−0.96	−0.96	−0.56	−0.64	−0.42
$\rho(\Delta_{credit}, \Delta_{GDP})$	0.97	0.97	0.92	0.83	0.69

[a]Under each reserves policy regime, ϕ is recalibrated to match the standard deviation of RRR (2.33%) during the intervention period.

To summarize, countercyclical reserve requirements are robustly found to countervail the impact of the financial accelerator in the current setup when alternative macroeconomic targets (that are popularly adopted by policymakers) are considered. Moreover, this type of policy design becomes more crucial when financial shocks are considered. With the guidance of our positive assessment of reserve requirement policies that are employed by several central banks around the globe, we now proceed to assessing their performance on the optimality grounds in the next section.

5.4 Optimal credit policy intensity

In this section, we discuss the possible objectives and the credit policy instrument of the central bank and search for the optimal intensity of this policy tool.

We follow the exogenous loss function approach, following a vast literature. This approach also helps us find an optimal level of the intensity of credit policy. Otherwise, the welfare-maximizing level of the policy intensity and the volatility of the required reserves policy at that intensity are infinite, since there is no real cost of adjusting the required reserve ratio aggressively and frequently.

Let us assume that the central bank's objective is to minimize an exogenously given loss function. Since we focus on the financial stability objective of the central bank, its loss function targeting financial stability reads

$$L=E[\lambda_y \sigma^2_{\hat{y}}+\lambda_{qs}\sigma^2_{\hat{qs}}+\lambda_{rr}\sigma^2_{\Delta rr}] \quad \lambda_y \geq 0, \lambda_{qs} \geq 0, \lambda_{rr} \geq 0, \tag{39}$$

where $\sigma^2_{\hat{y}}$, $\sigma^2_{\hat{qs}}$, and $\sigma^2_{\Delta rr}$ are theoretical variances of the log-deviations of output and total credit from their steady-state values, and of the changes in the credit policy instrument (i.e., the required reserves ratio), respectively. λ_y, λ_{qs}, and λ_{rr} reflect the policymaker's subjective weights of output stability, credit stability, and the stability of the policy instrument.

We put the variability of total credit into the loss function to be consistent with the fact that a central bank with a financial stability objective may want to prevent abnormal credit expansions and contractions to contain disruptive credit fluctuations.[33] We set its policy weight, λ_{qs}, to 1 following Glocker and Towbin (2012). Moreover, we include the variability of the policy instrument in the loss function, since the central bank wants to keep the fluctuations in the required reserves ratio at reasonable levels. If we do not include it in the loss function, optimal credit policy renders excessive volatility in the required reserves ratio. Therefore, we set λ_{rr} to 1 to make sure that the central bank is quite conservative about changing the required reserves ratio. Finally, regarding the policy weight of output stability, we set λ_y to 0.5 following Angelini, Neri, and Panetta (2012).

Figure 6 displays the loss values for all model economies as a function of the policy intensity parameter, ϕ. These model economies are the credit policy regime, the asset prices policy regime, and the output policy regime under only TFP and both shocks, respectively. We also plot each policy economy as separate panels in Figure 7 to see more transparently the inverted U-shape of loss functions associated with each policy. These plots also give us the ability to pin down the optimal reserve requirement response to credit growth, asset prices growth, and output growth under different sets of shocks.

Figure 7 shows that under only TFP shocks and under both shocks, credit policy is the least costly policy, whereas output policy is the most costly one in terms of loss values. The top left panel of the figure indicates that the optimal

33 Reinhart and Rogoff (2008) and Borio and Drehmann (2009) argue that excessive credit expansions help predict financial crises.

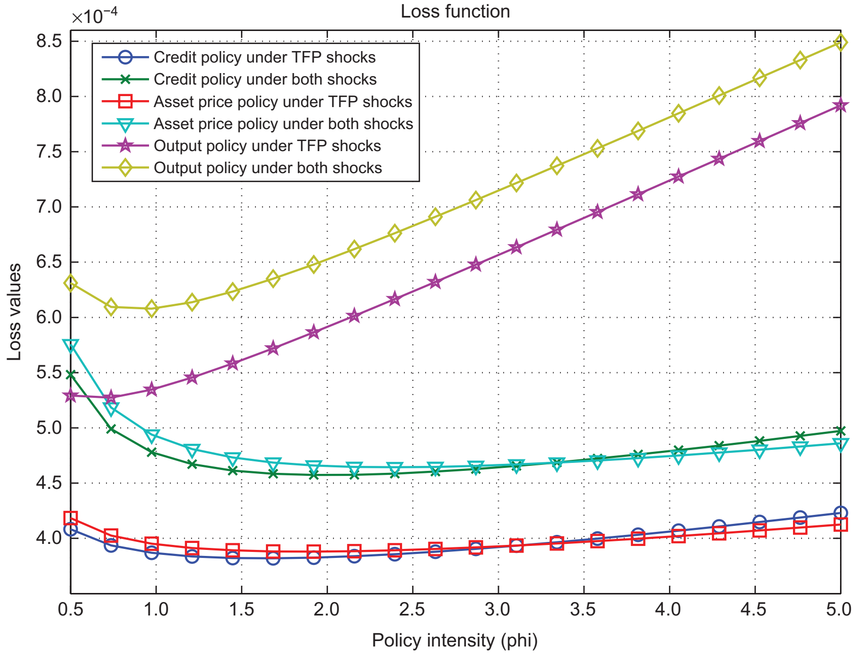

Figure 6 Loss function for all model economies.

intensity of reserve requirement policy that responds to credit growth under only TFP shocks and both shocks is equal to 1.6842 and 1.9211, respectively. As expected, the central bank should take a more aggressive stance if the economy is hit by both productivity and financial shocks. This result is still true when asset price and output policies are considered. The top right panel of the figure shows that the optimal ϕ of the RRR policy that responds to asset prices growth under only TFP shocks and both shocks is equal to 1.9211 and 2.3947, respectively. Lastly, the bottom panel illustrates that the optimal ϕ of the RRR policy that responds to output growth under only TFP shocks and both shocks is equal to 0.7368 and 0.9737, respectively. If we compare the optimal policy intensity across different types of policies, we find that the central bank should be the least aggressive in the case of the output policy and should be the most aggressive in the case of the asset prices policy.[34]

Table 6 shows the loss values associated with each alternative policy rule. For each policy rule, the policy intensity parameter, ϕ, is calibrated at its benchmark

34 Recall that the steady state of all of these economies is identical.

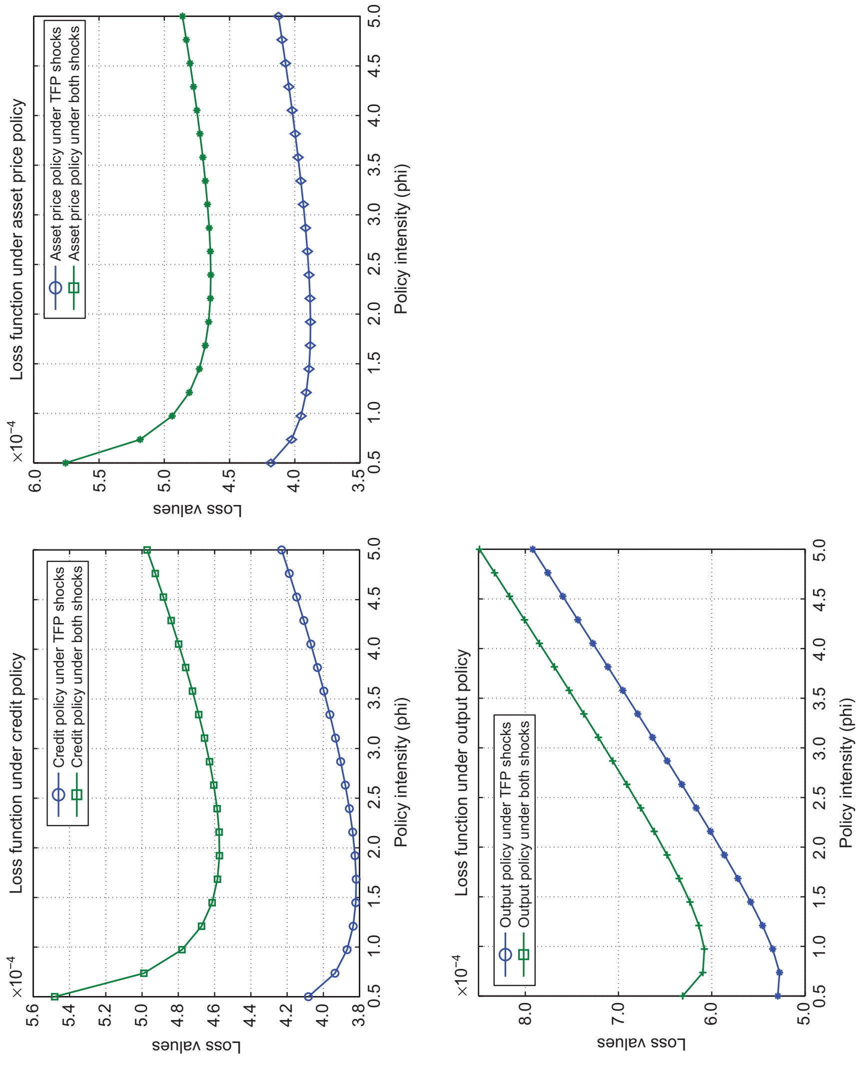

Figure 7 Loss function under different policies.

Table 6 Loss values under alternative policy rules.

	Fixed reserves policy	Credit policy	Output policy	Asset prices policy
Loss values	$\bar{rr}$=0.05 ϕ=0	$\bar{rr}$=0.05 ϕ=3.28[a]	$\bar{rr}$=0.05 ϕ=1.84[a]	$\bar{rr}$=0.05 ϕ=4.98[a]
Under only TFP shocks	4.3613e-04	3.9560e-04	5.8147e-04	4.1233e-04
Under both shocks	6.4556e-04	4.6789e-04	4.8579e-04	6.4341e-04

[a]Under each reserves policy regime, ϕ is calibrated to match the standard deviation of RRR (2.33%) during the intervention period.

value. The first row of the table displays the loss values under only TFP shocks. The time-varying credit and asset prices policies give loss values that are lower than the fixed reserves policy, whereas the time-varying output policy gives the highest value, indicating that the former policies dominate the fixed reserves policy and the output policy emerges as the worst. The second row of the table shows the loss values under both shocks. In this case, the fixed reserves policy gives the highest loss value, implying that all time-varying policies dominate the fixed reserves policy when both shocks hit the economy.

Here, we should note that we do not include the loss value associated with zero required reserves policy in the table in order to have a meaningful comparison across different policies. This is because there are first-order level differences between the no-reserves economy, the couple of fixed required reserves economies, and the credit policy economies. Therefore, we think that it is more intuitive to compare economies with positive required reserves in terms of volatility effects.

We should also emphasize that the second best of this model economy features a zero RRR policy, which is also confirmed by solving the optimal Ramsey problem of this economy. In other words, constrained efficiency implies that under financial frictions in the banking sector, the second best can be achieved only by a zero required reserves ratio.[35] This is straightforward to predict, since the magnitude of intermediated funds is going to be larger with no reserves, as we discuss in Section 4.3. Nevertheless, as mentioned in the introduction, we take the existence of positive RRRs as an institutional feature of the real world, and bringing a microfoundation to their existence is beyond the scope of this paper [as in Angeloni and Faia (2009); Christensen, Meh, and Moran (2011), Angelini, Neri, and Panetta (2012) on the analysis of capital requirements]. Indeed, our

35 The first best of this model economy is achieved when both monetary and financial frictions are removed.

exercise illustrates how a central bank can replace a time-invariant required reserves policy with a time-varying required reserves policy rule to bring the economy closer to its second best. This completes the analysis of optimal credit policy and in the next section, we carry out sensitivity analysis on the key parameters regarding financial frictions in the model.

6 Sensitivity analysis

In this section, we explore the impact of key model parameters on the effectiveness of credit policy in maintaining macroeconomic and financial stability. The comparisons are based on the implied volatilities of key model variables under fixed and time-varying reserve requirement policy regimes when TFP and financial shocks are realized over sufficiently long simulations of the model economy. The results are reported in Table 7. In all columns of the table, we change one parameter at a time and recalibrate the response parameter ϕ to match the volatility of the observed RRR. We leave the other parameters the same as in the benchmark model. We fix the way in which the central bank responds to shocks in order to prevent the arbitrarily strong or weak policy responses that might emerge for the benchmark value of ϕ when the sensitivity parameter of interest is tweaked. If the steady-state levels of bank leverage and credit spreads differ from the benchmark case for an alternative parameter level, we report the new steady-state values of these variables below the parameter value.

For that matter, we run credit policy for alternative values of (i) the fraction of diverted funds, λ, which is used to target the long-run value of credit spreads, determining the severity of financial frictions in the banking sector (top panel), (ii) the survival probability, θ, which is used to target the long-run value of bank leverage and the riskiness of the financial sector (middle panel), and (iii) the capital adjustment cost parameter, ϕ, which affects the transmission of shocks to the real sector via fluctuations in asset prices that are propagated by endogenous capital constraints of financial intermediaries (bottom panel). In each related column, the recalibrated value of ϕ is reported.[36]

- *Fraction of Diverted Funds, λ:* An increase in the fraction of diverted funds corresponds to an economy in which financial frictions are more severe because the moral hazard problem between banks and households becomes more intense. This is reflected as a smaller long-run value for bank leverage and a larger long-

36 Notice that the recalibrated values for ϕ vary in the range of [2.7, 4.13], whereas the benchmark value for this parameter is 3.28.

Table 7 Sensitivity of credit policy to selected model parameters.

Variable	Fixed reserves	Credit policy	Fixed reserves	Credit policy
	$\lambda=0.25$ ($\bar{\kappa}=12.85$)[a]	$\lambda=0.25$	$\lambda=0.75$ ($\bar{\kappa}=4.28$)	$\lambda=0.75$
	($\overline{R_k-R}=27$ bs. pt.)[a]	$\phi=3.73$[b]	($\overline{R_k-R}=67$ bs. pt.)	$\phi=2.82$
Real variables				
Output	2.25	1.61	2.79	1.81
Consumption	1.37	1.29	1.43	1.28
Investment	4.78	2.87	7.39	3.86
Hours	1.11	2.28	2.96	2.37
Financial variables				
Credit	1.42	0.88	2.15	1.17
Deposits	1.04	1.50	2.90	1.97
Net worth	20.91	6.49	15.90	7.19
Leverage	19.78	6.46	14.18	6.73
Credit spread	1.06	0.36	0.42	0.23
Asset prices	1.21	0.72	1.87	0.97
Monetary variables				
Inflation	0.11	0.32	0.28	0.29
$\rho(\Delta_{spread}, \Delta_{GDP})$	−0.88	−0.02	−0.86	−0.01
$\rho(\Delta_{credit}, \Delta_{GDP})$	0.96	0.86	0.97	0.68
	$\theta=0.955$ ($\bar{\kappa}=7.56$)	$\theta=0.955$	$\theta=0.97$ ($\bar{\kappa}=4.96$)	$\theta=0.97$
	($\overline{R_k-R}=52$ bs. pt.)	$\phi=3.355$	($\overline{R_k-R}=43$ bs. pt.)	$\phi=3.11$
Real variables				
Output	2.40	1.68	2.70	1.75
Consumption	1.38	1.27	1.40	1.28
Investment	5.63	3.25	6.91	3.56
Hours	1.75	2.31	2.70	2.35
Financial variables				
Credit	1.66	1.00	2.02	1.08
Deposits	1.53	1.60	2.46	1.78
Net worth	17.58	6.79	16.68	7.13
Leverage	16.23	6.57	15.01	6.73
Credit spread	0.53	0.23	0.68	0.34
Asset prices	1.43	0.82	1.75	0.90
Monetary variables				
Inflation	0.17	0.31	0.26	0.30
$\rho(\Delta_{spread}, \Delta_{GDP})$	−0.87	−0.04	−0.86	0.02
$\rho(\Delta_{credit}, \Delta_{GDP})$	0.96	0.83	0.97	0.73

(**Table 7** Continued)

Variable	Fixed reserves	Credit policy	Fixed reserves	Credit policy
	φ=0.5 ($\overline{\kappa}$=6.25)	φ=0.5	φ=13.75 ($\overline{\kappa}$=6.25)	φ=13.75
	($\overline{R_k - R}$=48 bs. pt.)	ϕ=4.13	($\overline{R_k - R}$=48 bs. pt.)	ϕ=2.7
Real variables				
Output	2.64	2.08	2.42	1.60
Consumption	1.16	1.12	1.58	1.40
Investment	7.43	5.36	5.20	2.52
Hours	2.28	2.19	2.03	2.35
Financial variables				
Credit	0.84	0.69	2.79	1.36
Deposits	1.37	1.29	2.25	1.86
Net worth	8.34	6.63	24.16	7.13
Leverage	7.94	6.54	21.72	6.68
Credit spread	0.31	0.30	0.78	0.27
Asset prices	0.14	0.10	2.63	1.27
Monetary variables				
Inflation	0.22	0.25	0.19	0.31
$\rho(\Delta_{spread}, \Delta_{GDP})$	−0.85	0.03	−0.87	0.03
$\rho(\Delta_{credit}, \Delta_{GDP})$	0.61	0.46	0.97	0.81

[a]The terms in parentheses denote the implied long-run level of bank leverage and credit spreads, respectively.
[b]For each sensitivity experiment, φ is recalibrated to match the standard deviation of RRR (2.33%) during the intervention period.

run value for credit spreads compared to the benchmark model. A smaller bank leverage is due to the tighter endogenous capital constraints faced by banks. Accordingly, tighter credit constraints result in higher credit spreads faced by nonfinancial firms. A comparison of the last two columns in the top panel of Table 7 with columns 3–4 of Table 4 reveals that when λ is larger, the credit policy (with the same policy variable volatility as in the benchmark model) is more effective in reducing the volatilities of output, consumption, investment, bank credit, and asset prices. Therefore, the importance of reserve requirement policies is enhanced when financial frictions become more severe. Notice also that a lower response parameter for the required reserves rule is generating the same volatility in the RRR. This means that when financial frictions are stronger, the responsiveness of the central bank increases as well.

- *Survival Probability, θ:* A larger value for survival probability reduces the long-run value of bank leverage because bankers can accumulate more net worth during their finite life. Consequently, stronger internal financing results in lower credit spreads in the long run. Coming to simulation results, the effectiveness of credit policy in reducing the volatilities of output, consumption, investment, bank credit, and asset prices is enhanced when steady-state bank leverage is smaller as a result of higher survival probability.
- *Capital Adjustment Cost Parameter, φ:* The value of the capital adjustment cost parameter is especially important because it affects the transmission of the financial accelerator mechanism to the asset prices without changing the steady state of the model. Specifically, when $\varphi=0$, asset prices do not fluctuate at all and the second-round effects of the financial accelerator do not operate via banks' capital constraints. As a result, a smaller φ reduces the propagation of the financial accelerator in the model. The comparison of the last four columns in the bottom panel of Table 7 shows that credit policy is much more effective in reducing the volatilities of all macroeconomic and financial variables when asset prices are more responsive to volatilities in bank capital (i.e., when φ is larger). This explanation is consistent with the impulse responses as well. Figure 8 reproduces the impulse responses of model variables led by a one-standard-deviation negative TFP shock in the fixed reserves (straight plots) and time-varying reserves (dashed plots) economies when $\varphi=0.5$. A comparison of Figure 8 with Figure 4 reveals two facts: (i) the straight plots in the former display less response in bank net worth, leverage, bank credit, credit spreads, and asset prices to the negative TFP shock, and (ii) the dashed plots again in the former illustrate that credit policy operates much less effectively in stabilizing financial variables when the propagation of the financial accelerator is dampened.[37]

7 Discussion and conclusion

Using reserve requirements to achieve financial stability has certain advantages and drawbacks. The main advantages are that (i) it is one of the two main policy tools that most central banks can use, (ii) the central bank does not directly face any costs, since reserve requirements effectively alter the financial sector's own balance sheet in order to provide liquidity to the system, and (iii) they might be used as a tax that affects the loan-deposit spreads on the banking system in

37 Investment is more volatile when φ is lower precisely because less of the adjustment to the adverse TFP shock comes through asset price changes.

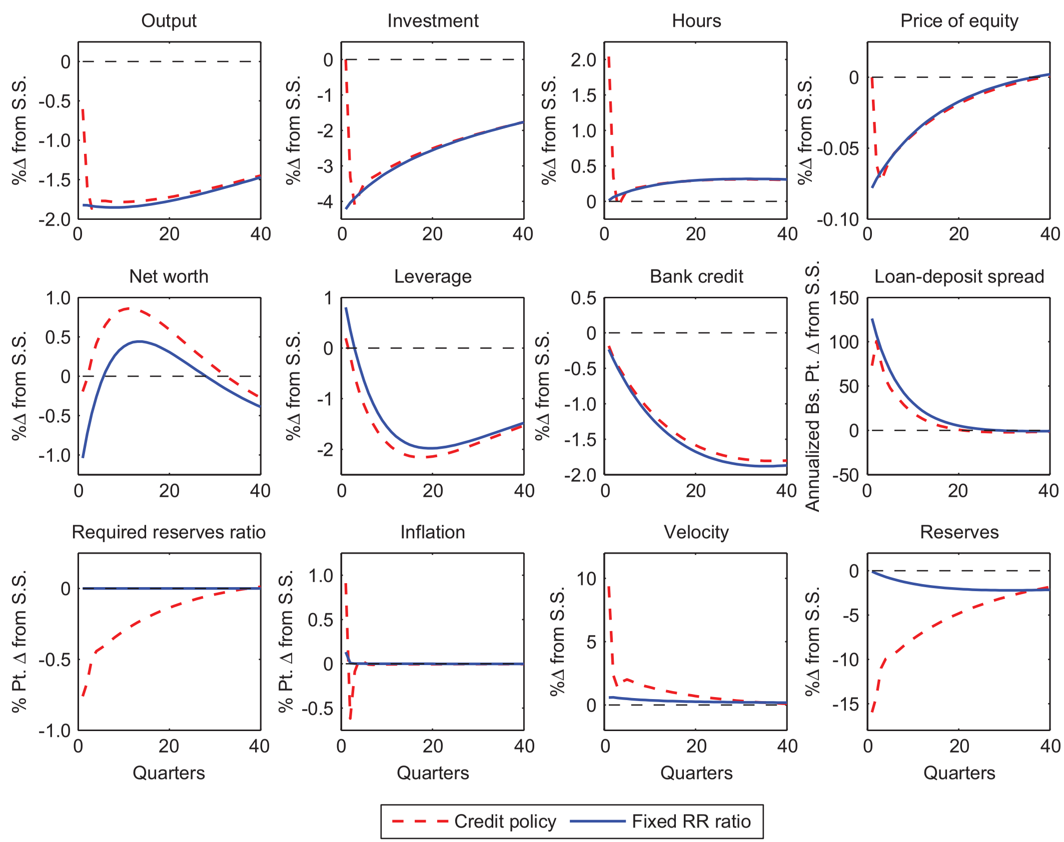

Figure 8 Impulse responses led by a 1-σ adverse TFP Shock with φ=0.5.

order to alter the cost of making loans if loan growth is a policy concern. Among some drawbacks of using reserve requirements are that (i) they put depository institutions at a competitive disadvantage compared to unregulated financial institutions, (ii) they might be circumvented by the banking sector to an extent that alternative ways of credit creation such as syndicated loans and currency swaps, which are not subject to reserve requirements, are used, and (iii) as stated in Lim et al. (2011), despite being raised to prevent predatory lending, increasing required reserves might render access to credit by prudent (but small-to-medium-size) firms too difficult, and lastly, (iv) required reserves might be substituted by overnight borrowing from the central bank if overnight borrowing rates are not too high (i.e., interest rate corridor is narrow). Our judgment is that policymakers around the globe are assessing the effectiveness of reserve requirements by considering these pros and cons.

One can assess the effectiveness of reserve requirements as a financial stability tool through their effects on credit spreads and bank credit in the nonfinancial sector. Other things being equal, we conjecture that the countercyclical implementation of reserve requirement ratios mitigates the decline in credit growth and accordingly moderates the rise in credit spreads in economic downturns, curbing excessive credit growth in boom periods.

To that purpose, we build a quantitative monetary DSGE model with a banking sector that is subject to time-varying reserve requirements imposed by the central bank and endogenous capital constraints due to an agency problem. We model reserve requirements as an exogenous policy rule that countercyclically responds to expected credit growth in the financial sector. We consider the effects of two different types of shocks: productivity and financial shocks. For each type of shock, we find that the time-varying required reserve ratio rule mitigates the negative effects of adverse shocks amplified by the financial accelerator mechanism on real and financial variables. In each case, it reduces the intertemporal distortions created by the credit spreads at the expense of generating higher inflation, pointing out the clear trade-off between price stability and financial stability faced nowadays by many central banks. It also reduces the volatilities of key variables such as output, consumption, investment, bank credit, loan spreads, and asset prices, indicating the role of reserve requirements as a credit policy instrument. Finally, we find that a time-varying reserve requirement policy achieves a higher welfare than a fixed reserve requirement policy.

This study illustrates that when financial frictions are important, monetary policy that adopts reserve requirement ratios as a credit policy instrument might have real effects even if there are no nominal rigidities. Yet, a number of caveats, shortcomings, and further research avenues need to be discussed. First, in order to avoid the curse of dimensionality, we resort to perturbation techniques instead of global approximation methods in the solution of the theoretical model. This prevents us from analyzing occasionally binding incentive compatibility constraints that might affect the dynamics of credit spreads. Second, one can introduce liquidity shocks in order to bring a microfoundation to holding reserves to rationalize the optimality of positive reserve requirements. Third, it might also be interesting to focus on the trade-off between price stability and financial stability in a framework in which an interest rate feedback rule is introduced under nominal rigidities as in Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). Introducing such trade-offs might be essential in adopting welfare measures based on consumers' utility rather than resorting to ad hoc loss functions. Lastly, it might also be worthwhile to study an open economy model to explicitly consider the effects of international capital flows in the design of required reserves policies, rather than capturing them partially by net worth shocks. This is because reversals in the risk appetite of global investors have a tendency to create credit cycles in emerging economies such as Turkey. Indeed, international capital flows have been pointed out as being among the motivating reasons for using reserve requirement policies by the CBRT in the aftermath of the recent crisis [see CBRT (2011-IV), Lim et al. (2011)] and Therefore, an extension of the current model including open economy features might yield important avenues for the researcher on the study of reserve requirements as a credit policy tool.

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Appendix

Appendix A: Banks' profit maximization problem

Let us conjecture that the bank's franchise value is given by

$$V_{jt}=\nu_t q_t s_{jt}+\eta_t n_t. \tag{40}$$

Comparing the conjectured solution for V_{jt} to the expected discounted terminal net worth yields the following expressions:

$$\nu_t q_t s_{jt}=E_t\sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^{i+1}\Lambda_{t,t+1+i}\left[R_{kt+1+i}-\left(\frac{R_{t+1+i}-rr_{t+i}}{1-rr_{t+i}}\right)\right]q_{t+i}s_{jt+i} \tag{41}$$

$$\eta_t n_{jt}=E_t\sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^{i+1}\Lambda_{t,t+1+i}\left[\frac{R_{t+1+i}-rr_{t+i}}{1-rr_{t+i}}\right]n_{jt+i}. \tag{42}$$

Let ESP_{t+i} stand for $\left[R_{kt+1+i}-\left(\frac{R_{t+1+i}-rr_{t+i}}{1-rr_{t+i}}\right)\right]$, and let RR_{t+i} stand for $\left[\frac{R_{t+1+i}-rr_{t+i}}{1-rr_{t+i}}\right]$. Therefore,

$$\nu_t q_t s_{jt}=E_t\sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^{i+1}\Lambda_{t,t+1+i}ESP_{t+i}q_{t+i}s_{jt+i} \tag{43}$$

$$\eta_t n_{jt}=E_t\sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^{i+1}\Lambda_{t,t+1+i}RR_{t+i}n_{jt+i}. \tag{44}$$

We write ν_t and η_t recursively using the above expressions. Let us begin with ν_t. To ease the notation, let us drop expectations for now:

$$\nu_t=\sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^{i+1}\Lambda_{t,t+1+i}ESP_{t+i}x_{t,t+i}, \tag{45}$$

where $x_{t,t+i}=\frac{q_{t+i}s_{jt+i}}{q_t s_{jt}}$. Let us separate (45) into two parts:

$$\nu_t=(1-\theta)\beta\Lambda_{t,t+1}ESP_t+\sum_{i=1}^{\infty}(1-\theta)\theta^i\beta^{i+1}\Lambda_{t,t+1+i}ESP_{t+i}x_{t,t+i}. \tag{46}$$

Rearrange the second term on the right-hand side of expression (46):

$$\nu_t = (1-\theta)\beta\Lambda_{t,t+1}ESP_t + \beta\Lambda_{t,t+1}\theta x_{t,t+1}\sum_{i=0}^{\infty}(1-\theta)\theta^{i+1}\beta^{i+1}\Lambda_{t+1,t+2+i}ESP_{t+1+i}x_{t+1,t+1+i}. \quad (47)$$

The infinite sum on the right-hand side of equation (47) is the one-period updated version of equation (45), given by

$$\nu_{t+1} = \sum_{i=0}^{\infty}(1-\theta)\theta^{i+1}\beta^{i+1}\Lambda_{t+1,t+2+i}ESP_{t+1+i}x_{t+1,t+1+i}, \quad (48)$$

where $x_{t+1,t+1+i} = \frac{q_{t+1+i}s_{jt+1+i}}{q_{t+1}s_{jt+1}}$.

Hence, we can rewrite (47) with expectations as follows:

$$\nu_t = E_t[(1-\theta)\beta\Lambda_{t,\, t+1}ESP_t + \beta\Lambda_{t,\, t+1}\theta x_{t,\, t+1}\nu_{t+1}]. \quad (49)$$

Let us continue with η_t. To ease the notation, let us drop expectations for now:

$$\eta_t = \sum_{i=0}^{\infty}(1-\theta)\theta^{i}\beta^{i+1}\Lambda_{t,t+1+i}RR_{t+i}z_{t,t+i}, \quad (50)$$

where $z_{t,t+i} = \frac{n_{jt+i}}{n_{jt}}$. Let us separate equation (50) into two parts:

$$\eta_t = (1-\theta)\beta\Lambda_{t,t+1}RR_t + \sum_{i=1}^{\infty}(1-\theta)\theta^{i}\beta^{i+1}\Lambda_{t,t+1+i}RR_{t+i}z_{t,t+i}. \quad (51)$$

Rearrange the second term on the right-hand side of expression (51):

$$\eta_t = (1-\theta)\beta\Lambda_{t,t+1}RR_t + \beta\Lambda_{t,t+1}\theta z_{t,t+1}\sum_{i=0}^{\infty}(1-\theta)\theta^{i+1}\beta^{i+1}\Lambda_{t+1,t+2+i}RR_{t+1+i}z_{t+1,t+1+i}. \quad (52)$$

The infinite sum on the right-hand side of equation (51) is the one-period updated version of equation (49), given by

$$\eta_{t+1} = \sum_{i=1}^{\infty}(1-\theta)\theta^{i+1}\beta^{i+1}\Lambda_{t+1,t+2+i}RR_{t+1+i}z_{t+1,t+1+i}, \quad (53)$$

where $z_{t+1,t+1+i} = \frac{n_{jt+1+i}}{n_{jt+1}}$.

Hence, we can rewrite equation (51) with expectations as follows:

$$\eta_t = E_t[(1-\theta)\beta\Lambda_{t,t+1}RR_t + \beta\Lambda_{t,t+1}\theta z_{t,t+1}\eta_{t+1}]. \tag{54}$$

The profit maximization problem by a representative bank is given by

$$V_{jt} = \max_{s_{jt}} E_t \sum_{i=0}^{\infty}(1-\theta)\theta^i\beta^{i+1}\Lambda_{t,t+1+i}ESP_{t+i}q_{t+i}s_{jt+i} + RR_{t+i}n_{jt+i}] \tag{55}$$

$$s.t.\ V_{jt} \geq \lambda q_t s_{jt} \quad (\mu_t), \tag{56}$$

where μ_t is the Lagrange multiplier associated with the incentive compatibility constraint. Using the conjectured solution for V_{jt} above, we can rewrite the intermediary's maximization problem using the Lagrangian,

$$Ł = \nu_t q_t s_{jt} + \eta_t n_{jt} + \mu_t[\nu_t q_t s_{jt} + \eta_t n_{jt} - \lambda q_t s_{jt}]. \tag{57}$$

The first-order conditions with respect to s_{jt} and μ_t are given, respectively, by

$$(1+\mu_t)\nu_t q_t = \mu_t \lambda q_t, \tag{58}$$

$$V_{jt} - \lambda q_t s_{jt} = 0. \tag{59}$$

Rearranging (58) gives us the following expression:

$$\nu_t = \frac{\mu_t \lambda}{(1+\mu_t)}. \tag{60}$$

Therefore, we establish that the incentive compatibility constraint binds ($\mu_t > 0$) as long as the expected discounted marginal gain of increasing bank assets is positive.

Appendix B: Competitive equilibrium conditions

The following are the optimality and market clearing conditions that are satisfied in a competitive equilibrium as defined in Section 3.6:

$$\Lambda_{t,t+1} = \frac{u_c(t+1)}{u_c(t)} \tag{61}$$

$$1=\beta E_t R_{t+1}\Lambda_{t,t+1} \tag{62}$$

$$c_t=\frac{\exp(\mu)-1+\hat{m}_t\hat{P}_t}{\hat{P}_t\exp(\mu)}+R_t b_t-b_{t+1} \tag{63}$$

$$\frac{u_l(t)}{w_t\hat{P}_t}=\beta E_t\left\{\frac{u_c(t+1)}{\hat{P}_{t+1}\exp(\mu)}\right\} \tag{64}$$

$$\kappa_t=\frac{\eta_t}{\lambda-\nu_t} \tag{65}$$

$$q_t s_t=\kappa_t n_t \tag{66}$$

$$q_t s_t=(1-rr_t)b_{t+1}+n_t \tag{67}$$

$$\varrho_{t,t+1}=\left(R_{kt+1}-\frac{R_{t+1}-rr_t}{1-rr_t}\right)\kappa_t+\frac{R_{t+1}-rr_t}{1-rr_t} \tag{68}$$

$$\chi_{t,t+1}=\varrho_{t,t+1}\frac{\kappa_{t+1}}{\kappa_t} \tag{69}$$

$$n_{et}=\theta\left\{\left[R_{kt}-\left(\frac{R_t-rr_{t-1}}{1-rr_{t-1}}\right)\right]\kappa_{t-1}+\left(\frac{R_t-rr_{t-1}}{1-rr_{t-1}}\right)\right\}n_{t-1} \tag{70}$$

$$n_{nt}=\epsilon n_{t-1} \tag{71}$$

$$n_t=n_{et}+n_{nt} \tag{72}$$

$$\nu_t=E_t\left\{(1-\theta)\beta\Lambda_{t,t+1}\left(R_{kt+1}-\frac{R_{t+1}-rr_t}{1-rr_t}\right)+\beta\Lambda_{t,t+1}\theta\chi_{t,t+1}\nu_{t+1}\right\} \tag{73}$$

$$\eta_t=E_t\left\{(1-\theta)\beta\Lambda_{t,t+1}\left(\frac{R_{t+1}-rr_t}{1-rr_t}\right)+\beta\Lambda_{t,t+1}\theta\varrho_{t,t+1}\eta_{t+1}\right\} \tag{74}$$

$$w_t=\exp(z_t)F_h(k_t,\, h_t) \tag{75}$$

$$R_{kt}=\frac{\exp(z_t)F_k(k_t,h_t)+q_t(1-\delta)}{q_{t-1}} \tag{76}$$

$$k_{t+1}=(1-\delta)k_t+\Phi\left(\frac{i_t}{k_t}\right)k_t \tag{77}$$

$$q_t=\left[\Phi'\left(\frac{i_t}{k_t}\right)\right]^{-1} \tag{78}$$

$$\exp(z_t)F(k_t,h_t)=c_t+i_t \tag{79}$$

$$s_t=k_{t+1} \tag{80}$$

$$1=l_t+h_t \tag{81}$$

$$\exp(\pi_t)=\exp(\mu)\frac{\widehat{P}_t}{\widehat{P}_{t-1}} \tag{82}$$

$$z_{t+1}=\rho_z z_t+\epsilon_{zt+1} \tag{83}$$

$$rr_t=\overline{r}r+\phi E_t[\log(q_{t+1}s_{t+1})-\log(q_t s_t)] \tag{84}$$

$$\frac{1}{\hat{P}_t}=\hat{m}_{t+1}+rr_t b_{t+1}. \tag{85}$$

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