

Monetary Policy Transmission with Heterogeneous Banks and Firms: The Case of China*

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First draft: February 14, 2021
Current draft: February 14, 2021

Abstract

We document that monetary policy has asymmetric effects on investments by large and small firms in China. Large firms' investment are highly responsive to monetary expansions, but less affected by monetary contractions. In contrast, small firms' investments are less responsive to monetary expansions, but significantly affected by monetary contractions. We argue that this asymmetric responses of large and small firms stem from their differential access to credits in a two-tiered banking system. Large firms borrow from the big state-owned banks, which have a strong depositor base, whereas small firms borrow mainly from small banks which does not have a large depositor base and therefore rely heavily on the inter-bank market for financing their loans to small firms. We build a DSGE model with heterogeneous banks, heterogeneous firms, and an inter-bank market that is calibrated to the Chinese data. We show that the model's quantitative predictions about the effects of monetary policy on large and small firms are consistent with the facts we documented.

*Ji Zhang gratefully acknowledges the financial support from the National Natural Science Foundation of China (No.72003102). Part of the research for this paper was done when Xiaodong Zhu was visiting the PBC School of Finance at Tsinghua University, and he thanks the school for its financial and research support. Correspondence: sguofeng@pbc.gov.cn, zhangji@pbcfsf.tsinghua.edu.cn, xiaodong.zhu@utoronto.ca.

1 Introduction

In this paper, we document that monetary policy has asymmetric effects on investments by large and small firms in China. During monetary expansions, investments of large firms increase significantly, whereas the responses of small firms' investments are limited. During monetary contractions, in contrast, tight monetary policy has only small effects on large firms, but significant negative effect on investments of small firms. We argue that this asymmetric responses of large and small firms to monetary policy stem from their differential access to credits in a two-tiered banking system.

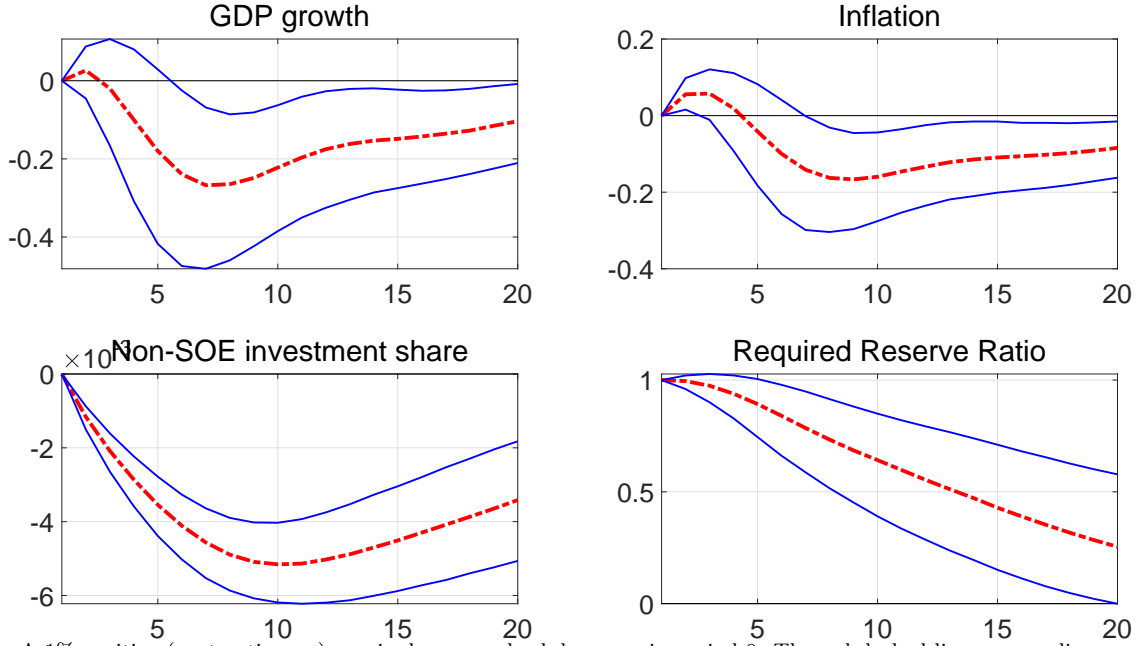
China's banking system consists of five large state-owned banks and many small commercial banks, most of which are local city banks. The large banks have a nationwide branch network and therefore a large and strong depositor base. In contrast, small banks can only attract deposits locally and have to compete with the branches of large banks for deposits. As a result, small banks rely heavily on the inter-bank market for financing its loans to firms. Large banks prefer to and indeed lend predominantly to large firms, partly due to their higher fixed costs of monitoring firms. Small banks have to secure funding from the inter-bank market and therefore face higher funding costs on the one hand, and have smaller fixed costs of monitoring local firms due to the geographic proximity on the other hand. The higher funding costs impede the small banks' competition with large banks on lending to large firms, while their advantage in monitoring costs make them the natural lenders of small firms. As a result, small banks tend to lend to small and risky firms.

We build a DSGE model with large and small banks, large and small firms, and an inter-bank market to examine quantitatively if the two-tiered banking system and the differential access to credits by the large and small firms can account for their differential responses to monetary policy. We calibrate our model to the Chinese data and find that the model can indeed generate the asymmetric responses we observe in the data.

Our paper contributes to the literature that focuses on the disproportionate impacts of monetary policy on small and large firms. Gertler and Gilchrist (1994) has documented that in the U.S., small firms account for a disproportionate share of the manufacturing decline after monetary tightening, and the reason is credit market frictions impede the ability of firms to smooth production. Chang et al. (2019) argue that lifting required reserve ratio benefits non-SOE firms since these firms largely borrow from the shadow banking sector which is not subject to the reserve requirement.

Our paper is also related to the literature investigating the asymmetric impact of contractionary and expansionary monetary policy. Chen et al. (2018) estimate the quantity-based monetary policy system in China and emphasize the role played by the rising shadow banking system in monetary policy transmission. Chen et al. (2019) investigate the asymmetric transmission of positive and negative monetary policy shock

Figure 1: **Impulse responses to a contractionary required reserve ratio shock — VAR**



Notes: A 1% positive (contractionary) required reserve shock happens in period 0. The red dashed lines are medians, and the blue solid lines are 68% confidence intervals. X-axis: time in quarters; Y-axis: annualized percentage change.

in China.

Our paper differs from the existing literature in the following aspects. First, we provide both macro- and micro-level evidence on the heterogeneous responses of large and small firms' investment under monetary policy shocks. Second, we accommodate both the asymmetric impacts (on large and small firms respectively) of contractionary and expansionary monetary policy, and the disproportionate responses between large and small firms under the same shocks in one framework, and explain the dual asymmetry with firms' differential access to credits in the two-tiered banking system in China.

We start by first presenting the empirical evidence about investment responses of large and small firms to monetary policy in China in [Section 2](#). We then present our DSGE model in [Section 3](#), the quantitative analysis of the model in [Section 4](#), and conclusion in [Section 5](#).

2 Empirical evidence

2.1 Macro-level evidence

VAR analysis — Disproportionate responses between large and small firms. We include output, inflation, investment, and required reserve ratio in a structural VAR model to investigate how the economy responds to a contractionary required reserve ratio shock. To achieve the identification of monetary policy

shocks, we follow the convention in the literature to assume that monetary policy shocks (shocks on required reserve ratio) cannot affect contemporaneous output and inflation. Output and inflation in the VAR are hp-filtered GDP growth and inflation implied by GDP deflator. The investment variable we use in the VAR analysis is the share of non-SOE enterprises' gross fixed capital formation ($I_{SF,t}$) in total non-government gross fixed capital formation (I_t), where the investment data we use is constructed by Chang et al. (2016). Due to the data availability, we use the investment of non-SOE/SOE firms to proxy that of small/large firms, since state-owned enterprises are mainly large ones. Our sample covers the period from 1995Q1 to 2017Q4 since the investment data is only available during this period.

Figure 1 reports the impulse responses to a contractionary monetary policy shock. The red dashed lines are the median responses, and the blue solid lines are the 68% confidence intervals. The responses of GDP growth and inflation decrease as expected, and are consistent with the results from the VAR model without investment presented in Figure B.1. The investment share of non-SOE firms decreases significantly, which means non-SOE firms are more responsive to contractionary monetary policy shocks and their investment decreases more than SOE firms.

Local projection analysis – Asymmetric impacts of expansionary and contractionary monetary policy shocks. Being aware of the disadvantages of the VAR analysis in its symmetric setup and strict identification assumption, we apply the local projection method, introduced by Jordà's (2005), to account for the asymmetric impacts of expansionary and contractionary monetary policy shocks, without making any restrictions on contemporaneous responses to monetary shocks.

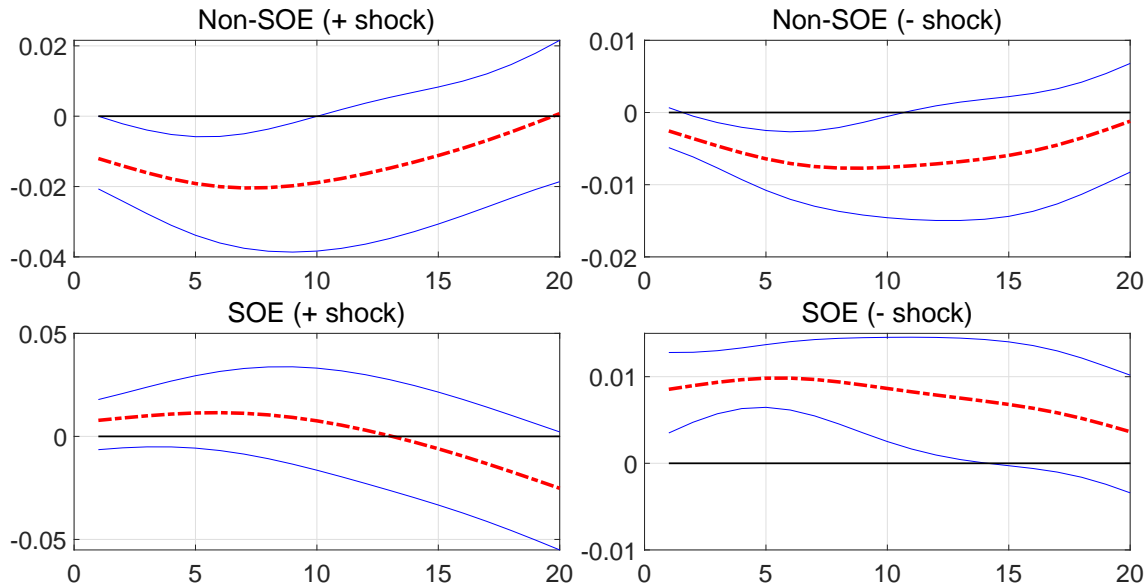
To explore the asymmetric impacts of positive and negative shocks to required reserve ratio, we separate the positive and negative shocks to required reserve ratio:

$$\frac{I_{SF,t}}{I_t} = b_2^+ * \max\{\hat{\epsilon}_{RRR,t}, 0\} + b_2^- * \min\{\hat{\epsilon}_{RRR,t}, 0\} + \gamma X_{t-p} + \epsilon_{2t} \quad (2.1)$$

where dependent variable is still the share of non-SOE investment in total investment, RRR_t is required reserve ratio, X_{t-p} is the contemporaneous and lagged control variables including GDP growth, inflation, and investment, $b_2^+(b_2^-)$ is the contemporaneous impact of a contractionary(expansionary) required reserve ratio shock. $\hat{\epsilon}_{RRR,t}$ represents the required reserve ratio shock, which is estimated separately from the policy rule on the required reserve ratio. The required reserve ratio is assumed to follow a Taylor-type rule, which responds to changes in output, inflation, and foreign reserves:

$$RRR_t = const. + \rho_{RRR} * RRR_{t-1} + (1 - \rho_{RRR}) * (\varphi_y * \Delta GDP_t + \varphi_{pi} * \Pi_t + \varphi_{fr} * fr_t) + \epsilon_{RRR,t}$$

Figure 2: Asymmetric responses of investment share to a required reserve ratio shock



Notes: The left(right) two panels are the responses of investment shares of non-SOE and SOE enterprises under a 1% positive(negative) required reserve shock happens in period 0. The red dashed lines are medians, and the blue solid lines are 68% confidence intervals. X-axis: time in quarters; Y-axis: annualized percentage change.

where GDP_t is output, Π_t is inflation, fr_t is foreign reserves, and the estimated residual is the reserve ratio shock, $\hat{\epsilon}_{RRR,t}$, used in (2.1).

To double-check whether the impacts of monetary policy shock on SOE and non-SOE's investments are compatible, we replace the dependent variable in (2.1) to be the share of SOE investment:

$$\frac{I_{LF,t}}{I_t} = b_2^+ * \max\{\hat{\epsilon}_{RRR,t}, 0\} + b_2^- * \min\{\hat{\epsilon}_{RRR,t}, 0\} + \gamma X_{t-p} + \epsilon_{2t} \quad (2.2)$$

The impulse responses implied by (2.1) and (2.2) are plotted in the first and second rows of Figure 2, respectively.

Figure 2 shows substantial asymmetric impacts of required reserve ratio shocks on investment share of non-SOE firms. No matter it is a positive(contractionary) or negative(expansionary) shock, investment share of non-SOE firms decreases significantly, and large firms' investment share increases and the increase is statistically significant under a negative shock.

2.2 Micro-level evidence

Besides the macro-level evidence, we also employ two micro-level databases with annual frequency data – Chinese Industrial Enterprises Database (from 1999 to 2007) and a survey data on the taxation of enterprises in China (from 2008 to 2015) – to investigate individual firms' investment behavior under different monetary

Table 1: **Effects of monetary policy on individual firm's investment**

Panel A: 1999-2007				
	Small firms		Large firms	
	Expansionary	Contractionary	Expansionary	Contractionary
Δr	-0.905*** (0.154)	-0.340** (0.163)	-6.313*** (0.292)	0.922 (0.969)
size	-0.025*** (0.003)	0.002*** (0.001)	-0.0003*** (0.0001)	0.002*** (0.000)
SOE	-0.698 (0.521)	0.241** (0.107)	-2.208*** (0.688)	-1.946*** (0.381)
L.GDP	-0.098*** (0.014)	0.023** (0.010)	-0.733*** (0.024)	-0.160*** (0.059)
firm FE	Y	Y	Y	Y
R^2	0.0049	0.0002	0.0049	0.0057

Panel B: 2008-2015				
	Small firms		Large firms	
	Expansionary	Contractionary	Expansionary	Contractionary
Δr	-0.052*** (0.003)	0.278*** (0.005)	-0.454*** (0.011)	1.481*** (0.9021)
size	0.000* (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000*** (0.000)
SOE	-0.054*** (0.019)	0.026 (0.016)	-0.309*** (0.067)	-0.442*** (0.067)
L.GDP	0.004*** (0.000)	-0.028*** (0.001)	0.032*** (0.001)	-0.241*** (0.003)
firm FE	Y	Y	Y	Y
R^2	0.0042	0.0106	0.0206	0.0570

Notes: Panel A reports the regression results using Chinese Industrial Enterprises Database from 1999 to 2007, and Panel B reports that using Chinese Tax Database from 2008 to 2015. Superscript *** indicates significance at 1% level, and numbers presented in parentheses.

policies. Since the sample period of each database is short, the required reserve ratio does not have sufficient variations, we switch to explore the impacts of an alternative type of monetary policy shock — a shock to interest rate.

The regression equation for Table 1 is

$$\frac{Inv_{it}}{\bar{I}_t} = \alpha + \beta_1 \Delta \hat{r}_t + \gamma X_{it} + \varepsilon_{it} \quad (2.3)$$

where $\left(\frac{Inv_{it}}{\bar{I}_t}\right)$ is the ratio between investment of firm i in period t (proxied by the change in fixed asset) and the average investment of all firms in the database in period t , r_t is the 7-day inter-bank pledged repo rate (R007)¹, $\Delta \hat{r}_t$ is the change in R007 instrumented by the change in U.S. Federal Funds rate, and X_{it} 's are control variables, including a dummy for SOE, firm size proxied by the number of employees, and lagged GDP. Firms with more than 100 employees are defined as large firms, and the rest ones are small firms. If

¹7-day repo rate among deposit institutions (DR007) is only available after 2014.

the interest rate increases compared with last year's level, we call the monetary policy a contractionary one, otherwise it is expansionary.

The estimation results employing the two databases are presented in Panel A and Panel B of [Table 1](#), respectively, and both databases predict similar results. Under expansionary monetary policy, both small and large firms' investment increases, while the increase in large firms' investment is in a larger magnitude. Under contractionary monetary policy, large firms' investment still increases (although insignificantly in the first sample), but small firms' investment has opposite responses in the two samples. In the first sample, small firms investment decreases with increasing interest rate, and in the second sample, it increases but in a smaller size compared to the increase in large firms' investment. The estimation results of individual firms' investment behavior confirm our previous findings with macro-level data.

In the next section, we build up a DSGE model to rationalize our empirical findings.

3 Model

The main framework of the model follows a standard New Keynesian model with financial frictions, which is introduced following Gertler and Karadi (2011), Carlstrom et al. (2017), and Sims and Wu (2020). The main differences of our model with the standard New Keynesian model are in the wholesale firms sector and the banking sector. Instead of assuming identical wholesale firms and banks, we differentiate them with their sizes. There are two types of wholesale firms, indicated by $j \in \{LF, SF\}$, where $j = LF$ stands for large firms, and $j = SF$ stands for small firms, and two types of banks, indicated by $e = \{LB, SB\}$, where LB stands for large banks, and SB stands for small banks.

3.1 Households

There is a continuum of households. Every household member works, consumes final consumption goods, saves in banks to get risk free return, obtains dividend from other sectors, transfers money to new established banks as startup net worth, and pays lump-sum taxes. The household's objective is given by

$$\max_{C_t, L_t, D_t} \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left[\log(C_t) - \psi_L \frac{L_t^{1+\phi_L}}{1+\phi_L} \right],$$

where $0 < \beta < 1$ is the discount factor, C_t is the consumption, L_t is the labor supply, ψ_L is the disutility parameter of labor, and ϕ_L is the inverse of Frisch elasticity of labor. The budget constraint of an individual household is

$$P_t C_t + D_t \leq \tilde{W}_t L_t + R_{t-1}^d D_{t-1} + DIV_t - P_t X - P_t T_t.$$

The prices of consumption goods is P_t , the deposits in banks D_t earn a risk-free gross interest rate R_t^d , \tilde{W}_t is the nominal wage rate received by a worker, DIV_t is nominal dividends paid by producers and banks, X is the real transfer to new banks as their startup net worth, and T_t is the net lump-sum tax.

Households' first order conditions include:

$$1 = R_t^d \mathbb{E}_t [\Lambda_{t,t+1} \Pi_{t+1}^{-1}], \quad (3.1)$$

$$\frac{\tilde{W}_t}{P_t} = \psi_L L_t^{\phi_L} C_t, \quad (3.2)$$

where $\Lambda_{t,t+1} \equiv \beta \frac{C_t}{C_{t+1}}$ is the stochastic discount factor, and $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross CPI-inflation.

3.2 Bonds

Government (type- j intermediate firms) issues long term bonds to finance their economic activities, and the long term bonds are approximated by perpetuities with coupon payments decaying at rate κ^B (κ^j), following Woodford (2011). That is, one unit of government (type- j firms') bond is sold at price Q_t^B (Q_t^j) at time t , and yields a coupon payment of 1 dollar at $t + 1$, and $(\kappa^B)^s$ ($(\kappa^j)^s$) dollars at $t + s + 1$. The bond returns follows

$$R_t^B = \frac{1 + \kappa^B Q_t^B}{Q_{t-1}^B} \quad (3.3)$$

$$R_t^j = \frac{1 + \kappa^j Q_t^j}{Q_{t-1}^j} \quad (3.4)$$

3.3 Banks

3.3.1 Large banks

A representative large bank i holds bonds issued by large firms $F_{i,t}^{LF}$, bonds issued by small firms $F_{i,t}^{SF}$, government bonds $B_{i,t}$, required reserve $RE_{i,t}$, and inter-bank loans to small banks $D_{i,t}^{IB}$. It finances the asset holdings with deposits from the households $D_{i,t}$ and its own net worth $N_{i,t}^{LB}$. A large bank has the option to hold bonds issued by small firms $F_{i,t}^{SF}$, but with an average transaction cost Δ_t for each dollar amount of small firms' bond it holds. The transaction cost represent the cost large banks have to pay to finance small firms.² The average transaction cost is a linear function of the real value of small firms' bond

²For example, the branches of large banks are far away from and hence not familiar with local small firms, so they have to pay higher investigating and monitoring costs, and large banks usually have more hierarchical layers for approving a project that finances small firms. Additionally, when there is administrative requirement from the central government that each large bank has to lend a minimum amount of credit to small firms, large banks even lower their lending rate to small firms in order to meet the requirement. So another source of cost to large banks is the abnormally low lending rate on loans to small firms. In the context of our model, it is expressed as a premium or transaction cost on top of the price of small firms' bond paid by large banks. Part of the premium goes back to small firms as a rebate from large banks' purchases on small firms' bond, and

purchased by the large banks: $\Delta_t = \bar{\Delta} + \tilde{\Delta} Q_t^{SF} f_{i_{LB},t}^{SF}$ ³. The bank's balance sheet writes as

$$Q_t^{LF} F_{i,t}^{LF} + Q_t^B B_{i,t} + D_{i,t}^{IB} + RE_{i,t} + (1 + \Delta_t) Q_t^{SF} F_{i_{LB},t}^{SF} = D_{i,t} + N_{i,t}^{LB} \quad (3.5)$$

The survival rate of a large bank is σ^{LB} .

Net worth of surviving banks evolves according to

$$\begin{aligned} N_{i,t}^{LB} = & (R_t^{LF} - R_{t-1}^d) Q_{t-1}^{LF} F_{i,t-1}^{LF} + (R_t^B - R_{t-1}^d) Q_{t-1}^B B_{i,t-1} + (R_{t-1}^{re} - R_{t-1}^d) RE_{i,t-1} + \\ & (R_{t-1}^{IB} - R_{t-1}^d) D_{i,t-1}^{IB} + [R_t^{SF} - (1 + \Delta_t) R_{t-1}^d] Q_{t-1}^{SF} F_{i_{LB},t-1}^{SF} + R_{t-1}^d N_{i,t-1}^{LB} \end{aligned} \quad (3.6)$$

Rewrite the equation in real terms:

$$\begin{aligned} \Pi_t n_{i,t}^{LB} = & (R_t^{LF} - R_{t-1}^d) Q_{t-1}^{LF} f_{i,t-1}^{LF} + (R_t^B - R_{t-1}^d) Q_{t-1}^B b_{i,t-1} + (R_{t-1}^{re} - R_{t-1}^d) re_{i,t-1} + \\ & (R_{t-1}^{IB} - R_{t-1}^d) d_{i,t-1}^{IB} + [R_t^{SF} - (1 + \Delta_t) R_{t-1}^d] Q_{t-1}^{SF} f_{i_{LB},t-1}^{SF} + R_{t-1}^d n_{i,t-1}^{LB} \end{aligned} \quad (3.7)$$

where the lowercase letters are the real terms of corresponding uppercase ones.

A large bank's objective is

$$V_{i,t}^{LB} = \max(1 - \sigma^{LB}) \sum_{s=1}^{\infty} (\sigma^{LB})^{s-1} \Lambda_{t,t+s} n_{i,t+s}^{LB},$$

which can also be expressed recursively as

$$\max V_{i,t}^{LB} = (1 - \sigma^{LB}) \Lambda_{t,t+1} n_{i,t+1}^{LB} + \sigma^{LB} \Lambda_{t,t+1} V_{i,t+1}^{LB},$$

where $\Lambda_{t,t+s} = \Lambda_{t,t+1} \cdots \Lambda_{t+s-1,t+s}$. Generally speaking, an enforcement problem exists since banks can divert some funds at the end of a period and claim bankruptcy. So normally, we require the banks value could not be lower than the amount of assets they can divert. However, large banks are guaranteed by the government, so the enforcement constraint for large banks is simple: we only require $V_{i,t}^{LB} \geq 0$.

The large banks should also satisfy the reserve requirement:

$$re_{i,t} \geq \tau_t d_{i,t} \quad (3.8)$$

this coincides with the fact that the borrowing cost for small firms from large banks is less than that from small banks.

³ $f_{i,t}^{SF} = F_{i_{LB},t}^{SF} / P_t$ is real private bond holdings of large banks. The linear functional form of average transaction cost implies that the large banks' total cost of purchasing small firms' bond is convex.

where τ_t is the required reserve ratio.

The first-order conditions with respect to $f_{i,t}^{LF}$, $b_{i,t}$, $d_{i,t}^{IB}$, $f_{i,t}^{SF}$, and $d_{i,t}$ are:

$$(R_{t+1}^{LF} - R_t^d) \Lambda_{t,t+1} \Omega_{t+1}^{LB} \Pi_{t+1}^{-1} = \omega_{i,t} \tau_t \quad (3.9)$$

$$(R_{t+1}^B - R_t^d) \Lambda_{t,t+1} \Omega_{t+1}^{LB} \Pi_{t+1}^{-1} = \omega_{i,t} \tau_t \quad (3.10)$$

$$(R_t^{IB} - R_t^d) \Lambda_{t,t+1} \Omega_{t+1}^{LB} \Pi_{t+1}^{-1} = \omega_{i,t} \tau_t \quad (3.11)$$

$$\left[R_{t+1}^{SF} - (1 + \bar{\Delta} + 2\tilde{\Delta} Q_t^{SF} f_{i_{LB},t}^{SF}) R_t^d \right] \Lambda_{t,t+1} \Omega_{t+1}^{LB} \Pi_{t+1}^{-1} = \omega_{i,t} \tau_t \quad (3.12)$$

$$(R_t^{re} - R_t^d) \Lambda_{t,t+1} \Omega_{t+1}^{LB} \Pi_{t+1}^{-1} = -\omega_{i,t} (1 - \tau_t) \quad (3.13)$$

where $\Omega_t^{LB} = 1 - \sigma^{LB}$ Define

$$\phi_{i,t}^{LB} = \frac{Q_t^{LF} f_{i,t}^{LF} + (1 + \Delta_t) Q_t^{SF} f_{i_{LB},t}^{SF} + Q_t^B b_{i,t}}{n_{i,t}^{LB}} \quad (3.14)$$

as an endogenous leverage ratio.

3.3.2 Small banks – enforcement constraint and time-varying survival rate

The main setup of small banks is similar to that of large banks, except that small banks face a enforcement constraint and a survival rate varying with inter-bank interest rate.

A representative small bank i holds bonds issues by small firms only, and it finances the asset holdings via borrowing from large banks in the inter-bank market and its own net worth. Its balance sheet follows

$$Q_t^{SF} F_{i_{SB},t}^{SF} = D_{i,t}^{IB} + N_{i,t}^{SB} \quad (3.15)$$

The survival rate of a small bank is σ_t^{SB} . When inter-bank interest rate increases, the bankruptcy risk of small banks is larger, that is, σ_t^{SB} decreases with inter-bank interest rate:

$$\log \sigma_t^{SB} = (1 - \rho_\sigma^{SB}) \log \sigma^{SB} + \rho_\sigma^{SB} \log \sigma_{t-1}^{SB} - (1 - \rho_\sigma^{SB}) \iota_R (\log R_t^{IB} - \log R^{IB}) + \epsilon_{\sigma,t}^{SB} \quad (3.16)$$

where σ^{SB} is the steady state value of σ_t^{SB} , ρ_σ^{SB} is the persistence of the shock process, and $\epsilon_{\sigma,t}^{SB} \sim IID \mathcal{N}(0, \sigma_\sigma^{SB})$ is a white noise. ι_R is the response coefficient to interest rate change, and the value of the coefficient is time-varying: $\iota_R > 0$ if $\log R_t^{IB} > \log R^{IB}$ and $\iota_R = 0$ otherwise, which means higher inter-bank interest rate raises the bankruptcy probability of small banks.⁴

⁴See [Appendix C](#) for the details on how to determine the size of ι when $\log R_t^{IB} > \log R^{IB}$.

Net worth in nominal of surviving banks evolves according to

$$N_{i,t}^{SB} = (R^{SF} - R_{t-1}^{IB})Q_{t-1}^{SF}F_{i_{SB},t}^{SF} + R_{t-1}^{IB}N_{i,t-1}^{SB}, \quad (3.17)$$

and in real term it writes as

$$\Pi_t n_{i,t}^{SB} = (R^{SF} - R_{t-1}^{IB})Q_{t-1}^{SF}f_{i_{SB},t}^{SF} + R_{t-1}^{IB}n_{i,t-1}^{SB}, \quad (3.18)$$

A small bank's objective is

$$\max V_{i,t}^{SB} = (1 - \sigma_t^{SB})\Lambda_{t,t+1}n_{i,t+1}^{SB} + \sigma_t^{SB}\Lambda_{t,t+1}V_{i,t+1}^{SB}$$

An enforcement problem exists since banks can divert some funds at the end of a period and claim bankruptcy. For the large banks to be willing to lend to small banks, the following constraint has to be satisfied

$$V_{i,t}^{SB} \geq \theta^{SB}Q_t^{SF}f_{i_{SB},t}^{SF} \quad (3.19)$$

θ^{SB} is the fraction of private bonds the bank can divert.

Guess $V_{i,t}^{SB} = a_t^{SB}n_{i,t}^{SB}$, where the coefficient does not depend on i , and define $\Omega_t^{SB} = 1 - \sigma_t^{SB} + \sigma_t^{SB}a_t^{SB}$.

The first-order conditions can be rewritten as

$$(R_{t+1}^{SF} - R_t^{IB})\Lambda_{t,t+1}\Omega_{t+1}^{SB}\Pi_{t+1}^{-1} = \frac{\lambda_{i,t}^{SB}}{1 + \lambda_{i,t}^{SB}}\theta^{SB} \quad (3.20)$$

When the enforcement constraint binds, we have

$$a_t^{SB}n_{i,t}^{SB} = \theta^{SB}Q_t^{SF}f_{i_{SB},t}^{SF} \quad (3.21)$$

Define the small bank i 's leverage ratio as⁵

$$\phi_{i,t}^{SB} = \frac{Q_t^{SF}f_{i,t}^{SF}}{n_{i,t}^{SB}} \quad (3.22)$$

3.4 Wholesale firms

We assume there are a continuum of intermediate firms, among which ξ fraction are large firms, and the rest are small ones. The firms are completely competitive and produce identical goods within each type.

⁵This definition is exactly the same as the tradition one: $lev_i^{SB} = 1 + d_t^{IB}/n_i^{SB}$ given the balance sheet of a small bank.

Each firm of type j has a constant probability γ^j of surviving to the next period⁶. They combine purchased capital and hired labor to produce wholesale output following the production function

$$Y_{Mt}^j(h) = A_t^j \left(u_t K_{t-1}^j(h) \right)^\alpha \left(L_{d,t}^j(h) \right)^{1-\alpha} - \Phi^j, \quad (3.23)$$

where α is the capital share in output, $Y_{Mt}^j(h)$, $u_t^j(h)$, $K_t^j(h)$, $L_{d,t}^j(h)$, and Φ^j are the output, capital utilization rate, capital input, labor input, and fixed cost of wholesale firm h of type j , respectively. A^j is the common productivity of wholesale firm of type j , and according to conventional wisdom, large firms generally have lower mean productivity, that is, $A^{LF} < A^{SF}$.

The wholesale firms purchase productive capital goods \hat{I}_t^j from capital producers, and accumulate physical capital following the standard law of motion:

$$K_t^j = \hat{I}_t^j + (1 - \delta(u_t^j))K_{t-1}^j \quad (3.24)$$

and $\delta(u_t^j)$ is the depreciation rate of capital, and it depends on the capital utilization rate: $\delta(u_t^j) = \delta_0^j + \delta_1^j(u_t^j - 1) + \frac{\delta_2}{2}(u_t^j - 1)^2$. The purchases of new capital good and labor force are financed via issuing perpetual bonds:

$$\psi^{LF} P_t^k \hat{I}_t^{LF} + \psi_w^{LF} W_t L_t^{LF} \leq Q_t^{LF} (F_t^{LF} - \kappa^{LF} F_{t-1}^{LF}) \quad (3.25)$$

$$\psi^{SF} P_t^k \hat{I}_t^j + \psi_w^v W_t L_t^{SF} \leq Q_t^{SF} (F_t^j - \kappa^{SF} F_{t-1}^{SF}) + \varsigma Q_t^{SF} F_{LB,t}^{SF} \quad (3.26)$$

where ψ^j is the ratio between the increase in firms' liability and the new purchases of capital, and $F_t^j - \kappa^j F_{t-1}^j$ is the new issuance of bonds. This can be interpreted as a "loan-in-advance constraint". Small firms' constraint contains one additional term $\varsigma Q_t^{SF} F_{LB,t}^{SF}$, indicating that they can get some rebate through selling bond to large banks, or equivalently, their financing cost from large banks is less than that from small banks. The reason is as describe in the setup of large bank sector that in order to meet the requirement on lending amount to small firms from the government, large banks even lower their lending rate to small firms.

Firms maximize their present value of dividends (the indicator of individual firm h is omitted for simplicity):

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ P_{M,t+s}^{LF} Y_{M,t+s}^{LF} - W_t L_{d,t+s}^{LF} - P_{t+s}^k \hat{I}_{t+s}^{LF} - F_{t+s-1}^{LF} + Q_{t+s} (F_{t+s}^{LF} - \kappa^{LF} F_{t+s-1}^{LF}) \right\}$$

⁶This assumption captures the phenomenon of ongoing births and deaths of firms, and prevents the firms to accumulate enough wealth to be fully self-financing.

subject to (3.23) - (3.25), and

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ P_{M,t+s}^{SF} Y_{M,t+s}^{SF} - W_t L_{d,t+s}^{SF} - P_{t+s}^k \hat{I}_{t+s}^{SF} - F_{t+s-1}^{SF} + Q_{t+s} (F_{t+s}^{SF} - \kappa^{SF} F_{t+s-1}^{SF}) + \varsigma Q_t^{SF} F_{LB,t}^{SF} \right\}$$

subject to (3.23), (3.24), and (3.26).

The first order conditions with respect to $L_{d,t}^j$, u_t^j , K_t^j , and $F_{M,t}^j$ are:

$$M_{2,t}^j W_t = (1 - \alpha) P_{M,t} A_t^j (u_t^j K_{t-1}^j)^\alpha (L_{d,t}^j)^{-\alpha} \quad (3.27)$$

$$p_t^k M_{1,t}^j \delta'(u_t^j) = \alpha p_{M,t} A_t^j (u_t^j K_{t-1}^j)^{\alpha-1} (L_{d,t}^j)^{1-\alpha} \quad (3.28)$$

$$p_t^k M_{1,t}^j = \mathbb{E} \Lambda_{t,t+1} \left[\alpha p_{M,t+1} A_{t+1}^j (u_{t+1}^j K_t^j)^{\alpha-1} u_{t+1}^j (L_{d,t+1}^j)^{1-\alpha} + (1 - \delta(u_{t+1}^j)) p_{t+1}^k M_{1,t+1}^j \right] \quad (3.29)$$

$$Q_t^j M_{2,t}^j = \mathbb{E} \Lambda_{t,t+1} \Pi_{t+1}^{-1} [1 + \kappa^j Q_{t+1}^j M_{2,t+1}^j] \quad (3.30)$$

where $M_{1,t}^j$ and $M_{2,t}^j$ are modified multipliers of (3.24) and (3.25) or (3.26), and

$$\psi^j = \frac{M_{1,t}^j - 1}{M_{2,t}^j - 1}. \quad (3.31)$$

3.5 Capital producer

A representative capital producer transfers raw investment I_t into productive capital goods \hat{I}_t according to:

$$\hat{I}_t = \left[1 - S \left(\frac{I_t}{I_{t-1}} \right) \right] I_t \quad (3.32)$$

where $S(\cdot)$ is the investment adjustment cost.

The capital producer maximizes the present value of discounted dividends:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ p_{t+s}^k \left[1 - S \left(\frac{I_{t+s}}{I_{t+s-1}} \right) \right] I_{t+s} - I_{t+s} \right\}$$

with the first-order condition:

$$1 = p_t^k \left[1 - S \left(\frac{I_t}{I_{t-1}} \right) - S' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] + \mathbb{E}_t \Lambda_{t,t+1} p_{t+1}^k S' \left(\frac{I_t}{I_{t-1}} \right) \left(\frac{I_t}{I_{t-1}} \right)^2 \quad (3.33)$$

3.6 Labor market

Labor contractors hire workers of different labor types, $L_{d,t}(h)$, through labor unions and produce homogenous labor service $L_{d,t}$ according to the production function

$$L_{d,t} = \left[\int_0^1 L_{d,t}(h)^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dj \right]^{\frac{\varepsilon_w}{\varepsilon_w - 1}}, \quad \varepsilon_w > 1,$$

where ε_w measures the elasticity of substitution among different labor types. The intermediate goods producers employ the homogenous labor service for the production. Labor contractors are perfectly competitive, and their profit maximization leads to the demand function for labor type h as

$$L_{d,t}(h) = L_{d,t} \left(\frac{W_t(h)}{W_t} \right)^{-\varepsilon_w}$$

where $W_t(h)$ is the wage paid for type- h labor.

Labor unions face Calvo (1983)-type wage rigidities. In each period, with probability $0 < \phi_w < 1$, labor union h cannot reoptimize the wage rate of labor type h and has to index the wage rate to lagged inflation at $0 < \gamma_w < 1$:

$$W_t(h) = W_{t-1}(h) \left(\frac{P_t}{P_{t-1}} \right)^{\gamma_w}.$$

With probability $1 - \phi_w$, labor union h chooses $W_t^*(h)$ to maximize its profits and all labor unions that reoptimize wages in period t set the same wage as $W_t^*(h) = W_t^*$:

$$\begin{aligned} \max_{W_t^*(h)} \quad & \mathbb{E}_t \sum_{s=0}^{\infty} \phi_w^s \Lambda_{t,t+s} \left[\left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{(1-\varepsilon_w)\gamma_w} W_t(h)^{1-\varepsilon_w} P_{t+s}^{\varepsilon_w - 1} \left(\frac{W_{t+s}}{P_{t+s}} \right)^{\varepsilon_w} L_{d,t+s} - \right. \\ & \left. \frac{\tilde{W}_{t+s}}{P_{t+s}} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{-\varepsilon_w \gamma_w} W_t(h)^{-\varepsilon_w} P_{t+s}^{\varepsilon_w} \left(\frac{W_{t+s}}{P_{t+s}} \right)^{\varepsilon_w} L_{d,t+s} \right]. \end{aligned}$$

The aggregate wage level evolves as

$$W_t^{1-\varepsilon_w} = (1 - \phi_w) (W_t^*)^{1-\varepsilon_w} + \phi_w \Pi^{\gamma_w * (1-\varepsilon_w)} W_{t-1}^{1-\varepsilon_w}. \quad (3.34)$$

3.7 Wholesale sector

Wholesale goods are composed of intermediate goods from both large and small firms, and the quantity of the wholesale goods is given by

$$Y_{M,t} = \left[\xi (Y_{M,t}^{LF})^{\frac{\zeta-1}{\zeta}} + (1 - \xi) (Y_{M,t}^{SF})^{\frac{\zeta-1}{\zeta}} \right]^{\frac{\zeta}{\zeta-1}}, \quad (3.35)$$

where $\zeta > 0$ is the elasticity of substitution between the goods produced in the two types of intermediate firms.

The demand curves for large and small firms' products are

$$Y_{M,t}^{LF} = \xi^\zeta \left(\frac{p_{M,t}^{LF}}{p_{M,t}} \right)^{-\zeta} Y_{M,t} \quad (3.36)$$

$$Y_{M,t}^{SF} = (1 - \xi)^\zeta \left(\frac{p_{M,t}^{SF}}{p_{M,t}} \right)^{-\zeta} Y_{M,t}. \quad (3.37)$$

3.8 Retailers

There is a continuum of retail firms of mass 1, indexed by z . These retail firms are monopolistically competitive and repack wholesale goods $Y_{M,t}$ into differentiated retail goods $Y_t(z)$. The final consumption and investment good is a CES aggregate of the repacked goods:

$$Y_t = \left[\int_0^1 Y_{M,t}(a)^{\frac{\varepsilon_p - 1}{\varepsilon_p}} da \right]^{\frac{\varepsilon_p}{\varepsilon_p - 1}}. \quad (3.38)$$

ε_p is the elasticity of substitution among differentiated goods. The price index is

$$P_t = \left[\int_0^1 P_{M,t}(z)^{1 - \varepsilon_p} dz \right]^{\frac{1}{1 - \varepsilon_p}}. \quad (3.39)$$

The retailers face Calvo (1983)-type price rigidities. The sale price can be changed in every period with probability $1 - \phi_p$, and the rest prices are index to past inflation at $0 < \gamma_p < 1$. The re-optimized price is $P_t^*(z)$, and the corresponding demand curve is $Y_{t+s}(z) = \left[\frac{P_t^*(z)}{P_{t+s}} \right]^{-\varepsilon} Y_{t+s}(z)$.

The optimal price $P_t^{j*}(z)$ solves

$$\max_{P_t^*(z)} \mathbb{E}_t \sum_{s=0}^{\infty} \phi_p^s \Lambda_{t,t+s} \left[P_t(z) \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{(1 - \varepsilon_p)\gamma_p} P_{t+s}^{\varepsilon_p - 1} Y_{t+s} - P_{M,t+s} P_t(h)^{-\varepsilon_p} \left(\frac{P_{t+s-1}}{P_{t-1}} \right)^{-\varepsilon_p \gamma_p} P_{t+s}^{\varepsilon_p - 1} Y_{t+s} \right].$$

As a fraction θ of prices stays unchanged, the aggregate price level evolves according to

$$P_t = \left[\phi_p \left(P_{t-1}^j \right)^{1 - \varepsilon_p} + (1 - \phi_p) \left(P_t^* \right)^{1 - \varepsilon_p} \right]^{\frac{1}{1 - \varepsilon_p}}. \quad (3.40)$$

3.9 Monetary authority

The policy rate R_t follows a simple Taylor (1993)-type interest rate rule:

$$\log\left(\frac{R_t}{R}\right) = \phi_r \log\left(\frac{R_{t-1}}{R}\right) + (1 - \phi_r) \left[\phi_\pi \log\left(\frac{\Pi_t}{\Pi}\right) + \phi_y \log\left(\frac{Y_t}{Y}\right) \right] + \epsilon_{r,t}, \quad (3.41)$$

where ϕ_r is a smoothing parameter, ϕ_π and ϕ_y are the sensitivity of interest rate to inflation and output fluctuations, respectively, R , Π , and Y are the steady state of R_t , Π_t , and Y_t , respectively, and $\epsilon_{r,t}$ is a shock to monetary policy following $IID \mathcal{N}(0, \sigma_{\chi^r})$.

We assume that both the deposit rate R_t^d is equal to the policy rate:

$$R_t^d = R_t, \quad (3.42)$$

and interest for reserves R_t^e is

$$R_t^e = \varkappa R_t, \quad (3.43)$$

with $\varkappa < 1$.

The required reserve ratio τ_t also follows a Taylor-type rule:

$$\log\left(\frac{\tau_t}{\tau}\right) = \phi_\tau \log\left(\frac{\tau_{t-1}}{\tau}\right) + (1 - \phi_\tau) \left[\phi_\pi^\tau \log\left(\frac{\Pi_t}{\Pi}\right) + \phi_y^\tau \log\left(\frac{Y_t}{Y}\right) \right] + \epsilon_{\tau,t}, \quad (3.44)$$

with τ being the steady state required reserve ratio, ρ_τ being the persistence of the process, ϕ_π^τ and ϕ_y^τ are the sensitivity of τ_t to changes in output and inflation, and $\epsilon_{\tau,t} \sim IID \mathcal{N}(0, \sigma_\tau)$ being a white noise.

3.10 Equilibrium

Labor market, capital market and credit market equilibrium require

$$L_t = (1 - \xi)L_t^{LF} + \xi L_t^{SF}, \quad K_t = (1 - \xi)K_t^{LF} + \xi K_t^{SF}, \quad F_{LB,t}^{SF} + F_{SB,t}^{SF} = F_t^{SF}. \quad (3.45)$$

The resource constraint follows

$$Y_t = C_t + I_t + G_t, \quad (3.46)$$

where G_t is government spending, which is assumed to be a constant.

4 Results

4.1 Model parameterization

Parameters are calibrated to match the data, and listed in [Table A.1](#). Capital share in production, α , is $1/3$, and the depreciation rate is 0.025. The inverse of the Frisch elasticity of labor supply is 1. The discount factor β is 0.99, implying a 4% annual nominal risk free interest rate. The steady state government spending is 18% of aggregate output. The curvature of investment adjustment cost function is 10.78. The persistence of monetary policy rule is 0.9, and the coefficients indicating the sensitivity of monetary policy to inflation and output are 1.5 and 0.25, respectively. The elasticity of substitution among differentiated final goods is 11, implying that the steady state price markup is 10%. The Calvo parameter for price stickiness is 0.75, meaning one particular firm can reset its price with probability 0.75 in each period.

Large firms' steady state common technology is normalized to 1, and small firms' common technology is 1.42. The elasticity of substitution among intermediate goods produced by large and small firms, ζ , is 3, and the share of large firms products in composing identical intermediate goods, ξ , is 0.43, so that the nominal share of large firms' products in intermediate goods sector is 30%. The steady state labor demand of large firm sector is 0.3.

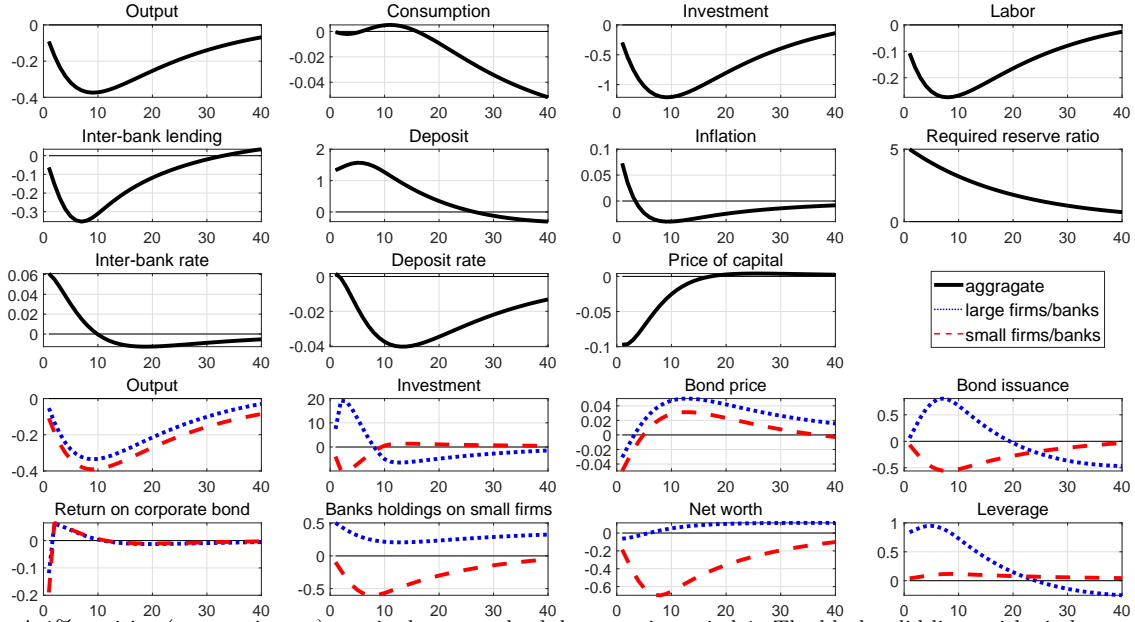
The survival rates for large and small banks are 0.9800 and 0.9310, respectively. The steady state leverage ratios for large and small banks are 1.5 and 2.5, respectively.

The excess return on small firms' bond is 4 times of that on large firms'. The resulting steady state annual returns on large and small firms' bond are 5% and 7.84%, respectively. The rebate parameter ς is set to 0.005, so that the small firms' financing cost from large banks is only 5.8%, which is more than 2% lower than that borrowing from small banks.

4.2 Impulse responses

[Figure 3](#) and [Figure 4](#) plot the impulse responses of key variables in the economy under 1% contractionary and expansionary required reserve ratio shocks, and [Figure 5](#) and [Figure 6](#) plot responses under 1% contractionary and expansionary interest rate shocks. The black lines with circles, blue solid lines, and red dashed lines represent aggregate variables, variables related to large firms and banks, and variables corresponding to small firms and banks, respectively. The X-axis plots time in quarters, and the Y-axis indicates the percentage changes (annualized for inflation and inter-bank interest rate) from the steady state.

Figure 3: Impulse responses to a contractionary required reserve ratio shock

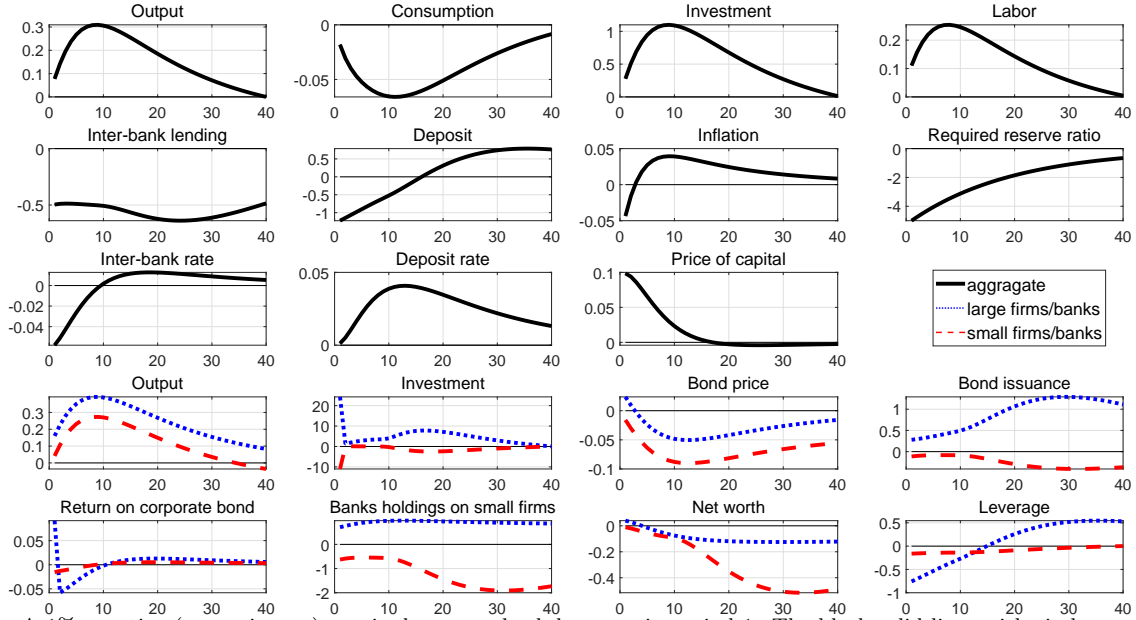


Notes: A 1% positive (contractionary) required reserve shock happens in period 1. The black solid lines with circles represent the responses of the aggregate variables, the blue solid lines represent responses of large firms or large banks, and the red dashed lines represent the responses of small firms or small banks. X-axis: time in quarters; Y-axis: annualized level changes for inflation, inter-bank rate, and deposit rate, level change for required reserve ratio, and percentage changes relative to the steady-state values for the rest.

4.2.1 Required reserve ratio shocks

Figure 3 plots the impulse responses to a contractionary required reserve ratio shock. Under such a shock, the aggregate economy is depressed, that is, aggregate output, consumption, investment, and employment all decline compared to the pre-shock or steady state values. Since with the same deposit level, large banks have to put more reserves in their central bank accounts, their credit supply in the inter-bank market is depressed. As a result, it is harder for the small banks to get funding, so that the inter-bank interest rate is higher. Since we assume that the small banks default risk increases with the rise of inter-bank rate, the net worth of small banks, which depends on small banks' survival rate, declines. Under this circumstance, small banks can provide less credit to small firms, so that the demand for corporate bond issued by small firms declines, and in turn the small firms' bond issuance and bond price drop. Without sufficient funding for purchasing productive investment goods, small firms' investment is also lower. Contrarily, large banks save relatively more money to finance large firms through cutting the inter-bank lending. As a result, large firms' bond issuance and price rise, and investment increases. Although the large firms collect more capital through investing more, the decline in employment and the depress of the aggregate economy still cause the large firms' output to decline inevitably. Unlike the strikingly large investment gap between small and large firms, the decrease in small firms' output is only slightly larger than that of the large firms'. This is

Figure 4: Impulse responses to an expansionary required reserve ratio shock

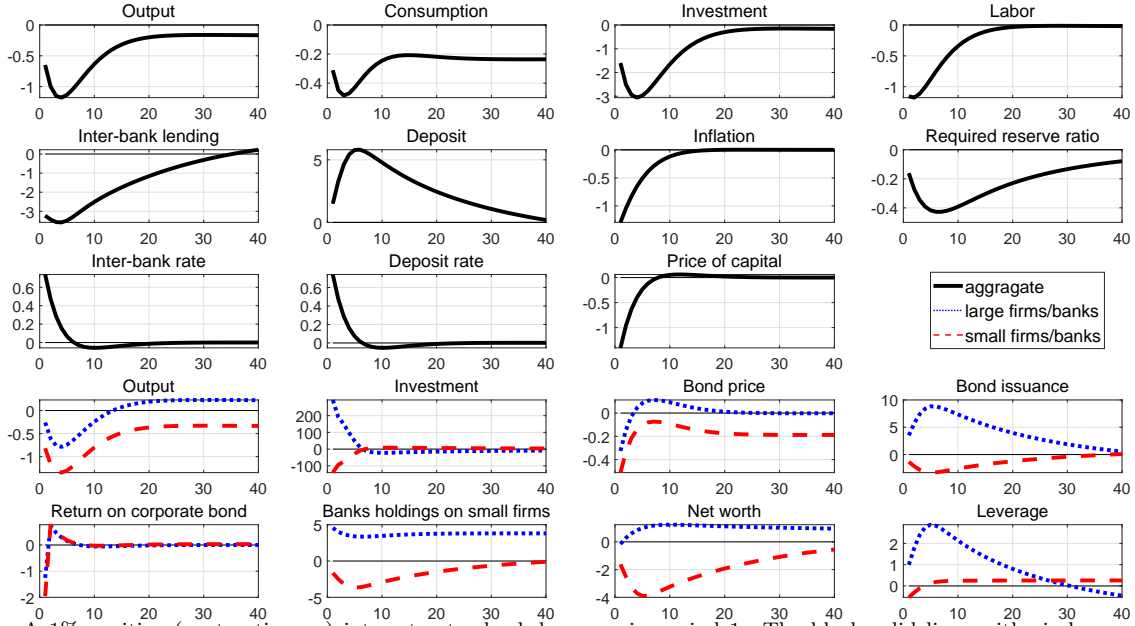


Notes: A 1% negative (expansionary) required reserve shock happens in period 1. The black solid lines with circles represent the responses of the aggregate variables, the blue solid lines represent responses of large firms or large banks, and the red dashed lines represent the responses of small firms or small banks. X-axis: time in quarters; Y-axis: annualized level changes for inflation, inter-bank rate, and deposit rate, level change for required reserve ratio, and percentage changes relative to the steady-state values for the rest.

because capital stock change relatively smaller and more slowly than investment does, and changes in capital utilization further compensates small firms' production.

Figure 4 plots the impulse responses to a expansionary required reserve ratio shock. Under a negative(expansionary) required reserve ratio shock, large banks have more credit to purchase large firms' and government bonds, and lend to small banks at the same deposit level. As a result, the rise in large banks' credit supply boosts large firms' bond price, and reduces the financing cost in the inter-bank market. Due to the boom in large firms' bond price, large banks' asset value appreciates, and their net worth increases and leverage ratio decreases accordingly. With the expansionary policy shock, large firms issue more bond to finance their investment on capital goods, and that helps to support their expansion in production. And the increases in large firms' bond issuance and bond price crowd out the large banks' credit supply in the inter-bank market, which lead to the drop in inter-bank lending. Since the small banks cannot get enough funding in the inter-bank market, small firms' expansions in bond issuance, investment, and production are limited. In fact, small firms' bond issuance, bond price and investment even decline under an expansionary required reserve ratio shock. With lower investment level, the increase in small firms' production mainly comes from the increase in labor and capital utilization.

Figure 5: Impulse responses to a contractionary interest rate shock



Notes: A 1% positive (contractionary) interest rate shock happens in period 1. The black solid lines with circles represent the responses of the aggregate variables, the blue solid lines represent responses of large firms or large banks, and the red dashed lines represent the responses of small firms or small banks. X-axis: time in quarters; Y-axis: annualized level changes for inflation, inter-bank rate, and deposit rate, level change for required reserve ratio, and percentage changes relative to the steady-state values for the rest.

4.2.2 Interest rate shocks

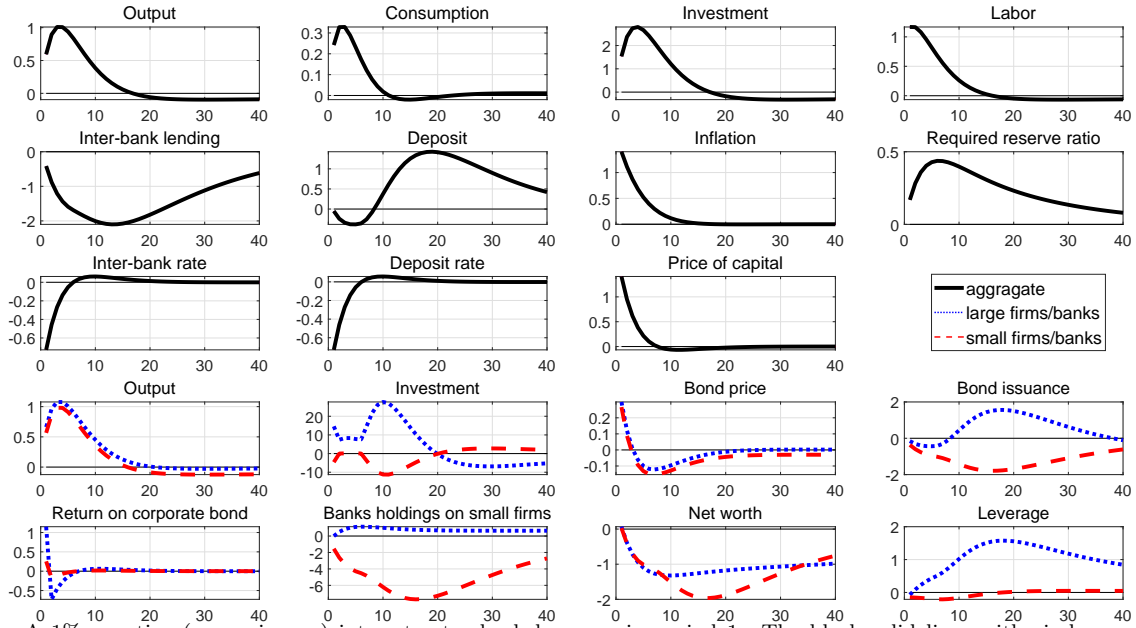
Figure 5 plots the impulse responses to a contractionary interest rate shock. Such a shock depresses the aggregate economy as expected: aggregate output, consumption, investment, and labor demand decrease. The tightening of monetary policy limits the large banks' ability to supply credit in the inter-bank market, so the inter-bank lending declines. The lack of credit on the inter-bank market naturally leads to decline in small firms' bond issuance, bond price, and investment.

Figure 6 plots the impulse responses to an expansionary interest rate shock. Under such a shock, aggregate economy booms, however, the inter-bank market shrinks because it is more profitable for large banks to purchase large firms' bond than to lend to small banks. As a result, we can observe rise in large firms' investment and decline in small firms' as under an expansionary required reserve ratio shock.

5 Conclusion

We employ a New Keynesian DSGE model with heterogeneous banks and firms to account for (1) the heterogeneous responses of large and small firms under the same monetary policy shock, and (2) the asymmetric impacts of contractionary and expansionary monetary policy shock on firms' responses in China. The key

Figure 6: Impulse responses to an expansionary interest rate shock



Notes: A 1% negative (expansionary) interest rate shock happens in period 1. The black solid lines with circles represent the responses of the aggregate variables, the blue solid lines represent responses of large firms or large banks, and the red dashed lines represent the responses of small firms or small banks. X-axis: time in quarters; Y-axis: annualized level changes for inflation, inter-bank rate, and deposit rate, level change for required reserve ratio, and percentage changes relative to the steady-state values for the rest.

mechanism we find is the two-tiered banking system in China and large and small firms have differential access to credits through this banking system.

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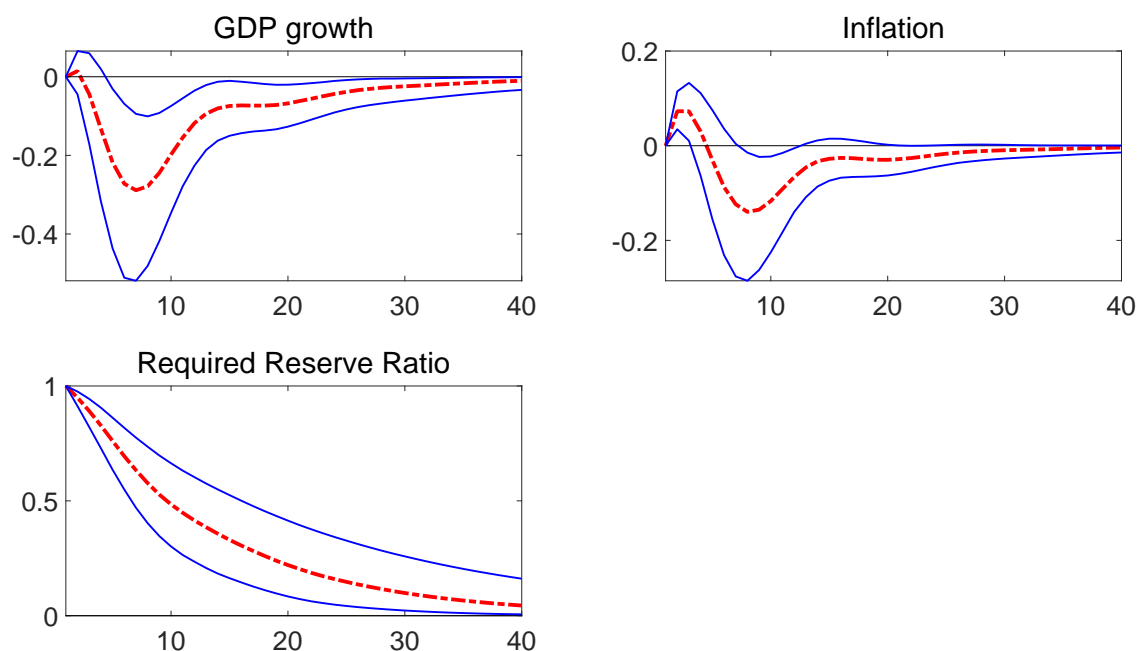
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Appendix A Tables

Table A.1: Calibration

Parameter	Value or target	Description
α	0.5	capital share
β	0.99	discount rate
b_h	0.7	habit formation
Π	1	steady state gross inflation
ϕ_L	1	inverse of Frisch elasticity of labor supply
ψ_L	1.1436	Labor disutility scaling parameter
δ_0^{LF}	0.035	steady state depreciation rate for large firms
δ_1^{LF}	0.0451	steady state utilization linear term for large firms
δ_2^{LF}	0.001	utilization squared term for large firms
δ_0^{SF}	0.0616	steady state depreciation rate for small firms
δ_1^{SF}	0.0717	steady state utilization linear term for small firms
δ_2^{SF}	0.001	utilization squared term for small firms
κ_I	2	investment adjustment cost parameter
ε_p	11	elasticity of substitution among retail goods
ε_w	11	elasticity of substitution among labor
ξ	0.43	steady state share of large firms' products
ζ	3	elasticity of substitution between large and small firms' products
ϕ_p	0.75	price rigidity parameter
ϕ_w	0.75	wage rigidity parameter
γ_p	0	price indexation
γ_w	0	wage indexation
κ	0.975	decay rate of government and corporate bonds coupon payment
ψ^{LF}	0.81	fraction of large firms' investment from debt
sp^{LF}	0.95%	steady state annual excess return on large firms' bond
sp^{SF}	3.81%	steady state annual excess return on small firms' bond
A^{LF}	1	large firms' steady state productivity
A^{SF}	1.42	small firms' steady state productivity
σ^{LB}	0.98	large banks' survival probability
σ^{SB}	0.931	small banks' survival probability
G	$\frac{G}{Y} = 0.2$	steady state government spending
τ	20%	steady state required reserve ratio
ρ_r	0.9	persistence of policy rate
ϕ_π	1.5	sensitivity of policy rate to inflation
ϕ_y	0.25	sensitivity of policy rate to output
\varkappa	0.995	ratio between interest on reserves and deposits
ι_R	14	sensitivity of small banks' recoverability to inter-bank interest rate
ρ_σ^{SB}	0.75	persistence of small bank's survival rate
ρ_τ	0.95	persistence of required reserve ratio
σ_τ	0.0025	standard deviation of monetary policy shock
σ_τ	0.0025	standard deviation of required reserve ratio shock
σ_σ^{SB}	0.0025	standard deviation of small bank's survival rate shock

Figure B.1: **Impulse responses to a contractionary required reserve ratio shock — no investment**

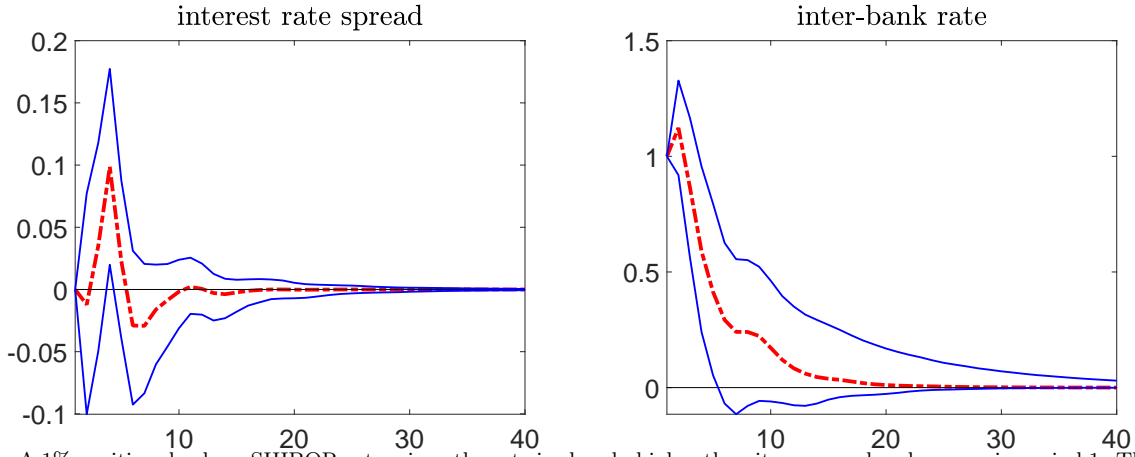


Notes: A 1% positive (contractionary) required reserve shock happens in period 1. The red dashed lines are medians, and the blue solid lines are 68% confidence intervals. X-axis: time in quarters; Y-axis: annualized percentage change.

Appendix B VAR analysis without investment

We use quarterly data on GDP growth, GDP deflator, and required reserve ratio from 1993Q1 to 2019Q4 to do the VAR analysis, and the impulse responses are in [Figure B.1](#), which shows reasonable impacts of required reserve ratio shocks on output and inflation: under a positive(contractionary) monetary policy shock, both output growth and inflation are depressed.

Figure C.2: Impulse responses to a positive shock on inter-bank interest rate



Notes: A 1% positive shock on SHIBOR rate, given the rate is already higher than its mean value, happens in period 1. The red dashed lines are medians, and the blue solid ones are 68% confidence interval. X-axis: time in months; Y-axis: level changes.

Appendix C Estimating small banks' sensitivity to interest rate rising

We use monthly average the interest rate spread between 3-month inter-bank certificates of deposit (rp_t) issued by joint-stock banks and by state-owned banks to proxy the risk premium of small banks over large banks in our model. 7-day pledged repo rate among deposit institutes (DR007) measures the inter-bank interest rate. The data is available from 2014M5 to 2020M8.

We include rp_t and $DR007_t$ as endogenous variables in a structural VAR model to investigate how the risk premium between small and large banks reacts when the inter-bank interest rate rises above the steady state value.

Figure C.2 plots the impulse responses under a positive shock on inter-bank interest rate. The risk premium increases by 0.1 percentage point, which means the risk premium is doubled from its average (0.957%). In turn, the bankruptcy rate of small banks, $1 - \sigma^{SB}_t$, doubles, which means the survival rate decreases from 0.9310 to 0.8620 (a over 7% decrease). So that we set $\iota = 14$ when $\log R_t^{IB} > \log R^{IB}$, and the persistence parameter of the σ_t^{SB} process to 0.5, which implies that once the inter-bank interest rate is higher than its steady-state by 1%, σ_t^{SB} will decrease by 5%.