BANK WHOLESALE FUNDING, MONETARY TRANSMISSION AND SYSTEMIC RISK: EVIDENCE FROM CHINA

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Abstract. We study how interbank wholesale funding in China influences monetary policy transmission under a dual-track interest-rate system and how it contributes to increasing systemic risks in recent years. By constructing a bank-panel dataset, we find that wholesale funding via interbank certificates of deposit not only facilitates policy interest rates to transmit into loan by non-state banks, but also leads to fast growth in their shadow banking activities as an unintended consequence. Accordingly, non-state banks with a heavier exposure to wholesale funding witness a larger increase in systemic risks in response to negative shocks to the economy since 2018. We advance a theoretical explanation of our empirical findings and quantify the trade-off of banking regulation on wholesale funding between the effectiveness of monetary policy transmission and exposure to systemic risks within this framework.

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I. Introduction

The transmission of monetary policy operates through the banking system. In emerging economies, however, interest rate control in deposit and/or lending markets as a financial depression policy are commonly adopted. As a result, it has been long difficult for policy interest rates to effectively transmit into bank credit supply via liquidity in the retail deposit market. Against this backdrop, interbank wholesale funding markets have become in recent years an important facilitator for monetary policy transmission in countries like China. At end-June 2016, wholesale funds accounted for 34 percent of mid- and small-sized Chinese banks' total source of funds, up from 29 percent at end-January 2015. This increasing use of wholesale funds, by raising the interconnectedness of banking system, has exposed China's banking system to increasing systemic risk due to unexpected negative shocks (e.g. trade war or Covid-19 crisis). For macroprudential regulation, therefore, it is first-order of importance to understand how the wholesale funding liquidity affects monetary policy interest-rate transmission in China and how exposure to wholesale funding contributes to systemic risks in China's banking sector.

In this paper, we construct micro data sets at the bank level to establish empirical evidence that in China, banks' exposure to wholesale funding facilitates the transmission of monetary policy into non-state banks' credit expansion, but at the same time, encourages them to invest aggressively into risky shadow assets. Our evidence suggests that non-state banks with higher exposure to wholesale funding face larger expected capital shortfall (systemic risks) since 2018, a period of accelerated GDP growth slowdown. We advance a theory to explain how, with deposit interest rate controls, wholesale funds markets facilitate the monetary transmission to the real economy, and how exposure to wholesale funding make banks more vulnerable to systemic risks as China's growth recedes. Both our empirical evidence and theoretical models highlight the trade-off regulation on bank wholesale funding faces between the effectiveness of monetary policy transmission and banking sector systemic risks.

Specifically, we make three distinctive contributions. First, we provide institutional details on China's interest-rate based monetary policy, the interbank wholesale funding markets, and their role in monetary policy transmission and systemic risks. One unique feature of China's interest-rate based monetary policy is its dual-track system, with fully liberalized interbank interest rates and a *de facto* ceiling on deposit rates. Such a dual-track system exacerbates the difference in the ability for state and non-state banks to draw deposits as sources of fund. State banks have natural advantage in drawing deposit than non-state banks, as the branches of the former are more widespread than the latter. The existence of explicit or implicit deposit rate ceiling make it more difficult for non-state banks to raise their deposits by offering much higher deposit rates than state banks.

Against this backdrop, we find that the cost of wholesale funding, measured by the average at-issue yield of interbank negotiable certificates of deposit ("NCDs" henceforth), track closely with policy interest rates. The loose monetary policy, moreover, triggered a boom in the NCD issuing volume by non-state banks during 2015-2017. Associated with this boom in wholesale funding is the rapid growth in non-state banks' total bank credit, including both traditional loans and shadow loans. By contrast, the growth of bank credit by state banks were much slower.

We also find that since 2018, Chinese economy has experienced a skyrocket in credit default in both shadow loans and bank loans by regional medium and small banks. Accompanied with the increase in credit defaults is the rapid increase in regional banks' systemic risks. These facts suggests a close connection between banks' reliance on wholesale funding for credit expansion and systemic risks.

As a second contribution of the paper, we construct three micro-level data sets at the level of individual banks and run panel regressions to shed light on the linkage among wholesale funding, monetary policy, and systemic risks. The first data set is a transaction-level data set on NCDs issuance between 2013 and 2019. The data set identifies, for each NCD, the name of issuing bank, issuing volume, at-issue yield, and the date it was issued. Using various measures of policy interest rates, we find that changes in monetary policy interest rate effectively pass through into the NCD yield and lead to more NCD issuance by non-state banks in response to policy easing, where there is no such evidence for state banks.

The second data set covers two major asset categories of individual banks, bank loans and risky non-loan assets. The latter is constructed as the sum of financial assets held for trading and financial assets available for sale, excluding central bank bills, government bonds and bond issued by policy banks in each of these two asset categories. What are left in these two asset categories are mostly corporate bonds and wealth management products. Thus, our measured risky non-loan assets on the balance sheet are connected to banks' off-balance shadow banking activities. A third data set is the data at daily frequency on domestically listed commercial banks' systemic risks, measured as expected capital shortfalls when there is a financial crisis. After converting it into quarterly frequency, we merge it with the data sets on NCD issuance and bank assets to form a bank-quarter data set covering the period of 2013Q4-2019Q1 for 22 domestically listed banks.

We then use our constructed bank-quarter data set to test whether banks' exposure to wholesale funding facilitate monetary policy transmission into bank credits and make banks more vulnerable to systemic risks when the economy experiences a deep recession. We obtain the following key empirical findings: (1) For non-state banks, larger NCD issuance increases the effectiveness of monetary policy transmission into bank credit, while it plays no role for monetary transmission into state banks' credit expansion; (2) As an unintended consequence, increase in shadow loans, instead of bank loans, is the main driver for non-state banks to increase their bank credit in response to monetary policy easing; (3) Non-state banks with a heavier exposure to NCDs witness a larger increase in systemic risks in responsive to negative shocks to GDP growth since 2018Q1.

As a third contribution of the paper, we explain our empirical findings by constructing a general equilibrium model with interbank wholesale funding markets. Following the seminal work of Gertler, Kiyotaki, and Prestipino (2016), our framework incorporates wholesale funding alongside with retail deposits as a potential source of bank fund and the possibility of runs on the wholesale markets. On top of it, two institutional facts of China are incorporated as key model ingredients: (i) a dual-track interest rate system with the existence of both deposit rate ceiling and fully liberalized interbank interest rates; (ii) a segmented deposit market between state and non-state banks, with the deposit supply elasticity of state banks higher than that of non-state banks. Moreover, our model features a deposit channel for the transmission of monetary policy into bank credit supply: banks are subject to reserve requirement and idiosyncratic shocks to deposit withdrawal. As a result, banks need to incur a cost to avoid reserve shortfall that is proportional to the policy interest rates, which, in reality, captures the marginal cost of borrowing from central bank via discount windows or in the interbank money market.

Given these features, our simulated results show that a cut in policy interest rates increases the expected returns for bank deposits and push the demand curve for deposit by both state and non-state banks to the right. With binding deposit rate ceiling, non-state banks are forced to switch to wholesale funding markets for alternative sources of fund.[1] State banks, on the other hand, can effectively raise their deposits due to the perfect elasticity of the deposit supply. As a result, state banks become the net supplier in the wholesale funding

[1]Without deposit rate ceiling, non-state banks can fund credit supply entirely from household deposits.

market and help transmit the increased liquidity due to monetary policy easing into non-state banks. This liquidity transmission, by reallocating capital from less productive state banks into more productive non-state banks, improve the aggregate productive efficiency and leads to an increase in aggregate output.[2]

Our model also predicts that without regulation on bank wholesale funding, monetary policy expansion would make non-state banks over-leveraged, due to the externality that lead individual banks to fail to take in accounts the effect of their own borrowing on the probability of bank runs in the wholesale funding markets. As a consequence, a severe negative aggregate productivity shock following a period of monetary expansion (like the case of China) would increase the run probability, even if the run probability is zero in the long run or in the absence of the negative shocks to the economy. An increase in the run probability, in turn, drastically raises the cost (risk premium) of wholesale funding for non-state banks. This not only makes them more difficult to finance via wholesale funding, but also through retail deposits by reducing their net worth. Accordingly, capital is reallocated to less productive agents, which amplified the negative shocks to the real economy.

We then use this framework to study the effects of optimal regulatory policy on wholesale funding. The particular policy we consider is a ceiling in NCDs issuance by non-state banks that restricts their leverage via wholesale funding. A novel prediction of our theory is that a tighter regulation on wholesale funding reduces the effectiveness of monetary policy transmission into the real economy, as it impedes the credit reallocation from state to non-state banks when the monetary policy is eased. On the other hand, a tightened regulation dampens the increase in the probability of runs in the wholesale funding markets and thus help mitigate the impacts of the negative productivity shocks on the whole economy. Our results therefore sheld light on how regulation on interbank wholesale funding trades off between the effectiveness of monetary policy transmission and fragility of the banking sector.

[2]State banks in our model are less efficient in capital management than non-state banks, which captures the fact that in China state-owned enterprises (SOEs) as main customers of state banks are in general less productive than non-SOEs. In reality, non-SOEs obtain their credit mostly from non-state banks, either in the form of bank loan or shadow loans.

Our paper contributes to the extensive literature on the role of banks in monetary policy transmission.[3] In particular, it is closely related to the following two papers. One is Drechscher, Savov, and Schnabl (2017), which is the first to study transmission of policy rates via cost and composition of banks' funding. They argue that banks with market power over deposits contract their deposit issuance when policy interest rates increases, which leads to outflow of deposit from the banking system. In response, banks increase wholesale funding to partially offset the deposit outflow. Similarly, in our model, if deposit rate ceiling is not binding (as for state banks), policy rates pass through to banks' credit supply through banks' demand for deposit, though under a different mechanism. However, as the deposit rate ceiling is binding for non-state banks, a cut in policy rates forces them to resort to wholesale funding to increase credit supply. As a result, in our model bank wholesale funds comove negatively with policy rates (as observed in China), as contrast to a positive comovement in Drechscher, Savov, and Schnabl (2017). Our paper also shares Bianchi and Bigio (2017)'s emphasis on the role of interbank market in monetary policy transmission. Their paper focus on short-term funding from interbank market as a substitute for bank reserve. Monetary policy, by affecting the cost of funding in the interbank money market, affect banks' portfolio allocation between reserve and bank loan. Our study, by contrast, focus on interbank wholesale funding market as a substitute for bank deposit. Monetary policy affect non-state banks credit supply via transmitting liquidity from state banks to non-state banks in the wholesale funding market.

Our empirical exercises connect to the empirical literature on the risk-taking channel of monetary policy. The literature identifies two channels for monetary policy to affect banks' risk taking. The first is the portfolio allocation channel. A cut in short-term interest rate lowers the returns for riskless assets and causes bank to shift toward riskier loans (e.g., Jiménez, Ongena, Peydró, and Saurina (2014)). Another channel is risk shifting channel, under which a higher policy interest rate raises the interest rate banks have to pay on deposit and forces banks to take more risks in loan granting (e.g. Dell'Ariccia, Laeven, and Suarez (2017)). In line with the findings of Jiménez, Ongena, Peydró, and Saurina (2014), we find

[3]The conventional channel for banks to play a role in monetary policy transmission is the bank lending channel (e.g. Bernanke and Blinder (1988), Bernanke and Blinder (1992), Kashyap and Stein (1994). Under this channel, central banks, by affecting the supply of bank required reserves, control banks' balance sheets. Another strand of this literature, pioneered by Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), focuses on balance sheets channel, under which unconventional monetary policy affects banks' lending ability via their net worth.

that non-state banks tend to take more risks in lending when the policy rate is cut. However, our results point to another channel for policy interest rates to affect banks' risk-taking. A cut in policy rates encourages banks that find it difficult to fund via retail deposits to borrow in the wholesale funding market and invest in non-loan risky assets (shadow assets). We show empirically that such dependence on wholesale funding has significant impacts on banks' exposure to systemic risks when the economy experiences a deep negative shock.

Our modeling of wholesale funding follows closely Gertler, Kiyotaki, and Prestipino (2016) ("GKP" henceforth).[4] The banking sector in GPK corresponds best to the shadow banking system, which is not subject to typical regulations on commercial banks that facilitate monetary policy transmission. By contrast, our paper focuses on monetary policy transmission via the traditional banking system. Thus, we incorporate the reserve requirement, which interacts with banks' deposit demand to form a deposit channel for monetary policy transmission. To our knowledge, our paper is the first to study the role of wholesale funding for monetary policy transmission. Our results show that under interest rate controls, a friction common in emerging economies, wholesale funding improves the effectiveness of monetary policy transmission. Both our empirical and theoretical results suggest that regulation on wholesale funding needs to take into accounts its impact on the effectiveness of monetary policy transmission, a feature absent in GKP.

Our paper contributes to the emerging literature on China's monetary policy transmission via the banking system. Chen, Ren, and Zha (2018) study the interaction between the quantity-based monetary policy and shadow banking activities. Liu, Wang, and Xu (2020) develop a theoretical model to explore the impacts of interest-rate liberalization on resource allocations both within and across sectors. More recently, Li, Liu, Peng, and Xu (2020) exploit a loan-level data to study the impacts of the implementation of Basel III capital regulation on banks' risk taking. Fang, Wang, and Wu (2020) study the effect of collateral based monetary policy on the cost of funding in the interbank markets. This paper is the first to study the role of bank wholesale funding for China's monetary policy transmission in a dual-track interest-rate system and systemic risks in the banking system from both empirical and theoretical perspectives.

[4]There is a fast growing literature on the role of banking leverage on macroeconomic stability or systemic risks, including, among many others, He and Krishnamurthy (2013), Brunnermeier and Sannikov (2014), Christiano and Ikeda (2014), Gertler and Kiyotaki (2015), He and Krishnamurthy (2019), Gertler, Kiyotaki, and Prestipino (2020). Most theoretical works in this literature, however, model banking leverage via retail deposits and abstract from wholesale markets.

The rest of the paper is organized as follows. Section II presents the institutional details regarding China's monetary policy system, banking system and wholesale funding markets. Section III discusses the new data sets we construct. Section IV provides panel regressions on the role of wholesale funding in the monetary transmission and systemic risks. Section V develops a theoretical model with wholesale funding and dual-track interest rate system and Section VI uses the model to explore how the presence of wholesale funding markets affect the effectiveness of monetary policy transmission and the banking system's vulnerability to systemic risks. Section VII concludes the paper.

II. China's Monetary Policy and Wholesale Funding Market

In this section, we discuss the institutional features regarding China's monetary policy system and banking system that are pertinent for our subsequent empirical analysis as well as our theoretical framework for interpreting our empirical findings. We start with description of China's monetary policy framework, followed by its banking system. After that, we discuss the development of China's wholesale funding markets, its relationship with transition of China's monetary policy framework and the banking systemic risks.

II.1. **China's Monetary Policy Framework and Banking System.**

II.1.1. *China's Monetary Policy Framework.* Between the mid 1990s and 2015 China adopted a gradualistic approach to deregulate its interest rate controls. The interest rate liberalization started with the liberalization of interbank interest rates. In 1996 and 1997, the interbank money market offered rates (CHIBOR) and repo rates were liberalized. In 2005, interbank deposit rates were liberalized. In recent years, the interbank repo market has far outsized CHIBOR market in turnover and liquidity and has replaced CHIBOR to be the most important short-term interbank interest rate (Wang (2020)).

The liberalization of the interbank money market interest rates has pushed the PBoC to use them as monetary policy target rates. The Shanghai Interbank Offered Rate ("SHIBOR" henceforth) was first established in 2007 as the benchmark interbank interest rates, with the aim to develop it as anchors of monetary policy. SHIBOR rates are set in a similar way to LIBOR, with the rates calculated as the arithmetic averages of the fixing of offered rates of each business day by participation banks. Since it is a quoted price than actual transacted prices, for much of the past decades, SHIBOR has limited representativeness. In 2015, the PBoC signed using R007, the 7-day reserve repo rates by all financial institutions in the interbank market, as the monetary policy targeted interested rate. Market sees the 7-day repo rates and three-month SHIBOR rates as the benchmarks for pricing other financial instruments.

Despite the full liberalization of interbank interest rates, the deregulation of RMB lending and deposit rates took much longer and are still incomplete. Since 1984, the benchmark lending and deposits rates have been used by PBoC as monetary policy instruments to guide commercial banks' lending and deposit rates. For a long time, banks' lending and deposit rates can only float within a certain range of the corresponding benchmark interest rates. After several rounds of adjustments to the floating ranges, the ceiling and floor on the lending rates were removed in 2004 and 2013, respectively. The floor and ceiling of deposit rates was removed in 2004 and 2015, respectively. However, in October 2015, to prevent price (interest rate) competition, major banks in China established a self-discipline mechanism of deposit interest rate determination, forcing upward floating ratio of banks' deposit rates not exceeding 50% of the benchmark deposit rate.[5]. In 2016, the Macroprudential Assessment System (MPA) further took into account banks' deposit rate pricing behavior to prevent price competition. Therefore, today China still features a dual-track interest rate system, with fully liberalization interbank interest rates, but a de facto ceiling on bank deposit interest rates.[6]

II.1.2. *Banking System.* As discussed in Chen, Ren, and Zha (2018), one distinctive characteristic of China's banking system is a division of state and non-state commercial banks. There are five state banks controlled and protected directly by the central government: the Industrial and Commercial Bank of China, the Bank of China, the Construction Bank of China, the Agricultural Bank of China, and the Bank of Communications.[7] The remaining commercial banks are non-state banks, including joint stock banks, city commercial banks and rural commercial banks. Non-state banks as a whole represent almost half the size of

[5]For example, if the benchmark deposit interest rate is 1.50%, the float-to-top deposit rate would be 2.25%

[6]Similarly, China had maintained implicit lending rate floor even after 2013, when the lending rate floor was officially removed. In August 2019, to remove such implicit floor, China's State Council and PBoC announced that Loan Prime Rate (LPR) will be the reference rate for lending by Chinese banks and the LPR is priced as a spread over the one-year rate offered by the PBoC through the medium-term lending facility (MLF) with the spead largely determined by banks' funding costs. In practice, however, since the primary dealers of MLF are mainly state and joint stock banks, it is difficult for medium and small banks to use LPR as their reference lending rates.

[7]The Bank of Communications, initially listed in the Hong Kong Stock Exchange, has officially become the fifth largest state-owned bank since May 16, 2006.

the entire banking system. In 2015, for example, the share of their assets was 47.38 percent and the share of their equity was 47.22 percent.

There are several important institutional differences between state and non-state banks. First is the sources of funding. Since state banks have branches across all provinces in China, but non-state banks' branches are either local, such as city or rural commercial banks, or have limited branches in other provinces than that where their headquarter is located. As a result, non-state banks are at serious disadvantages in drawing deposits related to state banks. The presence of deposit rate ceiling, either explicit or implicit, exacerbates such a disadvantage, as it is difficult for non-state banks to raise their deposits by offering much higher deposit rates than the benchmark deposit rates. Such a disadvantage can also be seen from the share of deposit in total liability. Among state banks, the share of deposits in interest bearing liability has been stably above 85% since 2009. For non-state banks, the corresponding share was only about 70% in 2013, before the boom of NCD markets took place.[8]

Second, the customer base and thus the credit risks that state and non-state banks face are also largely different. In terms of bank loans, state banks have for a long time served mainly state-owned enterprises (SOEs) that enjoy implicit guarantee of debt repayment by central or local governments. By contrast, non-state banks tend to lend to non-state enterprises, including real estate developer and other risky firms, such as small and medium non-SOEs, and charge for higher lending rates. In terms of off-balance sheet activities, state banks, controlled directly by the central government, adhere to the government's regulations for promoting the healthy banking system. As a result, state banks barely invest in risky shadow banking activities, and brought shadow assets back to their balance sheets. By contrast, as shown by Chen, Ren, and Zha (2018), non-state banks tend to engage in risky shadow loan activities and bring them to their balance sheets to circumvent various banking regulations regulations to reduce balance-sheet risks.

II.2. **Wholesale Funding Markets.** The traditional interbank wholesale funds market in China is an OTC market. As an important step of interest rate liberalization, in December 7, 2013[9], the PBC allowed commercial banks to restart issuing interbank negotiable certificate of deposit ('"NCD" henceforth), a bond that can circulate in the secondary market and serve as

[8]Moreover, the average cost of deposit for non-state banks has been always higher than state banks, with an average gap of 0.5%.

[9]In 2014, city commercial banks and rural commercial banks were allowed to issue NCD.

collateral for discount window loans (Medium-term Lending Facility, "MLF" henceforth). As China has decided to transit from a quantity based to a interest-rate based monetary policy in 2013, the original purpose of reestablishing NCD market is to facilitate the transmission of interest-rate based monetary policy into bank lending rates, especially for non-state banks, under the dual-track interest rate system, as NCDs provide an alternative cheap funding for non-state banks to retail deposits. The at-issue NCD yield is benchmarked against the SHIBOR rate. The maturity of NCD varies between one month and one year, with share of one-month and 3-month NCD 26% and 36%, respectively. The typical buyers of NCD are state banks (Amstad and He (2020)). As state banks enjoy cheap funding sources either from retail deposits or various central bank facilities, purchasing NCDs provides state banks an interest rate margin and, at the same time, allows the liquidity injected by PBC to transmit into medium and small banks.

During 2015-2016, China experienced a boom in interbank borrowing via NCDs. A main reason for the boom of NCD market is that since November 2014, the PBC has conducted a series of loose monetary policies. As the top left panel of Figure 1 shows, the 7-day reverse Repo rate (R007) dropped from 4.4 percent to 2.5 percent in 2015Q2 and this low interest rate persisted until 2016Q4, after which it gradually increased. A cut in R007 successfully transmitted into monetary market interest rates of longer maturity. During the same period, both quarterly SHIBOR rate and quarterly reverse Repo rate (R3M) dropped from 5 percent in 2015Q1 to 3 percent in 2015Q3. The top right panel of Figure 1 shows that the quarterly interest rate for NCD tracked closely with the SHIBOR rate and Reverse repo rate of the same maturity. A lower at-issue NCD yield encouraged the non-state banks to to expand their liability via NCD issuance.

The bottom left panel of Figure 1 shows that the issuance of NCD by non-state banks increased rapidly from less than 100 billion RMB in 2015Q1 to about 500 billion RMB in 2017Q3. By contrast, the issuance of state banks' NCD barely changed. Among all NCD, half of them were issued by joint-stock banks and about half of them are issued by city and rural commercial banks. Meanwhile, the state banks, benefiting from cheap credits of PBC, are the major buyers of NCDs. As show by the top right panel of Figure 1, the aggressive issuance of NCDs by non-state banks is associated with a fast expansion of their total bank credit, measured by both bank loans and shadow loans. The total bank credit by 2017Q3 was 1.9 times the value in 2013Q4, implying a 24% annual growth in bank credit during this period. By contrast, the increase of bank credit by state banks was much slower, with the total bank credit in 2017Q3 1.45 times the values in 2013Q4 (13% annual growth). The significantly faster pace of asset growth for Chinese banks, other than the country's big four, suggests that much of the current asset growth in the Chinese banking system is supported by wholesale funds rather than deposits.

II.3. **Systemic risks and regulation on wholesale funding.** The issuance of NCD (and interbank WMP) not only facilitated non-state banks in making bank loans, but also encouraged them to conduct shadow banking activities. Much of the funds financed by NCD, instead of making a loan, went to investment in non-loan risky assets, such as corporate bonds or assets issued by other financial institutions (e.g. interbank wealth management products or asset management plans), which were, in turns, largely invested in corporate bonds issued by firms in risky industries, such as real estate, that are restricted in obtaining bank loans after the 2009-2010 economic stimulus.[10] According to Amstad and He (2020), the interbank market is dominant in bond trading volume, taking 95% in terms of RMB volumes during 2013-2017. Within the interbank market, commercial banks form the largest group of institutional investors, holding about 57% of outstanding bonds in 2019. As a result, by issuing interbank CD and purchasing bonds or higher-return shadow assets, the medium and small banks earn an interest margin. Gu and Yun (2019) find that banks that have been more exposed to NCD activities tend to invest more in bond markets. However, such an effect is only significant for non-state banks, which suggests that they have stronger incentives to earn yield spreads between bond investments and NCD issuance than state banks.

The loose banking regulatory environment contributed to the risky taking behavior of medium and small banks by issuing NCDs. Unlike bank deposit, borrowing via NCDs are not subject to the reserve requirement. Also, to facilitate interest rate transmission, there were no upper limits on the NCD fraction of banks' total liability.[11] Second, the requirement for liquidity coverage ratio has not yet applied to banks with assets smaller than 200 billion RMB. This allows small and medium banks to borrow via NCD and lend long via shadow assets. In addition, the capital requirement for investing in NCD or interbank WMP is only

[10] In China, corporate bonds are traded in two segmented markets: the interbank market and the exchange market.

[11] In 2013, the PBoC mandated that interbank liability is limited to be one third of overall total bank liability. However, NCD is within the category of account payable bond, hence not belonging to interbank liability until recently.

25%, much lower than the 100% for commercial loan. This explains why medium and small banks would be more willing to use the funds from NCD to invest in risky non-loan assets.

The use of NCD for regulatory arbitrage has caused great concerns by Chinese policy makers about the risks in the financial system. Several macro prudential policies have been implemented since October 2016. First, to tighten the monetary policy, PBC increased the interest rate for reverse repo in 2016Q4. This essentially increased the interest rate for NCD. In July 2017, the interest rate for NCD increased to 4.89%, 80bps higher than the level at the beginning of the year. In 2017Q2, the Monetary Policy Report of PBoC stated that planned NCD issuance of current year could be no larger than one third of last year's total liability minus current year's interbank liability. This regulation started to apply to financial institutions with assets larger than 500 billion RMB starting from 2018Q1, and to all financial institutions starting from 2019Q1.

However, the fast growth of NCDs during the period of monetary easing has made the bank system vulnerable to contagion in the financial system. As the top left panel of Figure 2, the Chinese macroeconomy has been experiencing a deep recession since 2008Q2, since which the real GDP growth rates steadily declined.[12] As the growth of Chinese economy slowed down in 2018 and 2019, the credit default has started to skyrocketed since 2018. The top right panel of Figure 2 shows that both numbers and amount of corporate bond default has drastically increased from 2017 to 2018 and 2019. For example, the value of POEs' bond default increased from less than 40 bn RMB to about 160 bn RMB, a more than 4 times increase. By contrast, the corporate bond default by SOEs barely changed between 2017 and 2018-2019.[13] In addition, as the bottom right panel of Figure 2, non-state banks experienced a jump in non-performing loan rate in 2018 and kept increasing in 2019. The level of systemic risks for non-state banks has increased dramatically during 2018-2019 (the bottom right panel of Figure 2).[14] This is in contrast to a much slower growth of systemic risks for large banks throughout the sample period.

[12]The Covid-19 Pandemic in 2020 exacerbated this recession. Since most of our micro data ends at 2019Q4 or before, our paper focuses on the period before the outbreak of Covid-19 crisis. The message of the paper, however, carries over to the current Covid-19 crisis.

[13]The default rate for POEs increased from 1.5% to 4% in 2018 and 5% in 2019, while the default rate of SOEs is close to zero.

[14]In 2019, three regional banks, Bao Shang Bank, Heng Feng Bank and Jin Zhou Banks were bailout by the PBoC. All these three banks are non-state banks.

III. Microdata of Wholesale Funding Activity and Banks' Balance Sheet

In this section, we describe how we construct the data used in our empirical estimates and provide summary statistics.

III.1. **NCD transaction-level dataset.** Our primary data is a transaction level interbank CD, including the information on the name of the issuing bank, the total amount, the yield, starting dates, the maturity days, etc. Panel A of Table 1 reports the summary statistics. Between 2013Q4 and 2019Q1, a total of 78327 NCD was issued, while only 2441 were issued by the state banks.[15] The average issuing volume for an individual non-state banks is, however, less than half of that for state banks (0.86 bn RMB versus 2.05 bn RMB) In other words, non-state banks' NCD issuance take about 96.9% and 93.9% of the total NCD issued during this period. The annualized NCD issuance yield of non-stake banks are on average 3.78%, 0.29% higher than the state banks. For non-state banks, maturity ranges from 0.03 years to 3 years with a sample mean of 0.49 years, while for state banks, maturity ranges from 0.08 years to 2 years with a sample mean of 0.48 years.

III.2. **A quarterly bank panel dataset.** Another data set we construct is the bank-level data on the quarterly balance sheet information for individual banks. CSMAR database provide balance-sheet information from banks' annual financial report for a total of 228 banks, including those both listed and unlisted, Moreover, it also provides quarterly financial reports for listed banks. The quarterly reports of listed banks contains more info than their annual reports, including for example the detailed items within each asset category. We will use these information later on to construct the shadow loan later on.

To measure NCD issuance by individual banks, we sum up all individual NCD issuing volumes by a particular bank for a given quarter and merge it with other bank-level data to create a bank-quarter data set from 2013Q4 to 2019Q1. We use $NCD/Asset$ to measure NCD activity at bank level, where NCD is the aggregated issuance of NCD by quarter for a bank. Our analysis also includes various bank characteristics. ROA denotes the ratio of net earnings after dividend payout to total assets. LIQ is the ratio of liquid assets to total assets and IL is the ratio of interbank liability to total liability.

We construct risky non-loan assets for each of the 22 banks listed in Shanghai and Shenzhen Stock Exchange. For each bank, there are two major asset categories of non-loan assets:

[15]During this period, 288 banks issued NCD, including six state-owned banks, 11 joint stock banks, 96 city commerical banks, 91 rural commerical banks, 18 foreign banks, and 6 other banks.

AFV, financial assets held for trading and AFS, financial assets available for sale. We manually collect government bond, central bank bills and policy bank bond within each of these two category of non-loan assets from individual banks' quarterly reports on their website and exclude them from AFV and AFS. What are left in these two asset categories are mainly corporate bond, trust right and asset management plan, which we call $AFVX$ and $AFSX$. We measure shadow assets as the sum of $AFVX$ and $AFSX$.

We measure banks' systemic risks by SRISK, Building on the model of Acharya, Pederson, Philippon, and Richardson (2017), Brownlees and Engel (2017) propose a systemic risk measure, SRISK, which is defined as the expected capital shortfall of an institution during a financial crisis. The data on SRISK for listed banks are available on New York University's Volatility Institute website, which is updated daily.

Panel B of Table 1 reports the summary statistics for the bank panel data set. The mean of $NCD/Assets$ is higher for non-state banks (2.73%) than for state banks (0.15%). In terms of the composition of bank credit, on average state banks have a significantly higher $Loan/Assets$ ratio than non-state banks (52.5% versus 44.8%), but lower $ShadowLoan/Asset$ ratio (5.17% versus 7.57%).

III.3. **Data on monetary policy interest rates.** Our baseline measure of policy interest rate is the 7-day reverse Repo rate for all financial institutions (R007), including both depository institutions and other financial institutions.[16] As a robustness check, we also use 3-month reverse repo rate for all financial institutions (R3M) and 3-month SHIBOR rate as alternative measures of monetary policy. Since SHIBOR rate is quoted prices, it does not reflect actual transaction prices as R007. The market for 3-month reverse repo is much smaller compared with R007, with the trading volumes of the former only about 2% of the latter. All macro data can be obtained from CEIC.

As Panel C of Table 1 shows, the mean value of R007 (3.17%) is significantly lower than R3M (4.13%) and SHIBOR3M (3.93%). Moreover, the volatility of R007, measured as its standard deviation, is also lowest among the three. The shorter maturity and the less volatility of R007 makes it a better measure of monetary policy rates.

[16]Since 2017, the PBoC has used the 7-day reverse repo rate for depository institutions (DR007) as the intermediate targets. However, since the data series for DR007 is too short for our estimation, we use its best alternative R007.

IV. Empirical Evidence on the Role of Wholesale Funding for Monetary Transmission and Systemic Risks

In this section, we explore empirically the role of NCDs for monetary transmission and systemic risks. We achieve this task by asking by answering the following questions sequentially. Upon monetary easing, which types of banks issues more NCDs? For banks issuing NCDs, do they increase bank loan and non-loan risky assets in response to monetary easing as the monetary policy intended? Does higher exposure to NCD make banks' systemic risks, measured by their capital shortfall, more sensitive to negative shocks to the economy?

IV.1. **Impacts of monetary policy on NCD issuance.** In this section, we establish the empirical linkage between monetary policy and NCD issuance. We first explore the transmission of policy interest rates into at-issue NCD interest rate, followed by the transmission of monetary policy rate into NCD issuance volume. Since the issuing yield of each NCD depends on its maturity, we conduct the regression at the bond-level. The empirical specification is

$$i_{j,b,t} = \alpha I(NSB_b) + \beta R_{t-1} + \alpha_m m_{j,b,t} + \alpha_b + \tau_t + \gamma X_{b,t-1} + \epsilon_{b,t}$$

where $i_{j,b,t}$ denotes the issuing yield for a particular NCD indexed by j, issued by bank b at quarter t, R_{t-1} is the policy interest rate, measured as R007, R3M or SHIBOR3M. We lag the monetary policy rates by one period to avoid the endogeneity of monetary policy. $m_{j,b,t}$ is the maturity of the NCD, τ_t is the year fixed effect to control for other macroeconomic shocks than monetary policy changes, α_b is bank fixed effect, controlling for time-invariant unobserved heterogeneity across banks. $I(NSB_b)$ returns 1 if the issuing bank is a non-state bank and 0 otherwise. The regression controls for a set of observed bank characteristics ($X_{b,t-1}$), which are lagged for one quarter relative to the quarter of the policy change to avoid the endogeneity issue. These characteristics include the ratio of net profit to total assets (ROA), the ratio of liquid assets to total assets (LIQ), and the ratio of interbank liability to total liability (IL). The key estimate is the coefficient β, as it captures the extent to which changes in policy interest rate transmit into NCD rates.

Table 2 reports the regression results. Consistent with the summary statistics, the estimated coefficient α is positive and significant at 1 percent confidence level. The magnitude of the estimated coefficient suggests that the NCD issuance yield for an average non-state bank is about 0.4% higher than that for an average state bank. The higher issuance yield of

NCDs captures the fact that on average the credit risks of non-state banks are higher than state banks.

The estimated coefficient for monetary policy (β) is positive and significant at 1 percent confidence level across all three measures of policy interest rates. The point estimate indicates that a one-percent decrease in R007 leads to a 0.66% decrease in the NCD issuance yield. The pass-through of R3M and SHIBOR3M to NCD yield are somewhat lower, with the point estimate indicating that NCD yields decreases by 0.52 and 0.48 when R3M and SHIBOR3M reduce by one percent, respectively. Overall, the estimated results suggest that changes in monetary policy rates can effectively transmit into the NCD issuance yield.

We now estimate the impacts of policy interest rate on NCD issuance volume. As we discussed above, under the dual-track interest-rate system, the ability of drawing deposits is stronger for state banks than for non-state banks. Hence, we hypothesis that non-state banks tend to rely on NCD issuance more than state-bank to fund their credit supply when monetary policy is eased.

Specifically, we run the following unbalanced bank panel regression:

$$\begin{aligned} NCD_{b,t} = {} & \alpha R_{t-1} + \beta R_{t-1} \times I(NSB_b) + \eta I(NSB_b) \\ & + \gamma X_{b,t-1} + \alpha_b + \tau_t + \epsilon_{b,t} \end{aligned} \tag{1}$$

where $NCD_{b,t}$ is the total issuing volume of NCD by bank b at quarter t, scaled by the bank's total assets. The coefficient α captures the response of NCD issuance volume by state banks to monetary policy changes. The key estimate is the coefficient (β) on the interaction between monetary policy rate and the non-state bank dummy, which measures the differential impacts of monetary policy changes on NCDs issued by non-state banks. $X_{b,t-1}$ are a set of bank-level variables and their interaction with the lagged policy interest rates, and α_b and τ_t are bank and year fixed effects, respectively.

The first row of Table 3 shows that the estimated coefficient α is positive and significant at 1 percent confidence level across different measures of monetary policies. This suggests that upon monetary policy easing, state banks tend to reduce the issuance of NCDs (relative to their assets). This suggests that for state banks, when monetary policy is eased, they tend to rely on retail deposits, rather than NCDs, to expand their funding. Only when monetary policy is tightened and the deposit becomes more costly, state banks switch to NCDs.

By contrast, the second row of Table 3 shows that the coefficient β is negative and significant at 1 percent confidence level across different measures of monetary policy. This suggests that relative to state banks, non-state banks tends to rely more on NCDs issuance to expand their funding when monetary policy is eased. As shown in the bottom of the table, the total effect of monetary policy on non-state banks NCD issuance volume, captured by $\alpha + \beta$, is negative and statistically significant across all three measures of monetary policy interest rates. For example, column (1) suggest thats, when R007 reduces by one percent, for an average non-state bank, the NCD issuance volume would increase by 0.642 percentage point as a share of its total assets. The impacts of R3M and SHIBOR3M on NCD issuance are somewhat smaller than R007, consistent with a lower pass-through of R3M and SHIBOR3M on NCD issuing yield.

To summarize, our results suggest that a cut in monetary policy interest rates effectively reduces the NCD issuing yield. Moreover, upon monetary policy easing, non-state banks significantly increases the issuance of NCDs, while state banks significantly decrease NCD issuance. This opposite responses of NCD issuance to monetary policy by the two types of banks is consistent with the fact that as state banks have advantages in drawing deposits than non-state banks. Accordingly, upon monetary policy easing, non-state banks rely heavily on NCD issuance, while state banks rely mainly on expanding deposit, to increase their funding.

IV.2. **Role of NCDs for monetary policy transmission into bank credits.** In this section, we conduct empirical estimates of the transmission of monetary policy into bank credits. Our focus is on the extent to which NCD issuance facilitates monetary policy transmission. Our results above show that during the period of monetary policy easing, non-state banks tend to increase NCD issuance. Hence, we hypothesize that among non-state banks, those with higher NCD will increase their credit supply more as monetary policy is loosen. By contrast, for state banks, there is no such effect. This is because under the dual track interest-rate system, a cut in monetary policy interest rates could not channel sufficient bank deposit to non-state banks, while state banks can expand their funding via deposit. In reality, banks can advance credit via either bank loans or shadow loans in response to monetary policy. The former represents the intended consequence of establishing NCD markets, while the latter is the unintended consequences. To this end, we measure bank credits as either traditional bank loan, shadow bank loan (risky non-loan assets), or the sum of the two (total credit) and examine the role of NCDs for monetary policy transmission into each type of bank credit.

We run bank panel regressions as follows

$$L_{b,t} = \alpha NCD_{b,t-1} + \beta R_{t-1} \times NCD_{b,t-1} + \gamma X_{b,t-1} + \alpha_b + \tau_t + \epsilon_{b,t} \tag{2}$$

where $L_{b,t} \in \{BankLoan, ShadowLoan, TotalCredit\}$ is outstanding credit for bank b at quarter t, scaled by total assets. The specification also includes bank-level fixed effects (α_b) and quarterly fixed effects (τ_t). $X_{b,t-1}$ is a vector of bank characteristics at quarterly frequency and their interaction with the lagged policy interest rates. Note that the inclusion of quarterly fixed effects absorbs the main effects of monetary policy, but controls for all possible non-monetary aggregate shocks. We split the sample between state and non-state banks and run separate regressions for two these sub-samples. Our data for shadow loans ends at 2017Q4.[17] Therefore, our sample period for this particular regression is 2013Q4-2017Q4.

Column (1)-(3) of Table 4 shows that the coefficient β is insignificant across various measures of monetary policy rates. This suggests that larger issuance of NCD does not facilitate the transmission of monetary policy rates into bank loans for state banks. For non-state banks, the results are dramatically different. As shown by column (4)-(6). the estimated parameter β is significant at 5 percent confidence level for all measures of monetary policy. For example, column (4) suggests that when R007 reduces by one percent, for an average non-state bank, a one-percentage higher NCD will increase its bank loan by 0.25% percentage point relative to its total assets. Thus, NCD issuance facilitates monetary policy transmission into loan supply by non-state banks.

Table 5 provides the estimate when bank credit is measured as shadow loans. Similar to Table 4, neither the estimated parameter α or β is insignificant in column (1)-(3). This suggests that for state banks, issuance of NCD does not contribute to shadow loans or influence the elastic of shadow loans to monetary policy. By contrast, the coefficient α is positive and statistically significant. The point estimate suggests that 1 percentage point increase in NCD issuance is associated with a 1.334 percentage point increase in shadow loans as a share of bank assets (Column 4). This is consistent with non-state banks exploiting regulatory arbitrage to use NCDs to invest in shadow assets. More important for our purpose, the estimated β for non-state banks is negative and significant at 5 percent confidence level (column (4)-(6)) throughout different measures of monetary policy interest rates. This is consistent with the thesis that non-state banks, by issuing NCDs, increase their investment in shadow assets when monetary policy is loosen. In terms of the magnitude, column (4) shows that for an average non-state bank, a one percentage point increase in NCD issuance

[17]In 2018, Chinese banks changed their accounting standards and no longer reported the detailed items within each asset category, such as financial bonds or corporate bonds.

(in the last period) would lead to 0.41 percentage increase in the elasticity of shadow loan to monetary policy change. It is important to note that the magnitude of the estimated β is higher for shadow loan than traditional bank loans (0.25 percentage points).

Table 6 shows the role of NCDs for monetary transmission into total bank credit. Consistent with the results in Table 4 and 5, the statistical insignificance of the estimated β in column (1)-(3) suggests that for state banks, NCD issuance plays little role for the transmission of monetary policy into their total bank credit. This is not the case, again, for non-state banks. The estimated β is negative and significant at 5% (10%) confidence level for both R007 and SHIBOR3M (R3M), as shown by the second row of Column (4) to (6). For R007, the magnitude of β suggests that for an average non-state bank, a one-percentage higher NCD issuance leads to about 0.59 percentage increase in the elasticity of total bank credit to policy interest rate. According to the estimated β in Table 4 and 5, for an average non-state bank, more than 60% $(0.412/(0.412+0.247))$ of the increase in total bank credits associated with higher NCD goes to shadow loans.

In summary, we have the following key empirical findings regarding the roles of monetary transmission into bank credit: (1) For non-state banks, larger NCD issuance facilitates the monetary policy transmission into bank loans, while NCD issuance plays no role for monetary transmission into state banks. This asymmetry reflects the intended effects of NCDs for interest-rate transmission; (2) For non-state banks, larger NCD issuance during monetary policy easing encourages them to invest more into shadow assets, shown up as risky non-loan assets in their balance sheets. In other words, NCD markets creates the unintended consequence for non-state banks to divert liquidity into shadow banking. (3) Quantitatively, more than 60% of the increase in total bank credit attributable to NCD issuance goes to shadow loans when monetary policy eases.

IV.3. **Role of NCDs for systemic risks.** The results in the last section suggests that during the period of monetary easing, non-state banks tend to increase their leverage via NCDs to make risky investment in shadow assets as regulatory arbitrage. A natural question is to what extent NCD issuance by non-state banks contributes to their systemic risks when the Chinese macroeconomy experiences a slowdown in GDP growth. As figure 2 shows, since 2018, China's GDP growth rate has declined rapidly, which increased the probability in credit default. Since the maturity of NCDs is typically shorter than that of risky assets, a bank that was highly levered in NCDs in the past tends to have higher rollover risks of NCDs when defaults on bank credit increases. Thus, our hypothesis is that the systemic risks of non-state banks with higher NCD issuance is more sensitive to GDP growth slowdown. For state banks, NCDs play no roles for the transmission of negative shocks to GDP growth into systemic risks.

To highlight the impacts of NCDs on systemic risks during period economic slowdown, we estimate the impacts of NCDs for systemic risks for both the period before 2018 and after 2018 by including a triple interaction of GDP growth and NCD issuance with post-2017 dummy variable. We run the following bank panel regression:

$$\begin{aligned} SRISK_{b,t} = {} & \alpha_r NCD_{b,t-1} \times I(Year > 2017) + \beta_r g_{t-1} \times NCD_{b,t-1} \times I(Year > 2017) \\ & \alpha NCD_{b,t-1} + \beta g_{t-1} \times NCD_{b,t-1} + \gamma X_{b,t-1} + \alpha_b + \tau_t + \epsilon_{t,b} \end{aligned} \tag{3}$$

where $SRISK_{b,t}$ is the level of systemic risk for bank b at quarter t, g_{t-1} is the real year-over-year GDP growth rate at quarter $t-1$ to mitigate seasonality. $I(Year > 2017)$ is a dummy variable that equals one if the quarter t is either within or after the year 2018 and zero otherwise. The key estimate is the coefficient β_r, which captures the marginal effects of NCDs issuance on the responses of systemic risks to GDP growth. The specification also includes bank-level fixed effects (α_b) and quarterly fixed effects (τ_t). The latter controls for other macroeconomic shocks than GDP growth. $X_{b,t-1}$ is a vector of bank characteristics at quarterly frequency and their interaction with the lagged policy interest rates. Note that the inclusion of quarterly fixed effects absorbs the main effects of GDP growth rate as well as the main effect of the post-2017 dummy. The sample for this regression includes banks listed in Shanghai and Shenzhen Stock Exchange as the data for SRISK are for listed banks only.

Table 7 reports the estimated coefficients. Column (1) shows that the estimated coefficient α_r for state banks is insignificant. By contrast, α_r is significantly positive for non-state banks. This suggests that during the period of economic slowdown, exposures to NCDs is closely associated with systemic risks for non-state banks, while it is not true for state banks. The point estimate indicates that a one-percentage increase in NCDs as a share of banks' asset is associated with an increase in expected capital shortfall by 150.84 billions of RMB.

More important for our purpose, column (2) in Table 7 shows that for non-state banks, exposure to NCDs significantly increase the response of systemic risk to GDP growth during the period of economic slowdown. The estimated coefficient β_r is negative and significant at 5 percent confidence level. The point estimate suggests that a one percentage point increase in NCD issuance leads to a capital shortfall of 22.86 billions of RMB, when GDP growth falls by one percent. Interestingly, the estimated coefficients α and β for non-state banks are statistically insignificant. This is consistent with the view that the impacts of capital loss, say due to credit default, on banks' systemic risks are highly nonlinear (e.g. He and Krishnamurthy (2013)). During the normal time, when banks' capital is high, risky investment against higher leverage would not increase the probability of fire sales and expected capital shortfall, when the bank suffers from capital loss (say due to loan or bond default). However, when intermediary's capital is low, say in economic downturns, high leverage increases the chances for a bank to fire sale their risky assets and increase the capital shortfall when it suffer from capital loss.

Summary We find that for non-state banks with higher exposure to NCD, the sensitivity of expected capital shortfall to GDP growth is larger during the economic slowdown. This evidence, together with our empirical findings in previous sections, suggests a trade-off of wholesale funding liquidity (via NCD issuance) under the dual-track interest rate system: on the one hand, it facilitates the transmission of monetary policy into bank loans for non-state banks, which typically have a hard time in drawing deposits. On the other, the wholesale funding liquidity encourages for non-state banks to invest aggressively into risky assets as a regulatory arbitrage (against required reserve ratio). Accordingly, when the economy experienced a deep recession, those banks with higher exposure to NCDs would face larger expected capital shortfall (systemic risks) when they experience capital loss, say due to credit default.

In the next section, we use a theoretical model to explain our empirical findings. The model aims to address the following three questions: How does the presence of NCDs facilitate the transmission of monetary policy into credit supply of non-state banks? How does exposure to NCD make non-state banks more vulnerable to capital shortfall and bank runs when the economy experiences large negative shocks? How does banking regulation on NCD issuance trade off between effectiveness of monetary transmission and banks' exposure to systemic risks?

V. A banking model with wholesale funding markets and dual-track interest-rate system

As mentioned before, a focus of our paper is how wholesale funding market affects the effectiveness of monetary transmission, which, in turn, expose banks to systemic risks. In order to incorporate monetary policy transmission into our model, we need to model reserve requirement and deposit market in detail. Specifically, there are two distinctive ingredients. First, state and non-state banks both are subject to the reserve requirement, which by affecting banks' deposit demand, forms a typically deposit channel of monetary policy transmission. Second, deposit markets are segmented between state and non-state banks. Accordingly, the presence of deposit rate ceiling has asymmetric impact on these two types of banks. And this creates the need for wholesale funding market to play a role in monetary transmission.

We begin with describing the economic environment in Section V.1. In Section V.2, we characterize the portfolio choices for both non-state and state banks and provide the conditions for interbank market to be operative between them. Section V.3 establishes several theoretical predictions that are consistent with our empirical findings. The technical details of how to solve the bank's problem recursively, the definition of the equilibrium, and numerical algorithm are contained in Appendices A. Appendix B provides the proof of all lemmas and propositions.

V.1. **Environment.** Time is discrete, indexed by t and infinite horizon. Each period, there are two types of competitive banks, state and non-state banks indexed by $j \in \{S, NS\}$. Each type of banks can borrow in demand deposit, d^j or interbank bond ib^j and hold liquid assets (a^j) as reserves. Both types of banks can fund capital investment. In addition to banks, a representative household may fund capital investment directly, but less efficient than the banks.

There are two goods: a nondurable good and capital. Agent of type j uses capital and nondurable goods as inputs to produce output and capital at $t+1$, where type $j = S, NS$ or h stands for the state bank, the non-state bank, or the household. When k_t^j units of capital is input in period t, there is a payoff of $Z_{t+1}k_t^j$ units of goods in period t plus the left-over capital, where Z_{t+1} is an aggregate shock to productivity. To capture how monetary policy transmits into the real economy via capital reallocation, we assume that state banks, non-state banks and households have different levels of efficiency in monitoring or screening the investment projects, in that they need to pay different levels of management cost in making non-financial loans. The cost function is given by the following formulation:

$$F^j(k_t^j; K_t^j) = \alpha^j(K_t^j)k_t^j \tag{4}$$

with $\alpha^j \geq 0$, $j = S, NS$ or h for state banks, non-state banks and the household. (4) implies that the marginal cost of capital management is increasing in the total amount of capital, which implies that it is increasingly costly at the margin for banks or the household to absorb capital directly. We suppose the management cost is lowest for non-state banks and highest for the household (holding constant the level of capital). We normalize the management cost of non-state banks to be 0:

$$\alpha^{NS} = 0 < \alpha^{S} < \alpha^{h}. \tag{5}$$

For simplicity, we assume tha capital does not depreciate. The sum of total holdings of capital by each type of agent equals the total supply which we normalize to unity:

$$K^{S} + K^{NS} + K^{h} = \bar{K} = 1, \tag{6}$$

where K^S, K^{NS} and K^h denote the aggregate capital held by state banks, non-state banks and the household, respectively. Denote

$$R^{j}_{k,t+1} = \frac{(Q_{t+1} + Z_{t+1})}{Q_t + \alpha^{j} K^{j}_{t}} \tag{7}$$

as the rate of return to non-financial loans for agents of type j, where Q_t is the market price for capital.

V.1.1. *Reserve requirement.* Following Bianchi and Bigio (2017), each period after making their portfolio decisions, both state and non-state banks are subject to an idiosyncratic deposit withdrawal, $\omega_t d^j_t$, where $\omega \sim \mathscr{F}(\cdot)$. $\mathscr{F}_t(\omega_t)$ is the cumulative distribution of ω_t and follows uniform distribution on [-1,1]. Note that $\int_{-1}^{1} \omega_t d\mathscr{F}_t(\omega_t) = 0$. This means that no deposit withdrawals are made outside of the banking system. The shock ω_t captures the idea that deposits are constantly circulating within the banking system when payments are executed.

By law, each bank is subject to a reserve requirement at the end of the period,

$$a^j_t - \omega_t d^j_t \geq \rho\,(1-\omega_t)\, d^j_t$$

where ρ is the required reserve ratio set by the central bank. Since banks make portfolio decisions before the withdrawal shock is realized, their reserve might not be enough after ω_t is realized. The reserve shortfall is given by:

$$\begin{aligned} x^j_t &= \rho(1-\omega_t)d^j_t - (a^j_t - \omega_t d^j_t) \\ &= [\rho + \omega_t(1-\rho)]d^j_t - a^j_t \end{aligned} \tag{8}$$

If banks' reserve is less than what is required, they need to borrow directly from the central bank discount window at a rate R_b to recoup the shortage of reserve.[18] If they face a reserve surplus, they could deposit in the central bank within period to receive interest income from reserve. For simplicity, we assume that at the beginning of the period, they could perfectly insure themselves against the risk of reserve shortfall by paying to the central bank a fixed cost τn_t^j proportional to R_b, on top of the expected interest cost to recoup the reserve shortfall.[19] The total reserve recoup cost is given by:

$$\begin{aligned}\chi(x_t^j) &= R_{b,t}\int_{-1}^{1}[\tau n_t^j + (\rho + \omega_t(1-\rho))d_t^j - a_t^j]f(\omega_t)d\omega_t \\ &= R_{b,t}(\tau n_t^j + \rho d_t^j - a_t^j)\end{aligned} \tag{9}$$

Equation (9) implies that a relaxation of monetary policy (decreases in $R_{b,t}$) will reduce the total reserve recoup cost drops, which increases the returns for deposit.

V.1.2. *Households.* There is a representative household that contains a measure unity of family members. Within the household, a fraction s of the members are bankers and the remaining fraction $1 - s$ are workers. Each period the household receives an endowment W. Within the group of bankers, a fraction μ of bankers manages a non-state bank and a fraction $1 - \mu$ of bankers manage a state bank. Each banker, state or non-state, pays dividends to the household. Within the household, there is complete consumption insurance among workers and different types of bankers.

The household chooses consumption and and saving, and portfolio allocation among bank deposits, direct capital holding and foreign government bonds. There is turnover between bankers and workers. Each period, some bankers exit the business and become workers. Each banker of type j has i.i.d. probability σ^j of surviving until the next period and a probability $1 - \sigma^j$ of exiting. When they exit, they pay as dividends the residual net worth to the household. To keep the total population of workers and bankers constant, we assume that an equal number of workers become new bankers. In other words, each period the exiting state (nonstate) bankers are replaced by $(1 - \sigma^j)s(1 - \mu)$ $((1 - \sigma^j)s\mu)$ turned bankers.

[18]We assume that the only interbank market in our model is the interbank bond market, In reality, bank borrows short-term funds to cover reserve shortfall mostly from the interbank money market (e.g. Repo market). Without spread between interest rate on reserve and discount window rate, the discount window rate equals the money market interest rates if such markets exist.

[19]This assumption would make banks within each ownership type homogeneous ex post, thus greatly simplifying the computation burden.

Every period, new bankers enter with a fixed startup transfer from the household w^j, that is received only in the first period of life.

$$w^j = \frac{\zeta}{(1-\sigma^j)\, s}$$

To introduce the different deposit supply elasticities that each state or non-state bank faces, we assume that households need to incur a convex cost associated with deposit into the non-state banks, while there is no such cost for deposit into the state bank.

$$f\left(D_t^{NS}\right) = \frac{\xi}{\eta}\left(\frac{D_t^{NS}}{N_t^{NS}}\right)^{\eta} N_t^{NS}, \text{ with } \eta > 1, \xi > 0,$$

where D_t^j and N_t^j denote the total deposit and net worth into a bank of type $j \in \{S, NS\}$. Such convex cost may capture in reality that all state-banks in China have branches nationwide, while most non-state banks are local and have fewer branches than the state banks or even no branches outside of the province where their headquarters are located. As we will show later, the specification of such convex cost function make sure that within each bank type, banks with different net worth, given the deposit interest rate, face the same amount of deposit supply, normalized by their individual net worth, a feature that helps to make all bank decision variables linear in their individual net wealth. For simplicity, we assume that deposit into either state or non-state banks enjoy repayment guarantees from the government. Accordingly, deposits held in a bank from t to $t+1$ are one-period bonds that promise to pay the non-contingent gross rate of return $R_{d,t+1}^j$ at period $t+1$. [20]

We now describe the household optimization problem. Let C_t B_t and K_t^h denote the household choice of consumption, foreign bond and the capital investment, respectively. Then the household chooses $\left\{C_t, D_t^S, D_t^{NS}, B_t, K_t^h\right\}$ to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t \log C_t$$

subject to

$$\begin{aligned} &C_t + \sum_{j\in\{NS,S\}} D_t^j + f\left(D_t^{NS}\right) + \zeta + B_t + g(B_t) + \left(Q_t + \alpha^h K_t^h\right) K_t^h \\ =&W + \sum_{j\in\{NS,S\}} R_{d,t}^j D_{t-1}^j + \left(Z_t + Q_t\right) K_{t-1}^h + \Pi_t + RB_{t-1} + T_t, \end{aligned}$$

[20] In case of bank runs, the government taxes the household a lump-sum amount equal to the difference between the committed deposit repayment and the residual value of the bank assets.

where $R^j_{d,t}$ denotes the deposit interest rate in a bank of type j, promised at period t, ζ is the total startup funds to the entering bankers, Π_t is the total dividend payout from the exiting bankers, and T_t is the lump-sum transfer or tax (if negative), which we will discuss in Section V.1.4. $g(B_t) \equiv \frac{v}{2}B_t^2$ is a convex cost associated with investing foreign bond.

The first order conditions give

$$\left(R^S_{d,t+1}\right)^{-1} = E_t\Lambda_{t,t+1}, \tag{10}$$

$$\left(1 + f'\left(D^{NS}_t\right)\right)\left(R^{NS}_{d,t+1}\right)^{-1} = E_t\Lambda_{t,t+1}, \tag{11}$$

$$(1 + g'(B_t))R^{-1} = E_t\Lambda_{t,t+1}, \tag{12}$$

$$1 = E_t(\Lambda_{t,t+1}R^h_{k,t+1}), \tag{13}$$

where $\Lambda_{t,t+1} \equiv \beta\frac{C_t}{C_{t+1}}$ is the stochastic discount factor for the household.

Equations (10) and (12) jointly determine the supply of deposit for state banks

$$R^S_{d,t+1} = \frac{R}{1 + g'\left(B_t\right)}, \tag{14}$$

and equation (11) and (12) jointly determine the supply of deposit for non-state banks

$$R^{NS}_{d,t+1} - R^S_{d,t+1} = R^S_{d,t+1}\xi\left(\frac{D^{NS}_t}{N^{NS}_t}\right)^{\eta-1}. \tag{15}$$

Equation (14) and (15) implies a segmented deposit market between state and non-state banks: state banks face a perfectly elastic supply of deposit with the deposit rate independent of the deposit they receive, while non-state banks face an upward-sloping supply of deposit. Moreover, at all level of positive deposits, non-state banks always need to pay a higher deposit interest rate than state banks to obtain the funds.

We assume that the economy is subject to a deposit rate ceiling, that is, for $j \in \{S, NS\}$.

$$R^j_d \leq \overline{R}_d \equiv \lambda R^S_d \text{ with } \lambda > 1.$$

The segmented deposit market not only captures the advantage of state banks in attracting deposits, but also implies that the deposit rate ceiling has an asymmetric impacts between state and non-state banks when their deposit demand increase. As Figure 3 shows, the ceiling deposit rate $\bar{R}_d$ is higher than R^S_d, but lower than the equilibrium deposit rate for non-state banks. Accordingly, the ceiling is not binding for state banks, but binding for non-state banks. This forces non-state banks' deposit to be ψ^{NS}_d, instead of $\psi^{NS^*}_d$. Moreover, as the aggregate demand for both types of banks increase, say due to monetary policy easing, state banks' equilibrium deposit can effectively increase to $\psi^{S\prime}_d$. However, for non-state banks, the amount of deposit will be constrained by ψ_d^{NS}. This means that under the deposit rate ceiling, the deposit rate channel for monetary policy transmission does not work. Without deposit rate ceiling, by contrast, non-state banks can increase their deposit to $\psi_d^{NS'}$ by paying a higher deposit rate.

We restrict attention on the case that agents anticipate that a run will occur with positive probability in the future (but never happens ex post). Let p_t denotes the probability that agents assign at t to a bank run happening in $t+1$. In the following sections, we denote all variables in the run case as with star "*". Equation (13) gives the capital demand function for the households.

$$1 = E_{R_b,Z}[(1-p_t)\Lambda_{t,t+1}(\frac{Q_{t+1}+Z_{t+1}}{Q_t+\alpha^h K_t^h}) + p_t\Lambda^*_{t,t+1}(\frac{Q^*_{t+1}+Z_{t+1}}{Q_t+\alpha^h K_t^h})]. \tag{16}$$

Note that the expected capital return for the household is the weighted average of the capital returns between the no-run and the run case, as the probability of run is anticipated in our model.

V.1.3. *Bankers.* Each banker manages a bank. Apart from holding cash, banks funds capital investment by issuing deposits and borrowing from other banks in interbank bond market and using their own equity, or net worth. We refer to capital investment as "non-financial loans" to distinguish from interbank lending.[21] Banks can also lend in interbank markets.

The aggregate shocks (monetary policy shock R_b or productivity shock Z) are realized at the beginning of each period. Conditional on the shocks, the net worth of surviving bankers j at the beginning of period t is the sum of the gross return on cash and non-financial loans net of the cost of deposit and borrowing from others banks.

$$n_t^j = a_{t-1}^j R_{a,t} + (Q_t + Z_t)k_{t-1}^j - R_{ib,t} ib_{t-1}^j - R_{d,t}^j d_{t-1}^j, \tag{17}$$

where a_{t-1}^j, k_{t-1}^j denote cash and capital stock held by an individual bank of type j, and ib_{t-1}^j, and d_{t-1}^j denotes the interbank borrowing and deposit issued by individual bank j at $t-1$ respectively. $R_{a,t}, R_{ib,t}$ and $R_{d,t}^j$ is the gross interest rate on cash holding, interbank borrowing, and deposit for banks of type j.

During each period, a continuing bank j finances its non-financial loans, cash, and insurance premium for reserve shortfall with net worth, deposit or interbank borrowing. The

[21]To be consistent with our empirical findings, the concept of "non-financial loans" corresponds to the total bank credit, including both bank loans and shadow loans.

flow-of-funds constraint is as follows:

$$(Q_t + \alpha^j K_t^j)k_t^j = n_t^j + ib_t^j + d_t^j - a_t^j - \chi(x_t^j), \tag{18}$$

where Q_t is the price of capital. To limit the bankers' ability to raise funds, we introduce moral hazard problem: After making all portfolio decisions at the beginning of t, but still during the period, the banker decides whether to operate "honestly" or to divert funds for personal use. Operating honestly means holding assets until the payoffs are realized in period $t+1$ and then fulfilling corresponding obligations to creditors. To divert means to secretly channel funds away from investments in order to consume personally. If they choose to divert, they will be caught at the end of the period. Then the bankers' decision at t boils down to comparing the franchise value of the bank V_t, which measures the present discounted value of future payouts from operating honestly, with the gain from diverting funds. In this regard, rational creditors will not lend funds to the banker if he has an incentive to divert.

We assume that a banker j's ability to divert funds depends on both the sources and uses of funds. They could divert the fraction θ^j of funds raised from retained earnings or retail deposits, where $0 < \theta^j < 1$. On the other hand, they can only divert a fraction $\theta^j\omega$ of funds raised from interbank borrowing, where $0 < \omega \leq 1$. This captures the idea that banks are more efficient to monitor the lending in the interbank market than those lending through the retail deposit market. Accordingly, for a banker that borrows from the interbank market ($ib_t^j > 0$), the total amount of funds that he can divert is

$$\theta^j[(Q_t + \alpha^j K_t^j)k_t^j + a_t^j + \chi(x_t^j) - ib_t^j + \omega ib_t^j]$$

where $(Q_t + \alpha^j K_t^j) + a_t^j + \chi(x_t^j) - ib_t^j$ represents the value of total funds spending on non-financial loans, cash, and reserve insurance premium that is financed by net worth or deposits and where $\omega ib_t^j > 0$ represents the value of funds raised from the interbank market.

Similarly, for bankers that lend to other bankers, we assume that it is more difficult to divert interbank loans than other funds. Specifically, a banker j can only divert a fraction $\theta^j\gamma$ of its loans to other banks ib_t^j, where $0 < \gamma \leq 1$. Accordingly, the total amount of funds that a banker that lends on the interbank market can divert is given by

$$\theta^j[(Q_t + \alpha^j K_t^j)k_t^j + a_t^j + \chi(x_t^j) + \gamma(-ib_t^j)]$$

The banker must decide whether to divert at t, prior to the realization of uncertainty at $t+1$. The cost to the banker of the diversion is that creditors can force the bank into bankruptcy at the beginning of the next period. Thus, the banker's decision boils down to comparing the franchise value of the bank, V_t^j, with the gain from diverting funds. Any financial arrangement between the non-state banks or state banks and its creditors must satisfy the following incentive constraint:

$$\begin{aligned}&\theta^j[(Q_t+\alpha K_t^j)k_t^j+a_t^j+\chi(x_t^j)-(1-\omega)ib_t^j]\leq V_t^j,\ \text{if } ib_t^j>0\\&\theta^j[(Q_t+\alpha K_t^j)k_t^j+a_t^j+\chi(x_t^j)+\gamma(-ib_t^j)]\leq V_t^j,\ \text{if } ib_t^j<0\end{aligned}\tag{19}$$

In what follows, we restrict attention to the case in which

Assumption 1. $\omega+\gamma>1$.

That is, the sum of these parameters cannot be so small as to induce a situation of pure specialization by state banks, where these banks do not make non-financial loans directly but instead lend all their funds to non-state banks (see Lemma 2 in Section V.2). Since in practice state banks usually lend to state-owned enterprises to fund their capital investment, we think it reasonable to restrict attention to this case.

Finally, as a proxy for the regulation on banks' sufficiency of liquid assets, we impose a liquidity constraint to each individual banks.

$$a_t^j\geq\kappa n_t^j\tag{20}$$

We prove in Appendix B that Equation (20) is always binding. Intuitively, since the return for reserve is very low compared to capital investment, banks would hold the minimum liquid assets as required by the regulation.

We now turn to the optimization problem for the individual bank. Bankers of either type operate on behalf of the household and face an exiting probability of σ^j. The bank's objective is to maximize the expected present discounted value of the dividend payouts to the household. Since bankers are financially constrained, it is optimal for them to delay dividend payouts until exit. Accordingly, we can express the value of a continuing banker at the end of period t as the expected discounted value of the sum of net worth conditional on exiting and the value conditional on continuing as:

$$V_t^j=\max E_t[\Lambda_{t,t+1}(1-\sigma^j)n_{t+1}^j+\sigma^jV_{t+1}^j)]=\max E_t[\Omega_{t+1}^jn_{t+1}^j]\tag{21}$$

where

$$\Omega_{t+1}^j=\Lambda_{t,t+1}\left(1-\sigma^j+\sigma^j\frac{V_{t+1}^j}{n_{t+1}^j}\right)\tag{22}$$

Ω^j_{t+1} is the stochastic discount factor for a banker of type j, which equals to a probability weighted average of the discounted marginal value of net worth to existing (equal to unity) and to continuing bankers at $t+1$ (equal to $\frac{V^j_t}{n^j_t}$).

In general, three types of runs are possible: (1), a run on the non-state banks while leaving state banks intact; (2) a run on both non-state and state banks; and (3) a run on state banks only. We focus on (1) because it corresponds to what happened in practice.[22] We show the existence of an equilibrium with bank run by non-state banks in Appendix A.3, and the detail of solving run case in Appendix A.4. We could rewrite the value function above as the weighted average of values between the non-run and the run case:

$$V^j_t = \max E_{R_b,Z}[(1-p_t)\Omega^j_{t+1}n^j_{t+1} + p_t\Omega^{j*}_{t+1}n^{j*}_{t+1}] \tag{23}$$

where $\Omega^{j*}_{t+1} = \Lambda^*_{t,t+1}\left(1-\sigma^j+\sigma^j\frac{V^{j*}_{t+1}}{n^{j*}_{t+1}}\right)$, V^{j*}_{t+1} and n^{j*}_{t+1} are the value and net worth of bank j in the run case, $E_{R_b,Z}$ is the mathematical expectation with respect to the (R_b, Z) measure.

We can express the banker's evolution of net worth as:

$$n^j_{t+1} = a^j_t R_{a,t+1} + R_{k,t+1}(Q_t + \alpha^j K^j_t)k^j_t - R_{ib,t+1}ib^j_t - R^j_{d,t+1}d^j_t, \tag{24}$$

Then the banker's optimization problem is to solve (23) by choosing $(a^j_t, k^j_t, ib^j_t, d^j_t)$ subject to budget constraint (18), the incentive constraint (19), the liquidity constraint (20) and (24).

V.1.4. *Central Bank.* The central bank is owned by the household. Each period, the central bank issues reserve (IOU) to each type of banks and makes interest payments and principal on reserve issued in the previous period. In addition, the central bank receives the insurance premium on reserve shortfall from the banks. In the absence of bank runs, the central bank rebates to the household the net receipt as a lump-sum transfer

$$T_t = \sum_{j\in\{S,NS\}} [a^j_t - R_{a,t}a^j_{t-1} + \chi(x^j_t)].$$

In the case of bank runs, the central bank (government) would tax the household an extra amount equal to the gap between the promised obligation of the deposit and the liquidated values of non-state banks' assets.

$$T^*_t = \sum_{j\in\{S,NS\}} [a^j_t - R_{a,t}a^j_{t-1} + \chi(x^j_t)] - \left(1-u^{NS}_t\right) R^{NS}_{d,t} D^{NS}_{t-1}$$

where u^{NS}_t is the recovery rate of non-state banks' asset in the case of bank runs, as defined in Appendix A.3.

[22] For example, in May 2019, Baoshang Bank, a non-state bank, had a run.

V.2. **Characterization of Banks' Portfolio Choices.**

V.2.1. *Non-state banks.* In practice, non-state banks may raise funds from both wholesale funding and from deposits, so we focus on this kind of equilibrium. In particular, we restrict attention to model parameterization which generate an equilibrium where the conditions for the following Lemma 1 are satisfied:

Lemma 1. Under assumption 1, $d_t^{NS} > 0$, and incentive constraint is binding and

(1) the deposit rate ceiling is binding and $ib_t^{NS} > 0$, if and only if

$$0 < E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS} - R_{ib,t+1}]\} < \omega \min\{E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS}(1-\rho R_{b,t}) - R_{d,t+1}^{NS}]\}, \theta^{NS}\};$$

(2) the deposit rate ceiling is not binding and $ib_t^{NS} = 0$, if and only if

$$\begin{aligned} 0 &< (1-\gamma)E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS}(1-\rho R_{b,t}) - R_{d,t+1}^{NS}]\} < E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS} - R_{ib,t+1}]\} \\ &< \omega E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS}(1-\rho R_{b,t}) - R_{d,t+1}^{NS}]\} < \omega\theta^{NS}; \end{aligned}$$

In particular, $ib_t^{NS} = 0$ if and only the deposit rate ceiling is not binding.

We first explain the intuition for the case where the deposit rate ceiling is binding. If $E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS} - R_{ib,t+1}]\} < \theta^{NS}\omega$, then at the margin, the non-state bank gains by issuing IB and then diverting funds to its own account. Accordingly, as the incentive constraint (19) requires, rational creditors will restrict lending to the point where the gain from diverting equals the bank franchise value, which is what the non-state bank would lose if it cheated. In addition, for the deposit rate ceiling to be binding, it is necessary that for non-state banks, deposit is preferable to interbank borrowing as a source of fund. This implies a higher return for deposit than ib^{NS}, that is, $E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS} - R_{ib,t+1}]\} < \omega E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS}(1-\rho R_{b,t}) - R_{d,t+1}^{NS}]\}$. Finally, a strictly positive net return for issuing interbank bond ($E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS} - R_{ib,t+1}]\} > 0$) implies that the bank could gain by acquiring wholesale funding until the incentive constraint binds, thus $ib_t^{NS} > 0$.

A similar logic holds for the case where the deposit rate ceiling is not binding. The last inequality means that at the margin the non-state bank gains by issuing deposit and then diverting funds to its own account. Accordingly, rational creditors will restrict lending to the point where the gain from diverting equals the bank franchise value, which is what the non-state bank would lose if it cheated. Moreover, $E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS} - R_{ib,t+1}]\} < \omega E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS}(1-\rho R_{b,t}) - R_{d,t+1}^{NS}]\}$ means that the effective net return of issuing ib^{NS} is smaller than the effective return of d^{NS}, thus the bank should gain from issuing deposits to reduce wholesale funding. Therefore, when the deposit rate ceiling is not binding, $ib_t^{NS} = 0$. Moreover, $(1-\gamma)E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS}(1-\rho R_{b,t}) - R_{d,t+1}^{NS}]\}$ is the effective net return of lending one unit of ib. Hence, the second inequality implies that the net returns of lending in the interbank market is less than the net returns of borrowing from the interbank market, which make sure that non-state banks would not lend to other banks.

Given Lemma 1, we can simplify the evolution of bank net worth to

$$
\begin{aligned}
n_{t+1}^{NS} = [&(R_{k,t+1}^{NS} - R_{ib,t+1})\psi_{ib,t}^{NS} + (R_{k,t+1}^{NS}(R_{b,t}-1) + R_{a,t+1})\kappa \\
&+ (R_{k,t+1}^{NS}(1-R_{b,t}\rho) - \bar{R}_d)\psi_{d,t}^{NS} + R_{k,t+1}^{NS}(1-R_{b,t}\tau)]n_t^{NS}
\end{aligned}
$$

where $\psi_{d,t}^{NS}$ is constrained by deposit rate ceiling:

$$\psi_{d,t}^{NS} = \overline{\psi}_{d,t} \equiv \left(\frac{\overline{R}_d - R}{\xi R}\right)^{\frac{1}{\eta-1}}$$

We define ψ_t^{NS} as a non-state bank's effective leverage multiple, namely the ratio of assets to net worth, where assets are weighted by the relative ease of diversion:

$$
\begin{aligned}
\psi_t^{NS} &= \frac{Q_t k_t^{NS} + a_t^{NS} + \chi(x_t^{NS}) - (1-\omega)ib_t^{NS}}{n_t^{NS}} \\
&= \omega\psi_{ib,t}^{NS} + \psi_{d,t}^{NS} + 1.
\end{aligned}
$$

The weight ω is the ratio of how much a non-state bank can divert from wholesale funding relative to deposit and net worth.

In turn, we can simplify the non-state banks optimization problem to choose the leverage multiple to solve:

$$V_t^{NS} = \max_{\psi_t^{NS}} E_t\{\Omega_{t+1}^{NS}[\frac{1}{\omega}(R_{k,t+1}^{NS} - R_{ib,t+1})\psi_t^{NS} + g_t^{NS}]n_t^{NS}\} \tag{25}$$

subject to the incentive constraint

$$\theta^{NS}\psi_t^{NS}n_t^{NS} \le V_t^{NS},$$

where

$$
\begin{aligned}
g_t^{NS} \equiv\ &(R_{k,t+1}^{NS}(R_{b,t}-1) + R_{a,t+1})\kappa \\
&+ (R_{k,t+1}^{NS}(1-R_{b,t}\rho) - \bar{R}_d - \frac{R_{k,t+1}^{NS} - R_{ib,t+1}}{\omega})\left(\frac{\overline{R}_d - R}{\xi R}\right)^{\frac{1}{\eta-1}} \\
&+ R_{k,t+1}^{NS}(1-R_{b,t}\tau) - \frac{R_{k,t+1}^{NS} - R_{ib,t+1}}{\omega},
\end{aligned} \tag{26}
$$

is a function of $R_{b,t}$, $R_{a,t+1}$, $R_{k,t+1}^{NS}$ and $R_{ib,t+1}$.

Given the incentive constraint is binding under Lemma 1, we can combine the objective with the binding incentive constraint to obtain the following solution for ψ_t^{NS}:

$$\psi_t^{NS} = \frac{\omega E_t(\Omega_{t+1}^{NS} g_t^{NS})}{\theta^{NS}\omega - E_t[\Omega_{t+1}^{NS}(R_{k,t+1}^{NS} - R_{ib,t+1})]}, \tag{27}$$

which is increasing in expected asset returns $R_{a,t+1}$ and $R_{k,t+1}^{NS}$, and decreasing in expected interbank borrowing cost $R_{ib,t+1}$. Intuitively, the franchise value V_t^{NS} increases when returns on assets are higher and decreases when the cost of borrowing is higher. A higher V_t^{NS}, in turn, relax the incentive constraint, allowing non-state bank to leverage more.

From Equation (25) we obtain an expression from the franchise value per unit of net worth:

$$\frac{V_t^{NS}}{n_t^{NS}} = E_t\{\Omega_{t+1}^{NS}[\frac{1}{\omega}(R_{k,t+1}^{NS} - R_{ib,t+1})\psi_t^{NS} + g_t^{NS}]\}, \tag{28}$$

where ψ_t^{NS} is given by Equation (27) and Ω_{t+1}^{NS} is given by Equation (22). It is straightforward to show that $\frac{V_t^{NS}}{n_t^{NS}}$ exceeds unity: the shadow value of a unit of net worth is greater than one, since additional net worth permits the bank to borrow more and invest in assets earning an excess return. In addition, as we conjectured earlier, $\frac{V_t^{NS}}{n_t^{NS}}$ depend only on aggregate variables and not on bank-specific ones.

V.2.2. *State banks.* As discussed earlier, we focus on the case where state banks are both supplying non-financial loans and providing wholesale funding to non-state banks. In particular, we consider a parameterization where in equilibrium Lemma 2 is satisfied.

Lemma 2. Under Assumptions 1, $d_t^S > 0$, $ib_t^S \leq 0$, $k_t^S > 0$ and incentive constraint is binding if and only if

$$0 < E_t\{\Omega_{t+1}^S[R_{k,t+1}^S(1-\rho R_{b,t}) - R_{d,t+1}^S]\} = \frac{1}{(1-\gamma)}E_t\{\Omega_{t+1}^S[R_{k,t+1}^S - R_{ib,t+1}]\} < \theta^S, \tag{29}$$

and $ib_t^S = 0$ if and only if the deposit rate ceiling is not binding.

To explain the intuition, we rewrite the equality condition in Lemma 2 as $E_t\{\Omega_{t+1}^S[R_{ib,t+1}^S - (R_{d,t+1}^S + R_{k,t+1}^S\rho R_{b,t})]\} = \gamma E_t\{\Omega_{t+1}^S[R_{k,t+1}^S - (R_{d,t+1}^S + R_{k,t+1}^S\rho R_{b,t})]\}$. The left side is the effective net return of $(-ib^S)$, and the right side is the effective net return of k^S. Since $\gamma < 1$, this condition implies that $R_{ib,t+1}^S < R_{k,t+1}^S$. Intuitively, for state banks, the the interbank loans are less likely to default that non-financial loans, for them to be indifferent between ib and k^S, the returns for non-financial loans must be higher than the returns for non-financial loans. Note that the presence of reserve requirement and cost of recouping reserve shortfall increases the cost of deposit by $R_{k,t+1}^S\rho R_{b,t}$. Accordingly, when $R_{b,t}$ falls, the expected returns of deposit increases, which increases state-banks' supply of total credit. As with non-state banks, let ψ_t^S be a state bank's effective leverage multiple, where assets are weighted by γ, which is how the ratio of how much a state bank can diver from interbank loans to capital investment.

$$\begin{aligned}\psi_t^S &= \frac{(Q_t + \alpha^S K_t^S)k_t^S + a_t^S + \chi(x_t^S) + \gamma(-ib_t^S)}{n_t^S} \\ &= (1-\gamma)\psi_{ib,t}^S + \psi_{d,t}^S + 1.\end{aligned}$$

Given the restrictions implied by Lemma 2, we can express the state bank's optimization problem similar to the case of non-state bankers as choosing ψ_t^S to solve:

$$V_t^S = \max_{\psi_t^S} E_t\{\Omega_{t+1}^S[(R_{k,t+1}^S(1-\rho R_{b,t}) - R_{d,t+1}^S)\psi_t^S + g_t^S]n_t^S\}, \tag{30}$$

subject to

$$\theta^S \psi_t^S n_t^S \leq V_t^S.$$

where

$$g_t^S \equiv (R_{k,t+1}^S(R_{b,t}-1) + R_{a,t+1})\kappa + R_{k,t+1}^S(1 - R_{b,t}\tau)$$

is a function of $R_{b,t}$, $R_{a,t+1}$ and $R_{k,t+1}^S$.

Given Lemma 2, we can combine the objective with the binding incentive constraint to obtain the following solution for ψ_t^S:

$$\psi_t^S = \frac{E_t(\Omega_{t+1}^S g_t^S)}{\theta^S - E_t[\Omega_{t+1}^S(R_{k,t+1}^S(1-\rho R_{b,t}) - R_{d,t+1}^S)]}, \tag{31}$$

which is increasing in expected asset returns $R_{a,t+1}$ and $R_{k,t+1}^S$, and decreasing in expected deposit rate $R_{d,t+1}^S$.

Finally, from Equation (30) we obtain an expression from the franchise value per unit of net worth:

$$\frac{V_t^S}{n_t^S} = E_t\{\Omega_{t+1}^S[(R_{k,t+1}^S(1-\rho R_{b,t}) - R_{d,t+1}^S)\psi_t^S + g_t^S]\}.$$

As with non-state banks, the shadow value of a unit of net worth exceeds one, and depends only on aggregate variables.

V.3. **Analytical Properties Regarding the Effects of Monetary Policy.** In this section, we establish several propositions regarding theoretical predictions of the impacts of monetary policy. We show that upon a cut of monetary policy interest, (1) wholesale funding activity increases via both an increase in the demand and supply; (2) the demand of capital, and thus, non-financial loans by non-state banks increases; (3) the interest rate of interbank bond falls, when state banks' marginal cost of capital management is sufficiently small.

Proposition 1. When there is monetary ease, both the demand and the supply of wholesale funding would increase for a given capital price q, i.e.,

$$\frac{\partial ib_t^{NS}}{\partial R_{b,t}}\Big|_{Q_t=q} < 0,$$
$$\frac{\partial(-ib_t^{S})}{\partial R_{b,t}}\Big|_{Q_t=q} < 0.$$

Thus, the equilibrium amount IB_t increases.

The intuition is that when $R_{b,t}$ decreases, the reserve recoup cost and thus the effective cost of deposit drop. Accordingly, both state and non-state banks would like to increase their credit supply by leveraging more. For non-state banks, since their deposit demand is constrained due to the presence of deposit rate ceiling, they would increase the demand for wholesale funding. For state banks, from Lemma 2, it is easy to see that upon a cut in monetary policy rate, the marginal increase of the effective returns for interbank loans is higher than that of the effective returns for non-financial loans, as interbank loans are less likely to be diverted than non-financial loans. As a result, state banks always prefer to increase wholesale loans first. Thus, both the demand and supply of wholesale funding increase.

This proposition shows that the wholesale funding market would facilitate non-state banks to increase their liability in response to a cut in policy interest rates, even though their deposit demand is constrained under the deposit rate ceiling. Accordingly, we can establish the following proposition that upon monetary policy easing, non-state banks' supply of non-financial loans increases.

Proposition 2. When the policy interest rate is cut, the demand of capital investment by non-state banks increases, i.e.,

$$\frac{\partial k_t^{NS}}{\partial R_{b,t}}\Big|_{Q_t=q} < 0.$$

It is straightforward to understand why the demand from non-state banks k_t^{NS} increases. A drop of $R_{b,t}$ reduces reserve recoup cost. As a result, the effective returns of non-financial loans by non-state banks increases. Since the wholesale funding market allows them to borrow more, the demand of k_t^{NS} increases.

Our next proposition relates to the transmission of monetary policy interest rates to the interbank borrowing rate. In our empirical exercise in Section IV, we show that when the policy interest rate is cut, the at-issue yield of NCD declines. In the following proposition, we show that under some parameterization restriction, this feature holds in our model.

Proposition 3. With run probability p_t equal to 0 at steady state, the wholesale funding cost decreases with policy interest rate, i.e., $\frac{\partial R_{ib,t+1}}{\partial R_{b,t}} > 0$, if

$$\alpha^S \cdot [(Z_{t+1} + Q_{t+1})\frac{\partial K_t^S}{\partial R_{b,t}} - K_t^S \frac{\partial Q_{t+1}}{\partial R_{b,t}}] < \frac{\partial Q_{t+1}}{\partial R_{b,t}} Q_t - (Z_{t+1} + Q_{t+1})\frac{\partial Q_t}{\partial R_{b,t}}. \tag{32}$$

Intuitively, in equilibrium state banks make two types of loans, interbank lending ($-ib_t^S$) and non-financial loans (k_t^S). The no-arbitrage condition implies that the effective returns of these two assets are equal in equilibrium. Hence, in response to a cut in policy interest rates, a decrease $R_{ib,t+1}$ necessarily implies a decrease in $R_{k,t+1}^S$. The condition (32) ensures that $R_{k,t+1}^S$ would decrease when $R_{b,t}$ decreases. Since $R_{k,t+t}^S = \frac{(Z_{t+1}+Q_{t+1})}{Q_t+\alpha^S K_t^S}$, a cut in policy rates affects the expected capital returns for state banks via two offsetting channels. On the one hand, an increase in demand for capital by non-state banks pushes up the current-period capital price (Q_t), which reduces $R_{k,t+1}^S$.[23] This channel is captured by the right-hand-side of (32). On the other hand, a decrease in capital investment by state banks (K_t^S) at equilibrium would increase $R_{k,t+1}^S$ via a decrease in marginal cost of capital management. This channel is captured by the left-hand-side of (32). Hence, the inequality (32) makes sure that the first channel dominates, so that the marginal impact of $R_{b,t}$ on $R_{k,t+1}^S$ is positive. Given that the left-hand-side of (32) is positive[24], (32) implies an upper bound for α^S, $\frac{\frac{\partial Q_{t+1}}{\partial R_{b,t}} Q_t - (Z_{t+1}+Q_{t+1})\frac{\partial Q_t}{\partial R_{b,t}}}{(Z_{t+1}+Q_{t+1})\frac{\partial K_t^S}{\partial R_{b,t}} - K_t^S \frac{\partial Q_{t+1}}{\partial R_{b,t}}}$.

[23]We prove in Appendix B that Q_t must increase when $R_{b,t}$ decreases.

[24]This can be ensured by $\frac{\partial Q_{t+1}}{\partial R_{b,t}} < 0$ and $\frac{\partial K_t^S}{\partial R_{b,t}} > 0$, which always hold in our numerical results.

We give the intuition for the existence of upper bound of α^S: by Proposition 1, both the demand and the supply of wholesale funding would increase when the policy interest rate is cut. In order for $R_{ib,t+1}$ to decrease, the increase in demand for wholesale funding by non-state banks should be dominated by the increase in its supply. This implies that in equilibrium capital demand (or supply of non-financial loans) by non-state banks should not increase much. As state and non-state compete for capital investment, the relative capital demand by the non-state banks is governed by the difference between the efficiency of state banks and non-state banks $\alpha^S (= \alpha^S - \alpha^{NS})$. Accordingly, this imposes an upper bound for α^S.

In summary, Proposition 1 to 3 provide theoretical justifications on our empirical findings in Section IV regarding the impacts of policy interest rates on non-state banks' demand for wholesale funding, their total bank credit and wholesale borrowing interest rates. A natural question is what is the role of wholesale funding for monetary transmission into the macroeconomy and systemic risks and what's the trade-off of regulations on wholesale funding, which we explore in the next section.

VI. Role of wholesale funding for monetary transmission and systemic risks

In this section, we provide the simulated results of several numerical experiments of our model, and illustrate how wholesale funding could affect the monetary transmission, and generate systemic risks.[25] We then examine how the regulation on wholesale funding will trade off between systemic risks and the effectiveness of monetary policy. Overall these examples show that wholesale funding helps the transmission of monetary policy to real economy, but also increases the potential systemic risk during recession. Regulation on wholesale funding helps to control the systemic risks, and mitigates the impacts of the negative productivity shocks on the whole economy, but also impedes the transmission of monetary policy, and hinders the credit reallocation from state to non-state banks.

VI.1. **Role of wholesale funding for monetary transmission.** Figure 4 shows the response of the benchmark economy to an unanticipated shock to policy interest rate (R_b) by reducing the policy rate to half of its steady state value (0.575 percentage point). An cut of monetary policy interest rate reduces the cost of recouping reserve shortfall. As a result, both state and non-state banks increase their demand for deposit. However, since the

[25]There are 23 parameters in the model and their values are reported in Appendix Table S1.

deposit rate ceiling is binding for non-state banks, they need to resort to wholesale funding market to finance for investment in capital. State banks, on the other hands, are the net supplier of the wholesale funding market. The issuance of IB by non-state banks increases by 15.4% on impact. Consistent with the empirical findings in Section IV, the cost of the wholesale funding cost drops by 13 basis points in response to monetary policy easing. This suggests that in our model the increase in the wholesale funding is mainly driven by the increase in its supply.

As a result, the total capital help by non-state banks increase by 13.7 percent. Capital by state banks, on the other hand, drop on impact by about 3.2 percent from steady state. This liquidity transmission, by reallocating capital from less productive state banks into more productive non-state banks, leads to an increase in aggregate output by 0.9 percent on impact. Since the demand for capital increases, its price rises by 2.4 percent from the steady state.

An increase in aggregate output translates an increase in household consumption by 0.4%, as shown by the bottom left panel. This is because, as equation (14) suggests, a loose monetary policy would reduce the deposit interest rate for the state banks along with capital outflow. This would encourage households to increase their consumption on impact with a gradual decline thereafter. Finally, an increase in the capital prices increases the net worth of non-state banks and state banks by 45% and 14%, respectively. The increase of net worth will further propagate the monetary policy shocks through the standard financial accelerator channel. Note that throughout the monetary policy easing, the run probability is always kept zero, the steady state value, as an increase in the bank's net worth strengthens its balance sheet.

VI.2. **Role of wholesale funding for systemic risks.** We now turn to the role wholesale funding for systemic risks. Figure 5 shows the response of the economy to an unanticipated negative 4% shock to productivity Z_t, assuming that a run does not actually occur ex post. A negative productivity shocks reduce the demand for capital, which leads to a drop of capital prices by about 3.7%. As a result, non-state banks' asset value drops by about 70%. Consistent with our empirical results, this leads to an increase in the non-state banks' run probability p by 3.6%. Such an increase in the run probability is anticipated by state banks. State banks, thus reduce the supply of wholesale funding in the interbank market. Moreover, a fall in the net worth by non-state banks reduce their ability to use wholesale funding to roll over the debt. Accordingly, the IB issuance reduces by 35% and the quarterly cost of issuing IB increases by 9 basis points.

A contraction of wholesale funding market further reduces the demand for capital by non-sate banks, which reallocates capital from non-state banks to state banks. As a result, capital managed by non-state banks reduces by 34% and that by state banks increases by 19%. This capital reallocation, by reducing the aggregate productive efficiency, reduces the aggregate output by around 3.1%. Household consumption drops by about 1.2% on impact, due to a negative wealth effect from banks' profit and both state and non-state banks' deposit rates increase. Finally, the net worth of both non-state and state banks is reduced, by 70% and 22% respectively, which further amplifies and propagates the effects of negative productivity shocks on the economy.

Our results suggest that the presence of wholesale funding makes non-state banks over-leveraged, since they fail to take into accounts the externality effect of their own borrowing on the probability of bank runs in the wholesale funding markets. As a result, it leads to high systemic risks during recession, and the rising run probability, in turn, reducing the net worth of non-state banks, making them more difficult to finance either through wholesale funding or deposits. Capital is reallocated to less productive state banks and the household, which amplified the negative shocks to the real economy. The natural question is then how regulation on the wholesale funding plays a role in the economy.

VI.3. **Optimal regulation on wholesale funding markets.** In this section, we look at how regulation on wholesale funding trade off between the effectiveness of monetary transmission and exposure of the banking sector to systemic risks. On the one hand, the existence of deposit rate ceiling reduces the effectiveness of monetary policy transmission into the credit market, which provides a rationale for interbank bond markets. On the other hand, the decentralized interbank markets is inefficient for two reasons. First, there is a peculiar externality that leads non-state banks to fail to internalize the impacts of their leverage decision on the price of capital, which tend to encourage them to over borrow in the interbank bond markets. Second, state banks also fail to internalize the impacts of their investment decisions on interbank bonds on the run probability of non-state banks. The inefficiency of the decentralized equilibrium with regulation on interbank markets that trade off the effectiveness of monetary policy and exposure of the economy to systemic risks.

The particular policy we consider is a ceiling in NCDs issuance by non-state banks that restricts their leverage via wholesale funding. To compare with our benchmark results, we make sure that this ceiling is not binding at the steady state, and it only starts to bind when there is monetary policy ease. To be specific, the regulation is as give by:

$$ib_t^j \leq \phi ib_{ss}^j,$$

if $ib_t^j \geq 0$, where ib_{ss}^j is the steady state amount of ib^j.

The optimal regulation ϕ is chosen to maximize the representative household's welfare. Welfare gain under the optimal regulation on IB market relative to the benchmark model (without regulation) is measured as a permanent increase in consumption each period for the benchmark economy that would leave the representative household indifferent between living in an environment under the optimal regulation for interbank markets and in the benchmark economy. We introduce a negative 2.5% productivity shock Z_t that would be realized in period 9 with a probability ϱ. The realization of Z_t is unexpected during the period of monetary easing (the first 8 quarters). Denote C_t and C_t^* as the consumption level under the benchmark model and the case with optimal regulation. Denote V^o as the lifetime utility of household under the optimal regulation. Then, the welfare measure χ can be solved from

$$E_0 \sum_{t=0}^{\infty} \beta^t \log C_t (1+\chi) = E_0 \sum_{t=0}^{\infty} \beta^t \log C_t^* \equiv V^o;$$

To understand the trade-off of regulation on interbank market, we first show the impulse responses of the economy when monetary policy eases under optimal regulation on wholesale funding markets, assuming that the negative shocks to Z_t is never realized. Figure 6 compares the response of each variable to monetary policy ease with and without regulation on non-state banks' leverage with wholesale funding. With regulation, the quantity of IB will be restricted. As a result, IB increases by about 4%, as contrast to a 15% increase in the benchmark economy. The fact that the impulse response of IB is flat for 14 quarters suggests that during this period, the constraint on IB issuance is binding. As a result, capital demand by non-state banks is dampened, with an increase of only 4.1%, in contrast to a 13.7% increase in the case without regulation. Capital demand by the state bank, by contrast, increases by 3.5%. A smaller increase in capital demand also shows up as smaller increase in capital prices compared with the case without regulation. As a result, there is a much smaller improvement in capital allocation, as shown by a 0.42% increase in aggregate output on impact, less than half of the magnitude without regulation. The increase in household consumption on impact, accordingly is 0.26%, about half of the magnitude for the case without regulation. Hence, regulation on IB issuance reduces the effectiveness of monetary policy.

Figure 7 shows how various variables react differently between the economy with and without regulation, conditional on the realization of negative shocks to Z_t at period 9. As in Figure 6, during the period of monetary policy ease, the increase of IB and non-state banks' capital is much dampened compared with the case without regulation. Accordingly, the increase in aggregate output and household consumption during monetary policy ease is reduced by half as that without regulation. However, when the negative productivity shocks hit the economy, regulation on wholesale funding helps to alleviate the destructiveness of recession. The reduction of IB is only 20%, which is about half of its counterpart in the case without regulation. Accordingly, the drop of capital by non-state banks is about half of the case without regulation (20%). Aggregate output decreases by 1.85%, as contrast to a 3% drop in the case without regulation. The run probability by non-state banks increases by 1%, compared with 3.7% without regulation. The drop in consumption is persistently smaller than its counterpart without regulation.

The overall effect of the optimal regulation on output, welfare and run probability are reported in the right column of Table 8. To compare, we report the behavior of the decentralized economy in the left column. Regulation on wholesale funding markets cut the quarterly (unconditional) run probability from 2.26 to 0.64 percent. Without realization of the negative productivity shocks, the regulation on wholesale funding markets leads to a decrease in output by 0.47 percent on impact. However, the optimal regulation on wholesale funding helps to control the increase in the probability of run in the wholesale funding markets and thus mitigate the impacts of negative productivity shock on the real output by 0.64 percent when the negative Z_t is realized in period 9. Accordingly, the optimal regulation on wholesale funding market delivers a welfare gain of 0.14 percentage points of consumption relative to the decentralized equilibrium.

VII. Conclusion

This paper studies the role of wholesale funding for interest-rate based monetary policy transmission into bank credit supply and for the rapid increase in systemic risks of China's banking system since 2018. With three unique micro datasets, our key empirical finding is that wholesale funding via interbank certificates of deposit not only facilitates policy interest rates to transmit into loan supply by non-state banks, but also leads to fast growth in their shadow banking activities as an unintended consequence. Accordingly, non-state banks with a heavier exposure to wholesale funding witness a larger increase in systemic risks in response to negative shocks to the economy since 2018. In contrast, wholesale fund play no role for monetary policy transmission into state banks' credit supply.

We explain our empirical findings with a model that incorporates two China's institutional facts as key ingredients: a dual-track interest rate system and deposit market segmentation between state and non-state banks. The model uncovers a unique channel of monetary policy transmission via interbank wholesale fund: a cut in policy interest rates, by reducing the cost of recouping reserve shortfall, increases banks' deposit demand. The presence of deposit rate ceiling, however, prevents non-state banks to draw sufficient deposits to increase their credit supply. State banks, by contrast, can effectively raise their deposits due to the perfect elasticity of their deposit supply. As a result, state banks, as the net supplier in the wholesale funding market, help transmit the increased liquidity due to monetary policy easing into non-state banks. Such a channel of monetary transmission is in contrast to those in the literature, in which either wholesale funding plays no role in monetary policy transmission or move in the same direction of policy interest rates.

Consistent with our empirical results, our model also shows that non-state banks, by ignoring the externality effects of their borrowing on the probability of bank runs, tend to be over-leveraged via wholesale funding and invest in risky projects during a period of monetary easing. As a consequence, when the economy experiences a negative productivity shock, the run probability of non-states increase much faster relative to the case when bank wholesale funding is regulated. Regulation on wholesale funding, thus, faces a trade-off between the effectiveness of monetary policy transmission and banks' exposure to systemic risks. We hope our work lays an empirical and theoretical foundation for future research on optimal macroprudential regulation in interbank wholesale funding for both emerging and developed economies.

Table 1. Summary Statistics

Variables	Obs	Mean	Std.Dev.	Min	Max
Panel A: NCD Issuance Variables					
State Banks					
IssVol (bn RMB)	1644	1.65	2.96	0.01	31.60
Yield(%)	1634	3.82	0.70	2.20	5.70
Maturity(year)	1644	0.44	0.31	0.08	2.00
Nonstate Banks					
IssVol (bn RMB)	46375	1.02	1.72	0.01	48.29
Yield(%)	46354	3.99	0.81	1.90	6.10
Maturity(year)	46375	0.49	0.35	0.08	3.00
Panel B: Bank-level Variables					
State Banks					
NCD/Asset(%)	124	0.15	0.37	0.00	2.32
BankLoan/Asset(%)	104	52.20	2.76	46.88	57.55
ShadowLoan/Asset(%)	80	5.17	1.19	3.15	7.56
ROA(%)	124	0.99	0.23	0.48	1.40
IL(%)	123	8.12	4.52	0.00	18.35
LIQ(%)	124	4.40	1.59	1.54	8.29
SRISK(bn RMB)	104	53.17	16.67	17.38	80.94
Nonstate Banks					
NCD/Asset(%)	2982	2.73	3.61	0.00	22.83
BankLoan/Asset(%)	283	44.81	7.82	26.89	59.76
ShadowLoan/Asset(%)	194	7.57	6.48	0.55	29.09
ROA(%)	2978	0.89	0.36	0.02	2.47
IL(%)	2848	9.47	8.65	0.00	49.76
LIQ (%)	2982	9.60	6.98	0.00	54.07
SRISK(10bn RMB)	283	11.31	8.28	0.00	29.09
Panel C: Macro Variables					
R007(%)	22	3.17	0.65	2.42	4.71
R3M(%)	22	4.13	0.96	2.82	6.18
SHIBOR3M(%)	22	3.93	0.90	2.81	5.54

Notes: "NCD" stands for negotiable certificate of deposit, "IssVol" stand for issuing volume. "ROA" is the ratio of net income toy total assets, "IL" is ratio of interbank liability to total liability, "LIQ" stands for liquidity ratio, measured as the ratio of liquid assets to total assets, "SRISK" stands for the expected capital shortfalls given a financial crisis. "R007" is the 7-day reserve repo rate; "R3M" is the 3-month reverse repo rate; and "SHIBOR3M" stands for 3-month Shanghai Interbank Offered Rate.

Table 2. Transmission of Monetary Policy Interest Rates to NCD Yield

	R007	R3M	SHIBOR3M
	(1)	(2)	(3)
$I(NSB_b)$: α	0.431***	0.376***	0.409***
	(0.0293)	(0.0314)	(0.0370)
R_{t-1}: β	0.659***	0.524***	0.482***
	(0.0210)	(0.0129)	(0.0176)
Maturity: α_m	0.306***	0.314***	0.312***
	(0.0238)	(0.0192)	(0.0177)
ROA_{t-1}	-0.112	-0.108	-0.119
	(0.0641)	(0.0673)	(0.0616)
IL_{t-1}	-0.00287**	-0.00352**	-0.00378**
	(0.00108)	(0.00113)	(0.000999)
LIQ_{t-1}	0.00113	0.00185	0.00122
	(0.00101)	(0.00121)	(0.00134)
$BankFE$	YES	YES	YES
$YearFE$	YES	YES	YES
N	47988	47988	47988
$R-square$	0.6610	0.6851	0.6948

Notes: This table reports the regression results in which the dependent variable is a transaction-level observation of at-issue NCD yield. The right-hand-side variables include monetary policy interest rate (R_{t-1}), measured as R007, R3M or SHIBOR3M, a dummy variable that equals to one if a bank is a non-state bank and zero otherwise ($I(NSB_b)$) and the maturity of NCD ($Maturity$). The bank-level control variables include lagged net scaled by total assets(R_{t-1}), the lagged ratio of interbank liability to total liability (IL_{t-1}) and the lagged ratio of liquid assets to total assets (LIQ_{t-1}). The regressions of column (1), (2) and (3) control for bank and year fixed effects. Robust standard errors clustered by bank type are reported in parentheses. ***,**, and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

TABLE 3. Effect of Monetary Policy Interest Rates to NCD Volume

	R007	R3M	SHIBOR3M
	(1)	(2)	(3)
R_{t-1}: α	0.861**	0.382***	0.733***
	(0.227)	(0.0558)	(0.136)
R_{t-1} $\times I(NSB_b)$: β	-1.503***	-0.769***	-1.027***
	(0.162)	(0.0893)	(0.142)
$I(NSB_b)$: η	7.877***	6.405***	7.028***
	(0.956)	(0.736)	(0.853)
$R_{t-1}\times$ ROA_{t-1}	0.200	0.0310	0.0113
	(0.118)	(0.0775)	(0.113)
R_{t-1} $\times$ IL_{t-1}	-0.0366*	-0.0243*	-0.0339*
	(0.0149)	(0.0102)	(0.0149)
R_{t-1} $\times$ LIQ_{t-1}	0.0185	0.00836	0.00750
	(0.0123)	(0.00816)	(0.0117)
$\alpha+\beta$	-0.642***	-0.387***	-0.294**
$SingleTerm$	YES	YES	YES
$BankFE$	YES	YES	YES
$YearFE$	YES	YES	YES
N	2640	2640	2640
$R-square$	0.5861	0.5845	0.5867

Notes: This table reports the regression results in which the dependent variable is a bank-quarter observation of NCD issuing volume scaled by total assets. The right-hand-side variables include monetary policy interest rate (R_{t-1}), measured as R007, R3M or SHIBOR3M, a dummy variable that equals to one if a bank is a non-state bank and zero otherwise ($I(NSB_b)$) and the interaction between R_{t-1} and $I(NSB_b)$. The bank-level control variables include lagged net scaled by total assets(R_{t-1}), the lagged ratio of interbank liability to total liability (IL_{t-1}) and the lagged ratio of liquid assets to total assets (LIQ_{t-1}) and their interaction terms with R_{t-1}. The regressions of column (1), (2) and (3) control for bank and year fixed effects. Robust standard errors clustered by bank type are reported in parentheses. ***,**, and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Table 4. Effect of NCD in Monetary Transmission to Bank Loan

	State			non-state		
	R007	R3M	SHIBOR3M	R007	R3M	SHIBOR3M
	(1)	(2)	(3)	(4)	(5)	(6)
NCD_{t-1}: α	3.384	2.347	2.567	0.578*	0.508	0.349
	(3.945)	(5.443)	(5.102)	(0.323)	(0.298)	(0.235)
$R_{t-1} \times NCD_{t-1}$: β	-1.423	-0.821	-0.912	-0.247**	-0.163**	-0.135**
	(0.983)	(1.017)	(0.984)	(0.107)	(0.0744)	(0.0608)
$R_{t-1} \times ROA_{t-1}$	-2.779	-1.813	-2.395	5.761**	3.272*	3.587
	(1.487)	(0.915)	(1.142)	(2.672)	(1.790)	(2.285)
$R_{t-1} \times IL_{t-1}$	0.196***	0.111***	0.155**	0.0907*	0.0505*	0.0546*
	(0.0321)	(0.0235)	(0.0355)	(0.0443)	(0.0269)	(0.0265)
$R_{t-1} \times LIQ_{t-1}$	-0.187*	-0.130	-0.141	-0.0548	-0.0517	-0.0659
	(0.0813)	(0.0633)	(0.0827)	(0.0584)	(0.0357)	(0.0452)
$SingleTerm$	YES	YES	YES	YES	YES	YES
$BankFE$	YES	YES	YES	YES	YES	YES
$QuarterFE$	YES	YES	YES	YES	YES	YES
N	104	104	104	283	283	283
$R-square$	0.5225	0.4691	0.5429	0.7253	0.7242	0.7223

Notes: This table reports the regression results in which the dependent variable is a bank-quarter observation of outstanding bank loans scaled by total assets. The right-hand-side variables include lagged NCD issuing volume, scaled by total assets (NCD_{t-1}) and its interaction with monetary policy interest rate (R_{t-1}), measured as R007, R3M or SHIBOR3M. The bank-level control variables include lagged net scaled by total assets(R_{t-1}), the lagged ratio of interbank liability to total liability (IL_{t-1}) and the lagged ratio of liquid assets to total assets (LIQ_{t-1}) and their interaction terms with R_{t-1}. Column (1), (2) and (3) are for the sub-sample of state banks. Column (4), (5) and (6) are for the sub-sample of non-state banks. All regressions control for bank and quarter fixed effects. Robust standard errors clustered by bank are reported in parentheses. ***,**, and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Table 5. Effect of NCD in Monetary Transmission to Shadow Loan

	State			non-state		
	R007	R3M	SHIBOR3M	R007	R3M	SHIBOR3M
	(1)	(2)	(3)	(4)	(5)	(6)
NCD_{t-1}: α	-0.272	-2.756	-0.0381	1.334**	0.933**	1.132**
	(6.118)	(3.043)	(3.782)	(0.511)	(0.394)	(0.401)
$R_{t-1} \times NCD_{t-1}$: β	0.350	0.849	0.232	-0.412**	-0.204**	-0.273**
	(2.298)	(1.264)	(1.320)	(0.157)	(0.0908)	(0.0970)
$R_{t-1} \times ROA_{t-1}$	0.0653	0.181	-0.0381	2.975	2.363	2.262
	(0.938)	(0.403)	(0.324)	(2.945)	(2.010)	(3.023)
$R_{t-1} \times IL_{t-1}$	-0.0271	-0.0103	-0.0326**	-0.0379	-0.0188	-0.0331
	(0.0239)	(0.0126)	(0.0101)	(0.0352)	(0.0252)	(0.0264)
$R_{t-1} \times LIQ_{t-1}$	-0.108	-0.0793	-0.102	0.0325	0.0124	0.0367
	(0.0767)	(0.0653)	(0.0803)	(0.0623)	(0.0454)	(0.0509)
$SingleTerm$	YES	YES	YES	YES	YES	YES
$BankFE$	YES	YES	YES	YES	YES	YES
$QuarterFE$	YES	YES	YES	YES	YES	YES
N	80	80	80	194	194	194
$R-square$	0.4050	0.3977	0.4172	0.4538	0.4508	0.4554

Notes: This table reports the regression results in which the dependent variable is a bank-quarter observation of outstanding shadow loans scaled by total assets. The right-hand-side variables include lagged NCD issuing volume, scaled by total assets (NCD_{t-1}) and its interaction with monetary policy interest rate (R_{t-1}), measured as R007, R3M or SHIBOR3M. The bank-level control variables include lagged net scaled by total assets(R_{t-1}), the lagged ratio of interbank liability to total liability (IL_{t-1}) and the lagged ratio of liquid assets to total assets (LIQ_{t-1}) and their interaction terms with R_{t-1}. Column (1), (2) and (3) are for the sub-sample of state banks. Column (4), (5) and (6) are for the sub-sample of non-state banks. All regressions control for bank and quarter fixed effects. Robust standard errors clustered by bank are reported in parentheses. ***,**, and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

TABLE 6. Effect of NCD in Monetary Transmission to Total Credit

	State			non-state		
	R007	R3M	SHIBOR3M	R007	R3M	SHIBOR3M
	(1)	(2)	(3)	(4)	(5)	(6)
$NCD_{t-1} : \alpha$	-2.369	4.273	-0.0639	1.708**	1.211*	1.358**
	(14.08)	(9.540)	(8.296)	(0.736)	(0.636)	(0.621)
$R_{t-1} \times NCD_{t-1}$: β	-0.518	-2.151	-0.958	-0.589**	-0.310*	-0.376**
	(4.785)	(2.624)	(2.383)	(0.247)	(0.159)	(0.163)
$R_{t-1} \times ROA_{t-1}$	-2.524**	-1.998***	-3.546***	7.855**	5.655**	5.821
	(0.820)	(0.307)	(0.427)	(3.020)	(2.297)	(3.483)
$R_{t-1} \times IL_{t-1}$	0.191***	0.121***	0.133***	0.0611	0.0508	0.0480
	(0.0368)	(0.0239)	(0.0286)	(0.056)	(0.0383)	(0.0400)
$R_{t-1} \times LIQ_{t-1}$	-0.233**	-0.197**	-0.187**	-0.0346	-0.0491	-0.0471
	(0.0632)	(0.0517)	(0.0429)	(0.0658)	(0.0530)	(0.0529)
SingleTerm	YES	YES	YES	YES	YES	YES
BankFE	YES	YES	YES	YES	YES	YES
QuarterFE	YES	YES	YES	YES	YES	YES
N	80	80	80	194	194	194
$R - square$	0.6131	0.5909	0.6566	0.5730	0.5783	0.5709

Notes: This table reports the regression results in which the dependent variable is a bank-quarter observation of outstanding total bank credit scaled by total assets. The right-hand-side variables include lagged NCD issuing volume, scaled by total assets (NCD_{t-1}) and its interaction with monetary policy interest rate (R_{t-1}), measured as R007, R3M or SHIBOR3M. The bank-level control variables include lagged net scaled by total assets(R_{t-1}), the lagged ratio of interbank liability to total liability (IL_{t-1}) and the lagged ratio of liquid assets to total assets (LIQ_{t-1}) and their interaction terms with R_{t-1}. Column (1), (2) and (3) are for the sub-sample of state banks. Column (4), (5) and (6) are for the sub-sample of non-state banks. All regressions control for bank and quarter fixed effects. Robust standard errors clustered by bank are reported in parentheses. ***,**, and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Table 7. Effect of NCD on Bank Systemic Risk

	State	non-state
	(1)	(2)
$I(Year > 2017) \times NCD_{t-1} : \alpha_r$	305.6	15.84**
	(511.0)	(6.641)
$I(Year > 2017) \times g_{t-1} \times NCD_{t-1} : \beta_r$	-43.34	-2.286**
	(71.52)	(0.947)
NCD_{t-1}: α	-328.6	-8.635
	(512.2)	(6.422)
$g_{t-1} \times NCD_{t-1} : \beta$	46.75	1.236
	(71.79)	(0.915)
$g_{t-1} \times ROA_{t-1}$	0.222	13.99*
	(28.93)	(6.941)
$g_{t-1} \times IL_{t-1}$	-0.0832	-0.295***
	(0.843)	(0.0736)
$g_{t-1} \times LIQ_{t-1}$	0.500	0.276
	(1.851)	(0.188)
$SingleTerm$	YES	YES
$BankFE$	YES	YES
$QuarterFE$	YES	YES
N	104	283
$R - square$	0.7785	0.6763

Notes: This table reports the regression results in which the dependent variable is a bank-quarter observation of SRISK. The right-hand-side variables include lagged NCD issuing volume, scaled by total assets (NCD_{t-1}), real year-over-year GDP growth rate (g_{t-1}), a dummy variable that equals to one if a quarter belongs to 2018 and beyond and zero otherwise ($I(Year > 2017)$), and the double and triple interactions among these three variables. The bank-level control variables include lagged net scaled by total assets(R_{t-1}), the lagged ratio of interbank liability to total liability (IL_{t-1}) and the lagged ratio of liquid assets to total assets (LIQ_{t-1}) and their interaction terms with g_{t-1}. Column (1) is for the sub-sample of state banks and column (2) is for the sub-sample of non-state banks. Both regressions control for bank and quarter fixed effects. Robust standard errors clustered by bank are reported in parentheses. ***,**, and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

Table 8. Effect of Wholesale Funding Regulation

	Decentralized Economy	Optimal Regulation (ϕ=1.04)
Run Frequency	2.26 pct	0.64 pct
AVG Output Cond No Z Shock Δ from Decentralized Economy	0 pct	-0.47 pct
AVG Output Δ from Decentralized Economy	0 pct	0.64 pct
Welfare Gain Δ Consumption	0 pct	0.14 pct

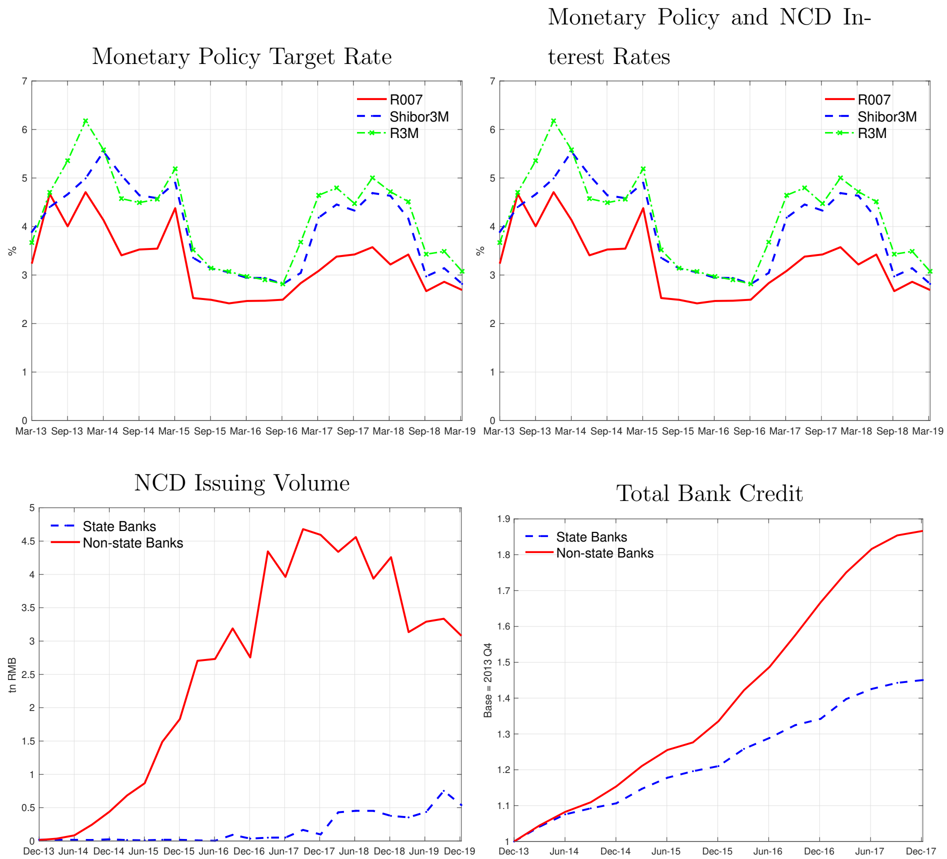

Figure 1. Monetary Policy and NCD Issuance

Notes: The four panels are organized as follows. The top left panel: monetary policy interest rates, measured as 7-day reverse repo rate (R007), 3-month reverse repo rate (R3M) or 3-month Shanghai Interbank Offered Rate (SHIBOR3M); The top left panel: at-issue 3-month NCD yield (AAA) and monetary policy rates of the same maturity; the bottom left panel: total NCD issuing volume by state and non-state banks; the bottom right panel: total bank credit by non-state bank and state banks, normalized by the respective 2013Q4 levels. We sum up the NCD issuing volume for each bank group from our transaction-level data on NCD issuance. The total bank credit is computed as the sum of bank loan and AFVX and AFSX, our measures of shadow assets in individual banks' balance sheets and is aggregated for each bank group.

Sources: The transaction-level data on NCD issuance, the bank panel data and CEIC.

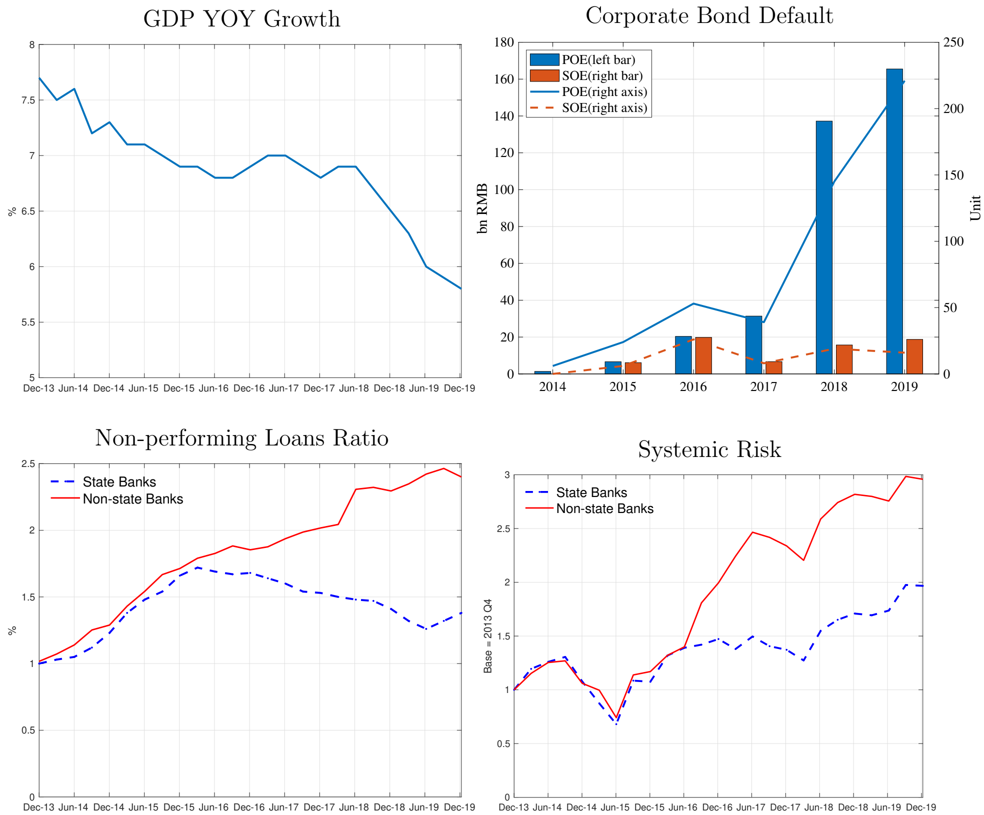

FIGURE 2. Credit Default and Systemic Risks during Recession

Notes: The four panels are organized as follows. The top left panel: real year-over-year GDP growth rate at quarterly frequency. The top right panel: corporate bond default amount and number. The bottom left panel: non-performing loan ratios of various types of banks. The bottom right panel: systemic risks of various types of banks.

Sources: CEIC, WIND and NBS.

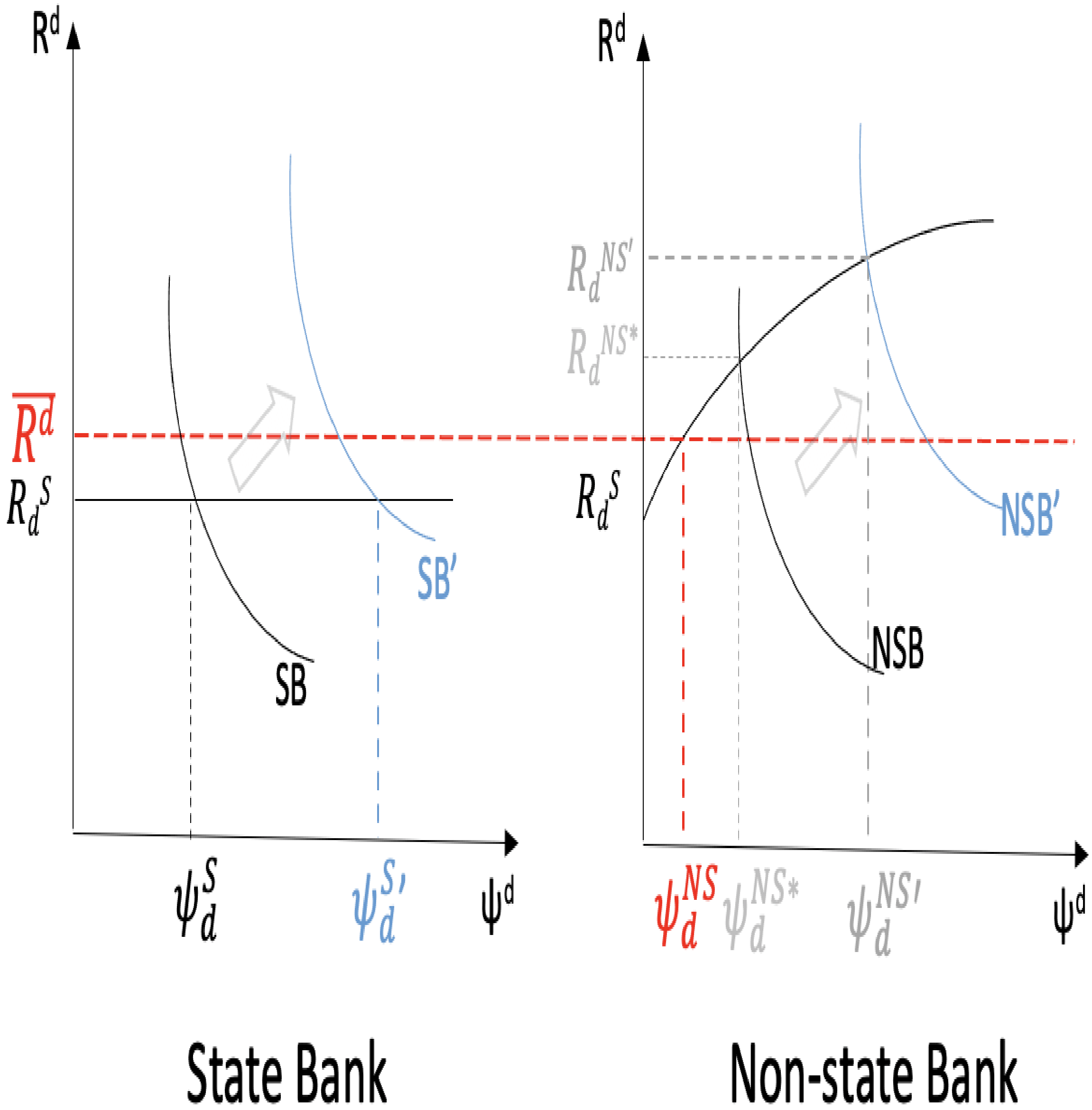

FIGURE 3. Effect of Monetary Policy Easing on Deposit Demand

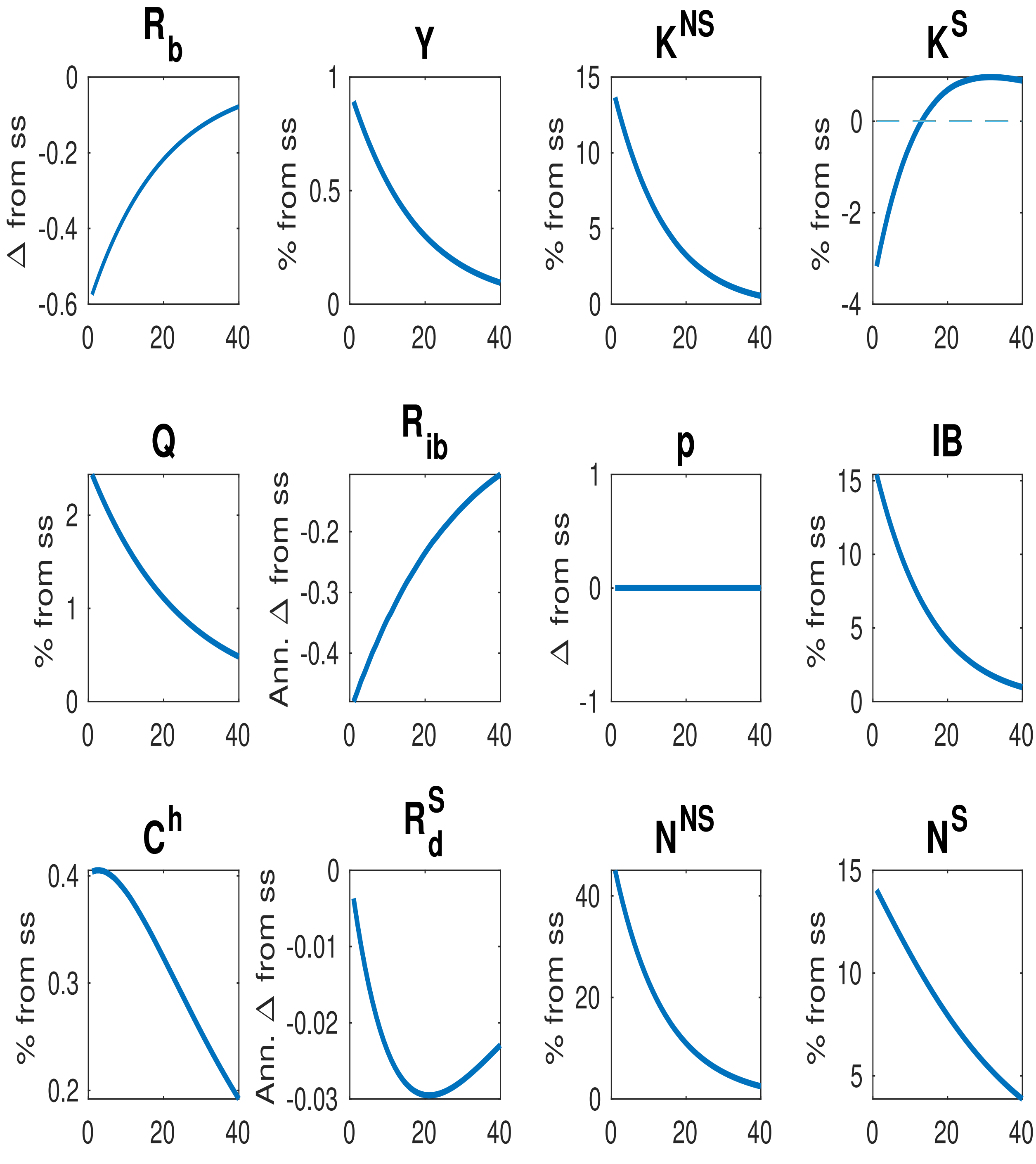

FIGURE 4. Impulse Response to Monetary Policy Shocks: Benchmark Model

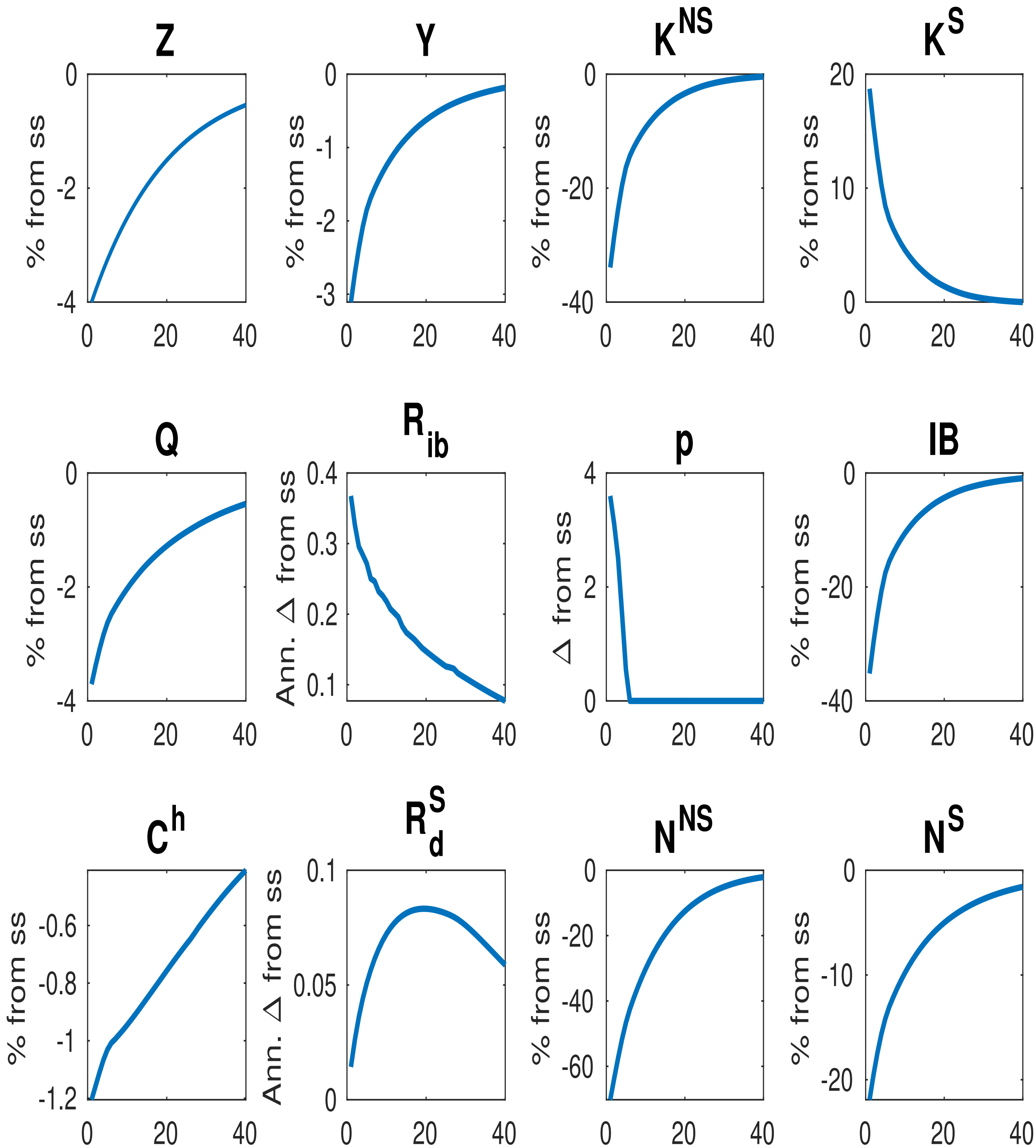

FIGURE 5. Impulse Response to Negative Productivity Shocks: Benchmark Model

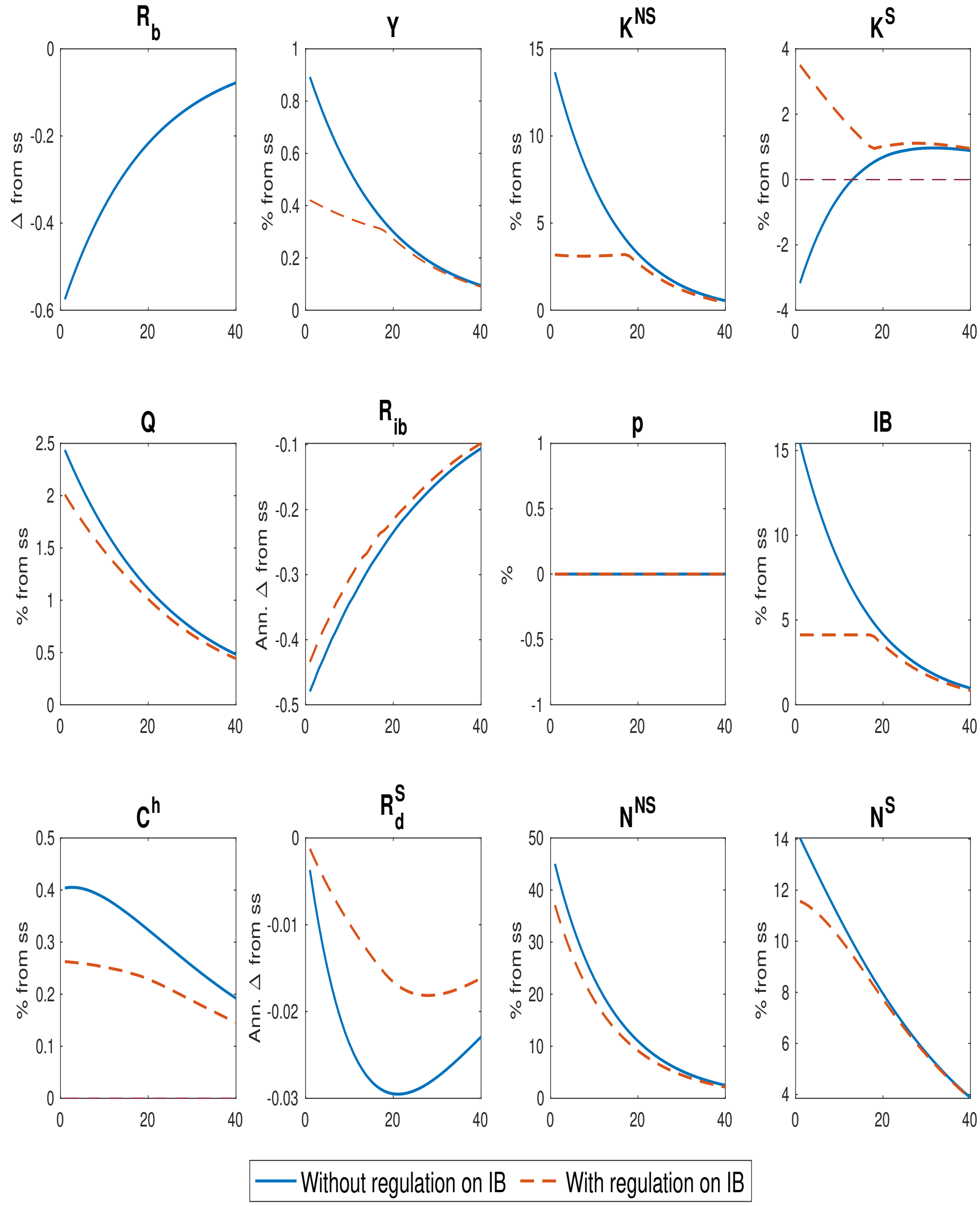

FIGURE 6. Impulse Response to Monetary Policy Shock: Regulation on Wholesale Funding

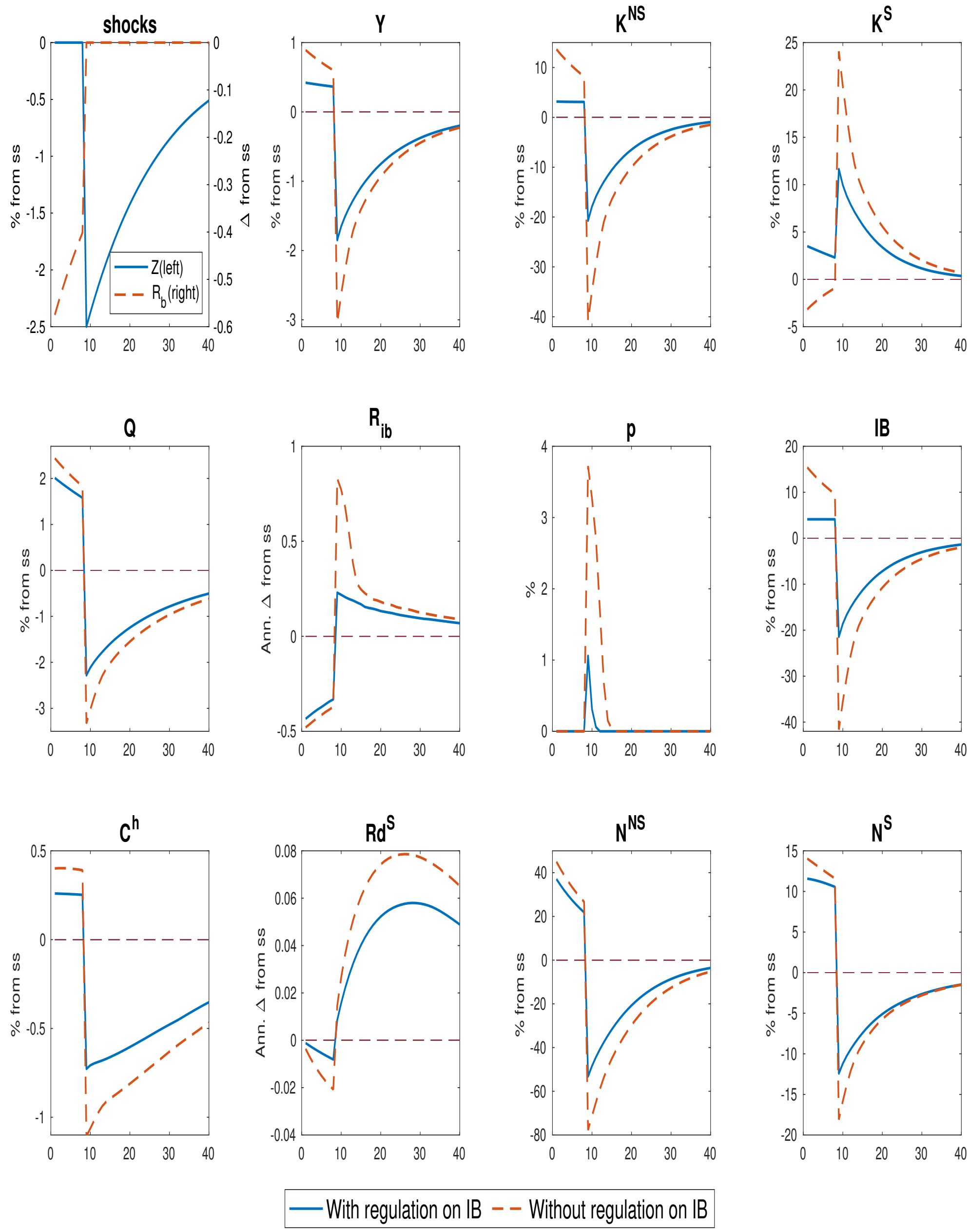

Figure 7. Monetary Policy Easing Followed by Negative Productivity Shocks: Role of Regulation on Wholesale Funding

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Appendix A. Additional Details of the Model

A.1. **Characteristics of Banks' Problem.** From (9), (17), (18), (21), (22) and (24), we get

$$\begin{aligned}\frac{V_t^j}{n_t^j} &= E_t(\Omega_{t+1}^j \frac{n_{t+1}^j}{n_t^j}) \\ &= E_t\{\Omega_{t+1}^j[(R_{k,t+1}^j(R_{b,t}-1)+R_{a,t+1})\frac{a_t^j}{n_t^j} + (R_{k,t+1}^j(1-\rho R_{b,t})-R_{d,t+1}^j)\frac{d_t^j}{n_t^j} \\ &+ (R_{k,t+1}^j - R_{ib,t+1})\frac{ib_t^j}{n_t^j} + R_{k,t+1}^j(1-R_{b,t}\tau)]\}\end{aligned} \tag{S1}$$

$R_{a,t+1}$, $R_{d,t+1}^j$ and $R_{ib,t+1}$ are the return or cost of reserve, capital, deposit and interbank borrowing. $R_{k,t+1}^j(1-R_{b,t}\tau)$ is the effective returns to non-financial loans funded by net worth, net of the fixed cost on insurance premium against reserve shortfall. $R_{k,t+1}^j(1-R_{b,t})-R_{a,t+1}$ is the opportunity cost of holding cash. $R_{k,t+1}^j(1-\rho R_{b,t})-R_{d,t+1}^j$ is the effective net return of deposit, which includes the cost of the marginal liquidity cost, $R_{k,t+1}^j - R_{ib,t+1}$ is the effective net returns of funds raised by wholesale borrowing. Note that since wholesale borrowing is not subject to reserve requirement, unlike deposit, there is no liquidity cost.

We can express the value per unit of net worth as

$$\frac{V_t^j}{n_t^j} = \mu_{a,t}^j\psi_{a,t}^j + \mu_{d,t}^j\psi_{d,t}^j + \mu_{ib,t}^j\psi_{ib,t}^j + \upsilon_{k,t}^j,$$

where

$$\mu_{a,t}^j = E_t\{\Omega_{t+1}^j[R_{k,t+1}^j(R_{b,t}-1)+R_{a,t+1}]\} \tag{S2}$$

$$\mu_{d,t}^j = E_t\{\Omega_{t+1}^j[R_{k,t+1}^j(1-\rho R_{b,t})-R_{d,t+1}^j]\} \tag{S3}$$

$$\mu_{ib,t}^j = E_t\{\Omega_{t+1}^j[R_{k,t+1}^j - R_{ib,t+1}]\} \tag{S4}$$

$$\upsilon_{k,t}^j = E_t\{\Omega_{t+1}^j R_{k,t+1}^j(1-\tau R_{b,t})\} \tag{S5}$$

$$[\psi_{ib,t}^j, \psi_{a,t}^j, \psi_{d,t}^j] = \frac{[ib_t, a_t^j, d_t^j]}{n_t^j} \tag{S6}$$

$\psi_{a,t}^j$, $\psi_{d,t}^j$ and $\psi_{ib,t}^j$ are reserves, deposits and wholesale funding per unit of net worth. It is easy to see that $\frac{V_t^j}{n_t^j}$ depends only on aggregate variables for each bank type and not on individual bank variables (such as net worth).

The incentive constraint Equation (19) can be written as

$$V_t^j \geq \theta^j[n_t^j + d_t^j + \omega ib_t \cdot I_{ib_t^j>0} + (1-\gamma)ib_t \cdot I_{ib_t^j<0}] \tag{S7}$$

where $I_{ib_t^j>0} = 1$ if $ib_t^j > 0$ and $I_{ib_t^j>0} = 0$ otherwise (and $I_{ib_t^j<0} = 1$ if $ib_t^j < 0$ and $I_{ib_t^j<0} = 0$ otherwise).

Then, a bank's problem becomes

$$\Psi = \max_{\psi_{a,t},\psi_{d,t},\psi_{ib,t}} (\mu_{a,t}\psi_{a,t} + \mu_{d,t}\psi_{d,t} + \mu_{ib,t}\psi_{ib,t} + \upsilon_{k,t}) \tag{S8}$$

subject to

$$\begin{aligned}
\theta[1 + \psi_{d,t} + \omega\psi_{ib,t} \cdot I_{ib_t>0} + (1-\gamma)\psi_{ib,t} \cdot I_{ib_t<0}] &\leq \mu_{a,t}\psi_{a,t} + \mu_{d,t}\psi_{d,t} + \mu_{ib,t}\psi_{ib,t} + \upsilon_{k,t} \\
&\psi_{a,t} \geq \kappa \\
&0 \leq \psi_{d,t} \leq \overline{\psi}_{d,t} \\
&1 + \psi_{d,t} + \psi_{ib,t} - \psi_{a,t} - \psi_{x,t} \geq 0
\end{aligned}$$

where $\psi_{x,t}$ is the reserve recoup cost per net worth. Figures S1 and S2 depict the feasible set and an indifference curve for non-state bankers and state bankers in our benchmark model.

Defining λ_t, $\lambda_{k,t}$ and $\lambda_{d,t}$ as Lagrangian multipliers of the incentive constraint, the non-negativity constraint of capital and the deposit rate ceiling constraint, we have the Lagrangian as

$$\begin{aligned}
\mathcal{L} = {} & (1+\lambda_t)(\mu_{a,t}\psi_{a,t} + \mu_{d,t}\psi_{d,t} + \mu_{ib,t}\psi_{ib,t} + \upsilon_{k,t}) \\
& - \lambda_t\theta[1 + \psi_{d,t} + \omega\psi_{ib,t} \cdot I_{ib_t>0} + (1-\gamma)\psi_{ib,t} \cdot I_{ib_t<0}] \\
& + \lambda_{k,t}(1 + \psi_{d,t} + \psi_{ib,t} - \psi_{a,t} - \psi_{x,t}) - \lambda_{d,t}(\psi_{d,t} - \overline{\psi}_{d,t})
\end{aligned}$$

The first order condition for $\psi_{a,t}$ is

$$\frac{\partial\mathcal{L}}{\partial\psi_{a,t}} = (1+\lambda_t)\mu_{a,t} - \lambda_{k,t}(1 - R_{b,t}) \leq 0$$

Since $R_{b,t}$ is smaller than 1, if $\mu_{a,t}^j \leq 0$, state and non-state banks would choose the least amount of reserve amount possible. Note that $R_{k,t+1}^j(1-R_{b,t}) - R_{a,t+1}$, the opportunity cost of holding cash, is positive, which implies $\mu_{a,t}^j \leq 0$. Thus we have feasible $\psi_{a,t} = \kappa$.[26]

We then discuss $\psi_{ib,t}$ and $\psi_{d,t}$. For the case of $\psi_{ib,t} \geq 0$, it is easy to check capital is positive, thus $\lambda_k = 0$.[27] Intuitively, non-state banks get funds from deposit and wholesale funding in order to invest in capital, and earn the spread of returns. If capital is not profitable, then non-state banks will not operate actively.

[26] In our numerical results, κ satisfies $\kappa \leq \rho\psi_d + \tau$ for both state and non-state banks. This make sure that $\psi_{x,t} \geq 0$, or equivalently $\psi_{a,t} \leq \rho\psi_{d,t} + \tau$.

[27] As equation (S5) shows, for effective returns to net worth to be positive, it is necessary that $\tau < \frac{1}{R_{b,t}}$.

The first order conditions are

$$\begin{aligned} &(1+\lambda_t)\mu_{ib,t} \leq \lambda_t \theta \omega \\ &\textit{where} = \ \textit{holds if } \psi_{ib,t} > 0, \textit{and} < \textit{implies } \psi_{ib,t} = 0. \end{aligned} \tag{S9}$$

$$\begin{aligned} &(1+\lambda_t)\mu_{d,t} \leq \lambda_t \theta + \lambda_{d,t} \\ &\textit{where} = \ \textit{holds if } \psi_{d,t} > 0, \textit{and} < \textit{implies } \psi_{d,t} = 0. \end{aligned} \tag{S10}$$

Thus, for the case of $\psi_{d,t} > 0$, we learn

$$\begin{aligned} &\psi_{ib,t} > 0, \ \textit{if } \mu_{ib,t} = \omega\left(\mu_{d,t} - \frac{\lambda_{d,t}}{1+\lambda_t}\right), \\ &\psi_{ib,t} = 0, \ \textit{if } \mu_{ib,t} < \omega\left(\mu_{d,t} - \frac{\lambda_{d,t}}{1+\lambda_t}\right). \end{aligned} \tag{S11}$$

In the special case that the deposit rate ceiling is not binding (or without deposit rate ceiling), the above conditions become

$$\begin{aligned} &\psi_{ib,t} > 0, \ \textit{if } \frac{\mu_{ib,t}}{\mu_{d,t}} = \omega; \\ &\psi_{ib,t} = 0, \ \textit{if } \frac{\mu_{ib,t}}{\mu_{d,t}} < \omega. \end{aligned}$$

Therefore, when $\mu_{ib,t} = \omega\left(\mu_{d,t} - \frac{\lambda_{d,t}}{1+\lambda_t}\right) < \omega\mu_{d,t}$, $\psi_{d,t} > 0$ when the deposit rate ceiling is binding, but $\psi_{d,t} = 0$ without deposit rate ceiling.

For the case of $ib \leq 0$ and $\lambda_{d,t} = 0$,[28] the first order conditions are

$$\begin{aligned} &(1+\lambda_t)\mu_{ib,t} + \lambda_{k,t} \geq \lambda_t \theta (1-\gamma) \\ &\textit{where} = \textit{holds if } \psi_{ib,t} < 0, \textit{and} > \textit{implies } \psi_{ib,t} = 0. \end{aligned} \tag{S12}$$

$$\begin{aligned} &(1+\lambda_t)\mu_{d,t} + \lambda_{k,t}(1 - R_{b,t}\rho) \leq \lambda_t \theta \\ &\textit{where} = \textit{holds if } \psi_{d,t} > 0, \textit{and} < \textit{implies } \psi_{d,t} = 0. \end{aligned} \tag{S13}$$

Thus for the case of $\psi_{d,t} > 0$ and $\psi_{ib,t} < 0$, we learn

$$\begin{aligned} &\psi_{k,t} > 0, \ \textit{if } \frac{\mu_{ib,t}}{\mu_{d,t}} = 1 - \gamma; \\ &\psi_{k,t} = 0 \ \textit{and } \lambda_{k,t} > 0, \ \textit{if } \frac{\mu_{ib,t}}{\mu_{d,t}} < 1 - \gamma. \end{aligned} \tag{S14}$$

where $\psi_{k,t} = \frac{(Q_t + \alpha K_t)k_t}{n_t}$.

[28]For state banks, the deposit rate ceiling is always not binding. Thus, we only consider the case $\lambda_{d,t} = 0$.

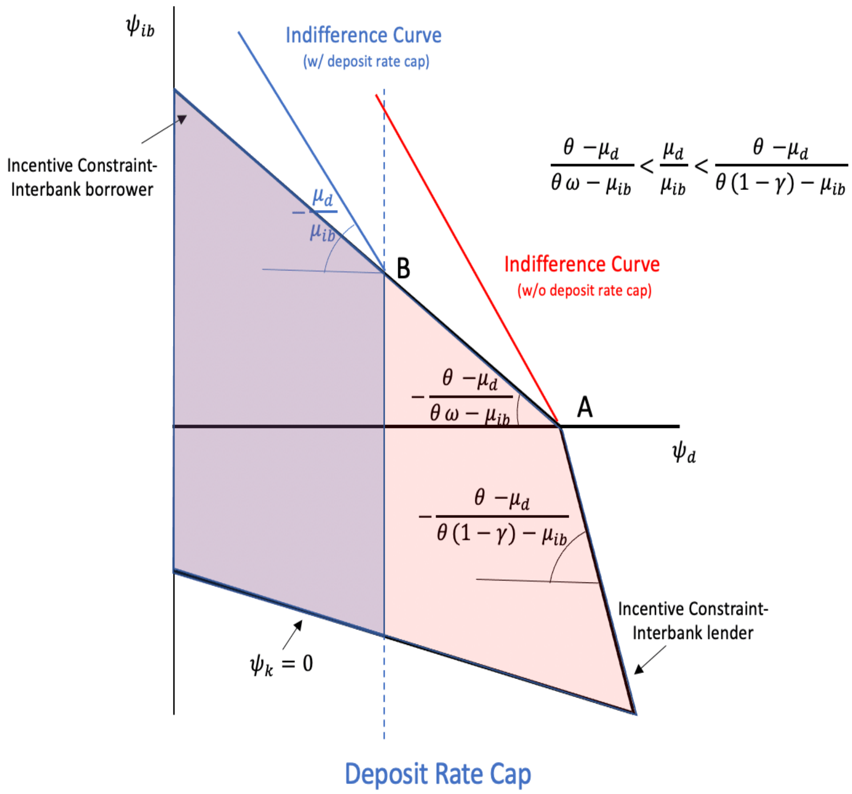

FIGURE S1. Non-state Bank's Optimization

Based on market clearing for interbank loans, and the assumption of active operation of banks [29], we have only the following possible patterns of equilibrium in the neighborhood of the steady state:

(A) Perfect specialization with active wholesale market: $\psi^S_{k,t} = 0, \psi^{NS}_{d,t} = 0, \psi^{NS}_{ib,t} > 0 > \psi^S_{ib,t}$

(B) Perfect specialization state banks with active wholesale market: $\psi^S_{k,t} = 0, \psi^{NS}_{d,t} > 0, \psi^{NS}_{ib,t} > 0 > \psi^S_{ib,t}$

(C) Perfect specialization non-state banks with active wholesale market: $\psi^S_{k,t} > 0, \psi^{NS}_{d,t} = 0, \psi^{NS}_{ib,t} > 0 > \psi^S_{ib,t}$

(D) Imperfect specialization with active wholesale market: $\psi^S_{k,t} > 0, \psi^{NS}_{d,t} > 0, \psi^{NS}_{ib,t} > 0 > \psi^S_{ib,t}$

(E) Inactive wholesale market: $\psi^S_{k,t} > 0, \psi^{NS}_{d,t} > 0, \psi^{NS}_{ib,t} = 0 = \psi^S_{ib,t}$

[29]Active operation means that banks will have at least one liability or one asset except reserve. For example, when $ib^{NS} = 0$, then d^{NS} must be positive, otherwise, non-state banks do not operate actively.

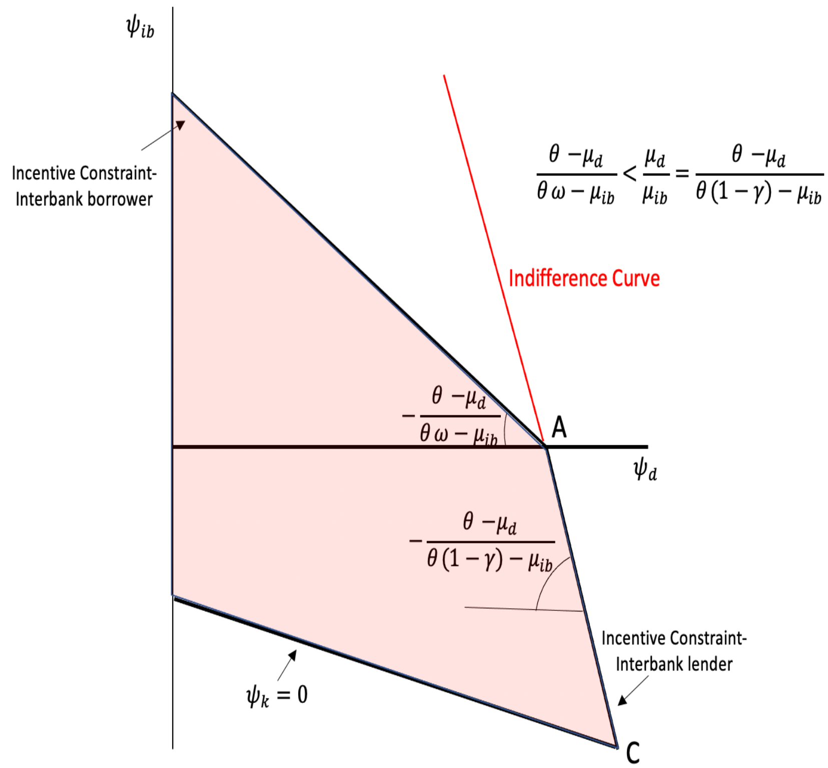

FIGURE S2. State Bank's Optimization

A.2. **Aggregation and Equilibrium without Bank Run.** Given that the ratio of assets and liabilities to net worth is independent of individual bank-specific factors and given a parameterization where Assumptions 1, Lemmas 1 and 2 are satisfied, we can aggregate across banks to obtain relations between total assets or liabilities net worth for both state and non-state banks. For each individual variable of the two types of banks, we use the the corresponding capital letter to denote its aggregate variable. According, for any individual variable l_t^j, the corresponding aggregate variable L_t^j is

$$L_t^j = \begin{cases} s\mu l_t^j & \text{if } j = NS \\ s(1-\mu) l_t^j & \text{if } j = S \end{cases}$$

Let A_t^{NS} and A_t^S be total reserve, D_t^{NS} and D_t^S be total deposits, $\chi\left(X_t^{NS}\right)$ and $\chi\left(X_t^S\right)$ be total reserve insurance cost, and $Q_t K_t^{NS}$ and $Q_t K_t^S$ be total non-financial loans held by non-state banks and state banks, IB_t be total wholesale funding, and N_t^{NS} and N_t^S total net worth in each respective banking sector. Then we have:

$$A_t^{NS} = \kappa N_t^{NS}, \tag{S15}$$

$$A_t^{S} = \kappa N_t^{S}, \tag{S16}$$

$$D_t^{NS} = \psi_{d,t}^{NS} N_t^{NS}, \tag{S17}$$

$$R_{d,t}^{S} = \frac{R}{1+\upsilon B_{t+1}} \tag{S18}$$

$$R_{d,t}^{NS} = \lambda R_{d,t}^{S} \tag{S19}$$

$$Q_t K_t^{NS} = N_t^{NS} + IB_t + D_t^{NS} - A_t^{NS} - \chi\left(X_t^{NS}\right), \tag{S20}$$

$$(Q_t + \alpha K_t^S) K_t^S = N_t^S - IB_t + D_t^S - A_t^S - \chi\left(X_t^S\right), \tag{S21}$$

$$E_t \Omega_{t+1}[R_{k,t+1}^S - R_{ib,t+1}] = (1-\gamma) E_t \Omega_{t+1}[R_{k,t+1}^S(1 - R_{b,t}\rho) - R_{d,t+1}^S] \tag{S22}$$

Summing across both surviving and entering bankers yields the following expression for the evolution of N_t:

$$N_t^{NS} = \sigma^{NS}[A_{t-1}^{NS} + (Z_t + Q_t)K_{t-1}^{NS} - R_{ib,t} IB_{t-1} - R_{d,t}^{NS} D_{t-1}^{NS}] + W^{NS}, \tag{S23}$$

$$N_t^{S} = \sigma^{S}[A_{t-1}^{S} + (Z_t + Q_t)K_{t-1}^{S} + R_{ib,t} IB_{t-1} - R_{d,t}^{S} D_{t-1}^{S}] + W^{S}, \tag{S24}$$

where $W^{NS} = (1-\sigma^j) f \mu w^{NS}$ ($W^S = (1-\sigma^j) f (1-\mu) w^S$) is the total endowment of entering non-state (state) bankers. The first term is the accumulated net worth of bankers that operated at $t-1$ and survived to t, which is equal to the product of the survival rate σ^j and the net earnings on bank assets. The total dividend to the household for exiting bankers at time t is given by

$$\Pi_t = \frac{N_t^S - W^S}{\sigma^S}\left(1-\sigma^S\right) + \frac{N_t^{NS} - W^{NS}}{\sigma^{NS}}\left(1-\sigma^{NS}\right),$$

and the total startup fund for the entering bankers is given by

$$\zeta = W^S + W^{NS}.$$

We calculate the net aggregate output as

$$Y_t = Z_t \overline{K} + W - \alpha^S \left(K_t^S\right)^2 - \alpha^h \left(K_t^h\right)^2 - f\left(D_t^{NS}\right) - g(B_t). \tag{S25}$$

Finally, the resource constraint is given by

$$C_t + B_t - B_{t-1} = Y_t + (R-1)\, B_{t-1}. \tag{S26}$$

where $B_t - B_{t-1}$ is the current account balance, and $Y_t + (R-1)\,B_{t-1}$ is gross national product.

The recursive competitive equilibrium without bank runs consist of aggregate quantities,

$$(A_t^{NS}, A_t^S, D_t^{NS}, D_t^S, \chi(X_t^{NS}), \chi(X_t^S), K_t^{NS}, K_t^S, N_t^{NS}, N_t^S, IB_t, Y_t, K_t^h, C_t, B_t)$$

prices

$$(Q_t, R_{d,t}^{NS}, R_{d,t}^S, R_{ib,t})$$

as a function of the state variables $(A_{t-1}^j, D_{t-1}^j, K_{t-1}^j, IB_{t-1}, B_{t-1}, Z_t)_{j=S,NS}$, which satisfy Equations (6), $(9)_{j=S,NS}$, (12), (16), (27), and (31).

A.3. **Conditions for a Bank Run Equilibrium.** We model non-state banks runs as a rollover panic. A self-fulfilling bank run equilibrium exists if an individual lender correctly believes that when all other lenders do not roll over their lending, he would lose money by rolling over. In our model, if one of the state banks believes that all other state banks would not roll over IB because the non-state bank could not fulfill their debt, then there may a run on wholesale funding channel. This condition is met if non-state banks' net worth goes to zero in the event of the runs.

In the normal equilibrium where a run does not occur, non-state banks have sufficient assets to pay their promised rate; in the run equilibrium, non-state banks are asked to be liquidated but the value of assets is below their promised obligation rate. Suppose the liquidation price of capital is Q^*, which is lower than the price at which capital trades normally, Q, because of state banks' and the household's limited ability to absorb capital. Therefore, a run on non-state bank sector is possible if the liquidation value, $(Z_{t+1}+Q_{t+1}^*)K_t^{NS}+R_{a,t+1}A_t^{NS}$, is smaller than their outstanding liability to interbank creditors, $R_{ib,t+1}IB_t$, and to depositors, $R_{d,t+1}^{NS}D_t^{NS}$. In this instance, the recovery rate in the event of a non-state bank run, u_t^{NS}, is the ratio of $((Z_{t+1} + Q_{t+1}^*)K_t^{NS} + R_{a,t+1}A_t^{NS}$ to $R_{ib,t+1}IB_t + R_{d,t+1}^{NS}D_t^{NS}$, and the condition for a non-state bank run equilibrium to exist is that the recovery rate is less than unity, i.e.,

$$u_{t+1}^{NS} = \frac{(Z_{t+1} + Q_{t+1}^*)K_t^{NS} + R_{a,t+1}A_t^{NS}}{R_{ib,t+1}IB_t + R_{d,t+1}^{NS}D_t^{NS}} < 1$$

The probability of a run p_t is specified as follows:

$$p_t = [1 - \min(E_t u_{t+1}^{NS}, 1)]^{\delta_p} \tag{S27}$$

A.4. **Algorithms for a numerical solution.** We use productivity shock Z with deposit rate ceiling as an example, the computation for the case with shock R_b is similar.

We define the ex-ante optimal values of surviving banks at time t:

$$\begin{aligned}
\bar{V}_t^{NS} &= [1-\sigma^{NS}+\sigma^{NS}\theta^{NS}(1+\psi_{d,t}^{NS}+\omega\psi_{ib,t}^{NS})]\frac{N_t^{NS}-W^{NS}}{\sigma^{NS}} \\
&= \Omega_t^{NS}\frac{N_t^{NS}-W^{NS}}{\sigma^{NS}} \\
\bar{V}_t^{S} &= [1-\sigma^{S}+\sigma^{S}\theta^{S}(1+\psi_{d,t}^{S}-(1-\gamma)\psi_{ib,t}^{S})]\frac{N_t^{S}-W^{S}}{\sigma^{S}} \\
&= \Omega_t^{S}\frac{N_t^{S}-W^{S}}{\sigma^{S}}
\end{aligned}$$

Let the state of the economy if a run has not happened be denoted by $x=(N^{NS},N^S,Z,B)$, and the state in case a run has happened be denoted by $x^*=(0,N^S,Z,B)$. We use iteration to approximate the functions

$$\{Q(x),C(x),\bar{V}^{NS}(x),\bar{V}^S(x),\Gamma(x)\}$$

and

$$\{Q^*(x),C^*(x),\bar{V}^{*S}(x),\Gamma^*(x)\}$$

where $\Gamma(x)$ and $\Gamma^*(x)$ are the laws determining the stochastic evolution of the state (see later).

The computational algorithm proceeds as follows:

(1) Determine a functional space to use for approximating equilibrium functions. (We use piecewise linear approximation).
(2) Fix a grid of values for the states in the case no run happens G, and for the state in case a run happens G^*.
(3) Set $j=0$ and guess initial values for

$$NRF_{t,j}=\{Q(x),C(x),\bar{V}^{NS}(x),\bar{V}^S(x),\Gamma(x)\}_{x\in G},$$

$$RF_{t,j}=\{Q^*(x),C^*(x),\bar{V}^{S*}(x),\Gamma^*(x)\}_{x\in G^*}.$$

The guess of $\Gamma(x)$ involves guessing $\{p_{t,j}(x),N_{t,j}^{NS'}(x),N_{t,j}^{S'}(x),N_{t,j}^{S'*}(x),Z'(Z),B'(x)\}$ which implies

$$\Gamma_{t,j}(x)=\begin{cases} x_{t,j}^{NR'}(x)=(N_{t,j}^{NS'}(x),N_{t,j}^{S'}(x),Z'(Z),B'(x)) & w.p. \quad 1-p_{t,j}(x) \\ x_{t,j}^{R'}(x)=(0,N_{t,j}^{S'*}(x),Z'(Z),B'(x)) & w.p. \quad p_{t,j}(x) \end{cases}$$

Similarly the guess for $\Gamma^*(x^*)$ involving guessing $\{\hat{N^{S\prime}_{t,j}}(x^*), Z'(Z), \hat{B}'(x^*)\}$ which implies

$$\Gamma^*_{t,j}(x^*) = ((1+\sigma^{NS})W^{NS}, \hat{N^{S\prime}_{t,j}}(x^*), Z'(Z), \hat{B}'(x^*))$$

(4) Iterate to find $NRF_{t,i+1}$ and $RF_{t,i+1}$ ($j \leq i < M = 10000$) as follows:
- NO RUN SYSTEM At any point $x = (N^{NS}_t, N^S_t, Z_t, B_t) \in G$, the system determining $\{\psi^{NS}_{a,t}, \psi^{NS}_{d,t}, \psi^{NS}_{ib,t}, \psi^{NS}_{k,t}, \psi^{NS}_{\chi,t}, \psi^{S}_{a,t}, \psi^{S}_{d,t}, \psi^{S}_{ib,t}, \psi^{S}_{k,t}, \psi^{NS}_{\chi,t}, Q_t, R^{NS}_{d,t}, R^{S}_{d,t}, K^{NS}_t, K^S_t,$

$K_t^h, C_t, IB_t, D_t^{NS}, D_t^S, A_t^{NS}, A_t^S, Y_t\}$ is given by

$$
\begin{aligned}
\frac{1}{R_{d,t}^S} &= \beta[(1-p_i(x_t))\frac{C_t}{C_i(x_i'^{NR}(x))} + p_i(x_t)\frac{C_t}{C_i^*(x_i'^{R}(x))}] \\
1 &= \beta[(1-p_i(x_t))\frac{C_t}{C_i(x_i'^{NR}(x))}\frac{Q_i(x_i'^{NR}(x)) + Z_{t+1}}{Q_t + \alpha^h K_t^h} + p_i(x_t)\frac{C_t}{C_i^*(x_i'^{R}(x))}\frac{Q_i^*(x_i'^{R}(x)) + Z_{t+1}}{Q_t + \alpha^h K_t^h}] \\
\psi_{a,t}^{NS} &= \kappa \\
A_t^{NS} &= \kappa N_t^{NS} \\
\psi_{a,t}^{S} &= \kappa \\
A_t^{S} &= \kappa N_t^{S} \\
R_{d,t}^S &= \frac{R}{1 + \upsilon B'(x)} \\
R_{d,t}^{NS} &= \lambda R_{d,t}^S \\
\psi_{d,t}^{NS\eta-1} &= \frac{(R_{d,t}^S - R_{d,t}^S)}{\xi R_{d,t}^S} \\
D_t^{NS} &= \psi_{d,t}^{NS} N_t^{NS} \\
\theta(1 + \psi_{d,t}^{NS} + \omega\psi_{ib,t}^{NS})N_t^{NS} &= \beta(1-p_i(x_t))\bar{V}_i^{NS}(x_i'^{NR}(x)) \\
IB_t^{NS} &= \psi_{ib,t}^{NS} N_t^{NS} \\
\psi_{x,t}^{NS} &= R_{b,t}(\tau + \rho\psi_{d,t}^{NS} - \psi_{a,t}^{NS}) \\
\psi_{k,t}^{NS} &= 1 + \psi_{ib,t}^{NS} + \psi_{d,t}^{NS} - \psi_{a,t}^{NS} - \psi_{x,t}^{NS} \\
Q_t K_t^{NS} &= \psi_{k,t}^{NS} N_t^{NS} \\
\theta(1 + \psi_{d,t}^{S} + (1-\gamma)\psi_{ib,t}^{S})N_t^{S} &= \beta[(1-p_i(x_t))\bar{V}_i^{S}(x_i'^{NR}(x)) + p_i(x_t)\bar{V}_i^{*S}(x_i'^{R}(x))] \\
(\psi_{d,t}^{S} + (1-\gamma)\psi_{ib,t}^{S})N_t^{S} &= D_t^S - (1-\gamma)(-IB_t^S) \\
IB_t &= IB_t^{NS} = (-IB_t^S) \\
\psi_{x,t}^{S} &= R_{b,t}(\tau + \rho\psi_{d,t}^{S} - \psi_{a,t}^{S}) \\
(Q_t + \alpha^S K_t^S)K_t^S &= N_t^S + D_t^S - IB_t - A_t^S - \psi_{x,t}^S N_t^S \\
\psi_{k,t}^{S} &= \frac{(Q_t + \alpha^S K_t^S)K_t^S}{N_t^S} \\
K_t^{NS} + K_t^S + K_t^h &= 1 \\
Y_t &= Z_t + W - \alpha^S(K_t^S)^2 - \alpha^h(K_t^h)^2 - f(D_t^{NS}) - g(B_t)
\end{aligned}
$$

One can find $R_{ib,t+1}$ from

$$\begin{aligned}
R_{ib,t+1} =& \frac{E_i\{\tilde{\Omega}^S(\Gamma_i(x))(\gamma R^{\tilde{S}}_{k,t+1} + (1-\gamma)(R^S_{d,t+1} + R_{b,t}\rho R^{\tilde{S}}_{k,t+1})\} - p_i(x)\Omega^{*S}(x_i^{\prime R}(x))R^*_{ib,t+1}}{(1-p_i(x))\Omega^S(x_i^{\prime NR}(x))} \\
=& \frac{E_i\{\tilde{\Omega}^S(\Gamma_i(x))(\gamma \frac{Z'(Z_t)+\tilde{Q}(\Gamma_i(x))}{Q_t+\alpha^S K^S_t} + (1-\gamma)(R^S_{d,t+1} + R_{b,t}\rho \frac{Z'(Z_t)+\tilde{Q}(\Gamma_i(x)}{Q_t+\alpha^S K^S_t})\}}{(1-p_i(x))\Omega^S(x_i^{\prime NR}(x))} \\
&- \frac{p_i(x)\Omega^{*S}(x_i^{\prime R}(x))u(x)R_{ib,t+1}}{(1-p_i(x))\Omega^S(x_i^{\prime NR}(x))}
\end{aligned}$$

where

$$\tilde{\Omega}^S(\Gamma_i(x)) = \begin{cases} \sigma^S \dfrac{\bar{V}^S_i(x_i^{\prime NR}(x))}{N_i^{\prime S} - W^S} & w.p. \quad 1-p_i(x) \\ \sigma^S \dfrac{\bar{V}^{*S}_i(x_i^{\prime R}(x))}{N_i^{\prime S} - W^S} & w.p. \quad p_i(x) \end{cases}$$

and $B'(x)$ from:

$$\frac{\upsilon}{2}B'(x)^2 + B'(x) - RB(x) + C(x) - Y(x) = 0$$

and finally $\{\bar{V}^{NS}_t, \bar{V}^S_t\}$are given by

$$\begin{aligned}
\bar{V}^{NS}_t &= [1-\sigma^{NS} + \theta\sigma^{NS}(1+\psi^{NS}_{d,t} + \omega\psi^{NS}_{ib,t})]\frac{N^{NS}_t - W^{NS}}{\sigma^{NS}} \\
\bar{V}^S_t &= [1-\sigma^S + \theta\sigma^S(1+\psi^S_{d,t} + (1-\gamma)\psi^S_{ib,t})]\frac{N^S_t - W^S}{\sigma^S}
\end{aligned}$$

where

$$\begin{aligned}
N^{\prime NS}_t &= \sigma^{NS}[R_{a,t+1}A^{NS}_t + (Z'(Z_t) + Q(x_i^{\prime NR}(x)))K^{NS}_t - R_{ib,t+1}IB_t - R^{NS}_{d,t+1}D^{NS}_t] + W^{NS} \\
N^{\prime S}_t &= \sigma^S[R_{a,t+1}A^S_t + (Z'(Z_t) + Q(x_i^{\prime NR}(x)))K^S_t + R_{ib,t+1}IB_t - R^S_{d,t+1}D^S_t] + W^S \\
N^{*\prime S}_t &= \sigma^S[R_{a,t+1}A^S_t + (Z'(Z_t) + Q^*(x_i^{\prime R}(x))K^S_t + R^*_{ib,t+1}IB_t - R^S_{d,t+1}D^S_t] + W^S \\
p_t &= [1 - \min\{1, \frac{(Z'(Z_t) + Q^*(x_i^{\prime R}(x))K^{NS}_t + A^{NS}_t}{R_{ib,t+1}IB_t + R^{NS}_{d,t+1}D^{NS}_t}\}]^{\delta_p}
\end{aligned}$$

- RUN SYSTEM Analogously at a point $x^* = (0, N^S_t, Z_t, B_t) \in G*$, the system determining $\{\psi^{*S}_{a,t}, \psi^{*S}_{d,t}, \psi^{*S}_{k,t}, \psi^{*S}_{\chi,t}, Q^*_t, K^{*S}_t, K^{*h}_t, D^{*S}_t, A^{*S}_t, C^*_t, R^{*NS}_{d,t}, R^{*S}_{d,t}, Y^*_t\}$

is given by

$$
\begin{aligned}
\frac{1}{R^{*NS}_{d,t}} &= \beta[\frac{C^*_t}{C_i(x^*_i)}] \\
R^{*S}_{d,t} &= \frac{R}{1+\upsilon \hat{B}'} \\
R^{*NS}_{d,t} &= \lambda R^{*S}_{d,t} \\
1 &= \beta[\frac{C^*_t}{C_i(x^*_i)} \frac{Q_i(x^*_i)+Z_{t+1}}{Q^*_t+\alpha^h K^{*h}_t}] \\
\psi^{*S}_{a,t} &= \kappa \\
A^{*S}_t &= \kappa N^S_t \\
\theta^S(1+\psi^{*S}_{d,t})N^S_t &= \beta \bar{V}_i^S(x^*_i) \\
D^{*S}_t &= \psi^{*S}_{d,t} * N^S_t \\
\psi^{*S}_{x,t} &= R_{b,t}(\tau+\rho\psi^{*S}_{d,t}-\psi^{*S}_{a,t}) \\
(Q^*_t+\alpha^S K^{*S}_t)K^{*S}_t &= N^S_t + D^{*S}_t - A^{*S}_t - \psi^{*S}_{x,t}N^S_t \\
\psi^{*S}_{k,t} &= \frac{(Q^*_t+\alpha^S K^{*S}_t)K^{*S}_t}{N^S_t} \\
K^{*S}_t + K^{*h}_t &= 1 \\
Y^*_t &= Z_t + W - \alpha^S(K^{*S}_t)^2 - \alpha^h(K^{h*}_t)^2 - g(B_t)
\end{aligned}
$$

and $\{\bar{V}^{*S}_t, \hat{N}'^S, \hat{B}'\}$ is given by

$$
\begin{aligned}
\bar{V}^{*S}_t &= [1-\sigma^S+\theta\sigma^S(1+\psi^{*S}_{d,t})]\frac{N^S_t - W^S}{\sigma^S} \\
\hat{N}'^S &= \sigma^S[R_{a,t+1}A^S_t + (Z'(Z_t)+Q(\Gamma^*_{t,i}(x^*)))K^{*S}_t - R^S_{d,t+1}D^{*S}_t] + W^S \\
\frac{\upsilon}{2}\hat{B}'^2 &+ \hat{B}' - RB_t + C^*_t - Y^*_t = 0
\end{aligned}
$$

(5) Define the difference between $i^{th}+1$ Function and i^{th} Function as $\Delta_{t,i+1}$, iterate until $\Delta_{t,i+1} < e-6$; otherwise, set

$$
\begin{aligned}
NRF_{t,i+1} &= (1-\alpha)NRF_{t,i} + \alpha NRF_t \\
RF_{t,i+1} &= (1-\alpha)RF_{t,i} + \alpha RF_t
\end{aligned}
$$

where $\alpha \in (0,1)$.

Appendix B. Proofs of Lemmas and Propositions

Based on the discussion in Appendix A, we can now give the proof of Lemma 1 and 2. We see from the two lemmas that deposit is always a cheaper source of funding than wholesale funding for non-state banks, thus without deposit rate ceiling, Equilibrium E is achieved (Point A in Figure S1). When there is deposit rate ceiling, $\psi_{d,t}^{NS}$ is constrained, $\psi_{ib,t}^{NS}$ becomes positive accordingly (Point B in Figure S1), which means that state banks are willing to provide ib whenever non-state banks need. This willingness should be reflected as the flexibility of state banks to replace capital investment with interbank loan, indicating the same effective return between these two assets (Line $\overline{AC}$ in Figure S2).

Proof of Lemma 1. We first prove the case when the deposit rate ceiling is binding. $\psi_{d,t} > 0$ if and only if (S10) holds with equality. $\psi_{ib,t} > 0$ if and only if (S9) holds with equality. Plugging (S10) into (S9), we obtain

$$\begin{aligned}\mu_{ib,t} &= \omega\left(\mu_{d,t} - \frac{\lambda_{d,t}}{1+\lambda_t}\right)\\ &< \omega\mu_{d,t}\end{aligned}$$

where the second inequality obtains from the fact that $\lambda_{d,t} > 0$. To make the incentive constraint binding ($\lambda_t > 0$), note that (S10) implies that

$$\begin{aligned}\mu_{d,t} &= \frac{\lambda_t\theta}{1+\lambda_t} + \frac{\lambda_{d,t}}{1+\lambda_t}\\ &< \theta + \frac{\lambda_{d,t}}{1+\lambda_t}\\ &= \theta + \mu_{d,t} - \frac{\mu_{ib,t}}{\omega}\end{aligned}$$

Hence, we have $\mu_{ib,t} < \theta\omega$.

We now prove that the non-state bank would prefer borrowing to lending in the wholesale fund market. (S12) and (S13) implies that for $ib_t^{NS} \geq 0$, it is necessary that $\mu_{ib,t} > (1-\gamma)\mu_{d,t}$. Assumption 1 and $\mu_{ib,t} = \omega\left(\mu_{d,t} - \frac{\lambda_{d,t}}{1+\lambda_t}\right)$ implies that

$$\mu_{ib,t} > (1-\gamma)\left(\mu_{d,t} - \frac{\lambda_{d,t}}{1+\lambda_t}\right).$$

which makes sure that the bank prefer to borrow to lending in the wholesale fund market.

We now prove the case when the deposit rate ceiling is not binding. Since $\lambda_{d,t} = 0$, (S11) shows that $\psi_{ib,t} = 0$ if and only if $\mu_{ib,t} < \theta\mu_{d,t}$. Then (S10) implies that the incentive constraint to be binding ($\lambda_t > 0$) if and only if

$$\mu_{d,t} = \frac{\lambda_t \theta}{1+\lambda_t} < \theta$$

Finally, we prove the "if" part of the lemma.

(i) Suppose $d_t^{NS} = 0$. For both cases (binding or unbinding deposit rate ceiling), since $E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS} - R_{ib,t+1}]\} < \omega E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS}(1-\rho R_{b,t}) - R_{d,t+1}^{NS}]\}$ (deposit is more profitable than wholesale funding), thus $ib_t^{NS} = 0$, which contradicts the assumption of active operation, thus $d_t^{NS} > 0$.

(ii) Suppose $ib_t^{NS} > 0$ when the deposit rate ceiling is not binding, then we should have $E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS} - R_{ib,t+1}]\} = \omega E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS}(1-\rho R_{b,t}) - R_{d,t+1}^{NS}]\}$, which makes a contradiction with the condition.

(iii) Suppose $ib_t^{NS} < 0$ when the deposit rate ceiling is not binding, then we should have $E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS} - R_{ib,t+1}]\} \leq (1-\gamma)E_t\{\Omega_{t+1}^{NS}[R_{k,t+1}^{NS}(1-\rho R_{b,t}) - R_{d,t+1}^{NS}]\}$, which makes a contradiction with the condition. Therefore, from (ii) and (iii), $ib_t^{NS} = 0$ when the deposit rate ceiling is not binding.

To show $\psi_{ib,t}^{NS} > 0$ when the deposit rate ceiling is binding, from equation (25), V_t^{NS} increases with ψ_t^{NS}. Thus, the optimal ψ_t^{NS} would lie on the incentive constraint line. Since $\psi_{d,t}^{NS}$ is restricted to $\bar{\psi}_{d,t}$, if we rewrite the problem (S8) with $\psi_{d,t}^{NS} = \bar{\psi}_{d,t}$, we can see that the optimal choice of $\psi_{ib,t}^{NS}$ should be such that the incentive constraint binding, which means $\psi_{ib,t}^{NS} > 0$. □

Proof of Lemma 2. We first prove the "only if" part of the Lemma. (S14) implies that $d_t^S > 0$, $ib^S < 0$, and $k^S > 0$ if and only if $0 < \mu_{ib,t} = \mu_{d,t}(1-\gamma)$, which proves the equality in (29). Moreover, (S13) implies that the incentive constraint is binding if and only if

$$\mu_{d,t} = \frac{\lambda_t \theta}{1+\lambda_t} < \theta$$

This proves the second inequality in (29).

Now we prove the "if" part of the lemma. From Equations (30), the optimal choice of $\psi_{d,t}^S$ should maximize the value function subject to the incentive constraint, hence $\psi_{d,t}^S > 0$. In addition, (29) implies that for state banks, lending in the interbank markets is preferable to making the non-financial loans as interbank loans are less likely to be diverted than non-financial loans. Hence, $\psi_{ib,t}^S < 0$.

Last, we prove $k^S > 0$ under Assumption 1 by contradiction. Suppose $k^S = 0$, which means that the equilibrium is either type (A) or (B). Equilibrium of type (A) and (B) require $\omega\mu_{d,t}^{NS} \leq \mu_{ib,t}^{NS}$ and $\mu_{ib,t}^{S} \leq (1-\gamma)\mu_{d,t}^{S}$. Thus

$$\begin{aligned} R_{ib,t+1} &\leq [1-\omega(1-\rho R_{b,t})]R_{k,t+1}^{NS} + \omega R_{d,t+1}^{NS} \\ R_{ib,t+1} &\geq [1-(1-\gamma)(1-\rho R_{b,t})]R_{k,t+1}^{S} + (1-\gamma)R_{d,t+1}^{S} \\ &= [1-(1-\gamma)(1-\rho R_{b,t})]R_{k,t+1}^{NS} + (1-\gamma)R_{d,t+1}^{S} \end{aligned}$$

This implies

$$[1-(1-\gamma)(1-\rho R_{b,t})]R_{k,t+1}^{NS} + (1-\gamma)R_{d,t+1}^{S} \leq [1-\omega(1-\rho R_{b,t})]R_{k,t+1}^{NS} + \omega R_{d,t+1}^{NS}$$

or

$$(\omega+\gamma-1)R_{k,t+1}^{NS}(1-\rho R_{b,t}) \leq \omega R_{d,t+1}^{NS} + (\gamma-1)R_{d,t+1}^{S} < (\omega+\gamma-1)R_{d,t+1}^{NS}$$

But this is a contradiction as $\omega+\gamma > 1$ and $R_{k,t+1}^{NS}(1-\rho R_{b,t}) > R_{d,t+1}^{NS}$(as $\mu_{d,t}^{S} > 0$) □

Proof of Proposition 1. We first prove

$$\frac{\partial ib_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} < 0.$$

When $Q_t = q$ is fixed, all prices except $R_{b,t}$ are fixed, so is $n_t^N S$. Hence, equation (27) implies that

$$\frac{\partial \psi_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} = \frac{\omega E_t(\Omega_{t+1}^{NS}\frac{\partial g_t^{NS}}{\partial R_{b,t}}|_{Q_t=q})}{\theta\omega - E_t[\Omega_{t+1}^{NS}(R_{k,t+1}^{NS} - R_{ib,t+1})]},$$

Therefore, for $\frac{\partial \psi_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} < 0$, it is equivalent to show that

$$\frac{\partial g_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} < 0$$

From equation (26), we have

$$\frac{\partial g_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} = R_{k,t+1}^{NS}(\kappa - \rho\psi_{d,t}^{NS} - \tau) < 0$$

Hence, $\frac{\partial \psi_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} < 0$. Since $\psi_{d,t}^{NS}$ is constrained by the deposit rate ceiling, $\psi_{ib,t}^{NS}$ and, thus, ib_t^{NS} would increase for a given capital price q,

We now prove

$$\frac{\partial(-ib_t^{S})}{\partial R_{b,t}}|_{Q_t=q} < 0.$$

From Lemma 2,

$$E_t\{\Omega_{t+1}^{S}[R_{ib,t+1}^{S} - (R_{d,t+1} + R_{k,t+1}^{S}\rho R_{b,t})]\} = \gamma E_t\{\Omega_{t+1}^{S}[R_{k,t+1}^{S} - (R_{d,t+1}^{S} + R_{k,t+1}^{S}\rho R_{b,t})]\} \quad \text{(S28)}$$

where the left side of (S28) is the expected effective net return of $(-ib_t^{S})$, denoted as $ER_{ib,t+1}^{S}$, and the right side is the expected effective net return of k_t^{S}, which we define as $ER_{k,t+1}^{S}$. Take partial derivative of both sides of (S28) with respect to $R_{b,t}$ with a given capital price q, we have:

$$\frac{\partial ER^S_{ib,t}}{\partial R_{b,t}} = \rho E_t \Omega^S_{t+1} R^S_{k,t+1} > \frac{\partial ER^S_{k,t}}{\partial R_{b,t}} = \gamma \rho E_t \Omega^S_{t+1} R^S_{k,t+1},$$

In other words, when $R_{b,t}$ decreases, $ER^S_{ib,t+1}$ increases by more than $ER^S_{k,t+1}$, which means that state banks would like to increase $(-ib^S_t)$ first. Therefore, we can take the demand of k^S_t unchanged when we discuss the change of supply of $(-ib^S_t)$.

We could rewrite the incentive constraint of state banks based on Equation (18) as follows:

$$\begin{aligned}
V^S_t &\geq \theta^S[(Q_t + \alpha^S K^S_t)k^S_t + a^S_t + \chi(x^S_t) + \gamma(-ib^S_t)] \\
&= \theta^S[(Q_t + \alpha^S K^S_t)k^S_t + a^S_t + R_{b,t}(\tau n^S_t + \rho d^S_t - a^S_t) + \gamma(-ib^S_t)] \\
&= \theta^S[(Q_t + \alpha^S K^S_t)k^S_t + a^S_t + R_{b,t}(\tau n^S_t + \rho \frac{(Q_t + \alpha^S K^S_t)k^S_t - ib^S_t + (1 - R_{b,t})a^S_t - n^S_t + \tau n^S_t R_{b,t}}{1 - \rho R_{b,t}} - a^S_t) + \gamma(\\
&= \theta^S[(\gamma + \frac{\rho R_{b,t}}{1 - \rho R_{b,t}})(-ib^S_t) + (Q_t + \alpha^S K^S_t)k^S_t + a^S_t + \frac{R_{b,t}}{1 - \rho R_{b,t}}(\tau n^S_t - a^S_t + \rho((Q_t + \alpha^S K^S_t)k^S_t + a^S_t - n^S_t) \\
&= \theta^S[\gamma(-ib^S_t) + (Q_t + \alpha^S K^S_t)k^S_t + a^S_t + \frac{R_{b,t}}{1 - \rho R_{b,t}}(\tau n^S_t - a^S_t + \rho((Q_t + \alpha^S K^S_t)k^S_t + a^S_t - n^S_t + (-ib^S_t)))]
\end{aligned} \tag{S29}$$

For a given capital price q, when $R_{b,t}$ decreases, state banks' net worth n^S_t and reserve a^S_t are fixed and k^S_t does not change. Thus,

$$\begin{aligned}
&\tau n^S_t - a^S_t + \rho((Q_t + \alpha^S K^S_t)k^S_t + a^S_t - n^S_t + (-ib^S_t)) \\
=&\tau n^S_t - a^S_t + \rho(d^S_t - \chi(x^S_t)) \\
=&(1 - \rho R_{b,t})(\tau n^S_t + \rho d^S_t - a^S_t) > 0
\end{aligned}$$

and

$$\frac{\partial \frac{R_{b,t}}{1-\rho R_{b,t}}}{\partial R_{b,t}} > 0.$$

Hence, the derivative of the last argument in the right-hand-side of (S29) with respect to $R_{b,t}$ is

$$\begin{aligned}
&\frac{\partial \frac{R_{b,t}}{1-\rho R_{b,t}}(\tau n^S_t - a^S_t + \rho((Q_t + \alpha^S K^S_t)k^S_t + a^S_t - n^S_t + (-ib^S_t)))}{\partial R_{b,t}} \\
&= \frac{\partial \frac{R_{b,t}}{1-\rho R_{b,t}}}{\partial R_{b,t}}(1 - \rho R_{b,t})(\tau n^S_t + \rho d^S_t - a^S_t) > 0.
\end{aligned}$$

It is easy to see from Equation (30) that

$$\frac{\partial V^S_t}{\partial R_{b,t}}\Big|_{Q_t = q} < 0$$

Hence, with binding incentive constraint for the state banks, equation (S29) implies that $\frac{\partial(-ib_t^S)}{\partial R_{b,t}}|_{Q_t=q} < 0$. In other words, the supply of wholesale funding increases for a given capital price q.

In sum, both the supply and demand of wholesale funding would increase, thus the equilibrium amount IB_t increases.

□

Proof of Proposition 2. Based on Equations (18) and (19), we may rewrite the incentive constraint for non-state banks as follows:

$$\begin{aligned} V_t^{NS} &\geq \theta^{NS}[Q_t k_t^{NS} + a_t^{NS} + \chi(x_t^{NS}) - (1-\omega) ib_t^{NS}] \\ &= \theta^{NS}[Q_t k_t^{NS} + a_t^{NS} + \chi(x_t^{NS}) - (1-\omega)(Q_t k_t^{NS} + a_t^{NS} + \chi(x_t^{NS}) - n_t^{NS} - d_t^{NS})] \\ &= \theta^{NS}[\omega(Q_t k_t^{NS} + a_t^{NS} + R_{b,t}(\tau n_t^{NS} + \rho d_t^{NS} - a_t^{NS})) + (1-\omega)(n_t^{NS} + d_t^{NS})] \end{aligned} \tag{S30}$$

For a given $Q_t = q$, taking partial derivative of (S30) with respect to $R_{b,t}$ with binding incentive constraint, we have

$$\begin{aligned} \frac{\partial V_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} =& \theta\omega \left[Q_t \frac{\partial k_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} + \tau n_t^{NS} + \rho d_t^{NS} - a_t^S \right] \\ =& E_t \left[\Omega_{t+1}^{NS} n_t^{NS} \frac{\partial g_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} \right] < 0 \end{aligned}$$

where the second equality is obtained from (28). Since $\tau n_t^{NS} + \rho d_t^{NS} - a_t^S > 0$, we have

$$\frac{\partial k_t^{NS}}{\partial R_{b,t}}|_{Q_t=q} < 0.$$

In other words, when $R_{b,t}$ decreases, the demand of k_t^{NS} needs to rise in order to make the incentive constraint binding.

□

Proof of Proposition 3. First, we show that Q_t must increase when $R_{b,t}$ decreases. We prove it by contradiction. Suppose Q_t decreases. Based on Equation (17), on the one hand, if $R_{ib,t}$ increases, then n_t^{NS} would decrease, thus V_t^{NS} decreases accordingly, which makes a contradiction, since banks would always get better with lower reserve recoup cost; on the other hand, if $R_{ib,t}$ decreases, then n_t^S would decrease, thus V_t^S decreases accordingly, which also makes a contradiction. Therefore, when $R_{b,t}$ decreases, Q_t increases.

We now prove that run probability p_t is not increasing when there is monetary ease shock. We prove it by contradiction. If p_t increases, from Equation (23), then for any given price Q_t, $\Omega_t^j n_t^j$ and $\Omega_t^{j*} n_t^{j*}$ are fixed, V_t^j would decrease since $\Omega_t^j n_t^j$ is larger than $\Omega_t^{j*} n_t^{j*}$, which makes a contradiction. Thus p_t is not increasing when $R_{b,t}$ decreases. Especially, if p_t is 0 at steady state, then p_t remains at 0 when there is monetary ease shock.

Thus, from Lemma 2, we could get $R_{ib,t+1}$ as a function of $R_{b,t}$ and $R^S_{k,t}$ with $p_t = 0$:

$$R_{ib,t+1} = \gamma R^S_{k,t+1} + (1-\gamma)(R^S_{d,t+1} + R_{b,t}\rho R^S_{k,t+1})$$

Since $R^S_{d,t+1}$ decreases by Equation (10), if $R^S_{k,t+1}$ decreases, $R_{ib,t+1}$ would decrease.[30] Therefore, to prove $\frac{\partial R^S_{ib,t+1}}{\partial R_{b,t}} > 0$ is equivalent to prove $\frac{\partial R^S_{k,t+1}}{\partial R_{b,t}} > 0$.

$$\begin{aligned}\frac{\partial R^S_{k,t+1}}{\partial R_{b,t}} &= \frac{\partial \frac{(Z_{t+1}+Q_{t+1})}{Q_t+\alpha^S K^S_t}}{\partial R_{b,t}} \\ &= \frac{[\frac{\partial Q_{t+1}}{\partial R_{b,t}} Q_t - (Z_{t+1}+Q_{t+1})\frac{\partial Q_t}{\partial R_{b,t}}] - [\alpha^S((Z_{t+1}+Q_{t+1})\frac{\partial K^S_t}{\partial R_{b,t}} - K^S_t \frac{\partial Q_{t+1}}{\partial R_{b,t}})]}{(Q_t+\alpha^S K^S_t)^2} > 0\end{aligned} \tag{S31}$$

(32) makes sure that the numerator of (S31) is positive. Hence, $\frac{\partial R^S_{k,t+1}}{\partial R_{b,t}} > 0$, and thus $\frac{\partial R_{ib,t+1}}{\partial R_{b,t}} > 0$.

□

[30] Note that since we assume once a shock hits, the shock obeys perfect foresight path back to the steady state, we drop the conditional expectation.

Table S1. Parameter Values for the Benchmark Model

β	Discount rate	0.99
σ^{NS}	Non-state bankers' survival probability	0.92
σ^{S}	State bankers' survival probability	0.98
θ^{NS}	Bankers seizure rate	0.25
θ^{S}	Bankers seizure rate	0.12
W^h	Household' endowment	0.045
W^{NS}	Non-state bankers' endowment	0.0004
W^{S}	State bankers' endowment	0.0004
ω	Non-state banker divertible proportion of NCD	0.46
γ	State bankers divertible proportion of NCD	0.67
ρ	Required reserve ratio	0.2
Z	Steady state productivity	0.016
R_b	Steady state policy interest rate	0.0115
R	Annualized foreign bond interest rate	1.04
λ	Annualized deposit rate ceiling ratio	1.001
R_a	Rate of return for cash	1
α^{NS}	Non-state banks' capital management cost	0
α^{S}	State banks' capital management cost	0.0063
α^{h}	Households' capital management cost	0.031
υ	Households' foreign bond convex cost parameter	0.0315
κ	liquidity constraint parameter	1.4
τ	Fixed cost of recouping reserve shortfall	1.3
ξ	Parameter for deposit supply function for non-state banks	0.00095
ϕ	Parameter for regulation on wholesale funding	1.04
ϱ	Probability of Z shock happens at period 9	0.6
δ_p	Power of the run probability function	0.5
ρ_z	Serial correlation of productivity shocks	0.95
ρ_{rb}	Serial correlation of monetary ease shocks	0.95