Portfolio Shifts and Financial Intermediation: A DSGE Analysis of U.S. Household Deposit Outflows

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Abstract

This paper develops a New Keynesian DSGE model with a segmented financial sector to study U.S. households' post-pandemic shift out of non-transaction deposits. Households allocate savings between deposits and bank-holding-company (BHC) debt subject to a financial-distress cost; BHC equity capital replaces lost deposits; retail banks extend credit lines; and a bank-funded shadow bank lends to risky borrowers. Monetary, macroprudential, and a production-loan purchase facility are embedded. Estimated using Bayesian techniques on U.S. data (2009:Q3–2025:Q2), the model simulates a 24.0 percent decline in deposits from 2022:Q1 to 2025:Q1, compared to a 20.4 percent decline in non-transaction deposits of U.S. households. A one-standard-deviation negative household financial-distress shock reduces deposit shares by 1.4 percent and increases BHC investment by 3.3 percent. It also reallocates credit away from traditional bank borrowers toward a shadow bank, raising its investment up to 0.2 percent after the shock. Variance decompositions attribute most movements in deposit shares to the household financial-distress shock, while technology, monetary and debt-to-investment shocks explain much of credit-volume variation.

1 Introduction

The composition of financial assets held by U.S. households has changed significantly since the COVID-19 pandemic. A notable change is the decrease in non-transaction deposits, as their share in total financial assets decreased by 1.9% and their level decreased by $1,936 billion in real values, which was a 20.4% decline from 2022:Q1 to 2025:Q1. Since deposits have been the main source of funding for depository institutions, this could trigger a significant change in the operations of banks and their borrowers.[1]

However, the relationships between agents in the financial market have become more complex, and the macroeconomic policies designed to stabilize the market and the economy have become more entangled. This makes it difficult to track the effects of the major change in the financial environment while maintaining a comprehensive view of the overall economy. To address this challenge, I develop a tractable DSGE model that incorporates the unprecedented decrease in deposits and recent observations in the U.S. financial market. The model is built upon well-established frameworks in the literature (Gasparini et al. (2024), Kumhof and Wang (2021), Lubello and Rouabah (2024), and Sims et al. (2023)).

The salient features of the model are summarized as follows. First, the change in household portfolio choices is modeled by introducing financial distress costs for holding financial assets other than deposits. An exogenous shock to the elasticity parameter of the cost function can shift the share of deposits held by the household. With this feature, I investigate the effects of changes in household portfolio choices on the overall economy.

Second, the substitution of funding sources of depository institutions is

[1]From 2022:Q1 to 2025:Q1, the time and savings deposits were 50.81% of total equity and liabilities of U.S. chartered depository institutions on average.

implemented to the model. It is based on observations of bank holding companies' (BHCs) operations. The investment of BHCs in their subsidiary banks has increased and replaced lost deposits while keeping the asset side of banks stable.[2] This feature generates more realistic dynamics in the banking sector, since banks would not simply decrease their lending activities when deposits decrease.[3] To represent the bank holding company and its different degree of risk aversion, I introduce a banker who optimally decides how much to invest in subsidiary banks by borrowing from the household.

Third, different types of lenders and borrowers are introduced to the model to represent the segmented financial market. The traditional banking sector lends to typical borrowers (intermediate good producers) in the production sector. I specify the loan contract as credit line loans, which are a widespread type of contract in the U.S. economy. The other financial intermediation is represented by a shadow bank's operations. The shadow bank in the model operates financial intermediation without supervision by financial authorities. To represent the intertwined relationship between depository and shadow banks, the model assumes that the shadow bank is funded by the traditional banks and lends to borrowers (startups) with risky profiles.

Fourth, the interaction between different borrowers in the production sector is introduced to the model. Inspired by the assumption in Lubello and Rouabah (2024) regarding an additional stage of production, I assume that the intermediate good producers rent capital inputs from startups. With their own capital, the intermediate good producers use the compounded capital in their production activities. Since investment and capital accumulation in production sectors are closely related to their borrowing activities by assumption,

[2]From 2022:Q1 to 2025:Q1, the share of time and savings deposits decreased by 5.52%, however the investment of BHCs increased by 1.12%.

[3]Begenau and Stafford (2022) also point out the possibility of substitution in the funding sources of banks, which could attenuate the impact of deposit fluctuations on lending.

changes in the loan market transmit to the real sector through this channel.

Finally, I implement and extend well-established frameworks of monetary and macroprudential policies in the model. The monetary policy framework is based on Sims et al. (2023) and Kumhof and Wang (2021), which represent the floor system of monetary policy relying on the adjustment of an interest rate on reserves of the central bank. The macroprudential policy framework is based on Gerali et al. (2010) and Angelini et al. (2014), introducing the capital regulation of banks under Basel III. Additionally, a government loan policy is implemented in the model. Based on the discussion of credit lines and firms' financial distress costs in Greenwald et al. (2020) and Amberg et al. (2023), the policy aims to provide additional liquidity to alleviate the financial distress of firms.

The model is calibrated to match key statistics of the U.S. economy and the suggestions in the literature. Additionally, parameters are estimated using the post-financial crisis U.S. data from 2009:Q3 to 2025:Q2. In estimation, the cyclical components of the data are used, which are drawn using the refined Beveridge-Nelson filter developed by Kamber et al. (2025) to handle large shocks such as the COVID-19 pandemic. Based on the analysis of the posterior distribution of the model, I conduct impulse response analysis and variance decomposition to quantify the effects of recent changes in household portfolio choices on the overall economy. Additionally, various robustness checks are performed to ensure the validity of the results and explore possible implications of the model.

The results are as follows. A one-standard-deviation negative shock to the elasticity parameter of the financial distress cost function generates a 1.44% decrease in the share of deposits held by the household. This induces a re-allocation of the funding source of the banking sector as the investment of the banker increases to replace the lost deposits in the funding of banks. For the asset side of the traditional banks, the stylized calibration of the model suggests an increase in loans to the shadow bank up to 0.13% whereas loans to intermediate good producers decrease up to 0.67% in subsequent periods after the shock. The reallocation of bank loans is due to different mechanisms in the model. First, the risk weight for loans to shadow banks is adjusted to be lower than that for the production sector, which induces banks under capital regulation to lend more to the shadow bank. Second, when the financial distress from the changing financial environment increases, the borrowers from the traditional banking sector (intermediate good producers) decrease their demand for loans from the traditional banks. Additionally, their investment decreases as their financing decreases. However, they need to meet the higher demand for the goods, so they rent more capital inputs from the borrowers of the shadow bank (startups). This leads to an increased demand for the capital supplied by startups, which increases the demand for loans from the shadow bank. In equilibrium, these mechanisms in the production sector result in more credit flowing to the shadow bank and its borrowers.

The estimation results imply that the model can capture the fluctuations of key macroeconomic variables in the U.S. economy and present stability in the system. A significant amount of change in the share of deposits held by the household is explained by the shock to the household's financial distress cost function. Additionally, a significant portion of the fluctuations in deposits and banker's bonds is explained by the identical shock. However, most of the variations in the loans from the traditional bank and other observation variables are explained by shocks including the monetary policy shock, the technology shock, and the debt-investment shock.[4]

[4] The debt-investment shock is an exogenous shock to the share of external financing in the investment of firms. A positive shock means that firms need more external financing to

Overall, this paper provides a tractable framework to represent the ongoing changes in the U.S. financial market. By incorporating stylized features based on recent observations, the model represents the reallocations of loans and funding observed in U.S. financial market. The model suggests that the macroprudential policy on the assessment of risk of loans could affect the credit distribution between different borrowers. Additionally, the management of financial distress of firms could be an essential factor for the credit distribution, especially when their investment is closely related to their borrowing. The deterioration of the financial environment such as a decrease in government loan to them, could lead to a significant increase in financial distress and decrease in loan demand to avoid additional costs. This results in a change in a composition of capital inputs, which affects the credit allocation sequentially. This could be an important channel to transmit shocks from the financial market to the real sector.

2 Motivations

2.1 Empirical Observations

The recent drastic decrease in non-transaction deposits in the U.S., without a significant change in household characteristics, suggests that the rapid change in the financial environment during the COVID-19 pandemic may have influenced household saving and investment behaviors. One can enrich this scenario by considering the response of the banking sector to changes in household portfolios. To replace lost deposits, which were banks' main source of funding, their parent bank holding companies increased investment in subsidiary banks. Additionally, this development is related to the recent increase in loans from

fund the same amount of investment.

banks to NBFIs as banks seek higher yields and less regulation in response to higher funding costs. Without strict supervision, NBFIs increased their loans to nonfinancial corporates, which might threaten the financial stability of the economy. Overall, this scenario and these observations suggest that meaningful reallocations in funding are underway in the U.S. financial market. This paper aims to provide a tractable framework to examine the scenario where those reallocations are triggered by the change in the households' portfolio choices.

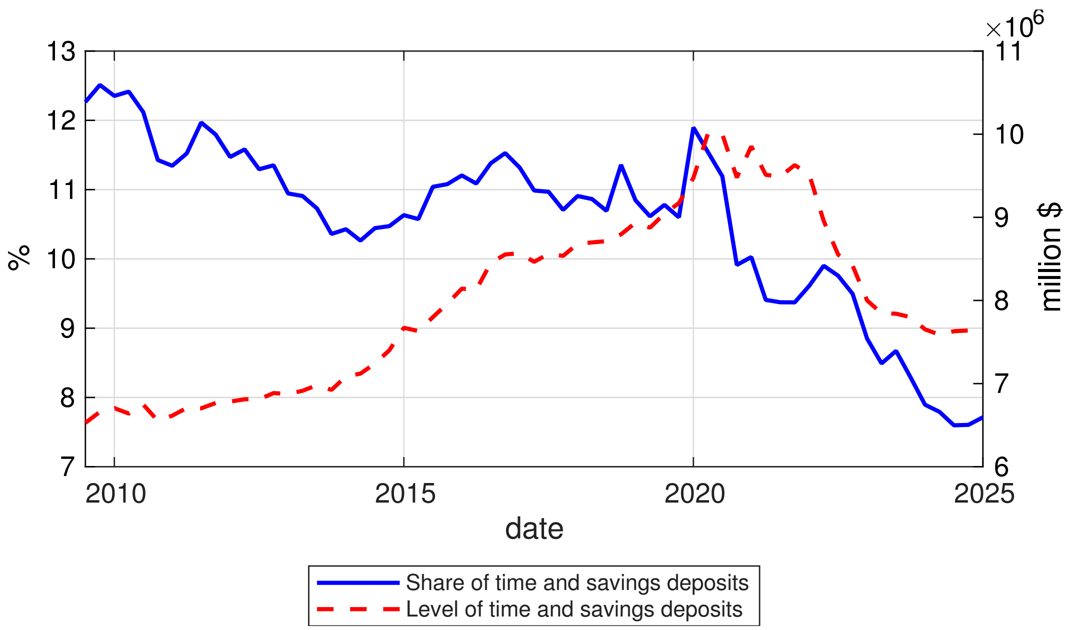


Figure 1: The share of non-transaction deposits

Figure 1 summarizes two observations: the decrease in real non-transaction deposits both in level and in share of total financial assets of U.S. households after the COVID-19 pandemic. From 2022:Q1 to 2025:Q1, U.S. households' real non-transaction deposit holdings including time and savings deposits decreased from \$9,516 billion to \$7,580 billion, which was a 20.4% decrease.[5] The

[5]All the balance sheet data in this document are obtained from "Z.1 Financial Accounts of the United States", Board of Governors of the Federal Reserve System. The data are transformed into real values using "Personal consumption expenditures" retrieved from the Bureau of Economic Analysis.

share of deposits in total financial assets of U.S. households also decreased from 9.6% to 7.7% during the same period.

Meanwhile, the other financial assets, as well as the total financial assets, show a different trend. Figure 2 shows the change in the composition of U.S. households' financial assets from 2009:Q3 to 2025:Q1 in real values. Total financial assets decreased by 0.8% from 2022:Q1 to 2025:Q1. However the equity and investment fund increased by 2.1% and money market funds increased by 58.7% during the same period. Although the expansion in the value of other financial assets such as corporate equities could partly explain the decrease in the share of deposits by increasing the denominator, the drastic decrease in the level of deposits is unique among all financial assets.

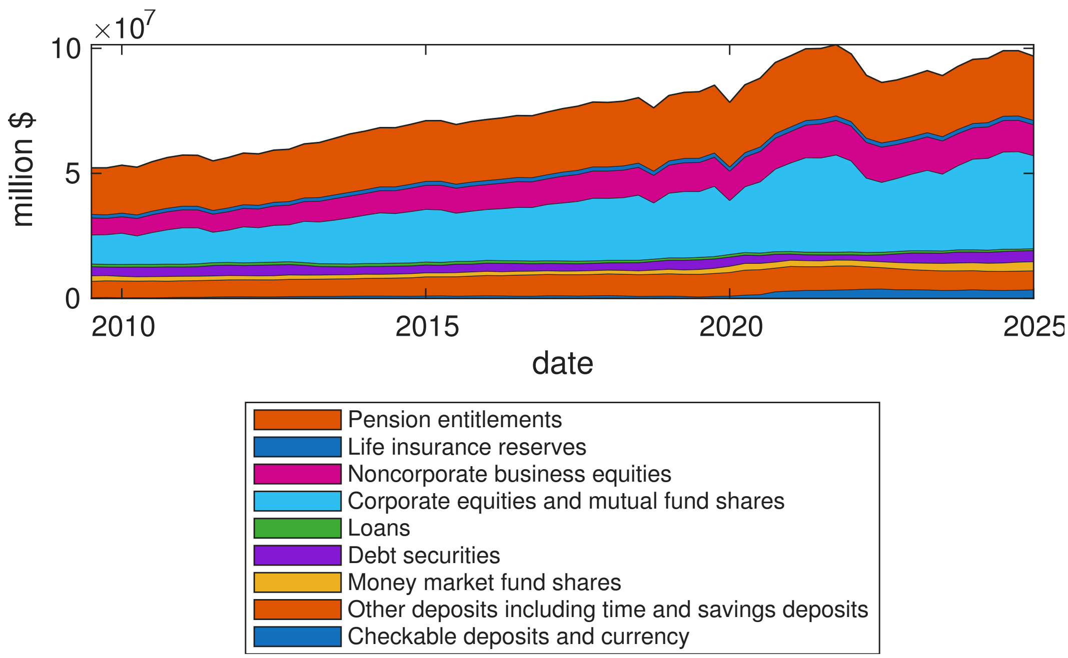


Figure 2: The composition of U.S. households' financial assets

From these observations, one may suspect that the deposits decreased since the rise in interest rates on them was not sufficient compared to that in returns from alternatives. Indeed, the reference interest rates increased significantly after the COVID-19 pandemic as shown in panel (a) of Figure 3. The maximum size of the spread was 4.25% in 2023:Q2. However, a simultaneous decrease in the level of deposits was unprecedented. From 2016:Q1 to 2019:Q2, for instance, the level of deposits increased even with the widening interest spread between the deposit and the policy rate where the maximum size of the spread was 2.18% in 2019:Q1. To explain the recent phenomenon, one must explain the difference in responses of households to the interest spreads of the two periods.

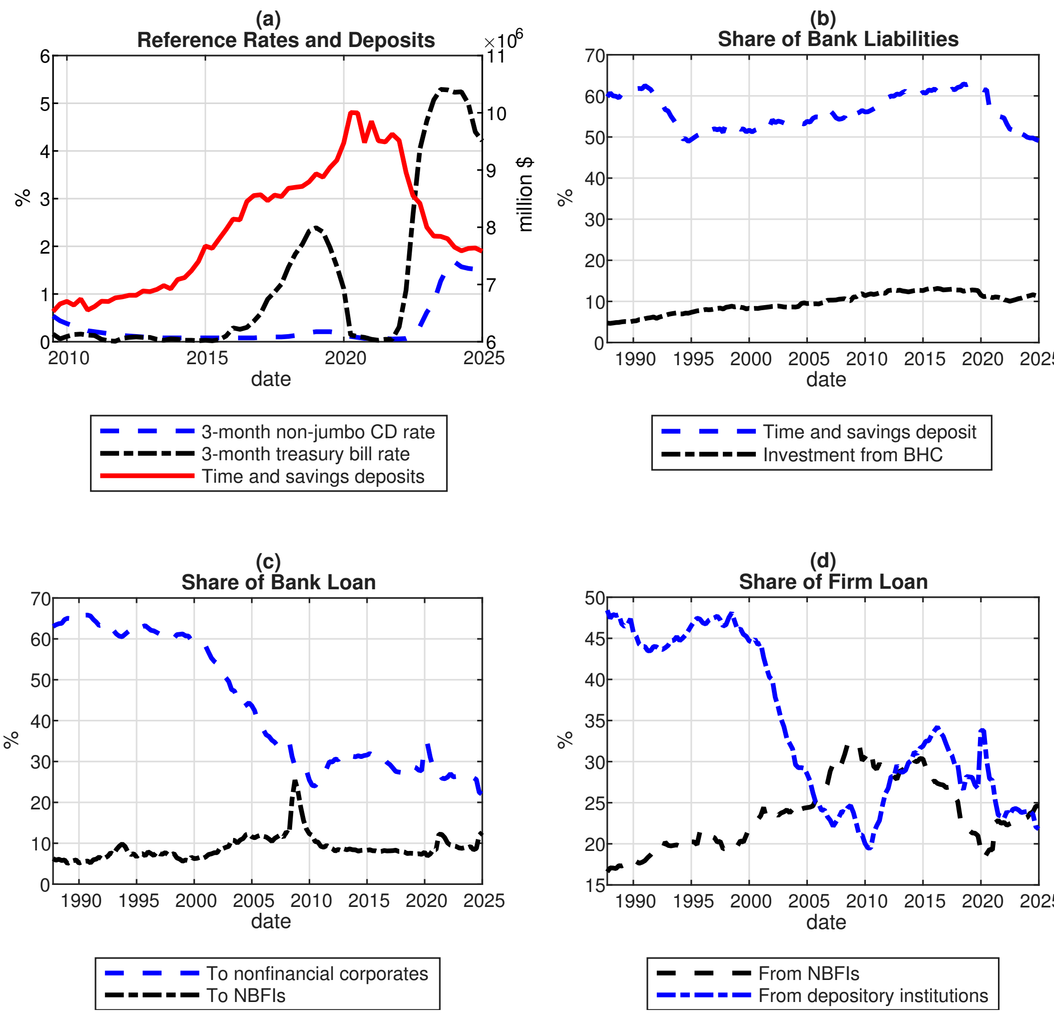


Figure 3: Empirical Observations on U.S. Financial Market

One plausible explanation is that households reallocated their portfolios toward assets offering higher returns as their risk profiles change. If households became more risk-tolerant and had more aggressive investment profiles, they would have reallocated more of their portfolios away from deposits. However, some indirect evidence such as little change in the average financial literacy and no dramatic increase in the stock market participation rate of U.S. adults during the period contradicts this argument.[6] Note that these observations cannot rule out the chance that U.S. households have replaced significant amount of deposits with other low-risk assets such as money market funds or Treasury securities without changing their overall risk exposure.[7] Indeed, the levels of money market funds and debt securities of households increased significantly after the COVID-19 pandemic as shown in Figure 2.

However, the sudden and drastic decrease in deposits is still puzzling. Even we embrace the idea of replacement with assets with similar risks but higher yields, the following question remains: Why is this time different from the previous episodes of rising interest rates? If there was no significant improvement in financial literacy of U.S. households on average and they had increased their deposit holdings despite the widening interest spread between deposit and alternatives before the pandemic as in (a) of Figure 3, what triggers the recent change in household portfolio choices particularly?

I suggest one possible answer to the question that a rapid change in the financial circumstances of U.S. households influenced their portfolio choices. For instance, the adoption of mobile banking increased significantly after the COVID-19 pandemic.[8] The technology adoption has made households more comfortable with mobile banking and online financial services, which gave

[6]TIAA Institute Personal Finance Index (P-Fin Index) show that there is no significant change in the average level of financial literacy of U.S adults from 2017 to 2025. Also, Gallup reports 62% of stock market participation rate of U.S. adults from survey. The rate did not recover to the pre-Global Financial Crisis level of 65% in 2007. See Appendix A.4 and Appendix A.5 for details.

[7]Yankov (2018) points out the chance of exiting the time deposit market of households with lower search costs. They would be more likely to switch to alternative investments such as money market funds for seeking higher yields.

[8]See Appendix A.6.

them greater access to financial products alternative to deposits. This can be connected to the discussion in the literature on the search costs of households interpreting the adoption of a new technology as a global decrease in search costs across households with different characteristics.[9] With a new technology, households could have moved their portfolios away from deposits with a fewer stages of physical visits to banks and less effort to compare alternatives.

The model of this paper is built upon analogous idea but implementing a concept of financial distress cost instead of search cost. I define the financial distress cost as the physical or psychological costs from holding a financial asset other than deposits. It can represent various costs such as the discomfort from bearing illiquidity risk, the variation in returns from alternatives, or the effort to manage multiple financial products parsimoniously. The concept of financial distress cost can be implemented straightforwardly in the household problem in DSGE framework, and one can easily generate the shift in household portfolio choices from the change in the cost function of the model.

Another empirical evidence is the change in the asset side of banks and the borrowing side of nonfinancial corporates. When households reallocated their portfolios away from deposits, banks faced a sharp decrease in the share of deposits in their total equities and liabilities as shown in panel (b) of Figure 3. The share decreased by 5.5% from 2022:Q1 to 2025:Q1, whereas the share of equity and other investments from bank holding companies increased by 1.17% during the same period. The increase in the share of investment is remarkable as the total equities and liabilities of banks decreased by 7.6% during the same period. On the asset side of banks, the share of loans to Nonbank Financial Intermediaries(NBFIs) increased by 2.6% whereas the share of loans

[9] For example, Yankov (2018) investigates the heterogeneity of search costs with different household characteristics. He models the asymmetric transmission of the policy rate to deposit rates based on the distribution of search costs.

to nonfinancial corporates decreased by 4.2% from 2022:Q1 to 2025:Q1. Panel (c) of Figure 3 summarizes these changes. In sum, it seems that banks are trying to replace the lost deposits by increasing the investment from their parent companies and seeking higher yields by lending more to NBFIs. This idea is consistent with the recent literature on the relationship between banks and NBFIs (Acharya et al. (2024), Berrospide et al. (2025)).

Finally, panel (d) of Figure 3 shows the change in the lending sources for loans to nonfinancial corporates. The share of loans from banks decreased by 1.3% from 2022:Q1 to 2025:Q1, whereas that from NBFIs increased by 2% during the same period.[10] This observation is consistent with the recent literature on the role of NBFIs in supplying credit to nonfinancial corporates (Cai and Haque (2024), Acharya et al. (2024)). The details of data construction are explained in the subsections of Appendix A.

2.2 Related Literature

This paper relates to several strands of research on the banking sector and financial intermediation. However, this paper primarily contributes to the literature on DSGE modeling featuring financial intermediation. Following seminal works in this literature such as Bernanke et al. (1999) and Kiyotaki and Moore (1997), many researchers have developed various extensions of workhorse models to explain different phenomena in the economy. This paper is also an extension built upon well-established frameworks in literature.

First, the model in this paper incorporates macroeconomic policy frameworks from the literature. Sims et al. (2023) provide a baseline framework to implement the floor system of monetary policy and quantitative easing (QE)

[10]The decline of the depository loan in the asset side of banks was more significant than that in the liability side of nonfinancial corporates. This could be due to the expansion in the balance sheet of banks regardless of the change in the source of funding.

or Large Scale Asset Purchase Programs (LSAP) by the central bank. Additionally, Kumhof and Wang (2021) suggest stylized forward-looking policy rules for these policies. The backbone of conventional and unconventional monetary policies in the model of this paper relies on them. However, this paper contributes by implementing a credit supply policy for the production sector of the economy. Incorporating results on financial constraints in the production sector from Greenwald et al. (2020) and Amberg et al. (2023), I model a government loan program, benchmarking the Main Street Lending Program (MSLP) by the Federal Reserve.

Second, I implement the macroprudential policy framework from Gerali et al. (2010) and Angelini et al. (2014). They provide a mechanism for the capital regulation of banks under Basel III in the form of banks' adjustment costs. I extend their intuitive and tractable mechanism to fit the enlarged financial system of this paper. Specifically, I modify the adjustment cost to cover different assets and liabilities of the traditional banking sector including reserves and equity investment of bank holding companies.

Third, the foundation of the financial system of this paper is built upon the framework of Lubello and Rouabah (2024). They provide an intuitive and manageable framework to implement two different types of financial intermediaries for different borrowers. I extend their framework in several ways to fit recent observations from the U.S. financial market.

First, I add an additional route for traditional banks' fund-raising from their holding companies to the model. This feature enables representation of the recent reallocation between banks' equity and liabilities. Second, I modify the fund-raising structure of the shadow bank more realistically. Instead of borrowing from households, I assume that the shadow bank is funded by traditional banks. This reflects recent observations on the intertwined relationship between banks and NBFIs (Acharya et al. (2024) and Berrospide et al. (2025)). Third, I differentiate the borrowers from the traditional bank and those from the shadow bank with respect to the form of loan contracts and their risk profiles. For the former, I implement a credit line loan contract inspired by Greenwald et al. (2020). For the latter, I assign a risky profile to the borrowers and allow for a chance of default on the loans following Gasparini et al. (2024). The risky characteristics of borrowers from the shadow bank are inspired by observations in Chernenko et al. (2022). Finally, I specify the relationship between different borrowers in the production sector to generate more realistic dynamics in the financial market. I assume that the borrowers from the shadow bank supply additional capital inputs, which are compounded into the production function of the borrowers from the traditional bank.

3 The Model

3.1 Overview

The model in this paper is based on a standard two-agent NK-DSGE model with financial intermediation. Building upon this well-established framework, I introduce two types of lenders and distinct borrowers to represent the segmented financial market. Additionally, I devise an interaction between these borrowers in the production sector to represent the reallocation in the financial market more realistically. Finally, I implement various macroeconomic policies to investigate their implications in the changed financial environment.

The real and financial sectors of the model are illustrated in Figure 4 and Figure 5, respectively. This section provides a bird's-eye view of the model by summarizing the key features of each agent.

First, a standard representative household consumes, works, and saves via

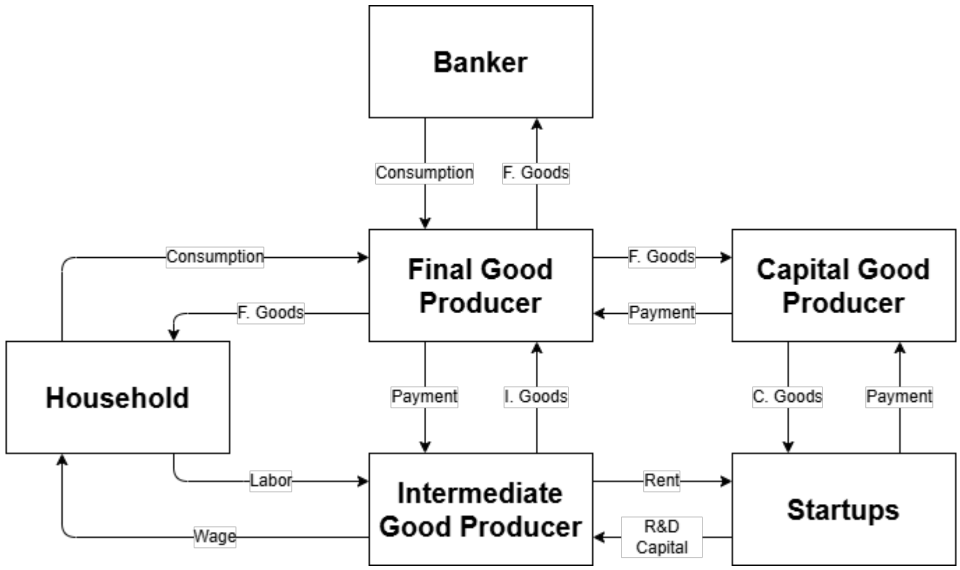


Figure 4: The Summary of Real Sector

The “F.Goods" represents final goods, “I.Goods" represents intermediate goods, and “C.Goods" represents capital goods.

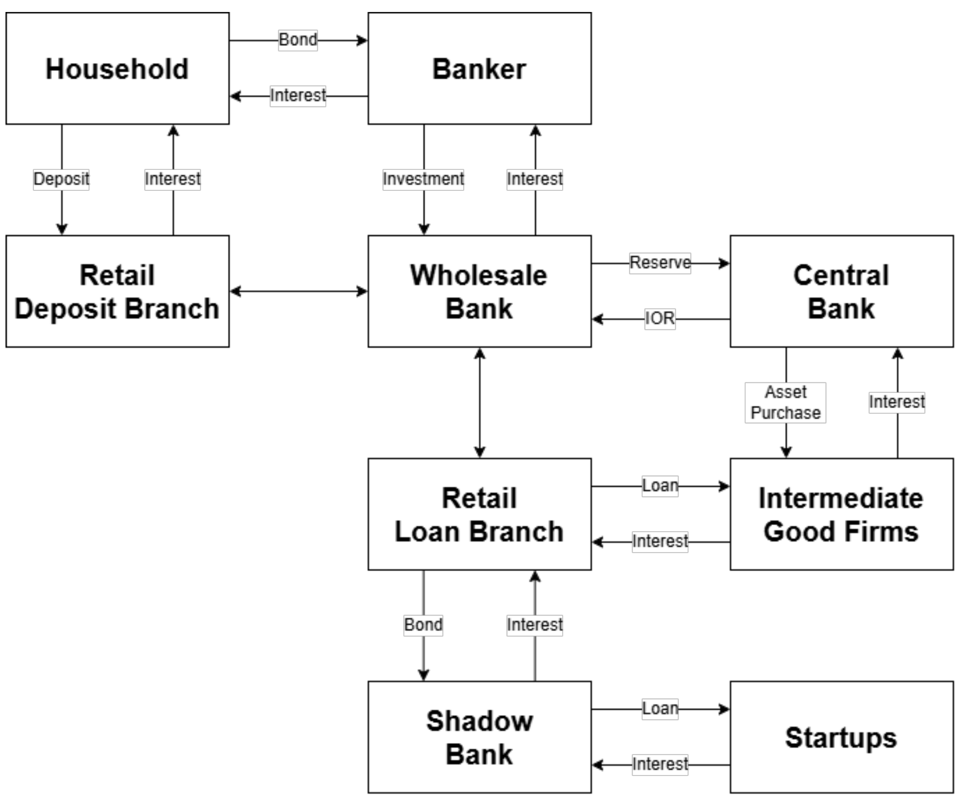


Figure 5: The Summary of Financial Sector

The “IOR” represents the interest on reserves from the central bank.

two different financial assets: deposits in the retail bank and banker's bonds. To guarantee positive holdings of both assets, I introduce a financial distress cost that decreases non-linearly in the share of deposits held in total savings. The household chooses the optimal share of deposits as it does for consumption and labor supply, to maximize its expected lifetime utility. In the optimization problem, the financial distress cost plays a crucial role in determining the portfolio allocation of the household.

Second, an additional household-type agent, called a banker, is introduced to the model. It represents BHCs in the real economy, which own depository institutions and invest in NBFIs. The main role of the banker is to raise funds from the household and invest in its subsidiary bank. However, the banker's decisions under a different risk profile and time preference from the household are also important in the dynamics of the financial market in the model.

Third, there are two types of banks in the financial sector: traditional banks and shadow banks. The financial intermediation of the traditional banking sector has a two-stage structure consisting of a wholesale bank and retail banks. The retail loan and deposit branches make contracts with the household, the production sector, and the shadow bank, respectively. I assume that the retail banks have Dixit-Stiglitz type monopolistic competition in both deposit and loan markets to model realistic interest rate spreads. In addition to the assets and liabilities from the retail branches, the wholesale bank manages its balance sheet with additional assets and liabilities such as reserves in the central bank's account and investment from the banker. It also retains its own capital as a portion of operating profit. With the help of the two-stage structure, macroeconomic policies are implemented to target the wholesale bank's operation only. The shadow bank is funded by the wholesale bank and lends to startups, who cannot borrow from the traditional banking sector. The shadow bank also retains some capital from its operating profit.

Fourth, production in this model is an extension of the standard two-stage production structure in the literature. In addition to the constant elasticity of substitution (CES) aggregation of goods from competitive intermediate good producers employing labor and their own capital, I introduce an additional input to the production sector. Specifically, I assume that the new input takes the form of capital, which is produced by a capital good producer using the final good. Then startups, who purchase the new capital from the capital good producer and rent it to the intermediate good firms.

Based on this production structure, the agents in the production sectors take the role of borrowers in the model. I assume that the intermediate good producers borrow from the retail banks, whereas the startups borrow from the shadow bank. Additionally, I assume a different form of loan contract for each borrower. The intermediate good producers borrow under a credit line contract, which allows them to adjust their loan utilization rate within the credit limit. To model the realistic behavior of borrowers under the credit line contract, I introduce a financial distress cost that increases in the share of bank loans in their total borrowing. For the startups, I assign a risky profile to them by introducing an idiosyncratic return shock on their operation. Based on this assumption, a stylized form of contract is implemented to connect the idiosyncratic shock to the debt payment of startups. This feature is also essential to represent the spread in loan rates observed between depository loans and loans from NBFIs.

Finally, the policy framework in this model is built upon well-established frameworks in the literature with some extensions. First, the interest-on-reserve (IOR)-based monetary policy framework is implemented. It has a typical Taylor-type rule and responds to the inflation and output gap. Additionally, a government loan program is implemented as an unconventional monetary policy to support the borrowers from the traditional banking sector. Second, the macroprudential policy framework under Basel III is implemented to regulate the financial intermediation of the traditional banking sector. Specifically, the wholesale bank receives penalty costs when its ratio of capital to risk-weighted assets deviates from the target ratio set by the macroprudential policy authority. A similar penalty cost is imposed on the banker when its investment in the wholesale bank relative to borrowing from the household deviates from the target double-leverage ratio.

In the following sections, the key mechanisms of each agent in the model are summarized. A detailed derivation of the model can be found in Appendix D.

3.2 Households

The household sector of this model has two notable features compared to the prototypical households in NK-DSGE models. First, a representative household holds two types of financial assets: deposits and banker's bonds similar to Lubello and Rouabah (2024). Second, the household pays financial distress costs increases with the share of banker's bonds held in total savings. Inspired by Dotsey and Ireland (1996) and Lubello and Rouabah (2024), I introduce a stylized cost function that the steady state share of deposits can be matched with the elasticity parameter of the cost function. This feature is helpful for modeling the recent sudden change in household portfolio choices.

A brief summary of the household sector is as follows: a representative household consumes (c_t) and works (h_t).[11] It holds two types of financial assets: deposits in the loan branch of retail banks (d_t) and bonds issued by

[11] A detailed derivation of the representative household's problem can be found in Appendix B.3.

the banker (b_t^b). It pays the financial distress cost ($\varPhi_t$) proportional to the amount of banker's bonds held. Additionally, the household owns the firms in the production sectors and receives dividends from them (D_t^f from the intermediate good firms, D_t^k from the capital-producing firms, and $(1-\iota)\chi^n \mathcal{W}_t^n$ from startups). In addition, the central bank transfers its operating profit (T_t^{cb}) to the household. Finally, it transfers a fixed amount X_0^{bhc} to the banker.

The household maximizes its expected lifetime utility discounted by its time preference β^h:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_h^t \left[\frac{1}{1-\frac{1}{\gamma_h}} \left\{ c_t^h \right\}^{1-\frac{1}{\gamma_h}} - \frac{\chi_h}{1+\frac{1}{\zeta_h}} \left\{ h_t^h \right\}^{1+\frac{1}{\zeta_h}} \right] \tag{1}$$

subject to its nominal constraint:

$$\begin{aligned} R_{t-1}^b P_{t-1} b_{t-1}^b + r_{t-1}^d P_{t-1} d_{r,t-1} + P_t w_t h_t^h + P_t Z_t^{total} \\ \geq P_t c_t^h + P_t b_t^b + P_t d_{r,t} + P_t d_t^h \varPhi(s_t) \end{aligned} \tag{2}$$

where the transfers are:

$$Z_t^{total} = D_t^f + D_t^k + (1-\iota)\chi^n \mathcal{W}_t^n + T_t^{cb} - X_0^{bhc}.$$

The financial distress cost designed after Dotsey and Ireland (1996) and Lubello and Rouabah (2024) is defined as:

$$\varPhi(s_t) \equiv \chi_{1,t} \left(\frac{1-s_t}{s_t} \right)^{\vartheta_t}. \tag{3}$$

Here, s_t denotes the share of deposits in the household's total savings d_t^h, and $\chi_{1,t}$ and ϑ_t represent the scale and elasticity of the function, respectively. To generate the desired dynamics in the share of deposits, s_t, I add an exogenous stochastic process, S_t^{ϑ} for ϑ_t. Additionally, $\chi_{1,t}$ is automatically defined as a function of ϑ_t to satisfy the steady state equilibrium conditions.

$$\vartheta_t = S_t^{\vartheta}\bar{\vartheta} \tag{4}$$

$$\log(S_t^{\vartheta}) = \rho_{\vartheta}\log(S_{t-1}^{\vartheta}) + u_t^{\vartheta} \tag{5}$$

$$\chi_1(\vartheta_t) = (\beta_h\bar{R}^b - 1)\left(\frac{1-\bar{s}}{\bar{s}}\right)^{1-\vartheta_t}\frac{\bar{s}^2}{\vartheta_t} \tag{6}$$

where $\bar{R}^b$ is the steady state gross return on banker's bonds, and the exogenous shock to ϑ_t is $u_t^{\vartheta} \overset{i.i.d.}{\sim} N(0, \sigma_{\vartheta}^2)$. Additionally, the deposits and banker's bonds are written as a share of total savings,

$$d_{r,t} = s_t d_t^h, \tag{7}$$

$$b_t^b = (1-s_t)d_t^h. \tag{8}$$

In a cashless economy, the representative household chooses consumption, labor supply, and portfolio allocation to maximize its utility, taking into account the budget constraint. What distinguishes this household sector from typical assumptions is the presence of the financial distress cost and additional assumptions on portfolio allocation. Given the assumptions above, the exogenous shock to the elasticity process variable ϑ_t will affect the household's decision on the share of deposits held in total savings. Specifically, I aims to implement a negative shock to ϑ_t, which generates a decrease in the share of deposits held by the household, s_t. The transmission of this shock to the overall economy will be the main focus of this paper and more discussion on this is provided in Section 5.

3.3 Banker

The banker in the model takes the role of a bank holding company (BHC) in the real economy. With the appearance of an additional household sector, which is not uncommon in the literature, it is introduced to the model to implement another source of funding for the traditional banking sector. Basically, fund-raising from the household and investment in the subsidiary bank are the main functions of the banker in the model. To supplement a simple structure of financial intermediation, borrowing, lending and leverage adjustment costs are introduced to prevent the corner solution in the banker's decisions. Specifically, the leverage adjustment cost is implemented to represent the regulation to prevent the excessive investment of BHCs in their subsidiary banks.

A representative banker consumes (c_t^b) and does not work. It raises funds from the household (b_t^b) and invests in the wholesale bank (e_t^b). It owns the wholesale, retail and shadow banks and receives dividends from them (D_t^b, D_t^{sb}). It also receives transfers from the household (X_0^{bhc}). It pays fund-raising, investment and leverage adjustment costs ($\mathcal{C}_{t-1}^{bhc,b}$, $\mathcal{C}_{t-1}^{bhc,e}$, $\mathcal{C}_{t-1}^{bhc}$). I assume that the costs occurring at $t-1$ are paid at t.[12]

The banker maximizes its expected lifetime utility discounted by its time preference β^b:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \left[\log\left(c_t^b\right)\right] \tag{9}$$

[12]For technical reasons, the remuneration and adjustment costs occur at $t-1$ and are paid at t. By assumption, the dividends which the banker receives at t are the portion of operation profit of banks at $t-1$ (for instance, see equation (16)). Thus the remuneration and adjustment costs of banks occur at $t-1$ but appear in the consolidated resource constraint at t. For simplicity, I assume that the timing of the payment of the same type of costs in the banking sector is identical.

subject to its nominal constraint:

$$
\begin{aligned}
& P_t b_t^b + P_{t-1}\mathcal{C}_{t-1}^{bhc,e} + R_{t-1}^{eb} P_{t-1} e_{t-1}^b + P_t D_t^b + P_t D_t^{sb} + P_t X_0^{bhc} \\
& \geq P_t c_t^b + R_{t-1}^b P_{t-1} b_{t-1}^b + P_t e_t^b + P_{t-1}\mathcal{C}_{t-1}^{bhc,b} + P_{t-1}\mathcal{C}_{t-1}^{bhc},
\end{aligned}
\tag{10}
$$

where the fund-raising cost is:

$$
\mathcal{C}^{bhc,b}\left(b_t^b\right) = \frac{\kappa_{bhc,b}}{1+\frac{1}{\theta^{bhc,b}}} \bar{b}^b \left(\frac{b_t^b}{\bar{b}^b}\right)^{1+\frac{1}{\theta^{bhc,b}}}, \tag{11}
$$

the investment cost is:

$$
\mathcal{C}^{bhc,e}\left(e_t^b\right) = \frac{\kappa_{bhc,e}}{1+\frac{1}{\theta^{bhc,e}}} \bar{e}^b \left(\frac{e_t^b}{\bar{e}^b}\right)^{1+\frac{1}{\theta^{bhc,e}}}, \tag{12}
$$

and the leverage adjustment cost is:

$$
\mathcal{C}^{bhc}\left(b_t^b, e_t^b, \nu_t^{bhc}\right) = \frac{\kappa_{bhc}}{2} \left(\frac{e_t^b}{b_t^b} - \nu_t^{bhc}\right)^2 e_t^b. \tag{13}
$$

A few remarks are in order. First, I assume the log utility function for the banker to dampen the inter-temporal substitution effect in its consumption decision.[13] Second, I assume the banker owns the wholesale, retail and shadow banks in the model. The assumption on the ownership of the shadow bank seems too strong, but it is acceptable when considering that BHCs and their subsidiaries are the main investors in the private credit market.[14] Third, I assume that only the investment cost will be covered by the subsidiary banks.

[13]The form of the utility function is directly related to the risk taking behavior of the banking sector. However, it is hard to pin down the exact level of risk aversion since it depends on the ownership structure, regulation frameworks, and macroeconomic conditions. See Laeven and Levine (2009) regarding the varying risk taking behavior of banks.

[14]Acharya et al. (2024) report the case of the Blackstone Private Credit Fund. In December 2022, 98% of the committed credits, which were from 18 out of 19 funding facilities, were provided by 13 banks including BHCs, for instance, Bank of America and Goldman Sachs.

This represents the pressure on the subsidiary banks' interest margin when the investment from the BHCs increases.[15] Finally, I implement the leverage adjustment cost, which has an analogous form to the capital adjustment cost in Gerali et al. (2010). The cost is essential to link the borrowing and investment decisions of the banker. More details of the leverage ratio regulation are provided in Section 3.6 and Appendix G.1.

3.4 Banking Sector

The banking sector consists of three types of banks: wholesale bank, retail banks, and shadow bank. The wholesale bank and retail banks represent the traditional banking sector. They are funded by deposits from the household and equity investment from the banker. They supply loans to the production sector and the shadow bank. Using the funds from the traditional banking sector, the shadow bank provides loans to the startups.

The two-stage structure in the traditional banking sector is a well-established framework in the literature (Gambacorta and Karmakar (2018), Angelini et al. (2014), Gerali et al. (2010)). One of the advantages of splitting the sector into two is to focus on the different subjects of interest in each type of bank. In this paper, the wholesale bank is the main target of monetary and macroprudential policies, whereas the retail banks' operations serve to model the interest rate spreads in deposit and loan markets. Additionally, the stickiness of retail interest rates is modeled in this framework.

[15] The Federal Deposit Insurance Corporation (FDIC) discusses the supervisory concerns regarding double leveraging in Federal Deposit Insurance Corporation (2004): "... supervisory concerns may arise as the parent issues long-term debt to fund equity capital in the subsidiaries. Although this capital-raising activity, known as "double leveraging," does increase equity capital in the subsidiary, too much debt at the holding company level can generate pressure on the subsidiary to upstream additional dividends."

3.4.1 Wholesale Banks

The wholesale bank's operation can be summarized into two components: the internal and external financial operations. The internal operation is the interaction with the retail banks. The wholesale bank purchases the retail loans: the demand for retail loans to intermediate good producers, $\tilde{\ell}_t^{f,b}$, and that to the shadow bank, b_t^{sb}. Also, the wholesale bank supplies funds, d_t, to the deposit sector of retail banks. The external operation is the interaction with the banker and the central bank. First, the wholesale bank receives equity investment from the banker, e_t^b. Second, the wholesale bank saves reserves, re_t, at the central bank's account. The balance sheet condition summarizes these operations:

$$\widetilde{\ell}_t^{f,b} + b_t^{sb} + re_t = d_t + e_t^b + X_t^b \tag{14}$$

where X_t^b represents the internal capital of the wholesale bank. Additionally, I assume a fixed dividend rate ν^b to be paid out of the bank's net worth following Brunnermeier and Koby (2018). Then, the internal capital accumulation rule is as follows:

$$X_{t+1}^b = (1-\nu^b)N_{t+1}^{b,total} \tag{15}$$

where $N_{t+1}^{b,total}$ is the total net worth of the wholesale and retail banks. This suggests that a fraction of the total profit of traditional banking sector is paid to the banker as dividends. Additionally, the retail banks do not operate with their own capital and are fully funded by the wholesale bank. I will define the total net worth at the end of the retail bank section.

The wholesale bank's net worth, N_{t+1}^b, is as follows:

$$\Pi_{t+1}N_{t+1}^b = R_t^f \widetilde{\ell}_t^{f,b} + R_t^{sb} b_t^{sb} + R_t re_t - R_t^d d_t - R_t^{eb} e_t^b - \mathcal{C}_t^b - \mathcal{C}_t^{bhc,e}, \tag{16}$$

where $\Pi_{t+1} = \frac{P_{t+1}}{P_t}$ is the gross inflation rate and R_t^s is the gross interest rate on different assets where $s \in \{f, sb, d, eb\}$.

The capital-asset ratio adjustment cost is defined as:

$$\mathcal{C}_t^b = \frac{\kappa_{Kb}}{2}\left(\frac{X_t^b + \rho^e e_t^b}{re_t + \omega_t^f \tilde{\ell}_t^{f,b} + \omega_t^{sb} b_t^{sb}} - \nu_t^k\right)^2 \left(X_t^b + \rho^e e_t^b\right). \tag{17}$$

The risk weights for wholesale loans to intermediate good producers and the shadow bank are ω_t^f and ω_t^{sb}, respectively, and they are defined as:

$$\omega_t^s = (1-\rho^s)\bar{\omega}^s + (1-\rho^s)\chi^s(y_t - y_{t-4}) + \rho^s \omega_{t-1}^s, \; s \in \{f, sb\}, \tag{18}$$

where κ_{Kb} is the adjustment cost parameter and ν_t^k is the target capital-asset ratio set by the macroprudential policy authority.

Then, the wholesale bank maximizes the expected net worth tomorrow discounted by the banker's stochastic discount factor, $\Lambda_{t,t+1}^b$:

$$\max \mathbb{E}_t \left[\Lambda_{t,t+1}^b N_{t+1}^b\right] \tag{19}$$

subject to the balance sheet condition.[16]

The wholesale bank's operation is the main target of monetary and macroprudential policies in the model. I assume the "floor system" for the monetary policy in the model, which means that the interest rate on reserves (IOR) is adjusted by the central bank. Also, I implement the capital-asset ratio adjustment cost to represent the capital regulation on banks. The functional form of the cost is designed after Gerali et al. (2010) and Angelini et al. (2014) but is modified to include investment from the banker and reserves.

The parameterization of the macroprudential policy is based on the Basel III

[16] The banker's stochastic discount factor is defined by $\Lambda_{t,t+1}^b = \beta_b \mathbb{E}_t\left[\frac{\lambda_{t+1}^b}{\lambda_t^b}\right]$. Here, λ_t^b is the nominal Lagrange multiplier for the banker's budget constraint.

Risk-based capital requirements and the calculation of RWA for credit risk.[17] The risk weights for the assets on the wholesale banks' balance sheet are set to align with the Basel III requirements. First, the steady state risk weight for reserves is normalized to 1. Second, I add 20% more weights to the steady state risk weights for wholesale loans to intermediate good producers and the shadow bank.[18] Then the value of ρ_e is endogenously determined to satisfy the Basel III requirements and the steady state equilibrium of the model. To pin down the value of the parameter, I assume that the banker's investment in the wholesale bank, e_t^b, represents the second tier capital under Basel III.[19]

3.4.2 Retail Banks

Loan Branch

The loan branch of retail banks provides retail loans to intermediate good producers, $\ell_{r,t}^f$, and the shadow bank, $b_{r,t}^{sb}$, in aggregate. It raises funds by selling those loans to the wholesale bank. Following Gerali et al. (2010), I assume that the retail banks are price setters who face loan demand schedules with elasticities $\varepsilon^{b,f}$ and $\varepsilon^{b,sb}$ for each type of loan. This enables the model to capture the stickiness of retail interest rates and represent the interest rate spread from the policy rate. Finally, the remuneration costs, $\mathcal{C}_t^{b,f}$ and $\mathcal{C}_t^{b,sb}$, for each loan are added to the retail loan operation to obtain additional stickiness in the prices as in Gerali et al. (2010) and Gambacorta and Karmakar (2018).

The objective function for retail bank j in the loan branch is given as

[17] Basel Committee on Banking Supervision (2020b), Basel Committee on Banking Supervision (2020a).

[18] The risk weight for the exposures to sovereign and central banks with external rating of AAA to AA− is 0%. The risk weight for the exposures to corporates with an external rating of counterparty of AAA to AA− is 20%. See Basel Committee on Banking Supervision (2020b) for the details.

[19] See Appendix B.2 for the detailed proof.

follows:

$$\max_{r_t^f(j), r_t^{sb}(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \lambda_t^b \Big[r_t^f(j) \widetilde{\ell}_{r,t}^{f,b}(j) + r_t^{sb}(j) b_{r,t}^{sb}(j) \tag{20}$$

$$- \left(R_t^f \tilde{\ell}_t^{f,b}(j) + R_t^{sb} b_t^{sb}(j) \right) - \mathcal{C}_t^{b,f} - \mathcal{C}_t^{b,sb} \Big],$$

where the remuneration costs are defined as follows:

$$\mathcal{C}_t^{b,f} = \frac{\kappa_{b,f}}{2} \left(\frac{r_t^f(j) - 1}{r_{t-1}^f(j) - 1} - 1 \right)^2 \left(r_t^f - 1 \right) \widetilde{\ell}_{r,t}^{f,b} \tag{21}$$

$$\mathcal{C}_t^{b,sb} = \frac{\kappa_{b,sb}}{2} \left(\frac{r_t^{sb}(j) - 1}{r_{t-1}^{sb}(j) - 1} - 1 \right)^2 \left(r_t^{sb} - 1 \right) b_{r,t}^{sb} \tag{22}$$

The retail bank j faces the demand schedules:

$$\widetilde{\ell}_{r,t}^{f,b}(j) = \left(\frac{r_t^f(j) - 1}{r_t^f - 1} \right)^{-\varepsilon^{b,f}} \tilde{\ell}_{r,t}^{f,b} \tag{23}$$

$$b_{r,t}^{sb}(j) = \left(\frac{r_t^{sb}(j) - 1}{r_t^{sb} - 1} \right)^{-\varepsilon^{b,sb}} b_{r,t}^{sb}. \tag{24}$$

Here, $r_t^s(j)$ is the retail gross interest rate on loans set by retail bank j, and r_t^s is the aggregate retail interest rate on the loans where $s \in \{f, sb\}$.

Deposit Branch

The deposit branch of retail banks issues retail deposits to the household, $d_{r,t}$, and lends funds to the wholesale bank. Similar to the loan branch, the retail banks in the deposit branch are also price setters who face deposit supply schedules with elasticity ε_t^d. The retail interest rate on deposits, $r_t^d(j)$, is set by each retail bank j. The objective function of retail bank j in the deposit branch is given as follows:

$$\max_{r_t^d(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \lambda_t^b \left[-r_t^d(j) d_{r,t}(j) + R_t^d d_t(j) \right] \tag{25}$$

where the demand schedule for deposits is given as follows:

$$d_{r,t}(j) = \left(\frac{r_t^d(j) - 1}{r_t^d - 1} \right)^{-\varepsilon_t^{b,d}} d_{r,t}, \tag{26}$$

where r_t^d is the aggregate retail interest rate on deposits.

Additionally, I assume that the elasticity ε_t^d follows the process:

$$\varepsilon_t^{b,d} = (1 - \rho^{b,d})\bar{\varepsilon}^{b,d} + (1 - \rho^{b,d})\chi^{b,d}(R_t - R_{t-1}) + \rho^{b,d}\varepsilon_{t-1}^{b,d}, \tag{27}$$

which is analogous to the process of risk weights in Angelini et al. (2010). As Driscoll and Judson (2013) points out, the deposit rates in the U.S. are upward sticky in relation to the movement of the policy rate. The process (27) captures this feature with $\chi^{b,d} > 0$. When the policy rate increases, the elasticity of deposit supply increases, meaning that the retail banks suppress the increase in interest rates on deposits more than before. The detailed discussion of the deposit rate stickiness is provided in Appendix G.2.

Total Net Worth of Wholesale and Retail Banks

Given the specification of retail banks' operation, the total net worth of the traditional banking sector, $N_t^{b,total}$, is defined as follows:

$$\begin{aligned} \Pi_{t+1} N_{t+1}^{total} &= \Pi_{t+1} \left(N_{t+1}^b + N_{t+1}^r \right) \\ &= \left(r_t^f - r_t^d \right) \widetilde{\ell}_{r,t}^{f,b} + \left(r_t^{sb} - r_t^d \right) b_{r,t}^{sb} + \left(R_t - r_t^d \right) re_t \\ &- \left(R_t^{eb} - r_t^d \right) e_t^b + r_t^d X_t^b - \mathcal{C}_t^b - \mathcal{C}_t^{b,f} - \mathcal{C}_t^{b,n} \end{aligned} \tag{28}$$

where N^b_{t+1} is the net worth of the wholesale bank and N^r_{t+1} is that of the retail banks.

3.4.3 Shadow Banks

The shadow bank borrows from the retail banks, b^{sb}_t, and lends to startups, b^n_t. Its balance sheet is as follows:

$$b^n_t = b^{sb}_t + X^{sb}_t, \tag{29}$$

where X^{sb}_t is the inner capital of the shadow bank.

The shadow bank earns a net interest margin from its operations and pays two types of costs: the lending cost $\mathcal{C}^{sb,n}_t$ and the monitoring cost m^{sb}_t. The net worth of the shadow bank is defined as follows:

$$N^{sb}_{t+1} = (\Pi_{t+1})^{-1}\left(R^{fn}_{t+1}b^n_t - r^{sb}_t b^{sb}_t - \mathcal{C}^{sb,n}_t - m^{sb}_t\right). \tag{30}$$

The interest rate on loans to startups, R^{fn}_{t+1}, is an ex-post gross rate that reflects the idiosyncratic return shock faced by startups.[20]

The lending cost is designed following the cost of making loans in Kumhof and Wang (2021):

$$\mathcal{C}^{sb,n}_t = \frac{\kappa^{sb,n}}{1+\frac{1}{\theta^{sb,n}}}\bar{b}^n\left(\frac{b^n_t}{\bar{b}^n}\right)^{1+\frac{1}{\theta^{sb,n}}}, \tag{31}$$

which is proportional to the amount of loans to startups. The lending cost prevents the shadow bank from lending an infinite amount and ensures a positive interest rate margin on the shadow bank's financial intermediation. The monitoring cost occurs when the shadow bank receives payments on defaulted loans from startups.

[20] The detailed discussion of the loan contract between the shadow bank and startups is provided in the subsection for startups.

The shadow bank maximizes the expected net worth tomorrow discounted by the banker's stochastic discount factor. The objective function is given as follows:

$$\max \mathbb{E}_t \left[\Lambda^b_{t,t+1} N^{sb}_{t+1}\right] \tag{32}$$

subject to the balance sheet condition (29). Similar to the wholesale bank, I assume a fixed dividend rate ν^{sb} to be paid out of the shadow bank's net worth following Brunnermeier and Koby (2018). The inner capital accumulation rule is then as follows:

$$X^{sb}_{t+1} = (1 - \nu^{sb}) N^{sb}_{t+1} \tag{33}$$

3.5 Production Sector

The backbone of the production sector is the standard two-stage production structure in the DSGE literature: competitive intermediate good production and final good aggregation with the Constant Elasticity of Substitution (CES) technology. In addition to this standard structure, capital-producing firms and startups are introduced to the model. The startups purchase capital from the capital-producing firms using loans from the shadow bank and rent it to the intermediate good producers.

As in Lubello and Rouabah (2024), the structure of the production sector is designed to capture the different types of financing in the real economy. First, the intermediate good producers are the borrowers from the traditional banking sector. The loan contract takes the form of a credit line, which is a common practice in the U.S. corporate loan market. Second, the startups are the borrowers from the shadow bank. The difference of startups as a borrower is that they are risky who face an idiosyncratic return shock. The loan contract between shadow bank and startups reflects this to represent the characteristics of borrowers from the private credit market. With these stylized assumptions, the model captures the differences in the interest spreads observed in the U.S. data.

Finally, the stylized asset purchase policy is implemented in the model. The basic idea of the policy is that there is a government loan that has a better term of conditions than those from the traditional banking sector. The detailed discussion of the policy's implications is provided in the following sections.

3.5.1 Intermediate Good Producers

A continuum of intermediate good producers indexed by j produce differentiated goods using labor $h_t(j)$, internal capital $K_t(j)$, and rented capital from startups $K_t^n(j)$. The production technology is given as follows:

$$y_t(j) = S_t^a \left(h_t(j)\right)^{1-\alpha} \left[\left(K_t(j)\right)^{1-\zeta} \left(K_t^n(j)\right)^{\zeta}\right]^{\alpha} \tag{34}$$

where S_t^a is the technology shock process following:

$$\log(S_t^a) = \rho^a \log(S_{t-1}^a) + u_t^a. \tag{35}$$

Here, ζ is the share of rented capital from startups in total capital. The internal capital $K_t(j)$ accumulates according to a conventional law of motion:

$$K_t(j) = (1-\delta)K_{t-1}(j) + I_t(j). \tag{36}$$

where δ is the depreciation rate and $I_t(j)$ is the investment of intermediate good producer j.

To introduce rigidities in price and investment, I assume that intermediate good producers pay adjustment costs when they change the price of their goods and the level of investment. The price adjustment costs are the standard Rotemberg-type cost functions in the literature.[21] The adjustment costs are defined as follows:

$$G_{P,t}(j) = \frac{\phi_p}{2} y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\Pi_t} - 1 \right)^2 \tag{37}$$

$$G_{I,t}(j) = \frac{\phi_I}{2} I_t \left(\frac{I_t(j)}{I_{t-1}(j)} - 1 \right)^2 . \tag{38}$$

where ϕ_p and ϕ_I are the adjustment cost parameters for price and investment, respectively.

Based on these conventional settings, I assume that intermediate good producers borrow from retail banks and the loan contract has a form of credit line. The bank loan to intermediate good producer j consists of two components: the committed loan $\ell_t^{f,b}(j)$ and the utilization rate $u_t^f(j)$. The concept of the credit line loan in the model is based on the idea that the committed loan is pre-determined and the firm decides how much of it to use. Analogous to capital utilization in the literature, the capital should not change simultaneously with the utilization rate to obtain a unique value of the utilization rate.

Considering the procedure of credit line loans in practice, I assume that the committed loan is pre-determined by the earnings before interest, taxes, depreciation, and amortization (EBITDA) in the previous period. The leverage constraint (39) is based on the empirical evidence in Greenwald et al. (2020).[22]

$$P_{t+1}\ell_{t+1}^f(j) \geq \theta_t^\pi \Pi_t^{EBITDA}(j). \tag{39}$$

[21] Christiano et al. (2005), Kumhof and Wang (2021) and Lubello and Rouabah (2024).

[22] Credit line loans are a common practice in the U.S. corporate loan market. Greenwald et al. (2020) report a positive correlation between credit line borrowing capacity and EBITDA. They analyze firm-level data in the U.S. from 2012:Q3 to 2019:Q4 and show that 53% of total used credit was issued as credit line loans. They also find that the utilization rate of credit line loans is between 40% and 60% and that the rate decreases to below 40% as firm size increases.

The EBITDA is defined as

$$\Pi_t^{EBITDA}(j) = P_t y_t(j) - P_t w_t h_t(j) - P_t r_t^{k,n} K_t^n(j),$$

which is the revenue minus the factor costs in the model. Here, θ_t^π is the multiplier for the constraint and follows the process:

$$\theta_t^\pi = S_t^\pi \bar{\theta}^\pi \tag{40}$$

$$\log(S_t^\pi) = \rho^\pi \log(S_{t-1}^\pi) + u_t^\pi \tag{41}$$

where S_t^π is the shock process to the multiplier. The process captures exogenous changes in the valuation of firms' EBITDA from the financial sector.

Next, I link the borrowing of firms to investment. The assumption that firms increase debt when they invest more is not uncommon in the literature.[23] I assume that the total borrowing is under-bounded by the multiplication of investment. The constraint for the total borrowing is given as follows:

$$\psi_t^L I_t(j) \leq \ell_t^f(j) \tag{42}$$

$$\psi_t^L = S_t^u \bar{\psi}^L \tag{43}$$

$$\log(S_t^u) = \rho^u \log(S_{t-1}^u) + u_t^u. \tag{44}$$

where $\ell_t^f(j) = u_t^f(j)\ell_t^{f,b}(j) + \tilde{\ell}_t^{f,cb}(j)$ is the total loan from both retail banks and the central bank, $\tilde{\ell}_t^{f,cb}(j)$. Given the calibration of the model, constraint (42) always binds. The shock process S_t^u captures exogenous changes in the ratio of borrowing and investment, ψ_t^L.

The last remark concerns the financial distress cost. The cost function for

[23] See Carlstrom et al. (2017) and Lubello and Rouabah (2024).

intermediate good firm j is defined as:

$$\varphi_t = \kappa_f \left(\frac{\tilde{\ell}_t^{f,b}(j)}{\ell_t^f(j)} \right)^{\theta_u} = \kappa_f \left(1 + \frac{\tilde{\ell}_t^{f,cb}(j)}{u_t^f(j)\ell_t^{f,b}(j)} \right)^{-\theta_u}, \tag{45}$$

where κ_f and θ_u are the scale and elasticity of the function, respectively. I assume the cost increases when the share of loans from retail banks in total loans increases. Using the market clearing condition of loans, the cost function can be rewritten as the second expression in (45). The stylized function suggests that an increase in the cost from the bank loan, but a decrease from the governmental loan.[24] This aligns with the idea that loans from the government have better contract terms.

In summary, intermediate good producer j maximizes expected lifetime profit considering the household's stochastic discount factor[25]:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t^h \Pi_t^F(j) \tag{46}$$

subject to (34), (36), (39), and (42), and the final good firm's demand for intermediate goods:

$$y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\theta} y_t. \tag{47}$$

The nominal profit of intermediate good firm j, $\Pi_t^F(j)$, is defined as follows:

$$\begin{aligned} \Pi_t^F(j) =& P_t(j)y_t(j) + P_t\ell_t^f(j) - P_t w_t h_t(j) - r_{t-1}^f P_{t-1}\ell_{t-1}^f(j) \\ & - P_t r_t^{k,n} K_t^n(j) - P_t I_t(j) - P_t G_{P,t}(j) - P_t G_{I,t}(j) - P_t \varphi_t(j). \end{aligned} \tag{48}$$

[24]As the committed credit, $\ell^{f,b}$ is a predetermined variable in the model, an increase in the utilization rate will increase the share of loans from the bank, resulting in the increase of distress.

[25]The stochastic discount factor is defined by $\Lambda_{t,t+1}^h = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}^h}{\lambda_t^h} \right]$. Here, λ_t^h is the nominal Lagrange multiplier for the household's budget constraint, and the real Lagrange multiplier is $\Lambda_t^h = \lambda_t^h / P_t$.

The first order conditions of the intermediate good producers' problem are provided in Appendix D.6.

3.5.2 Capital Good Producers

Given the initial capital stock, capital good producers produce additional capital goods for startups using final goods. There is also an investment adjustment cost which has an identical form to that of intermediate good producers. The details of the capital good producers' problem are provided in Appendix D.7.

3.5.3 Startups

The startups are borrowers from the shadow bank who purchase new capital goods from capital producing firms and lend them to intermediate good producers. The original setup of the startups follows Gasparini et al. (2024), however, there are two modifications to fit the context of this paper. First, intermediate good producers rent the new capital as an additional input. Second, the startups borrow from the shadow bank, not the traditional banking sector.

The gist of the startups' problem is the idiosyncratic return shock and the debt contract based on the realization of it. The idiosyncratic shock process is defined as follows:

$$\omega_{t+1}^n(j) \overset{i.i.d.}{\sim} \text{lognormal}\left(1, \sigma_t^n\right) \tag{49}$$

$$\sigma_t^n = \bar{\sigma}^n S_t^n \tag{50}$$

$$\log S_t^n = \rho^n \log S_{t-1}^n + u_t^n, \tag{51}$$

where $\omega_{t+1}^n(j)$ is the idiosyncratic shock for startup j at the end of period

$t+1$. The parameter σ_t^n is the standard deviation of the shock process, S_t^n. The process captures exogenous changes in the uncertainty of startups' returns from the financial sector.

The realized real operating profit of startup j at the end of the period is $\omega_{t+1}^n(j) R_{t+1}^n q_t^n K_{t+1}^n(j)$, where R_{t+1}^n is the gross return on capital for startups, q_t^n is the real price of new capital goods, and $K_{t+1}^n(j)$ is the capital stock purchased by startup j. Based on the realized return, the debt contract is designed as follows:

$$\text{Debt payment} = \begin{cases} \bar{\omega}_{t+1}^n R_{t+1}^n q_t^n K_{t+1}^n(j) & \text{if } \omega_{t+1}^n(j) \geq \bar{\omega}_{t+1}^n \\ \omega_{t+1}^n(j) R_{t+1}^n q_t^n K_{t+1}^n(j) & \text{if } \omega_{t+1}^n(j) < \bar{\omega}_{t+1}^n. \end{cases} \tag{52}$$

In other words, startups pay the fixed debt payment if the realized $\omega_{t+1}^n(j)$ is above the threshold whereas they pay all of their operating profit to the shadow bank if it is below the threshold. In the latter case, the shadow bank must pay a monitoring cost to receive the payment from the defaulted loans. The cost is assumed to be a fixed share, μ^n, of the default debt payment of firm j, $\omega_{t+1}^n(j) R_{t+1}^n q_t^n K_{t+1}^n(j)$.

Given the setup above, the shadow bank's participation constraint can be defined using the expected return from loans to startups. The startups maximize their expected wealth subject to the participation constraint of shadow bank. The details of the startups' problem are elaborated in Appendix D.8.

3.6 Central Bank and Macroeconomic Policies

There are four types of macroeconomic policies in the model: conventional monetary policy using the interest rate on reserves, asset purchase policy using the central bank's balance sheet, and two macroprudential policies using leverage regulation and capital regulation in the banking sector.

First, the central bank in the model issues reserves, re_t, to the wholesale bank and pays the interest rate R_t on them. The framework behind the monetary policy follows Sims et al. (2023); however, I distinguish the interest rate on reserves from the short-term rates that affect the household's inter-temporal decisions. Thus the change in policy rate is transmitted to household's through the traditional banking sector. This additional transmission mechanism generates a more realistic response of the economy to monetary policy shocks. I discuss the sticky transmission mechanism in Appendix G.2.

The policy rate is determined by a typical Taylor-type rule responding to inflation and output deviations from the steady state:

$$R_t = \bar{R}\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{m_\pi}\left(\frac{y_t}{\bar{y}}\right)^{m_y} S_t^i \tag{53}$$

$$\log S_t^i = \rho^i \log S_{t-1}^i + u_t^i \tag{54}$$

The specification of the monetary policy rule without interest rate smoothing follows Kumhof and Wang (2021). This can be interpreted as a forward-looking and continuous attempts to adjust inflation. In the baseline model, the response to the output gap is muted ($m_y = 0$), whereas the response to inflation, m_π, and the standard deviation of the monetary policy shock, $\sigma_t^{u^i}$, are estimated.

Second, the asset purchase policy is implemented in the model. The central bank lends to intermediate good producers using the newly issued reserves.

The policy rule has an analogous form to the Taylor-type rule:

$$\tilde{\ell}_t^{f,cb} = re_t \tag{55}$$

$$re_t = \bar{re} \left(\frac{\Pi_t}{\bar{\Pi}} \right)^{-q_\pi} \left(\frac{\mathbb{E}_t \ell_{t+1}^f}{\bar{\ell}^f} \right)^{-q_\ell} S_t^q \tag{56}$$

$$\log(S_t^q) = \rho^q \log(S_{t-1}^q) + u_t^q \tag{57}$$

where S_t^q is the shock process to the reserve policy. The parameters q_π and q_ℓ are the response coefficients to inflation and the amount of total committed credit line loans. The framework behind the asset purchase policy in Sims et al. (2023) was originally designed to boost aggregate demand in the economy by purchasing bonds issued by the household sector when the output gap falls below the steady state. However, I assume that the central bank supports the production sector by providing loans with loose terms and conditions. This is modeled after the Main Street Lending Program (MSLP) by the Federal Reserve in 2020, which is one of the unconventional monetary policies during the COVID-19 pandemic period.[26] In the baseline model, the response to inflation is muted ($q_\pi = 0$), and the response to committed loans is estimated.

Third, I assume that the financial authority sets the capital-asset ratio for the wholesale bank. The process for the ratio is the following:

$$\nu_t^k = \left(1 - \rho^k\right) \bar{\nu}^k + \left(1 - \rho^k\right) \left[\chi^k \left(\frac{\tilde{\ell}_t^{f,b} + b_t^{sb}}{y_t} - \frac{\bar{\tilde{\ell}}^{f,b} + \bar{b}^{sb}}{\bar{y}} \right) \right] + \rho^k \nu_{t-1}^k \tag{58}$$

The process is designed after the macroprudential policy rule in Angelini et al. (2014). The steady state target ratio, $\bar{\nu}^k$, is set to 10.5% following the Basel III requirements for the capital adequacy ratio of 8% and the capital conservation

[26]See Board of Governors of the Federal Reserve System (2025b). For eligible borrowers, the loans issued under the MSLP have a five-year maturity, deferral of principal payments for two years, and deferral of interest payments for one year.

buffer of 2.5%.[27] χ^k determines the cyclicity of the capital regulation. In the baseline model, $\chi^k > 0$, which means that the target ratio increases when the assets of banks expand relative to output, asking for more equity and liabilities to back up their balance sheets or for shrinkage of assets. Additionally, the χ^k is highly relevant to the determinacy of the equilibrium in the model, and I discussed this in Section 5.3.3.

Finally, I assume that the financial authority sets the leverage ratio for the banker. The policy rule for the leverage ratio is as follows:

$$\nu_t^{bhc} = \left(1 - \rho^{bhc}\right) \bar{\nu}^{bhc} + \left(1 - \rho^{bhc}\right) \left[\chi^{bhc} \left(\frac{e_t + b_t^b}{y_t} - \frac{\bar{e} + \bar{b}^b}{\bar{y}}\right)\right] + \rho^{bhc} \nu_{t-1}^{bhc} \quad (59)$$

The macroprudential policy is implemented to test the effect of controlling indebtedness within the banking sector. The form of the policy rule is analogous to the capital-asset ratio process for the wholesale bank. The estimates of $\chi^{bhc} < 0$ in the baseline model means that the policy decreases the target leverage ratio when the balance sheet relative to output widens. In this case, the banker should either decrease the equity investment or increase the liabilities to minimize the leverage adjustment cost. The target steady state leverage ratio for the banker, $\bar{\nu}^{bhc}$, is set to 1.2 based on the discussion in Federal Reserve Bank of Richmond (2020).[28] The role of χ^{bhc} is discussed in Appendix G.1.

[27] Basel Committee on Banking Supervision (2020a) and Basel Committee on Banking Supervision (2020b).

[28] The double leverage ratio refers to the ratio of a bank holding company when its total investment in subsidiary banks over its total equity is greater than 1. Following Federal Reserve Bank of Richmond (2020), a high double leverage ratio can harm subsidiary banks when their parent companies require significant bank dividends to service those obligations.

3.7 Market Clearing Conditions and Exogenous Shocks

The markets in the model clear in each period. There are markets for labor (h_t), banker's bonds (b_t^b), retail deposits (d_t), equity investment (e_t^b), retail loans to intermediate good producers ($\tilde{\ell}_t^{f,b}$) and the shadow bank (b_t^{sb}), reserves (re_t), capital goods (K_t^n), and loans to startups (b_t^n), and only the loan market for intermediate good producers and the final good market are explicitly written here.

The loan market for intermediate good producers clears as follows:

$$\ell_t^f = \tilde{\ell}_t^{f,b} + \tilde{\ell}_t^{f,cb}. \tag{60}$$

The final good market clears as follows:

$$y_t = c_t^b + c_t^h + I_t + I_t^n + \text{Costs}, \tag{61}$$

where the costs in the economy are categorized as:

$$\begin{aligned}
\text{Financial distress cost} &= d_t^h \varPhi(s_t) + \varphi_t \\
\text{Adjustment cost} &= G_{P,t} + G_{I,t} + G_{I,t}^n \\
\text{Remuneration cost} &= \left(\mathcal{C}_{t-1}^{bhc,b} + \mathcal{C}_{t-1}^{b,f} + \mathcal{C}_{t-1}^{b,sb} + \mathcal{C}_{t-1}^{sb,n}\right) \Pi_t^{-1} \\
\text{Macroprudential cost} &= \left(\mathcal{C}_{t-1}^{bhc} + \mathcal{C}_{t-1}^{b}\right) \Pi_t^{-1} \\
\text{Monitoring cost} &= m_t^{sb}.
\end{aligned}$$

The exogenous aggregate shocks in the model are shocks to technology, committed credit, debt-investment, monetary policy, asset purchase policy and household financial distress shock. There is also an idiosyncratic shock process for startups. For coherence, I assume identical shock processes, which are forward-looking, persistent, and modeled with the AR(1) process of the log of auxiliary variables, S_t^s where $s \in \{a, \pi, u, i, q, n\}$:

$$\log(S_t^s) = \rho^s \log(S_{t-1}^s) + u_t^s$$

where ρ^s are the persistence parameters and u_t^s are the i.i.d. innovations with zero mean and standard deviation σ^s.

4 Parameterization

The calibration of the parameters in the model has three objectives. First, I match key interest spreads to their empirical counterparts in the U.S. economy after the COVID-19 pandemic. Second, the "deep" parameters are made consistent with the DSGE literature. Third, parameters for which estimates are not easily obtained from the data are estimated using U.S. data after the Global Financial Crisis. Details of the calibration process are elaborated in Appendix F. Here, I summarize the key calibration choices.

First, I begin with the household's discount factor β^h, which is set to 0.995. This implies a steady state annual retail deposit interest rate, $\bar{r}^d$, of 2%. As the weighted-average interest rates on 3-month Certificates of Deposits (CDs) were around 1.5% in 2024, the calibration is within a reasonable range. The annual policy interest rate target, $\bar{R}$, is set to 3%, which is greater than the steady state retail deposit interest rate. This figure is supported by recent projections for the long-run federal funds rate.[29] To calibrate the borrowing interest rate of the banker from the household in steady state, $\bar{R}^b$, I assume the steady state spread of the interest rate on the banker's bond over the policy rate to be 0.1% in annual terms to match Moody's Aaa corporate bond yield

[29] Board of Governors of the Federal Reserve System (2025a).

spread from 2023:Q1 to 2024:Q3.

The steady state spreads on loans are the steady state spread between the lending rates and the policy rate, $\bar{R}$. The spread on retail loans to intermediate good producers is calibrated to match the average annual C&I loan spread of 1.75% calculated by Pandolfo (2025). Next, the spread on retail loans to the shadow bank is set to 1.92% in annual terms, based on the average annual spread on private debt funds provided by Berrospide et al. (2025).[30] The steady state spread on loans from shadow banks is calibrated at 6% in annual terms as calculated by Pandolfo (2025). Finally, the steady state spread on the return on capital for startups is set to 9% in annual terms. I set this target as the "Internal Rate of Return (IRR)" on venture capital, relying on the historical value from 1983 to 2009 reported in Koch (2014).

Second, I estimate parameters that are not directly observable from the data or easily obtained from public sources using U.S. data after the Global Financial Crisis. The estimation targets the persistence and response parameters of macroeconomic policies, adjustment cost coefficients, risk weight processes and the standard deviations of shocks. Details of the estimation are elaborated in Appendix C.3. Analysis of the estimation results will be discussed in later sections.

Third, there are parameters that are not common in the literature. The steady state multiplier of the committed credit line constraint, $\bar{\theta^{\pi}}$, targets the reasonable range obtained from the dataset of Greenwald et al. (2020). Details of the derivation are elaborated in Appendix C.2. The steady state utilization rate, $\bar{u}^f$, is set to 0.4 from the same dataset. Furthermore, parameters for elasticities are set parsimoniously to values between 0.5 and 2. Finally, the share of rented capital from startups in total capital, ζ, is set to 0.21. This

[30] NBFIs make secured or senior loans to medium- and small-sized businesses in private debt (credit) market. See Acharya et al. (2024) for details.

figure is based on the investment-to-GDP ratio of the U.S. in 2023, and targets the depreciation rate of startups' capital to be near 15% in annual terms, which is the conventional assumption in the R&D literature.[31]

5 Analysis of the Model

5.1 Impulse Response Analysis

In this section, I analyze the impulse response of the economy to the financial distress shock affecting the representative household. The key finding is that a negative shock to the elasticity process variable ϑ_t triggers a reallocation of household portfolios away from deposits toward banker's bonds, which subsequently propagates through the financial and production sectors and affects the real economy. The mechanism operates through several interconnected channels involving the household, banker, traditional banks, shadow banks, intermediate good producers, and startups.

Figure 6, 7 and 8 present the impulse responses of key macroeconomic variables to a negative one standard deviation shock to the household's financial distress cost process, S_t^{ϑ} for different steady state values of deposit share, $\bar{s}$.[32] The following paragraphs describe the shock's transmission mechanism. The numbers are calculated based on the baseline model with the steady state share of deposits, $\bar{s} = 0.60$.

Household Portfolio Reallocation. The negative shock to S_t^{ϑ} reduces

[31] I set the counterpart of the startups' investment-to-GDP ratio as the R&D investment (NIPA)-to-GDP ratio in 2023, which was 0.036 (See Guci et al. (2025)). Also, I set the counterpart of the intermediate good producers' investment-to-GDP ratio as the gross domestic investment minus the R&D investment-to-GDP ratio in 2023, which was 0.179. The data are retrieved from the Federal Reserve Economic Data (FRED) database. Regarding the depreciation rate of the R&D capital, see Li and Hall (2020).

[32] The estimates of $\sigma_{u^{\vartheta}}$ is 0.024 given the baseline deposit share, $\bar{s} = 0.60$. The discussion on the value of $\bar{s}$ is discussed in 5.3.1.

the elasticity of the financial distress cost function, making it less costly for the household to hold an additional banker's bond relative to deposits. Consequently, the household optimally decrease deposit holdings, and the share of deposit drops by 1.44% at the impact of the shock. Although the household decides to decrease the share reflecting the change in marginal financial distress cost, the total cost increases because of the form of the cost function. The increase in costs reduces household consumption and total savings. To maintain income, the household supplies more labor, which exerts downward pressure on wages.

Banker's Response and Investment Reallocation. The banker responds to the increased demand for their bonds by expanding borrowing from the household and increasing investment in the wholesale bank. This behavior is optimal for minimizing the leverage adjustment cost specified in equation (59). The banker's consumption increases as her net worth rises, which offsets the decline in household consumption, and the total consumption increases by 0.23%. However, the reallocation of funding sources leads to a contraction in the total equity and liabilities of whole banks by 0.07%, since the increase in banker's investment does not fully compensate for the decline in deposits.

Credit Reallocation by Traditional Banks. Traditional banks respond to the change in their funding structure by reallocating credit across different borrowers. The wholesale bank faces a tightening balance sheet constraint but benefits from improved capital-asset ratios due to increased equity investment from the banker. Risk weights on different types of loans adjust according to equation (18), with a 0.60 pp decrease of risk weights on loans to shadow banks and 0.87 pp decrease of those on loans to intermediate good producers upon impact of the shock. This differential adjustment incentivizes banks to increase lending to shadow banks relative to intermediate good producers.

The loan to shadow banks increases by 0.02% at impact; however, it gradually rises up to 0.13% after 7 quarters. Conversely, bank loans to intermediate good producers decrease by 0.27% at impact and continue to decline up to 0.67% after 5 quarters.

Investment and Borrowing Decisions of Intermediate Good Producers. Intermediate good producers adjust their investment and borrowing in response to changes in credit supply and their financial distress costs. The expected increase in EBITDA, driven by higher output, lower wages, and moderate increases in rental costs, leads to an expansion in committed credit lines, which increases up to 0.14% within 3 quarters after the shock.Anticipating this expansion, the central bank reduces government loans to intermediate good producers more than 0.15% after the shock according to the asset purchase policy rule in equation (55). Producers respond by decreasing their credit line utilization rate to minimize financial distress costs as specified in equation (45). Since borrowing is linked to investment through constraint (42), investment in own capital declines by 0.22%. To meet increased aggregate demand with reduced own capital, producers increase their demand for rented capital from startups by up to 0.16% in 10 quarters.

Expansion of Shadow Banking and Improvement in Startup Conditions. The reallocation of credit toward shadow banks and the increased demand for rented capital from startups lead to an expansion of the shadow banking sector. Shadow banks obtain more funding from traditional banks and channel these resources to startups. The increased credit supply to startups improves their financial conditions by reducing the debt payment-to-operating profit ratio, which in turn lowers the default rate, and increases the expected return on capital by 0.16 pp. Although the rental rate on capital initially increases due to higher demand, it subsequently declines as startups accumulate more capital.

Macroeconomic Implications. The aggregate effect on the economy resembles a positive supply shock in standard DSGE models. Total production increases by 0.15% to meet higher aggregate demand, while the price level experiences a sequential decline up to 0.01% after a year. The marginal cost of production initially rises at impact due to the combined effects of factor price adjustments. However, in subsequent periods, the marginal cost declines as wages remain depressed and capital accumulation progresses. The decrease in wages dominates in early periods, while the decline in rental rates becomes more important as startups' capital accumulates. As wages recover and investment by intermediate good producers returns to steady state levels, the marginal cost and price level gradually converge back to their long-run values.

In summary, a negative financial distress shock to the household triggers a sequential reallocation across the financial system. The initial portfolio shift away from deposits reduces funding for traditional banks, which respond by reallocating credit toward shadow banks. This credit reallocation benefits startups and indirectly supports production, resulting in a net increase in output despite a contraction in investment by intermediate good producers. The mechanism highlights the importance of interconnections between different segments of the financial system in propagating shocks to the real economy.

5.2 Estimation

I estimated the model using Bayesian techniques with U.S. data from 2009:Q3 to 2025:Q2. Using the posterior estimates of the parameters, I conducted variance decomposition of key variables with respect to selected shocks and analyzed the contribution of each shock to fluctuations in the economy. The results show that shocks to the financial distress cost of the household

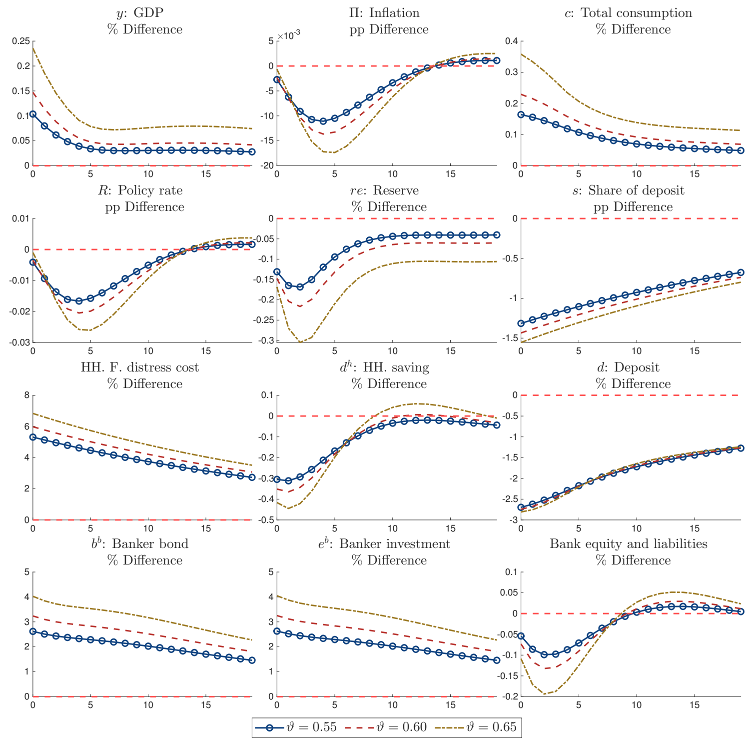


Figure 6: Impulse Responses to Financial Distress Shock (1)

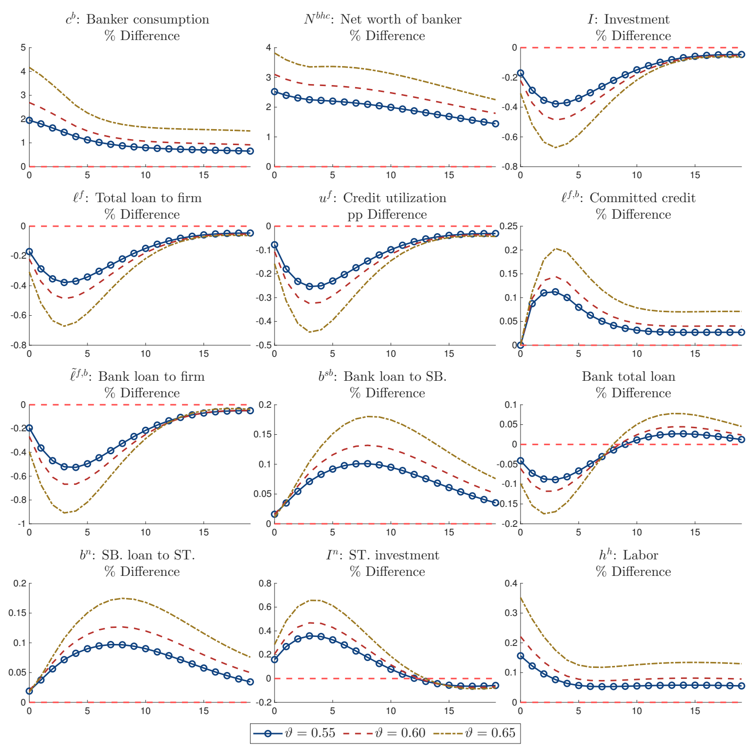


Figure 7: Impulse Responses to Financial Distress Shock (2)

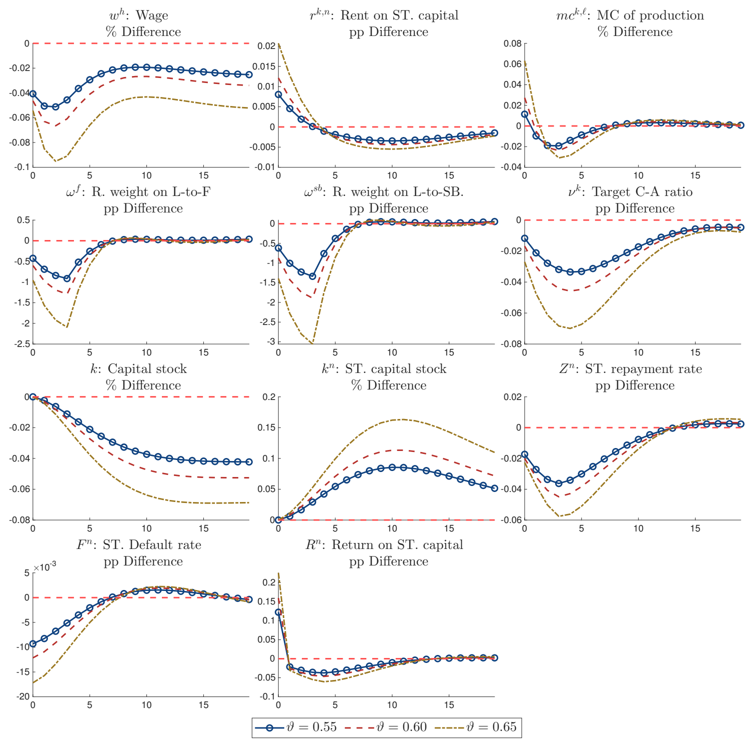


Figure 8: Impulse Responses to Financial Distress Shock (3)

explain almost all fluctuations in the share of deposits. For instance, after 2022:Q1, 92% of variations in the share of deposits are explained by these shocks on average. Additionally, these shocks explain a significant portion of fluctuations in the sources of funding for banks. For instance, 18.9% and 22.7% of variations in deposits and banker's bonds are explained by these shocks on average after 2022:Q1, respectively. However, the explanatory power of the shock for credit supplies is very limited. This is due to the lack of interactions between the share of deposits and the financial market in the model. The details of the estimation are summarized in Appendix C.3, and the estimated parameters are presented in Table 6. In this section, I summarize the key findings from the estimation results.

Figure 9 presents the variance decomposition of selected variables with respect to five shocks: technology, monetary policy, asset purchase, debt-investment, and financial distress shocks to the household. First, the Kalman smoother based on the posterior means from Bayesian estimation generates a smoothed series for the selected variables. The variables represent percentage deviations from steady state, except for the share of deposits with pp deviations. Then, using the smoothed series and shocks, I conducted variance decomposition of the following endogenous variables: the share of deposits in total household savings, deposits, banker's bonds to the wholesale bank, and loans to the shadow bank. Additionally, I included the results for observables: the first difference of log of GDP growth, the inflation rate, the policy rate, and the proxy for the deposit share.[33]

The smoothed series exhibit large fluctuations to capture movements in the data, especially during the COVID-19 pandemic period. The model does not have an absorbing mechanism for the pandemic period; thus, the estimated size of shocks becomes larger as the shocks must explain the observed movements.

Several remarks can be made regarding the variance decomposition results. First, the share of deposits in total household savings and its observations are almost entirely explained by financial distress shocks to the household. This is due to the stylized structure of household portfolio choice in the model.

Second, a significant portion of fluctuations in deposits and banker's bonds is explained by financial distress shocks to the household. Additionally, the smoothed series for deposits exhibits a decrease from 2023 onward. The portion explained by financial distress shocks decreases during this period, and recent fluctuations are mainly explained by technology and monetary policy shocks.

Third, financial distress shocks cannot explain much of the fluctuations in credit supplies. The variations in credit supply are mainly explained by technology, monetary policy, and debt-investment shocks. However, the variation in loans to intermediate good producers from retail banks is explained less

[33] See the details of data construction in Appendix C.3.

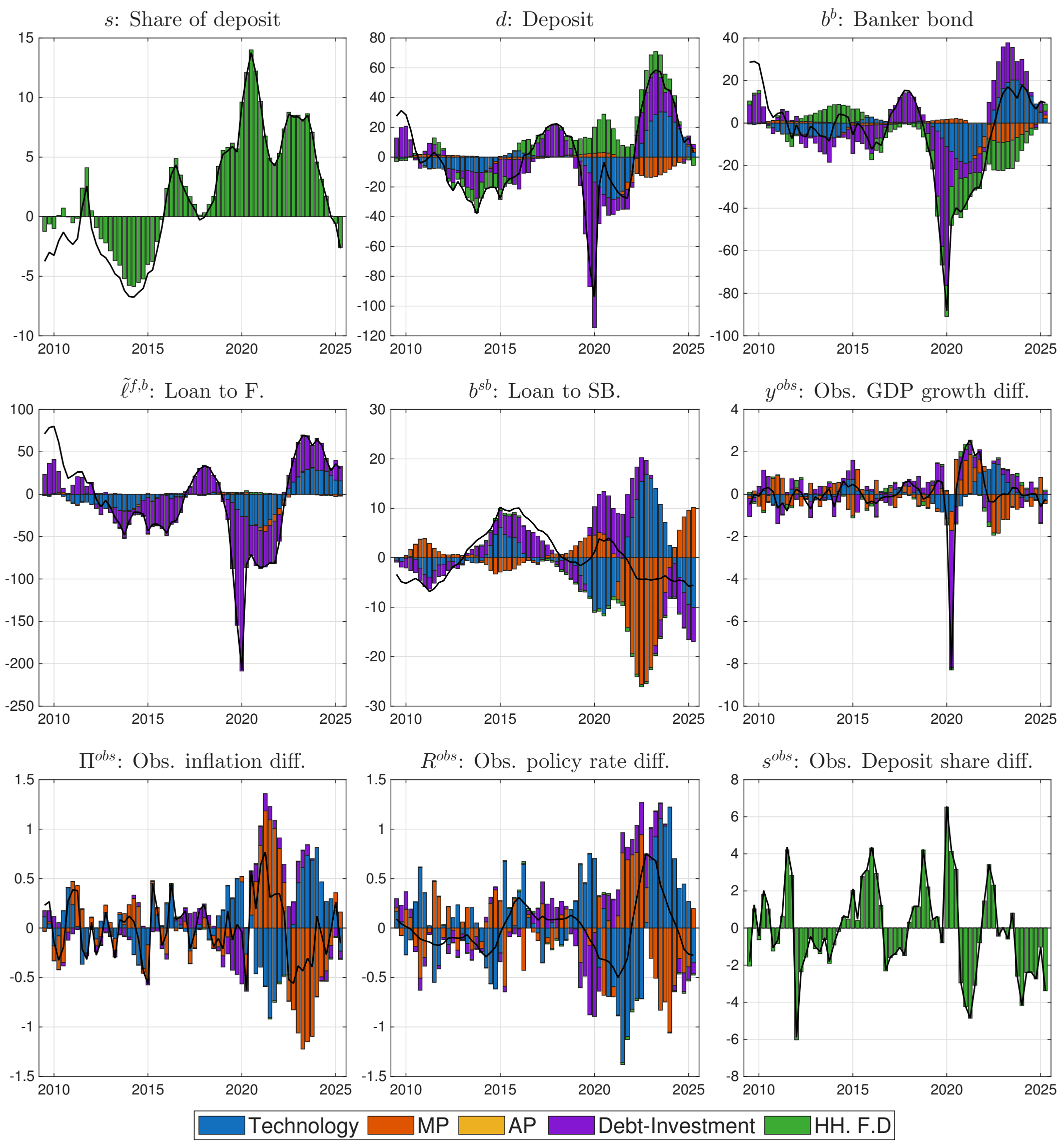


Figure 9: Variance decomposition of selected variables and shocks (Blue = Technology Shock, Orange = Monetary Policy Shock, Yellow = Asset Purchase Shock, Purple = Debt-Investment Shock, Green = Financial Distress Shock to Households)

by monetary policy shocks, whereas that to the shadow bank is significantly explained by these shocks. The smoothed series for loans show a significant decrease after the pandemic. As the liabilities of traditional banks shrink, the model must generate a similar shrinkage in the assets of traditional banks under the limited asset management mechanism in the model. Additionally, the model does not allow any trends, so the results do not contradict empirical findings directly.

Fourth, fluctuations in other observables—GDP growth, inflation rate, and policy rate—are mainly explained by technology, monetary policy, and debt-investment shocks. For instance, the recent change in inflation after the COVID-19 pandemic is mainly explained by monetary policy shocks in the model. Another interesting result is the large decrease in the GDP growth rate in 2020:Q2, which is mainly explained by the debt-investment shock. The shock explains 78% of the variation in the observation variable during this period. What the model suggests is that the debt-to-investment ratio increased significantly, or that more financing was constrained for intermediate good producers to sustain the same level of investment during this period. Without decreasing investment, more debt from the traditional banks worsened the financial distress of producers, resulting in inefficiency in the production sector.[34]

In summary, the estimation results suggest that financial distress shocks to the household are the main driver of fluctuations in the share of deposits and the sources of funding for banks. However, these shocks have limited explanatory power for fluctuations in credit supplies. The results imply that other shocks, such as technology, monetary policy, and debt-investment shocks, are more relevant to fluctuations in credit supplies in the model. This is due

[34] Appendix H.6 contains the impulse responses of selected variables to the debt-investment shock.

to the lack of interactions between the share of deposits and the credit market in the model.

5.3 Robustness Checks

I conducted robustness checks for decisions in the model setup and parameterization. First, I examined the robustness of changes in the steady state share of deposits to macroeconomic policies. I then demonstrated that a 5% change in the steady state share of deposits does not alter the efficacy of monetary and asset purchase policies in the model. Second, I examined the effects of the asset purchase policy and the pro-cyclical response of risk weights on the economy. Third, I verified the determinacy of the equilibrium when macroprudential policies and monetary policy are activated simultaneously. Additional examinations of the model are provided in Appendix G, which includes robustness checks for the following aspects: the parameters of the financial distress cost function and the credit utilization rate, the leverage ratio regulation for the banker, and the sticky retail deposit interest rate.

5.3.1 Steady State Analysis

The steady state analysis focuses on the household's portfolio choice between retail deposits and the banker's bond. The analysis suggests that changes in $\bar{\vartheta}$ do not dramatically alter the real sector of the economy; however, they significantly affect the household's portfolio choice and the banker's balance sheet.

The specific form of the financial distress cost function (3) has a useful property for representing different regimes in the household's portfolio choice. While holding $\bar{\vartheta} > 0$ to guarantee positive holdings of both types of financial assets, stationary inflation without trend ($\bar{\Pi} = 1$) and equilibrium conditions induce $\bar{s} = \bar{\vartheta}$ in the steady state equilibrium. Based on this property, one can easily change the steady state deposit share by adjusting $\bar{\vartheta}$.[35]

The baseline value for $\bar{\vartheta}$ is set to 0.60, which implies that the steady state deposit share is 60%. There are technical and empirical reasons behind this choice. From the U.S. data, the share of nontransaction deposits is obtained using the debt securities and equity of the bank holding companies, which was 0.63 in 2025:Q2.[36] Additionally, setting $\bar{\vartheta}$ greater than 0.80 causes determinacy issues in the model with baseline parameterization. The value of $\bar{\vartheta}$ near 0.80 also generates extreme responses in the impulse response analysis. Therefore, I set the baseline value of $\bar{\vartheta}$ to 0.60 to balance empirical relevance and technical feasibility. To examine the robustness of changes in the steady state deposit share, I analyzed two additional cases where $\bar{\vartheta}$ is set to 0.55 and 0.65, representing a 5% decrease and increase from the baseline value, respectively. The following paragraphs summarize the key findings from the steady state analysis.

The results of changing $\bar{\vartheta}$ on the steady state equilibrium of the model are summarized in Figure 10. The figure lists the full set of steady state variables affected by changes in $\bar{\vartheta}$. The figure shows that the steady state deposit share changes one-to-one with $\bar{\vartheta}$, and the coefficient of the distress cost, $\bar{\chi}^1$, is adjusted accordingly. Since the financial distress cost of the household decreases with $\bar{\vartheta}$, the total saving of the household slightly increases with this parameter change. Other variables such as the banker's investment, banker's bonds, the distress cost, and other adjustment costs of the banker decrease with $\bar{\vartheta}$. The adjustment costs increase proportionally to the size of the banker's balance sheet.

[35]See Appendix B.1 for the derivation of $\bar{s} = \bar{\vartheta}$. Regardless of this result, $\bar{\chi_1}$ is a function of $\bar{\vartheta}$ in the steady state equilibrium to match the time preference of the household, β_h, and the calibration of the steady state gross interest rate on the banker's bond, $\bar{R}^b$.

[36]The value is calculated as $\frac{\text{household deposits}}{\text{household deposits+BHC debt and equity}}$.

Additionally, the steady state GDP and household consumption change only slightly across different values of $\bar{\vartheta}$. Related variables and parameters such as the steady state shadow price of consumption and the coefficient for labor disutility are also stable. One notable observation is that the dividend rate of banks slightly increases with $\bar{\vartheta}$. This is solely due to the decrease in investment from the banker to the wholesale bank, as determined by the steady state equilibrium condition of the wholesale bank.

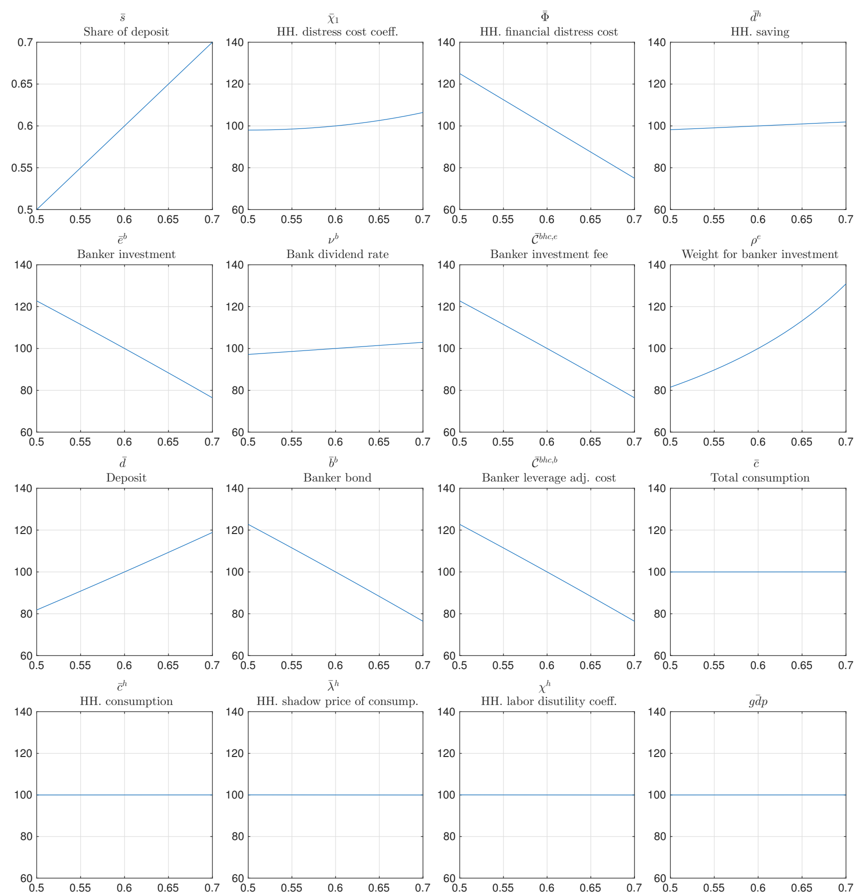


Figure 10: Steady state effects of different $\bar{\vartheta}$

Notes: The baseline value for the household financial distress cost parameter, $\bar{\vartheta}$, is 0.60. Variables other than the steady state deposit share are plotted as a ratio to the baseline value, set to 100.

The Efficacy of Macroeconomic Policies

When the steady state deposit share changes, the efficacy of macroeconomic policies may be altered. To verify this, I analyzed the efficacy of the two main macroeconomic policies in the model: monetary policy and the asset purchase policy. In summary, the efficacy of these policies appears to be preserved when the baseline value of $\bar{\vartheta} = 0.60$ deviates to 0.55 or 0.65.

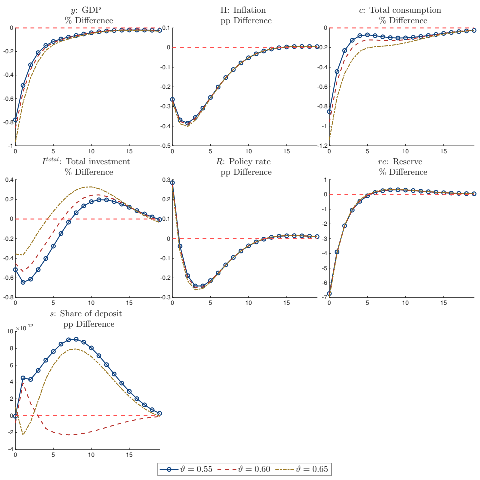
Positive shocks to monetary policy and the asset purchase policy are assumed to be one standard deviation shocks to the shock processes S_t^i and S_t^q, respectively. Figure 11 shows the IRFs of selected variables to these shocks with different values of $\bar{\vartheta}$.

First, the IRFs to the monetary policy shock show that the essential dynamics of policy rate adjustment are not affected by changes in the steady state deposit share. However, differences in the deposit share significantly change the magnitude of responses in borrowing and investment by intermediate good producers. Through the debt-investment channel of intermediate good producers and the capital-asset ratio regulation of the wholesale bank, the degree of response to the shock of crucial variables such as output, investment, and capital stock is altered.

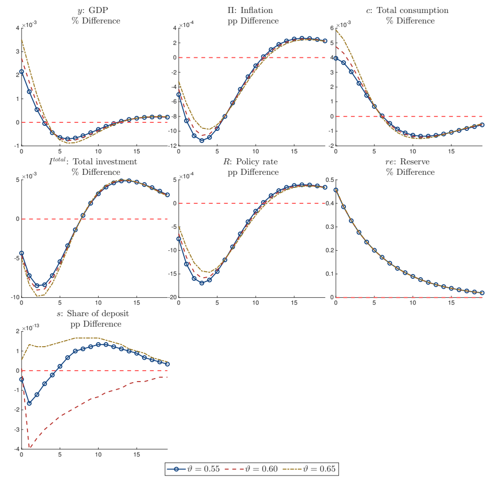
Second, the IRFs to the asset purchase policy shock also show that the essential dynamics of reserve adjustment are not affected by changes in the steady state deposit share. Changes in the responses of household and banker consumption are notable. With less borrowing from the household sector, the marginal increase in the banker's consumption in response to the shock is greater, whereas household consumption decreases more with a higher deposit share. These changes are transmitted to the real sector through labor supply and wages. However, the responses of variables are intrinsically similar across different values of $\bar{\vartheta}$.

In summary, I could not find dramatic changes in the IRFs to the major macroeconomic policies when $\bar{\vartheta}$ and the steady state share of deposits changed.

The IRFs for selected variables in response to other shocks in the model with different values of $\bar{\vartheta}$ are presented in Appendix H.



(a) IRFs to Monetary Policy Shock



(b) IRFs to Asset Purchase Policy Shock

Figure 11: IRFs to Policy Shocks with different $\bar{\vartheta}$
Notes: The baseline value for the household financial distress cost parameter, $\bar{\vartheta}$, is 0.60.

5.3.2 The Role of Credit Policies for Intermediate Good Producers

The two credit policies for intermediate good producers in the model are the risk-weight adjustment of traditional bank loans and the active reserve policy by the central bank in response to expected EBITDA deviations of intermediate good producers. Both policies dampen the flow of credit to the shadow bank following a negative financial distress shock to the household.

The risk weight adjustment processes are defined in equation (18). Following this process, the risk weights for both types of loans from traditional banks decrease as output increases relative to its steady state at the impact of the shock. This implies that the marginal cost of holding risk-weighted assets decreases and the interest rates on loans decrease more compared to the case without risk weight adjustment. However, the risk weight process also accelerates the adjustment of interest rates on loans, resulting in a faster recovery of credit supply to intermediate good producers.

The reserve policy by the central bank defined in equation (55) also facilitates credit supply to intermediate good producers. When the central bank decreases loans to intermediate good producers in anticipation of an increase in producers' EBITDA, firms reduce their borrowing from traditional banks by less. Consequently, the total response of credit supply to intermediate good producers is similar whether the reserve policy is active or inactive. However, when the reserve policy is inactive, the share of loans from traditional banks decreases more, resulting in a larger decrease in the financial distress cost. Interest rates reflect the change in the financial distress cost and decrease more without the reserve policy. This results in a non-negligible slower recovery of credit supply to intermediate good producers without the active reserve policy.

5.3.3 Determinacy of the Model as a Function of Monetary and Macroprudential Policy Parameters

In this section, I analyze the determinacy of the equilibrium when both macroprudential policy and monetary policy are activated. The stylized model allows only counter-cyclical capital regulation to stabilize the economy when paired with a relatively strong contractionary monetary policy.

Figure 13 shows the determinacy region of the model equilibrium according to the policy parameters m^{π} and χ^k, given the baseline calibration. The results show that relatively strong suppression of inflation deviations in the monetary policy rule ($m^{\pi} > 1$) combined with counter-cyclical capital regulation ($\chi^k > 0$) results in determinacy of the equilibrium. The model does not allow procyclical capital regulation, i.e., $\chi^k < 0$, for any value of m^{π}.

A remark is warranted regarding the discussion in Angelini et al. (2014) about the interaction between monetary policy and macroprudential policy.

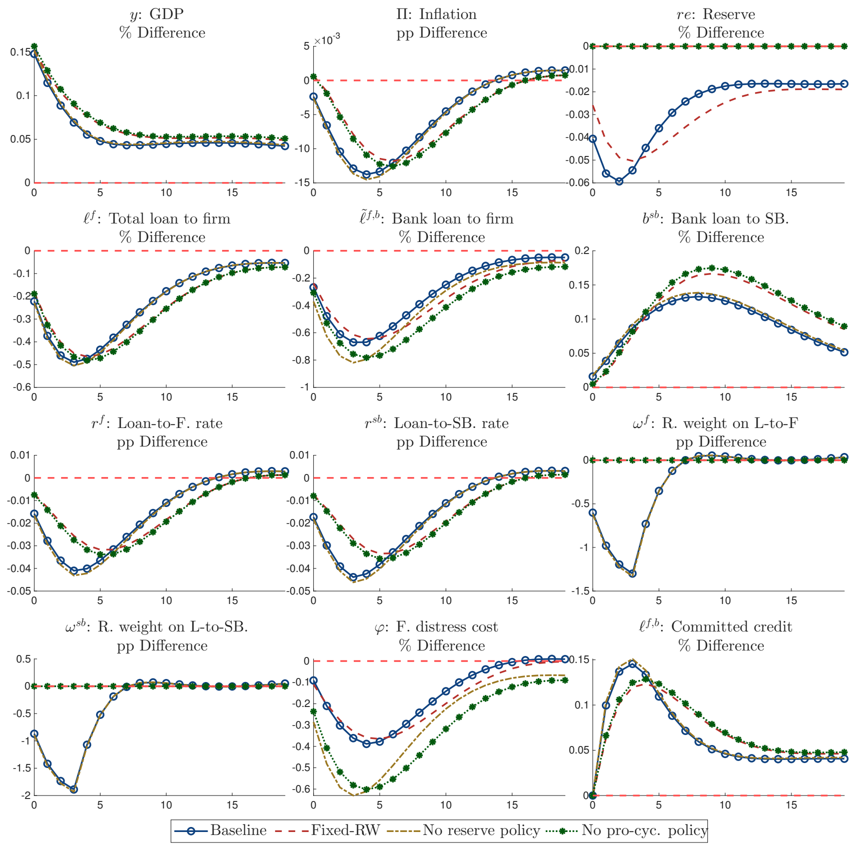


Figure 12: IRFs to Financial Distress Shock with and without credit policies

Notes: The figure shows the IRFs to a negative one standard deviation shock to the household financial distress cost process, S_t^{ϑ}, with and without credit policies for intermediate good producers. The blue solid lines with marker represent the IRFs with both credit policies, while the brown dashed lines represent the IRFs without both credit policies.

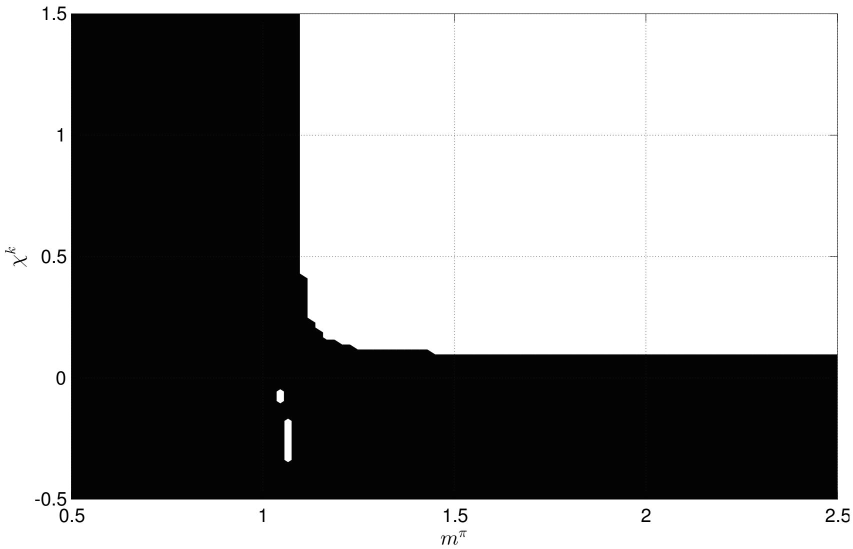


Figure 13: Determinacy as a function m^π and χ^k

Notes: The figure shows the determinacy of the equilibrium according to changes in the response coefficient to the inflation deviation in the monetary policy rule, m^π, and the response coefficient to the credit supply relative to output in the capital regulation, χ^k, given the baseline calibration. The shaded area represents the indeterminacy of the equilibrium.

Since the model in this paper assumes counter-cyclical capital regulation in the baseline calibration, excessive credit shrinkage during downturns is possible. As banks' assets relative to output can increase during recessions, this will raise the target capital-asset ratio for banks, potentially resulting in a further decrease in credit supply to the real economy.

Related to this issue, I analyzed the impulse response of the economy to a positive committed credit shock under the baseline calibration. The results show that counter-cyclical capital regulation can generate a larger decrease in credit supply to the shadow bank and startups following the impact of the shock.

An unexpected increase in the committed credit line generates inefficiency in the allocation of funds in the economy, with more credit flowing to intermediate good producers from traditional banks. This results in decreased credit supply to the startup sector and increased investment by intermediate good producers. The resulting inefficiency in the production sector generates inflationary pressure in the economy with a decrease in output. Reduced hiring shrinks household savings, thereby decreasing the source of funding for banks.

Although this stagflationary phenomenon occurs, the target capital-asset ratio for banks increases as banks' assets relative to output widen. Without additional funding sources, banks must decrease their credit supply to the real economy to meet the new target capital-asset ratio. This results in a further decrease in credit supply to the shadow bank and startups.

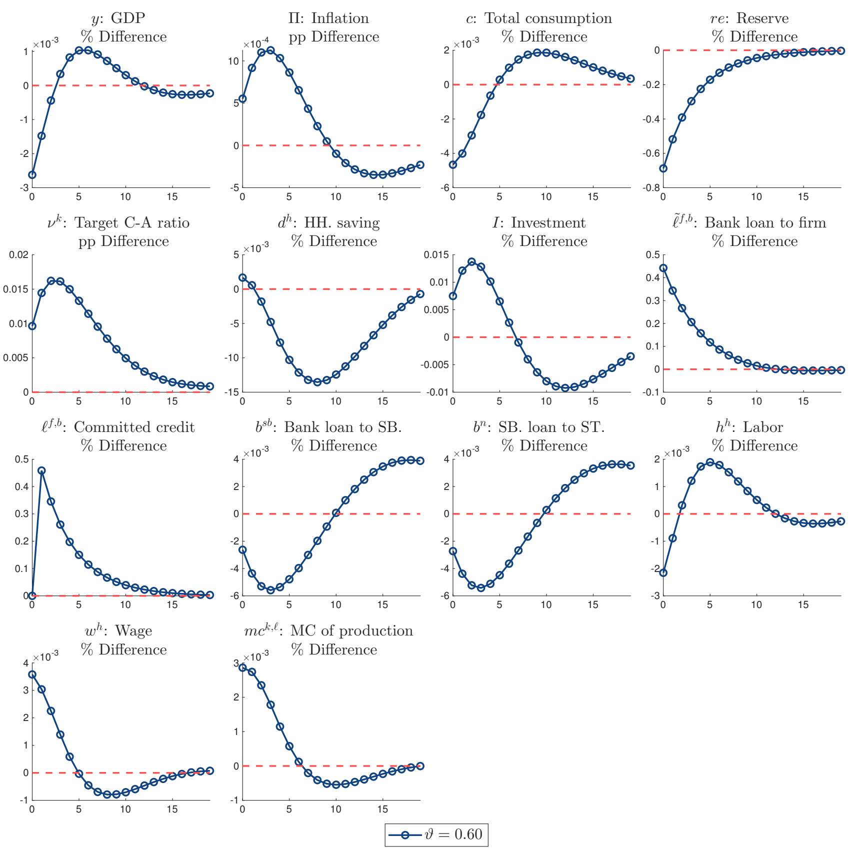


Figure 14: Positive Committed Credit Shock with Counter-Cyclical Capital Regulation

Notes: The figure shows response of selected variables to a positive one standard deviation shock to the committed credit process, S_t^{π}, under the baseline calibration.

6 Conclusion

This paper develops a DSGE model with a banking sector that captures the recent trend of declining deposit shares in total household savings within a tractable framework. The importance of this decline is highlighted by the fact that it triggers a reallocation of funding sources for banks and affects credit supply to the real economy. To capture this mechanism and the observed changes in credit supply in the U.S. financial market, I introduced a separate banking sector—the shadow bank—and risky borrowers who cannot access the traditional banking sector. Additionally, I introduced different macroeconomic policies to capture the recent dynamics in the flow of funds in the U.S. economy.

The model is estimated using U.S. data from 2009:Q3 to 2025:Q2 within a Bayesian framework. From the estimation, I obtained estimates of the parameters for the stylized features of the model. The impulse response analysis shows that a negative shock to the household's financial distress costs can generate a reallocation of funding sources for banks and affect credit supply to the real economy. Although the model is limited in capturing the effects of financial markets on the deposit share, it suggests a notable mechanism of shock transmission through the relationship between borrowers from separated banking sectors. Specifically, the following mechanisms are highlighted for the reallocation of credit supply triggered by the shift in deposit shares: (i) the reassessment of risk weights on banks' assets, (ii) the role of government loans in alleviating financial distress in the production sector, and (iii) the structure of production and the substitutability between inputs from separate sectors.

There are caveats to different aspects of the model. First, the interactions between the deposit share and the financial market are limited; that is, the household's portfolio choices affect the financial market, but feedback from the financial market to portfolio choices is dampened. This is one reason behind the variance decomposition results of credit volume. Second, the model lacks a mechanism to handle large shocks such as the COVID-19 pandemic. This results in larger estimated shock sizes compared to the literature and prevents the model from using additional data of financial assets. However, these limitations also provide avenues for future research. For instance, introducing bidirectional feedback between the household's portfolio choices and financial markets could enrich the analysis of the transmission mechanism of shocks to deposit shares. Introducing a mechanism to handle large shocks could also improve estimation results and provide more reliable policy implications. In addition, further analysis of optimal macroeconomic policy mix could be conducted within the framework of the model.

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Appendix A. Additional Figures and Tables

A.1 Liabilities of U.S. Chartered Depository Institutions

Figure 15 presents the real equities and liabilities of U.S. chartered depository institutions. The data are from L.111 of Z.1 Financial Accounts of the United States, adjusted using the Personal Consumption Expenditures (PCE) deflator (2017=100). The data were retrieved from the Federal Reserve Economic Data (FRED) database.

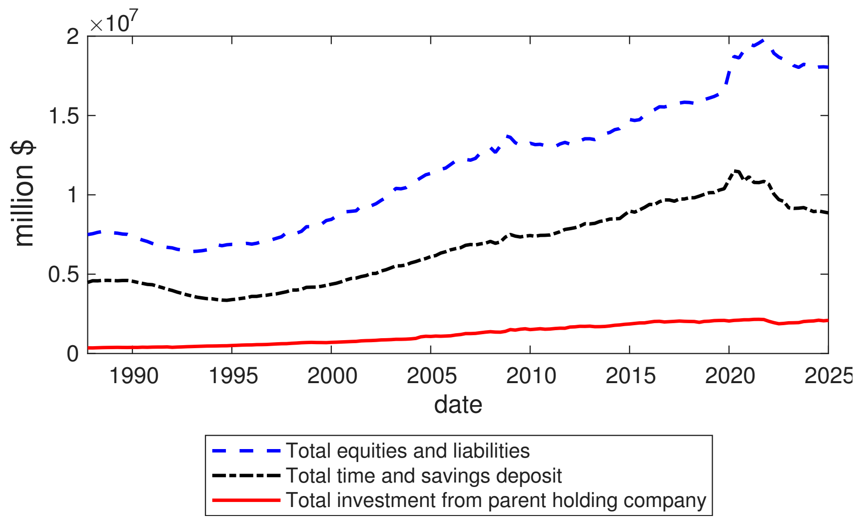

Figure 15: Liabilities of U.S. Chartered Depository Institutions

A.2 Loans from U.S. Chartered Depository Institutions

Figure 16 presents the real loans from U.S. chartered depository institutions to nonfinancial corporates and NBFIs. The data are from L.215 of Z.1 Financial Accounts of the United States, adjusted using the Personal Consumption Expenditures (PCE) deflator (2017=100). The data were retrieved from the Federal Reserve Economic Data (FRED) database. The loan to NBFIs covers the loan to "Domestic financial sectors" (FL793168005), which includes private depository institutions, life insurance companies, government-sponsored enterprises (GSEs), issuers of asset-backed securities, and mortgage real estate investment trusts (mREITs), following Board of Governors of the Federal Reserve System (2024a).

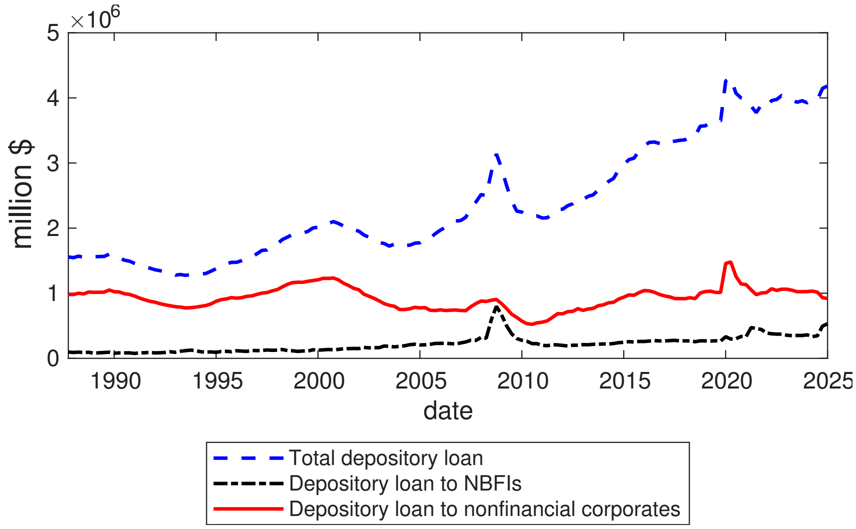

Figure 16: Loans from U.S. Chartered Depository Institutions

A.3 Loans to Nonfinancial Corporates

Figure 17 presents the real loans to nonfinancial corporates from depository institutions and NBFIs. The data are from L.103 and L.216 of Z.1 Financial Accounts of the United States, adjusted using the Personal Consumption Expenditures (PCE) deflator (2017=100). The data were retrieved from the Federal Reserve Economic Data (FRED) database.

To derive the loans from NBFIs, I select different sorts of loans in L.216. Specifically, I include loans from life insurance companies, mutual funds, ABS issuers, brokers, and other financial businesses. I excluded loans from the household sector (FL153069803). Additionally, I include loans from "Finance company loans to business" (FL103169535) in the loans from NBFIs. Following Board of Governors of the Federal Reserve System (2024a), "Finance companies" are defined as companies where 50 percent or more of their assets are held in loans and lease assets. U.S.-chartered depository institutions, cooperative banks, credit unions, investment banks, and industrial loan corporations are not included among them.

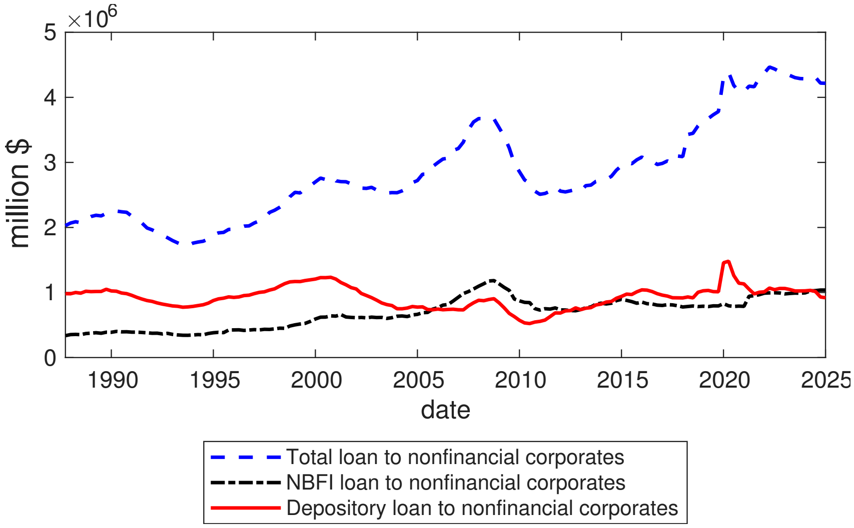

Figure 17: Loans to Nonfinancial Corporates

A.4 Financial Literacy of U.S. Adults

The Teachers Insurance and Annuity Association of America (TIAA) Personal Finance Index (P-Fin Index) measures the financial literacy of U.S. adults through 28 questions covering eight key areas: earning, consuming, saving, investing, borrowing and managing debt, insuring, comprehending risk, and go-to information sources.[37] The survey is conducted online with a representative sample of U.S. adults aged 18 and older, with sample sizes increasing from approximately 1,000 respondents before 2021 to around 3,000 thereafter. TIAA weights the responses to ensure representativeness of the U.S. adult population.

The data show a little variation in financial literacy scores over the nine-year period, with the percentage of correct responses ranging between 48%

[37] Yakoboski et al. (2025).

Table 1: Financial Literacy of U.S. Adults: P-Fin Index Results

Year	Percentage Correct
2017	49%
2018	50%
2019	51%
2020	52%
2021	50%
2022	50%
2023	48%
2024	48%
2025	49%
Average	**49.7%**

Source: TIAA Institute Personal Finance Index (P-Fin Index), various years.
Note: Sample sizes are approximately 1,000 respondents (2017-2020) and 3,000 respondents (2021-2025). The P-Fin Index measures financial literacy through 28 questions covering eight key areas of personal finance.

and 52%. The average score across all years is 49.7%, indicating that only half of questions have been answered correctly each year. Notably, there is no discernible upward trend that would support the hypothesis of improving financial sophistication among households during the period of interest.

A.5 Stock Market Participation Rate of U.S. Adults

Gallup (2024) reports the annual stock market participation rate of U.S. adults from 2009 to 2024. The survey is conducted with U.S. adults aged 18 and older. During the telephone interview, respondents answer the following question: "Do you, personally, or jointly with a spouse, have any money invested in the stock market right now—either in an individual stock, a stock mutual fund, or in a self-directed 401(k) or IRA?" Figure 18 presents the stock market participation rate of U.S. adults over the period. The data show an upward trend in stock market participation after the COVID-19 pandemic up to 62%, however the rate remains below the highest level of 65% before the Global Financial Crisis in 2007.

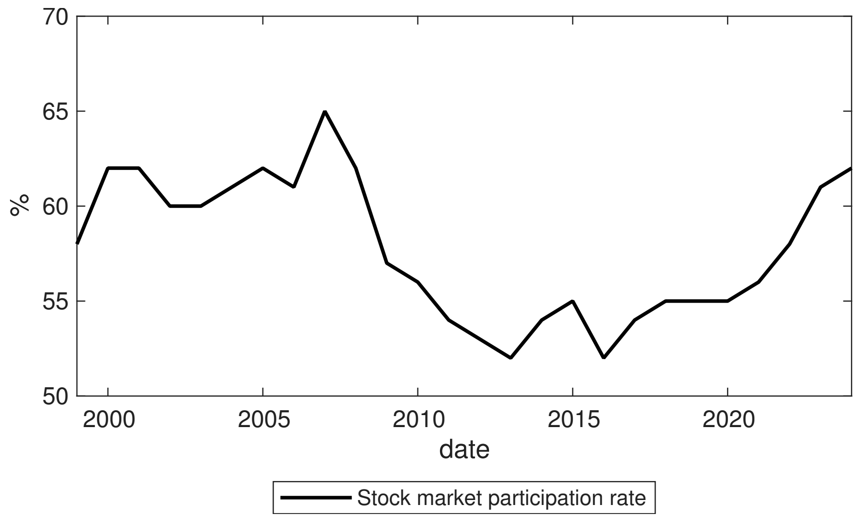

Figure 18: Stock Market Participation Rate of U.S. Adults

A.6 Number of Mobile Banking Customers

Figure 19 presents the number of mobile banking customers of JPMorgan Chase and Bank of America from 2013 to 2024. The data were retrieved from *Statista*.[38] Here, the active mobile banking customers are defined similarly for both banks. [39] defines active mobile customers as those who have logged in to any mobile platform within the last 90 days. [40] defines active mobile banking users as active users over the past 90 days.

The data show a steady increase in the number of mobile banking customers for both banks over the period. The number of mobile banking customers for JPMorgan Chase increased from approximately 15.6 million in 2013 to 57.8

[38] JPMorgan Chase (2025a), Bank of America (2025b).
[39] JPMorgan Chase (2025b)
[40] Bank of America (2025a)

million in 2024. Similarly, Bank of America saw an increase from around 14.4 million in 2013 to 40.0 million in 2024. This trend reflects the growing adoption of mobile banking services among consumers in the U.S.

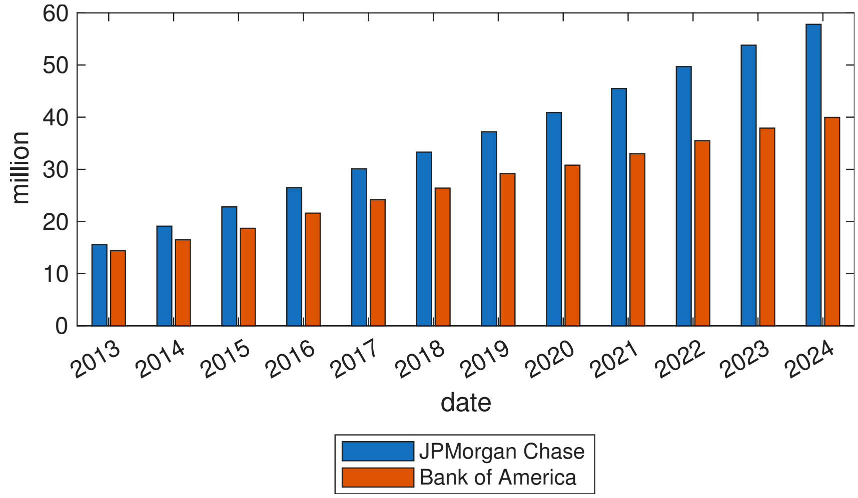

Figure 19: Number of Mobile Banking Customers

Appendix B. Proofs and Derivations

B.1 Proof of Steady State Share of Deposits

In this section, I derive the steady state share of deposits, $\bar{s}$ equals the steady state variable of elasticity of household financial distress cost, $\bar{\vartheta}$.

The first-order conditions of the household's optimization problem with respect to the total savings d_t^h and the share of deposits s_t in steady state are as follows:

$$
\begin{aligned}
d_t^h: &\quad \beta_h \bar{\Pi} \left(\bar{R}^b (1-\bar{s}) + \bar{r}^d \bar{s} \right) = 1 + \Phi(\bar{s}) \\
s_t: &\quad \beta_h \bar{\Pi} \left(\bar{R}^b - \bar{r}^d \right) = -\Phi'(\bar{s}).
\end{aligned}
$$

Using $\beta^h \bar{r}^d = 1$ from the steady state of the household's inter-temporal Euler equation, the problem simplifies to:

$$
\begin{aligned}
\beta_h \bar{\Pi} \bar{R}^b (1-\bar{s}) + \bar{\Pi}\bar{s} &= 1 + \Phi(\bar{s}) \\
\beta_h \bar{\Pi} \bar{R}^b - \bar{\Pi} &= -\Phi'(\bar{s}).
\end{aligned}
$$

I assume that there is no trend in inflation, or $\bar{\Pi} = 1$. Then, the two equations above become:

$$
\begin{aligned}
\beta_h \bar{R}^b (1-\bar{s}) + \bar{s} &= 1 + \Phi(\bar{s}) \\
\beta_h \bar{R}^b - 1 &= -\Phi'(\bar{s}).
\end{aligned}
$$

Combining the two equations above, I obtain:

$$
(1 - \Phi'(\bar{s}))(1-\bar{s}) + \bar{s} = 1 + \Phi(\bar{s})
$$

Rearranging the equation gives:

$$1 - \varPhi'(\bar{s}) - \bar{s} + \varPhi'(\bar{s})\bar{s} + \bar{s} = 1 + \varPhi(\bar{s})$$

which simplifies to:

$$\varPhi'(\bar{s})(1 - \bar{s}) + \varPhi(\bar{s}) = 0.$$

or equivalently,

$$\bar{s} = F(\bar{s}) \equiv \frac{\varPhi(\bar{s})}{\varPhi'(\bar{s})} + 1.$$

When the function $\varPhi$ is defined as

$$\varPhi(s_t) = \chi_1 \left(\frac{1 - s_t}{s_t} \right)^{\vartheta_t},$$

$F(s_t)$ is calculated as follows:

$$F(s_t) = \frac{\chi_1 \left(\frac{1-s_t}{s_t} \right)^{\vartheta_t}}{-\chi_1 \vartheta_t \left(\frac{1-s_t}{s_t} \right)^{\vartheta_t - 1} \left(\frac{1}{s_t^2} \right)} + 1 = -\frac{s_t(1 - s_t)}{\vartheta_t} + 1.$$

Finally, I have

$$\bar{s} = -\frac{\bar{s}(1 - \bar{s})}{\bar{\vartheta}} + 1 \implies \bar{s} = \bar{\vartheta}.$$

B.2 Derivation of the Capital Weight of Equity Investment

In this section, I derive the capital weight of equity investment, ρ_e, in the bank's capital regulation based on the Basel III framework for bank capital adequacy requirements.

Basel III requires banks to maintain a minimum of 6% of tier 1 capital and 8% of total capital against their risk-weighted assets. Additionally, the capital conservation buffer requires banks to hold an additional 2.5% of risk-weighted assets for all banks. Given these requirements, the target capital-asset ratio ν^k in steady state should satisfy the following two conditions:

$$\nu^{k1} = \frac{\bar{X}^b}{\bar{re} + \bar{\omega}^f \bar{\tilde{\ell}}^{f,b} + \bar{\omega}^{sb} \bar{b}^{sb}} = 6\%$$
$$\nu^{k2} = \frac{\bar{X}^b + \rho_e \bar{e}^b}{\bar{re} + \bar{\omega}^f \bar{\tilde{\ell}}^{f,b} + \bar{\omega}^{sb} \bar{b}^{sb}} = 8\% + 2.5\%$$

The ratio between the two conditions is as follows:

$$\frac{\nu^{k1}}{\nu^{k2}} = \frac{\bar{X}^b}{\bar{X}^b + \rho_e \bar{e}^b} = \frac{6\%}{10.5\%},$$

and rearranging the equation with respect to ρ_e gives

$$\rho_e = 0.75 \times \frac{\bar{X}^b}{\bar{e}^b}.$$

The value of ρ_e is endogenously determined by the steady state equilibrium of the model.

B.3 Derivation of the Representative Household's Problem

In this section, I derive the representative household's problem by aggregating the optimization problems of household member $i \in [0, 1]$.

A member of the representative household, $i \in [0, 1]$ maximizes the expected lifetime utility:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_h^t \left[\frac{1}{1 - \frac{1}{\gamma_h}} \left\{ c_t^h(i) \right\}^{1 - \frac{1}{\gamma_h}} - \frac{\chi_h}{1 + \frac{1}{\zeta_h}} \left\{ h_t^h(i) \right\}^{1 + \frac{1}{\zeta_h}} \right]$$

subject to the budget constraint:

$$
\begin{aligned}
R^b_{t-1}P_{t-1}b^b_{t-1}(i) + & r^d_{t-1}P_{t-1}d_{r,t-1}(i) + P_t w_t h^h_t(i) + P_t Z^{total}_t \\
& \geq P_t c^h_t(i) + P_t b^b_t(i) + P_t d_{r,t}(i) + P_t b^b_t(i)\phi(i)
\end{aligned}
$$

where the transfer $Z^{total}_t = D^f_t + D^k_t + (1-\iota)\chi^n \mathcal{W}^n_t + T^{cb}_t - X^{bhc}_0$, is identical across members.

Assume that a member $i \leq s_t$ saves through deposits, while a member $s_t < i \leq 1$ saves through bank bonds. Additionally, assume that the amount of saving is the same for all members, i.e. $b^b_t(i) = d_{r,t}(i) = d^h_t$. Then, the aggregated budget constraint can be rewritten as follows:

$$
\begin{aligned}
& R^b_{t-1}P_{t-1}\int_{s_t}^1 d^h_{t-1}di + r^d_{t-1}P_{t-1}\int_0^{s_t} d^h_{t-1}di + P_t w_t \int_0^1 h^h_t(i)di + P_t Z^{total}_t \\
& \geq P_t \int_0^1 c^h_t(i)di + P_t \int_{s_t}^1 d^h_t di + P_t \int_0^{s_t} d^h_t di + P_t \int_{s_t}^1 d^h_t \phi(i)di
\end{aligned}
$$

Rearranging the equation above gives:

$$
\begin{aligned}
& R^b_{t-1}P_{t-1}(1-s_t)d^h_{t-1} + r^d_{t-1}P_{t-1}s_t d^h_{t-1} + P_t w_t h^h_t + P_t Z^{total}_t \\
& \geq P_t c^h_t + P_t(1-s_t)d^h_t + P_t s_t d^h_t + P_t d^h_t \int_{s_t}^1 \phi(i)di
\end{aligned}
$$

using the symmetry of the household members, where $c^h_t(i) = c^h_t(j) = c^h_t$ and $h^h_t(i) = h^h_t(j) = h^h_t$ for all $i, j \in [0,1]$.

Finally, I define the aggregate financial distress cost, $\varPhi(s_t)$, as follows:

$$
\varPhi(s_t) \equiv \int_{s_t}^1 \phi(i)di,
$$

From the results above, one can derive the representative household's lifetime utility (1) and its budget constraint (2).

Appendix C. Estimation of Parameters

C.1 Estimation of the Process of Markdown on Retail Deposit Interest Rate

In this section, I estimate $\rho^{b,d}$ and $\chi^{b,d}$, the parameters in the process of the elasticity of deposit issuance by retail banks, $\varepsilon_t^{b,d}$, defined in equation (27).

From the first order condition of retail bank j in the deposit branch, the elasticity of deposit issuance $\varepsilon_t^{b,d}$ is given as follows:

$$\varepsilon_t^{b,d} = \frac{r_t^d - 1}{r_t^d - R_t}$$

Using the U.S. data on the 3-month CD rates smaller than \$100,000 as the retail interest rate on deposits, r_t^d, and the 3-month Treasury bill rates as the short-term policy rate, R_t, I generated the time series of $\varepsilon_t^{b,d}$ from 2022:Q2 to 2025:Q2. Subsequently, I estimated the parameters in the process:

$$\varepsilon_t^{b,d} = (1 - \rho^{b,d})\bar{\varepsilon}^{b,d} + (1 - \rho^{b,d})\chi^{b,d}(R_t - R_{t-1}) + \rho^{b,d}\varepsilon_{t-1}^{b,d}.$$

The estimation results are summarized in Table 2. The estimates of $\bar{\varepsilon}^{b,d}$, $\rho^{b,d}$, and $\chi^{b,d}$ are -0.43, 0.49, and 120.53, respectively. All parameters are statistically significant at the 5% level. Only the estimates of $\rho^{b,d}$ and $\chi^{b,d}$ are employed. $\bar{\varepsilon}^{b,d}$ is determined endogenously from the steady state equilibrium of the model.

Table 2: Estimation Results of the Process of Markdown on Retail Deposit Interest Rate

Parameter	**Estimate**	**Std. Error**	**p-value**
$\bar{\varepsilon}^{b,d}$	-0.43	0.07	0.008[1]
$\rho^{b,d}$	0.49	0.17	0.018
$\chi^{b,d}$	120.53	19.55	0.010[2]

[1] For constant term in the regression.
[2] For the coefficient on the change in the policy rate.
Note: The estimation is conducted using OLS on the time series data from 2022:Q2 to 2025:Q2.

C.2 Derivation of the Steady State Multiplier on Credit Line Constraint

In this section, I derive the adequate range for the steady state multiplier on the credit line constraint, $\bar{\theta}^{\pi}$, using firm-level data. Using the dataset from Greenwald et al. (2020), I calculated the ratio between the committed credit line and EBITDA from 2012Q2 to 2019Q4. The data sources include FR Y-9C filings, FR Y-14Q H.1. data, Compustat, and Orbis. The dataset contains 156,010 observations across 31,209 firms.

The number of firms per quarter is approximately 1,700 and is not evenly distributed across quarters. Since there were outliers with small EBITDA values that generated extremely high ratios, I calculated the 25th percentile, median, and 75th percentile of the ratio for each quarter. The results are summarized in Figure 20. For the entire sample period, the 25th percentile and median of the ratio are quite stable compared to the high volatility of the 75th percentile. The averages of the 25th percentile, median, and 75th percentile are 0.19, 0.97, and 4.86, respectively. In each year, the distribution of the ratio exhibits right-skewed characteristics.

Based on the results above, I set the adequate range for the steady state

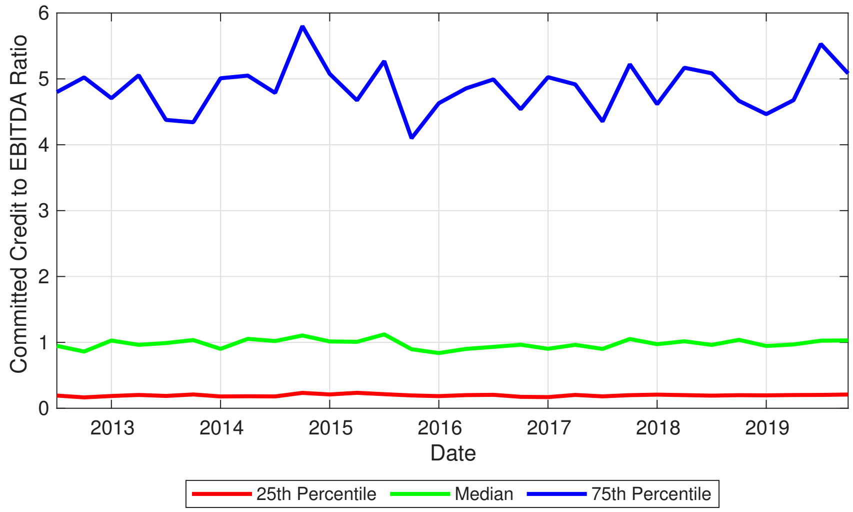

Figure 20: Credit Line to EBITDA Ratio

multiplier on the credit line constraint $\bar{\theta}^{\pi}$ between 1 and 1.5, which covers the median of the ratio.

C.3 Estimation of the Model using Bayesian Techniques

The parameteres are estimated using Bayesian techniques. In this section, I summarize the data treatment, prior distributions of parameters, and estimation results.

I employ the U.S. data of real GDP per capita, inflation, policy rate, real household deposits per capita, and holding companies' equities and debt from 2009:Q3 to 2025:Q2. The data are retrieved from FRED, and details are summarized in Table 3. The data treatment is as follows. First, level data are transformed into real per capita terms using inflation and population data. Then I log-transform the data and take the first difference. After that, I detrend them using the filter provided by Kamber et al. (2025). Based on the Beveridge-Nelson filter, they provide a filtering method to handle large shocks such as the COVID-19 pandemic. Since the data include the pandemic period (2020:Q1-Q2), their filter is useful for drawing the cyclical components of the data. Then extracted components are matched with the model-generated counterparts in the estimation. The model counterparts are the first differences of the log of variables.

Second, the 3-month Treasury bill rates and shadow rates are transformed into quarterly gross rates. Similarly, I derive the first difference of the log of the gross rates and de-trend them using the same filter. Third, I generate an empirical counterpart of the share of deposits using household deposits and holding companies' debt and equities. Aligning with other observables, I take the log of the shares and de-trend the first difference.[41] Finally, all cyclical components are demeaned after de-trending, as the model in this paper does not assume any trend in inflation or technology development in the steady state equilibrium. Figure 21 plots the observed variables.

The estimated parameters and their prior distributions are summarized in Table 5. There are a few remarks regarding the prior distributions. First, the priors for persistence parameters and the standard deviations of shocks follow Gerali et al. (2010). The prior distributions for them are not tuned for different processes and shocks. Second, the risk weight parameters and adjustment cost parameters are set to wide prior distributions relative to their means. As mentioned in Gerali et al. (2010), the priors for these parameters are difficult to set due to the lack of available data. Thus, I set wide prior distributions for these parameters following the literature. Third, the priors for the policy parameters are set to be relatively informative with narrow distributions. The mean of the distributions are set near their posterior modes from preliminary estimations. This is because the model has a non-linear structure, and the

[41] To obtain the empirical counterpart of the deposit share in the model, I match the banker's bond to the debt and equity of holding companies. Following Board of Governors of the Federal Reserve System (2024b), holding companies are "Parent-only bank holding companies, savings and loan holding companies and security holding companies that file Federal Reserve Board form FR Y-9LP, FR Y-9SP, or FR 2320".

posterior distributions of the policy parameters are quite sensitive to the prior distributions. Thus, I set informative priors to avoid unreliable estimation results. The posterior distributions are summarized in Table 6.

There are parameters that are not included in the estimation although they do not have clear guidance from the literature. For instance, the elasticities of adjustment costs $\bar{\vartheta}$, $\theta^{bhc,b}$, $\theta^{bhc,e}$, and $\theta^{sb,n}$ are not estimated. Due to the non-linearity of the model, estimating them using the DSGE model does not provide reliable results. Instead, I set them parsimoniously and attempt to estimate the coefficients of adjustment costs.

A final remark concerns the data choice. I do not include household deposits and bank holding companies' debt and equity separately, although they are used to generate the empirical counterpart of the share of deposits. Other available data such as investment and consumption are also excluded. However, it turns out that the model cannot fit the dynamics of these observables even with measurement errors.[42] Without amplification of some parameters, the model cannot fit the data well. Thus, I limit the data for estimation to four key macroeconomic variables. One common result from robustness checks with different data choices is the amplification of the return shock on the risky borrower. Investigating the reason behind this result and the limitation of the model is left for future research.

Table 3: Data Sources and Descriptions

FRED Code	Variable Name	Unit
A939RX0Q048SBEA	Real GDP per capita	Chained 2017 Dollars
DPCERD3Q086SBEA	Personal consumption expenditures (implicit price deflator)	Index 2017=100
TB3MS	3-Month Treasury Bill Secondary Market Rate	Percent
BOGZ1FL193030205Q	Households; Other Deposits Including Time and Savings Deposits	Millions of Dollars
BOGZ1LM733181105Q	Holding Companies; Equity and Investment Fund Shares Excluding Mutual Fund Shares and Money Market Fund Shares	Millions of Dollars
HCDSL	Holding Companies; Debt Securities	Millions of Dollars
POPTHM	Population	Thousands
–	Shadow rates (Wu and Xia (2016))	Percent

All data are quarterly from 2009:Q3 to 2025:Q2.

Source: Shadow rates are retrieved from Federal Reserve Bank of Atlanta.
Others are from Federal Reserve Economic Data (FRED), Federal Reserve Bank of St. Louis.

[42] For the measurement errors, a uniform distribution is used, and the ranges for the distribution are limited to a fraction of the target data's dispersion.

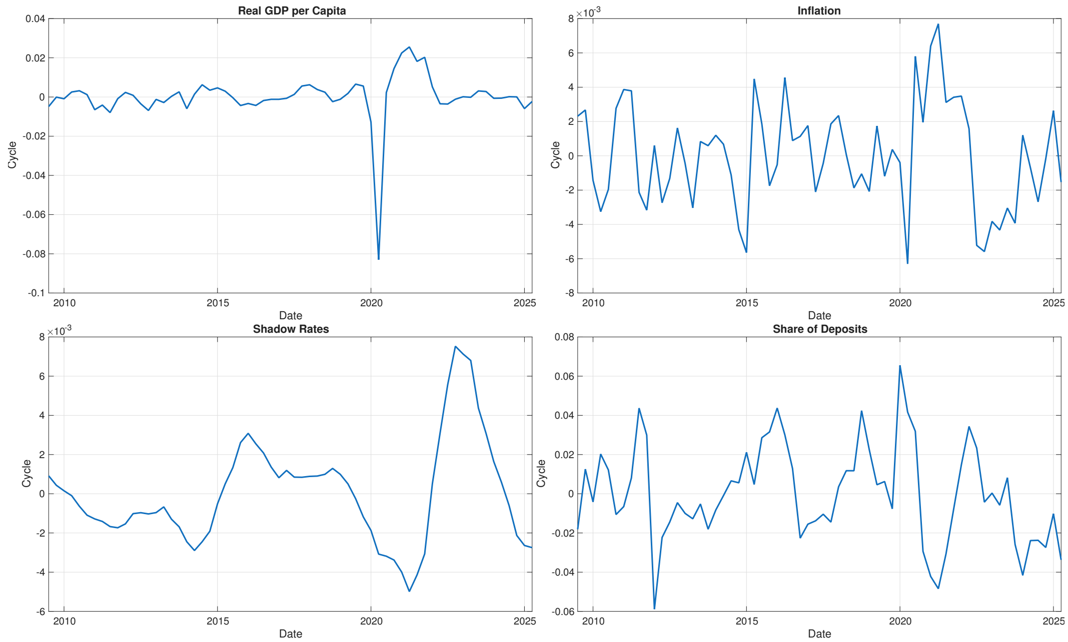

Figure 21: U.S. Observable Variables Used in Estimation

The technical details of the estimation process are the following. First, the observation equations are specified following Pfeifer (2014). The observation equations are the first difference of logs of the model variables as follows:

$$
\begin{aligned}
\mathrm{gdp}_t^{obs} &= \log(\mathrm{gdp}_t) - \log(\mathrm{gdp}_{t-1}) \\
\Pi_t^{obs} &= \log(\Pi_t) - \log(\Pi_{t-1}) \\
R_t^{obs} &= \log(R_t) - \log(R_{t-1}) \\
s_t^{obs} &= \log(s_t) - \log(s_{t-1})
\end{aligned}
$$

Following Kumhof and Wang (2021), I assume that the real GDP data correspond to real output excluding adjustment costs, and define an auxiliary variable $\mathrm{gdp}_t = c_t^h + c_t^b + I_t + I_t^n$.

The estimation is conducted using the Bayesian approach with the Metropolis-Hastings algorithm. Five blocks of 500,000 posterior draws are obtained after a 50% burn-in. During the estimation, the scale parameter of the proposal distribution's covariance matrix is adjusted to achieve an acceptance rate of approximately 30%.[43]

The convergence of the posterior the Brooks-Gelman-Rubin diagnostic provided by Dynare. The univariate and mutivariate convergence diagnostics indicate that all parameters have converged successfully.[44]

The priors and posteriors of the parameters are summarized in Figures 22 and 23.

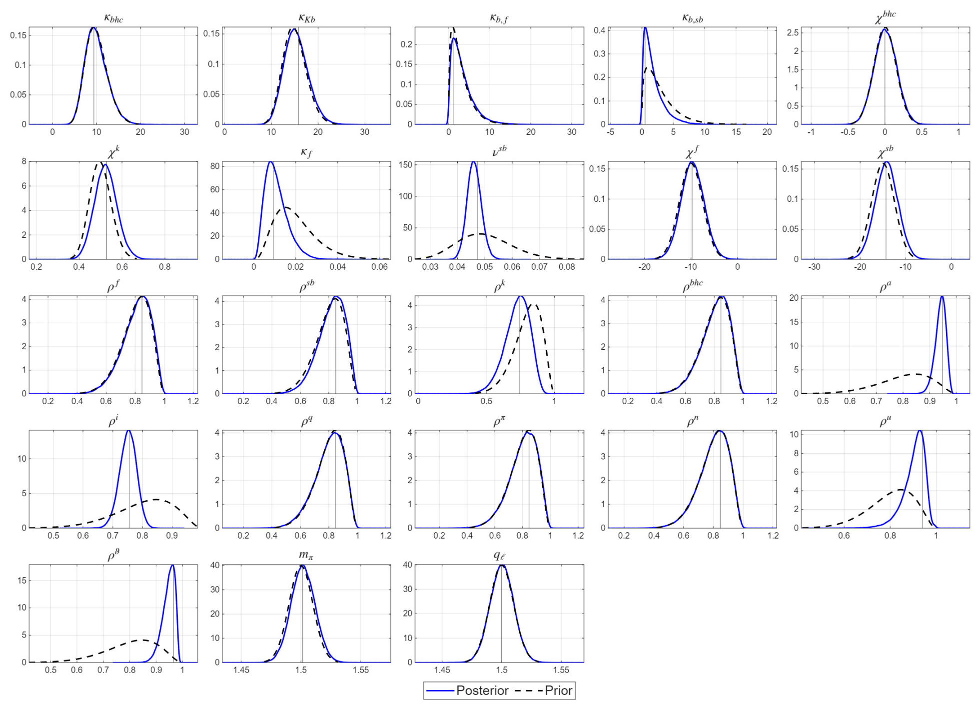

Figure 22: Priors and Posteriors of Estimated Parameters

[43]The acceptance ratios for the five chains are 30.3%, 30.0%, 30.2%, 30.4%, and 30.1%.

[44]Dynare provides the graphical outputs of the convergence diagnostics for the 80% interval. The results are available upon request.

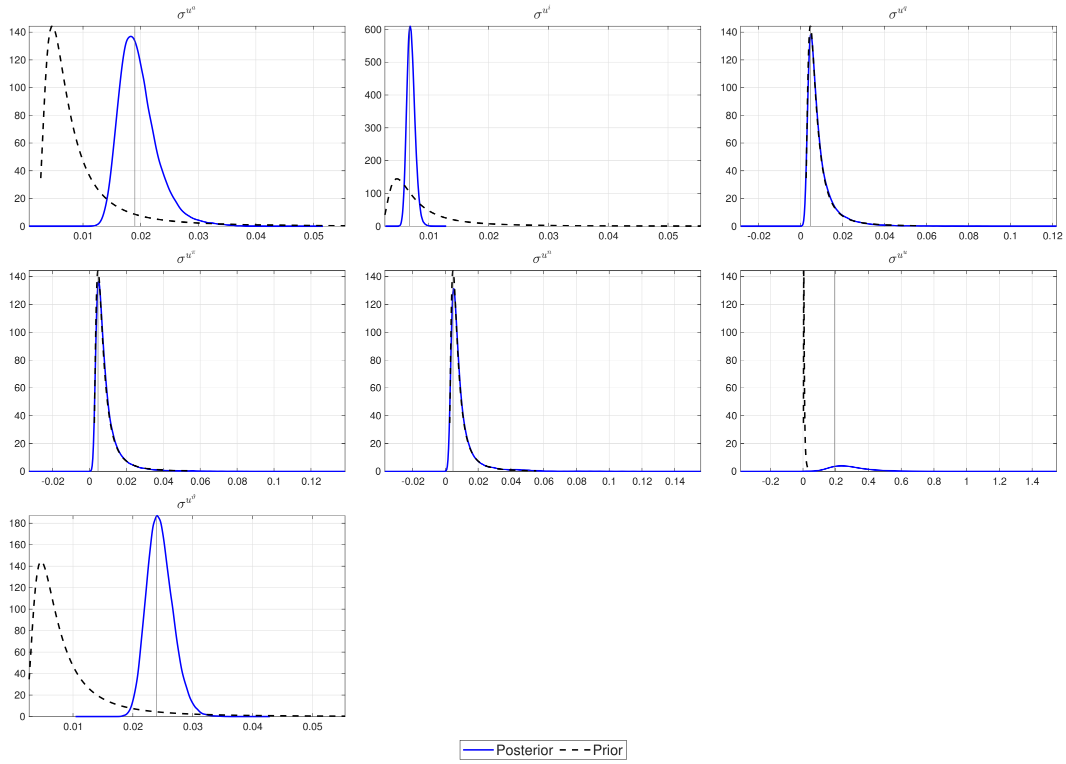

Figure 23: Priors and Posteriors of Estimated Shock Standard Deviations

Appendix D. Full Nonlinear Model

Lower case letters denote real variables. The parameters are elaborated in the calibration section.

D.1 Households

List of variables:
$c_t =$ consumption.
$h_t =$ labor supply.
$b_t^b =$ banker bond demand.
$d_t =$ deposit demand.
$D_t^f =$ dividend from intermediate good firm.
$D_t^k =$ dividend from capital good firm.
$Z_t =$ operational profit of central bank.
$\mathcal{W}_t^n =$ wealth of startups.
$\Phi(s_t) =$ financial distress cost.
$s_t =$ share of depositors.

$P_t =$ nominal price of final good.
$w_t =$ labor income.
$R_t^b =$ interest rate on banker's bond.
$r_t^d =$ retail interest rate on deposit.
$X_0^{bhc} =$ fixed transfer to banker.

D.1.1 Optimization Problem

- Objective function:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_h^t \left[\frac{1}{1-\frac{1}{\gamma_h}} \left\{ c_t^h \right\}^{1-\frac{1}{\gamma_h}} - \frac{\chi_h}{1+\frac{1}{\zeta_h}} \left\{ h_t^h \right\}^{1+\frac{1}{\zeta_h}} \right]$$

- Budget constraint:

$$\begin{aligned} R_{t-1}^b P_{t-1} b_{t-1}^b + r_{t-1}^d P_{t-1} d_{r,t-1} + P_t w_t h_t^h + P_t Z_t^{total} & \\ \geq P_t c_t^h + P_t b_t^b + P_t d_{r,t} + P_t d_t^h \Phi(s_t) & \end{aligned}$$

where $Z_t^{total} = D_t^f + D_t^k + (1-\iota)\chi^n \mathcal{W}_t^n + T_t^{cb} - X_0^{bhc}$.

- Lubello and Rouabah (2024) Financial distress cost:

$$\Phi(s_t) \equiv \chi_{1,t} \left(\frac{1-s_t}{s_t} \right)^{\vartheta_t}$$

$$\vartheta_t = S_t^{\vartheta} \bar{\vartheta}$$

$$\log(S_t^{\vartheta}) = \rho_{\vartheta} \log(S_{t-1}^{\vartheta}) + u_t^{\vartheta}$$

$$\chi_1(\vartheta_t) = (\beta_h \bar{R}^b - 1) \left(\frac{1-\bar{s}}{\bar{s}} \right)^{1-\vartheta_t} \frac{\bar{s}^2}{\vartheta_t}$$

- Lubello and Rouabah (2024) Deposits and banker's debt:

$$d_{r,t} = s_t d_t^h, \quad b_t^b = (1-s_t) d_t^h$$

D.1.2 Lagrangean

$$
\begin{aligned}
\max_{c_t, h_t, d_t^h, s_t,} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_h^t & \Bigg[\frac{1}{1-\frac{1}{\gamma_h}} \left\{c_t^h\right\}^{1-\frac{1}{\gamma_h}} - \frac{\chi_h}{1+\frac{1}{\zeta_h}} \left\{h_t^h\right\}^{1+\frac{1}{\zeta_h}} \\
& + \lambda_t^h \left(R_{t-1}^b \left(1-s_{t-1}\right) \Pi_t^{-1} d_{t-1}^h + r_{t-1}^d s_{t-1} \Pi_t^{-1} d_{t-1}^h + w_t^h h_t^h + Z_t^{total} \right. \\
& \left. - \left(c_t^h + d_t^h + d_t^h \Phi(s_t) + X_0^{bhc}\right)\right) \Bigg]
\end{aligned}
$$

where $\Pi_{t+1} = \frac{P_{t+1}}{P_t}$.

D.1.3 First-Order Conditions

- FOC for consumption c_t^h:

$$\lambda_t^h = \left(c_t^h\right)^{-\frac{1}{\gamma_h}}$$

- FOC for labor supply h_t^h:

$$h_t^h = \left(\lambda_t^h \frac{w_t^h}{\chi_h}\right)^{\zeta_h}$$

- FOC for saving d_t^h:

$$\mathbb{E}_t \left[\Lambda_{t,t+1}^h \Pi_{t+1}^{-1} \left(R_t^b (1-s_t) + r_t^d s_t\right)\right] = 1 + \Phi(s_t)$$

  where $\Lambda_{t,t+1}^h = \beta_h \frac{\lambda_{t+1}^h}{\lambda_t^h}$.

- FOC for share of deposit s_t:

$$\mathbb{E}_t \left[\Lambda_{t,t+1}^h \Pi_{t+1}^{-1} \left(R_t^b - r_t^d\right)\right] = -\Phi'(s_t)$$

- FOC for deposit demand $d_{r,t}$:

$$\mathbb{E}_t\left[\Lambda^h_{t,t+1}\Pi^{-1}_{t+1}r^d_t\right] = 1$$

D.2 Banker

List of variables:
$c^b_t =$ consumption by banker.
$b^b_t =$ banker debt supply.
$e^b_t =$ equity investment in wholesale bank.
$D^b_t =$ dividend from wholesale and retail banks.
$D^{sb}_t =$ dividend from shadow bank.
$\mathcal{C}^{bhc,b}_t =$ cost of borrowing.
$\mathcal{C}^{bhc}_t =$ double-leverage adjustment cost.
$R^{eb}_t =$ interest rate on equity investment.
$X^{bhc}_0 =$ fixed transfer from the household.

D.2.1 Optimization Problem

- Objective function:

$$\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t_b \left[\frac{1}{1-\frac{1}{\gamma_b}}\left\{c^b_t\right\}^{1-\frac{1}{\gamma_b}}\right]$$

- Budget constraint:

$$P_t b^b_t + R^{eb}_{t-1}P_{t-1}e^b_{t-1} + P_{t-1}\mathcal{C}^{bhc,e}_{t-1} + P_t D^b_t + P_t D^{sb}_t + P_t X^{bhc}_0$$
$$\geq P_t c^b_t + R^b_{t-1}P_{t-1}b^b_{t-1} + P_t e^b_t + P_{t-1}\mathcal{C}^{bhc,b}_{t-1} + P_{t-1}\mathcal{C}^{bhc}_{t-1}$$

- Kumhof and Wang (2021) The cost of issuing debt:

$$\mathcal{C}^{bhc,b}_t = \frac{\kappa_{bhc,b}}{1+\frac{1}{\theta^{bhc,b}}}\bar{b}^b\left(\frac{b^b_t}{\bar{b}^b}\right)^{1+\frac{1}{\theta^{bhc,b}}}$$

- Kumhof and Wang (2021) Additional earning from equity investment:

$$\mathcal{C}_t^{bhc,e} = \frac{\kappa_{bhc,e}}{1+\frac{1}{\theta^{bhc,e}}} \bar{e}^b \left(\frac{e_t^b}{\bar{e}^b}\right)^{1+\frac{1}{\theta^{bhc,e}}}$$

- Angelini et al. (2010) The cost of leverage ratio adjustment:

$$\mathcal{C}_t^{bhc} = \frac{\kappa_{bhc}}{2} \left(\frac{e_t^b}{b_t^b} - \nu_t^{bhc}\right)^2 e_t^b$$

D.2.2 Lagrangean

$$\max_{c_t^b, b_t^b, e_t^b} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \Bigg[\frac{1}{1-\frac{1}{\gamma_b}} \left\{c_t^b\right\}^{1-\frac{1}{\gamma_b}}$$
$$+ \lambda_t^b \Big(b_t^b + R_{t-1}^{eb} \Pi_t^{-1} e_{t-1}^b + \Pi_t^{-1} \mathcal{C}_{t-1}^{bhc,e} + D_t^b + P_t X_0^{bhc}$$
$$- \Big(c_t^b + R_{t-1}^b \Pi_t^{-1} b_{t-1}^b + e_t^b + \Pi_t^{-1} \mathcal{C}_{t-1}^{bhc,b} + \Pi_t^{-1} \mathcal{C}_{t-1}^{bhc} \Big)\Big)\Bigg]$$

D.2.3 First-Order Conditions

- FOC for consumption c_t^b:

$$\lambda_t^b = \left(c_t^b\right)^{-\frac{1}{\gamma_b}}$$

- FOC for debt supply b_t^b:

$$\mathbb{E}_t \left[\Lambda_{t,t+1}^b \Pi_{t+1}^{-1} \left(R_t^b + \frac{\partial \mathcal{C}_t^{bhc,b}}{\partial b_t^b} + \frac{\partial \mathcal{C}_t^{bhc}}{\partial b_t^b} \right) \right] = 1$$

where $\Lambda_{t,t+1}^b = \beta_b \frac{\lambda_{t+1}^b}{\lambda_t^b}$.

- FOC for equity investment in wholesale bank e_t^b:

$$\mathbb{E}_t\left[\Lambda_{t+1}^b\Pi_{t+1}^{-1}\left(R_t^{eb}+\frac{\partial\mathcal{C}_t^{bhc,e}}{\partial e_t^b}-\frac{\partial\mathcal{C}_t^{bhc}}{\partial e_t^b}\right)\right]=1$$

D.3 Wholesale Bank

D.3.1 Optimization Problem

List of variables:
$N_t^b =$ net worth.
$\widetilde{\ell}_t^{f,b} =$ wholesale lending supply to retail banks (intermediate good firm loan).
$b_t^{sb} =$ wholesale lending supply to retail banks (shadow bank loan).
$re_t =$ reserve demand.
$d_t =$ wholesale deposit supply to retail banks (household's deposit).
$e_t^b =$ equity demand.
$\mathcal{C}_t^b =$ capital-asset ratio adjustment cost.
$X_t^b =$ internal capital.
$R_t^f =$ wholesale interest rate on firm lending.
$R_t^{sb} =$ wholesale interest rate on shadow bank lending.
$R_t =$ policy interest rate.
$R_t^d =$ wholesale interest rate on deposit.

- Net worth:

$$\Pi_{t+1}N_{t+1}^b=R_t^f\widetilde{\ell}_t^{f,b}+R_t^{sb}b_t^{sb}+R_t re_t-R_t^d d_t-R_t^{eb}e_t^b-\mathcal{C}_t^b-\mathcal{C}_t^{bhc,e}$$

- Angelini et al. (2014) The cost of capital-asset ratio adjustment:

$$\mathcal{C}_t^b=\frac{\kappa_{Kb}}{2}\left(\frac{X_t^b+\rho^e e_t^b}{re_t+\omega_t^f\widetilde{\ell}_t^{f,b}+\omega_t^{sb}b_t^{sb}}-\nu_t^k\right)^2\left(X_t^b+\rho^e e_t^b\right)$$

  - Risk weight process:

$$\omega_t^s=(1-\rho^s)\,\bar{\omega}^s+(1-\rho^s)\,\chi^s\,(y_t-y_{t-4})+\rho^s\omega_{t-1}^s$$

where $s \in \{f, sb\}$.

- Balance sheet condition:

$$\widetilde{\ell}_t^{f,b} + b_t^n + re_t = d_t + e_t^b + X_t^b$$

- Brunnermeier and Koby (2018) Capital accumulation formula:

$$X_{t+1}^b = (1 - \nu^b) N_{t+1}^{b,total}$$

where $N_{t+1}^{b,total} = N_{t+1}^b + N_{t+1}^r$, the sum of wholesale and retail bank net worth.

- Objective function:

$$\max \mathbb{E}_t \left[\Lambda_{t,t+1}^b N_{t+1}^b \right]$$

D.3.2 Lagrangean

$$\max_{\widetilde{\ell}_t^{f,b}, b_t^{sb}, re_t, e_t^b} \mathbb{E}_t \Lambda_{t,t+1}^b \Pi_{t+1}^{-1} \left(\left(R_t^f - R_t^d \right) \widetilde{\ell}_t^{f,b} + \left(R_t^{sb} - R_t^d \right) b_t^{sb} + \left(R_t - R_t^d \right) re_t \right.$$
$$\left. - \left(R_t^{eb} - R_t^d \right) e_t^b + R_t^d X_t^b - \mathcal{C}_t^b - \mathcal{C}_t^{bhc,e} \right)$$

D.3.3 First-Order Conditions

- FOC for firm lending supply to retail banks:

$$\mathbb{E}_t \left[\Lambda_{t,t+1}^b \Pi_{t+1}^{-1} \left(R_t^f - R_t^d - \frac{\partial C_t^b}{\partial \widetilde{\ell}_t^{f,b}} \right) \right] = 0$$

- FOC for shadow bank debt supply to retail banks:

$$\mathbb{E}_t \left[\Lambda^b_{t,t+1} \Pi^{-1}_{t+1} \left(R^{sb}_t - R^d_t - \frac{\partial C^b_t}{\partial b^{sb}_t} \right) \right] = 0$$

- FOC for reserve demand:

$$\mathbb{E}_t \left[\Lambda^b_{t,t+1} \Pi^{-1}_{t+1} \left(R_t - R^d_t - \frac{\partial C^b_t}{\partial re_t} \right) \right] = 0$$

- FOC for equity investment demand:

$$\mathbb{E}_t \left[\Lambda^b_{t,t+1} \Pi^{-1}_{t+1} \left(-R^{eb}_t + R^d_t - \frac{\partial C^b_t}{\partial e^b_t} - \frac{\partial C^{bhc,e}_t}{\partial e^b_t} \right) \right] = 0$$

D.4 Retail Bank

List of variables:
$N^r_t =$ net worth of retail bank.
$\widetilde{\ell}^{f,b}_{r,t} =$ retail lending to intermediate good firms.
$b^{sb}_{r,t} =$ retail lending to shadow bank.
$d_{r,t} =$ retail deposit demand from the household.
$\mathcal{C}^{b,f}_t =$ remuneration cost of firm lending.
$\mathcal{C}^{b,sb}_t =$ remuneration cost of shadow bank lending.
$r^f_t =$ retail interest rate on firm lending.
$r^{sb}_t =$ retail interest rate on shadow bank lending.
$r^d_t =$ retail interest rate on deposits.
$\varepsilon^{b,f}_t =$ elasticity of demand for firm loans.
$\varepsilon^{b,sb}_t =$ elasticity of demand for shadow bank loans.
$\varepsilon^{b,d}_t =$ elasticity of supply for deposits.

D.4.1 Optimization Problem

- The net worth of retail banks:

$$N^r_{t+1} = \Pi^{-1}_{t+1}\left(r^f_t \widetilde{\ell}^{f,b}_{r,t} + r^{sb}_t b^{sb}_{r,t} - r^d_t d_{r,t}\right.$$
$$\left. - \left(R^f_t \widetilde{\ell}^{f,b}_t + R^{sb}_t b^{sb}_t - R^d_t d_t\right) - \mathcal{C}^{b,f}_t - \mathcal{C}^{b,sb}_t\right)$$

- The net worth of depository banks in total:

$$\begin{aligned}\Pi_{t+1} N^{total}_{t+1} &= \Pi_{t+1}\left(N^b_{t+1} + N^r_{t+1}\right)\\ &= \left(r^f_t - r^d_t\right)\widetilde{\ell}^{f,b}_{r,t} + \left(r^{sb}_t - r^d_t\right) b^{sb}_{r,t} + \left(R_t - r^d_t\right) re_t\\ &- \left(R^{eb}_t - r^d_t\right) e^b_t + r^d_t X^b_t - \mathcal{C}^b_t - \mathcal{C}^{b,f}_t - \mathcal{C}^{b,sb}_t\end{aligned}$$

- Gambacorta and Karmakar (2018) The retail loans and deposit demand schedules:

$$\begin{aligned}\widetilde{\ell}^{f,b}_{r,t}(j) &= \left(\frac{r^f_t(j) - 1}{r^f_t - 1}\right)^{-\varepsilon^{b,f}_t} \widetilde{\ell}^{f,b}_{r,t}\\ b^{sb}_{r,t}(j) &= \left(\frac{r^{sb}_t(j) - 1}{r^{sb}_t - 1}\right)^{-\varepsilon^{b,sb}_t} b^{sb}_{r,t}\\ d_{r,t}(j) &= \left(\frac{r^d_t(j) - 1}{r^d_t - 1}\right)^{-\varepsilon^{b,d}_t} d_{r,t}\end{aligned}$$

- Objective function for loan branches:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t_b \lambda^b_t \left[r^f_t(j)\widetilde{\ell}^{f,b}_{r,t}(j) + r^{sb}_t(j) b^{sb}_{r,t}(j)\right.$$
$$\left. - \left(R^f_t \widetilde{\ell}^{f,b}_t(j) + R^{sb}_t b^{sb}_t(j)\right) - \mathcal{C}^{b,f}_t - \mathcal{C}^{b,sb}_t\right]$$

- Objective function for deposit branches:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \lambda_t^b \left[-r_t^d(j) d_{r,t}(j) + R_t^d d_t(j) \right]$$

- Gambacorta and Karmakar (2018) Remuneration costs for lending:

$$\mathcal{C}_t^{b,f} = \frac{\kappa_{b,f}}{2} \left(\frac{r_t^f(j) - 1}{r_{t-1}^f(j) - 1} - 1 \right)^2 \left(r_t^f - 1 \right) \widetilde{\ell}_{r,t}^{f,b}$$

$$\mathcal{C}_t^{b,sb} = \frac{\kappa_{b,sb}}{2} \left(\frac{r_t^{sb}(j) - 1}{r_{t-1}^{sb}(j) - 1} - 1 \right)^2 \left(r_t^{sb} - 1 \right) b_{r,t}^{sb}$$

- The process of elasticity of deposit supply (stickiness of the retail deposit interest rate):

$$\varepsilon_t^{b,d} = (1 - \rho^{b,d}) \bar{\varepsilon}^{b,d} + (1 - \rho^{b,d}) \chi^{b,d} (R_t - R_{t-1}) + \rho^{b,d} \varepsilon_{t-1}^{b,d}$$

D.4.2 Lagrangean

- Loan branches

$$\max_{r_t^f(j), r_t^{sb}(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \lambda_t^b \Bigg[\left(r_t^f(j) - 1 \right) \left(\frac{r_t^f(j) - 1}{r_t^f - 1} \right)^{-\varepsilon_t^{b,f}} \widetilde{\ell}_{r,t}^{f,b} + \left(r_t^{sb}(j) - 1 \right) \left(\frac{r_t^{sb}(j) - 1}{r_t^{sb} - 1} \right)^{-\varepsilon_t^{b,sb}} b_{r,t}^{sb} - \left(R_t^f \tilde{\ell}_t^{f,b}(j) + R_t^{sb} b_t^{sb}(j) \right) - \mathcal{C}_t^{b,f} - \mathcal{C}_t^{b,sb} \Bigg]$$

- Deposit branches

$$\max_{r_t^d(j)} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \lambda_t^b \left[- \left(r_t^d(j) - 1 \right) \left(\frac{r_t^d(j) - 1}{r_t^d - 1} \right)^{-\varepsilon_t^{b,d}} d_{r,t} + R_t^d d_t(j) \right]$$

D.4.3 First-Order Conditions

- To derive the first-order conditions, I replace $r_t^s(j)$ with $\mathfrak{r}_t^s(j) = r_t^s(j) - 1$ and optimize the Lagrangean with respect to it. After deriving the FOCs, I recover $r_t^s(j)$.

- FOC for lending supply to intermediate good producers:

$$1 - \varepsilon_t^{b,f} + \varepsilon_t^{b,f} \frac{R_t^f - 1}{r_t^f - 1} - \kappa_{b,f} \left(\frac{r_t^f - 1}{r_{t-1}^f - 1} - 1 \right) \frac{r_t^f - 1}{r_{t-1}^f - 1}$$
$$+ \mathbb{E}_t \left[\Lambda_{t,t+1}^b \kappa_{b,f} \left(\frac{r_{t+1}^f - 1}{r_t^f - 1} - 1 \right) \left(\frac{r_{t+1}^f - 1}{r_t^f - 1} \right)^2 \frac{\widetilde{\ell}_{t+1}^{f,b}}{\widetilde{\ell}_t^{f,b}} \right] = 0$$

- FOC for lending supply to shadow bank:

$$1 - \varepsilon_t^{b,sb} + \varepsilon_t^{b,sb} \frac{R_t^{sb} - 1}{r_t^{sb} - 1} - \kappa_{b,sb} \left(\frac{r_t^{sb} - 1}{r_{t-1}^{sb} - 1} - 1 \right) \frac{r_t^{sb} - 1}{r_{t-1}^{sb} - 1}$$
$$+ \mathbb{E}_t \left[\Lambda_{t,t+1}^b \kappa_{b,sb} \left(\frac{r_{t+1}^{sb} - 1}{r_t^{sb} - 1} - 1 \right) \left(\frac{r_{t+1}^{sb} - 1}{r_t^{sb} - 1} \right)^2 \frac{b_{t+1}^{sb}}{b_t^{sb}} \right] = 0$$

- FOC for deposit demand from household:

$$-1 + \varepsilon_t^{b,d} - \varepsilon_t^{b,d} \frac{R_t^d - 1}{r_t^d - 1} - \kappa_{b,d} \left(\frac{r_t^d - 1}{r_{t-1}^d - 1} - 1 \right) \frac{r_t^d - 1}{r_{t-1}^d - 1}$$
$$+ \mathbb{E}_t \left[\Lambda_{t,t+1}^b \kappa_{b,d} \left(\frac{r_{t+1}^d - 1}{r_t^d - 1} - 1 \right) \left(\frac{r_{t+1}^d - 1}{r_t^d - 1} \right)^2 \frac{d_{t+1}}{d_t} \right] = 0$$

D.5 Shadow Bank

List of variables:
$N_t^{sb} =$ net worth of shadow bank.
$b_t^n =$ lending supply to startups.
$b_t^{sb} =$ borrowing demand from retail banks.
$X_t^{sb} =$ internal capital.
$\mathcal{C}_t^{sb,n} =$ cost of lending to startups.

$m_t^{sb} =$ monitoring cost for default loans.
$R_{t+1}^{fn} =$ return on fictitious firm lending.

D.5.1 Optimization Problem

- The balance sheet:

$$b_t^n = b_t^{sb} + X_t^{sb}$$

- Net worth:

$$N_{t+1}^{sb} = (\Pi_{t+1})^{-1}\left(R_{t+1}^{fn} b_t^n - r_t^{sb} b_t^{sb} - \mathcal{C}_t^{sb,n} - m_t^{sb}\right)$$

- The cost of lending to startups:

$$\mathcal{C}_t^{sb,n} = \frac{\kappa^{sb,n}}{1+\frac{1}{\theta^{sb,n}}}\bar{b}^n\left(\frac{b_t^n}{\bar{b}^n}\right)^{1+\frac{1}{\theta^{sb,n}}}$$

- Balance sheet condition:

$$b_t^n = b_t^{sb} + X_t^{sb}$$

- Brunnermeier and Koby (2018) Capital accumulation formula:

$$X_{t+1}^{sb} = (1-\nu^{sb})N_{t+1}^{sb}$$

- Objective function:

$$\max \mathbb{E}_t\left[\Lambda_{t,t+1}^b N_{t+1}^{sb}\right]$$

D.5.2 Lagrangean

$$\max_{b_t^n} \mathbb{E}_t \Lambda^b_{t,t+1} \Pi^{-1}_{t+1} \left(\left(R^{fn}_{t+1} - r^{sb}_t \right) b^n_t - \mathcal{C}^{sb,n}_t - m^{sb}_t \right)$$

D.5.3 First-Order Conditions

$$\mathbb{E}_t \Lambda^b_{t,t+1} \Pi^{-1}_{t+1} \left[\left(R^{fn}_{t+1} - r^{sb}_t \right) - \frac{\partial \mathcal{C}^{sb,n}_t}{\partial b^n_t} \right] = 0$$

D.6 Intermediate Good Producers

List of variables for intermediate good firm j:
$y_t(j) =$ output of intermediate good.
$h_t(j) =$ labor demand.
$I_t(j) =$ investment.
$K_t(j) =$ owned capital stock.
$K^n_t(j) =$ rented capital from startups.
$\ell^f_t(j) =$ total credit.
$\ell^{f,b}_t(j) =$ committed credit line.
$\ell^{f,cb}_t(j) =$ government loan.
$u^f_t(j) =$ credit line utilization rate.
$P_t(j) =$ price of intermediate good.
$r^{k,n}_t =$ rental rate on capital from startups.
$mc^{kl}_t =$ marginal cost of production.
$q_t =$ Tobin's Q (price of capital).
$G_{P,t}(j) =$ Price adjustment cost.
$G_{I,t}(j) =$ Investment adjustment cost.
$\varphi_t(j) =$ Financial distress cost.

D.6.1 Optimization Problem

- Nominal profit of firm j:

$$\begin{aligned} \Pi^F_t(j) =& P_t(j) y_t(j) + P_t \ell^f_t(j) - P_t w_t h_t(j) - r^f_{t-1} P_{t-1} \ell^f_{t-1}(j) \\ & - P_t r^{k,n}_t K^n_t(j) - P_t I_t(j) - P_t G_{P,t}(j) - P_t G_{I,t}(j) - P_t \varphi_t(j) \end{aligned}$$

where $\ell_t^f(j) = u_t^f(j)\ell_t^{f,b}(j) + \ell_t^{f,cb}(j)$.

- Kumhof and Wang (2021), Gasparini et al. (2024) Inflation adjustment cost:

$$G_{P,t}(j) = \frac{\phi_p}{2} y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\Pi_t} - 1 \right)^2$$

- Christiano et al. (2005) Investment adjustment cost:

$$G_{I,t}(j) = \frac{\phi_I}{2} I_t \left(\frac{I_t(j)}{I_{t-1}(j)} - 1 \right)^2$$

- Financial distress cost:

$$\varphi_t = \kappa_f \left(\frac{\tilde{\ell}_t^{f,b}}{\ell_t^f} \right)^{\theta_u}$$

- Credit line limit constraint:

$$P_{t+1}\ell_{t+1}^{f,b}(j) \geq \theta_t^\pi \Pi_t^{EBITDA}(j)$$

where the earnings before interest, taxes, depreciation, and amortization (EBITDA), $\Pi_t^{EBITDA}(j) = P_t y_t(j) - P_t w_t h_t(j) - P_t r_t^{k,n} K_t^n(j)$.

  - The shock process for θ_t^π:

$$\theta_t^\pi = S_t^\pi \bar{\theta}^\pi$$

$$\log(S_t^\pi) = \rho^\pi \log(S_{t-1}^\pi) + u_t^\pi$$

- Loan in advance constraint:

$$\psi_t^L P_t I_t(j) \leq P_t \ell_t^f(j)$$
$$\psi_t^L = S_t^u \bar{\psi}^L$$

  – The shock process for u_t^f:

$$\log(S_t^u) = \rho^u \log(S_{t-1}^u) + u_t^u$$

- Production technology:

$$y_t(j) = S_t^a \left(h_t(j)\right)^{1-\alpha} \left[\left(K_t(j)\right)^{1-\zeta} \left(K_t^n(j)\right)^{\zeta}\right]^{\alpha}$$

  – The technology shock process S_t^a:

$$\log(S_t^a) = \rho^a \log(S_{t-1}^a) + u_t^a$$

- Final good firm's demand for intermediate goods:

$$y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\theta} y_t$$

  – Dixit–Stiglitz aggregation of intermediate goods:

$$y_t = \left(\int_0^1 y_t(j)^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}$$

  – Aggregate price index:

$$P_t = \left(\int_0^1 P_t(j)^{1-\theta} dj\right)^{\frac{1}{1-\theta}}$$

- Owned capital accumulation formula:

$$K_{t+1}(j) = (1-\delta)K_t(j) + I_t(j)$$

D.6.2 Lagrangean

$$\begin{aligned}
&\max_{\left\{P_t(j),\ell_{t+1}^{f,b}(j),u_t^f(j),h_t(j),I_t(j),K_{t+1}(j),K_{t+1}^n(j)\right\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_h^t \lambda_t^h \Big[\left(P_t(j)\right)^{1-\theta} \left(P_t\right)^{\theta-1} y_t \\
&+ u_t^f(j)\ell_t^{f,b}(j) + \tilde{\ell}_t^{f,cb}(j) - w_t h_t(j) - r_{t-1}^f \left(u_{t-1}^f(j)\ell_{t-1}^{f,b}(j) + \tilde{\ell}_{t-1}^{f,cb}(j) \right) \Pi_t^{-1} \\
&- r_t^{k,n} K_t^n(j) - I_t(j) - G_{P,t}(j) - G_{I,t}(j) - \varphi_t \\
&- mc_t^{kl} \left(\left(P_t(j)\right)^{-\theta} \left(P_t\right)^{\theta} y_t - S_t^a h_t(j)^{1-\alpha} \left[\left(K_t(j)\right)^{1-\zeta} \left(K_t^n(j)\right)^{\zeta} \right]^{\alpha} \right) \\
&+ \eta_t^f \left(\ell_{t+1}^f(j)\Pi_{t+1} - \theta_\pi \left(\left(P_t(j)\right)^{1-\theta} \left(P_t\right)^{\theta-1} y_t - w_t h_t(j) - r_t^{k,n} K_t^n(j) \right) \right) \\
&+ q_t^k \left((1-\delta)K_t(j) + I_t(j) - K_{t+1}(j) \right) \\
&+ \eta_t^u \left(u_t^f(j)\ell_t^{f,b}(j) + \tilde{\ell}_t^{f,cb}(j) - \psi_t^L I_t(j) \right) \Big]
\end{aligned}$$

D.6.3 First-Order Conditions

- Using the symmetry across intermediate good firms, I drop the index j in the following FOCs.

- FOC for price setting $P_t(j)$:

$$\begin{aligned}
\mu mc_t^{k\ell} - (1 - \eta_t^f \theta_\pi) = {} & \phi_p(\mu - 1) \left(\frac{\Pi_t}{\Pi_{t-2,t-1}} - 1 \right) \frac{\Pi_t}{\Pi_{t-2,t-1}} \\
& - \mathbb{E}_t M_t \frac{y_{t+1}}{y_t} \phi_p(\mu - 1) \left(\frac{\Pi_{t+1}}{\Pi_t} - 1 \right) \frac{\Pi_{t+1}}{\Pi_t}
\end{aligned}$$

where $\mu = \frac{\theta}{\theta-1}$.

- FOC for credit line limit $\ell_{t+1}^{f,b}(j)$:

$$\eta_t^f \Pi_{t+1} = -\mathbb{E}_t \Lambda_{t,t+1}^h \left(u_{t+1}^f - \frac{\partial \varphi_{t+1}}{\partial \ell_{t+1}^f} + \eta_{t+1}^u u_{t+1}^f \right) + \mathbb{E}_t \beta_h^2 \frac{\lambda_{t+2}^h}{\lambda_t^h} r_{t+1}^f u_{t+1}^f \Pi_{t+2}^{-1}$$

- FOC for credit utilization $u_t^f(j)$:

$$\eta_t^u = \mathbb{E}_t \Lambda_{t,t+1}^h \left[r_t^f \Pi_{t+1}^{-1} \right] - 1 + \frac{\partial \varphi_t}{\partial u_t^f} \frac{1}{\ell_t^{f,b}}$$

- FOC for labor demand $h_t(j)$:

$$w_t h_t = (1-\alpha) \frac{mc_t^{kl} y_t}{1 - \eta_t^f \theta_t^\pi}$$

- FOC for investment $I_t(j)$:

$$q_t = \left(1 + \phi_I \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right) - \psi_t^L \eta_t^u - \mathbb{E}_t \Lambda_{t,t+1}^h \left(\phi_I \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right)$$

- FOC for owned capital $K_{t+1}(j)$:

$$q_t = \mathbb{E}_t \Lambda_{t,t+1}^h \left[\alpha \left(1 - \zeta \right) mc_{t+1}^{kl} \frac{y_{t+1}}{K_{t+1}} + q_{t+1}(1-\delta) \right]$$

- FOC for rented capital from startups $K_{t+1}^n(j)$:

$$\left(1 - \eta_{t+1}^f \theta_{t+1}^\pi \right) r_{t+1}^{k,n} = \alpha \zeta mc_{t+1}^{kl} \frac{y_{t+1}}{K_{t+1}^n}$$

D.7 Capital Good Producers

List of variables:
$Q_t^n =$ nominal price of capital.
$I_t^n =$ investment.
$G_{I,t}^n =$ investment adjustment cost.
$q_t^n =$ Tobin's Q.

D.7.1 Optimization Problem

- Nominal profit of capital good producers:

$$\Pi_t^K = Q_t^n I_t^n - P_t I_t^n - P_t G_{I,t}^n$$

- Christiano et al. (2005) Investment adjustment cost:

$$G_{I,t}^n = \frac{\phi_I^n}{2} I_t^n \left(\frac{I_t^n}{I_{t-1}^n} - 1 \right)^2$$

- Capital accumulation formula:

$$K_{t+1}^n = (1-\delta) K_t^n + I_t^n$$

D.7.2 Lagrangean

$$\max_{I_t^n} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta_h^t \lambda_t^h \left(q_t^n I_t^n - I_t^n - G_{I,t}^n \right)$$

D.7.3 First-Order Conditions

$$
\begin{aligned}
q_t^n = 1 + \frac{\phi_I^n}{2}\left(\frac{I_t^n}{I_{t-1}^n} - 1\right)^2 + \phi_I^n\left(\frac{I_t^n}{I_{t-1}^n} - 1\right)\frac{I_t^n}{I_{t-1}^n} \\
- \mathbb{E}_t \Lambda_{t,t+1}^h \left(\phi_I^n\left(\frac{I_{t+1}^n}{I_t^n} - 1\right)\left(\frac{I_{t+1}^n}{I_t^n}\right)^2\right)
\end{aligned}
$$

D.8 Startups

- The startups are identical to "entrepreneurs" in Gasparini et al. (2024) who are exposed to idiosyncratic return shock.
- A crucial difference is that startups borrow from shadow bank instead of traditional banks.
- Also, the capital rented from startups is additional inputs for intermediate good producers.

D.8.1 Optimization Problem

- Net worth of startup j, $n_t^n(j)$:

$$n_t^n(j) = q_t^n K_{t+1}^n(j) - b_t^n(j)$$

- Rate of return on capital R_t^n:

$$R_t^n = \frac{r_t^{k,n} + (1-\delta^n)q_t^n}{q_{t-1}^n}\Pi_t$$

- Wealth of startup j, $\mathcal{W}^n_{t+1}(j)$:

$$P_{t+1}\mathcal{W}^n_{t+1}(j) = \left(1 - \Gamma^n_{t+1}\right) R^n_{t+1} P_t q^n_t K^n_{t+1}(j)$$

  where Γ^n_{t+1} is the fraction of return that goes to shadow bank as a debt payment.

- The relationship between wealth and net worth in aggregate.

  - A portion of startups exit and bring their wealth $\mathcal{W}^n_{t+1}(j)$ to the household. The aggregate amount of their wealth is equivalent to a portion of total startups' wealth, which is $\chi^n \mathcal{W}^n_{t+1}$.
  - The household transfers a fraction of ι of exiting startups' wealth to new startups.
  - Then the aggregate net worth of startups, n^n_{t+1}:

$$n^n_{t+1} = \left(1 - \chi^n + \iota\chi^n\right) \mathcal{W}^n_{t+1}$$

- Idiosyncratic return shock process, $\omega^n_{t+1}(j)$:

$$\omega^n_{t+1}(j) \overset{i.i.d.}{\sim} \text{lognormal}\left(1, \sigma^n_t\right)$$

  where

$$\begin{aligned} \sigma^n_t =& \bar{\sigma}^n S^n_t \\ \log S^n_t =& \rho^n \log S^n_{t-1} + u^n_t \end{aligned}$$

- Financial contract with shadow bank.

  - A startup j borrows $b^n_t(j)$ from the shadow bank.

- The startup j faces the idiosyncratic return shock $\omega^n_{t+1}(j)$ at $t+1$.
- The startup j's payment to the shadow bank depends on the realization of $\omega^n_{t+1}(j)$.
- For a threshold $\bar{\omega}^n_{t+1}(j)$, a startup j with $\omega^n_{t+1}(j) \geq \bar{\omega}^n_{t+1}(j)$ will pay $\bar{\omega}^n_{t+1}(j)R^n_{t+1}q^n_t K^n_{t+1}(j)$.
- A startup j with $\omega^n_{t+1}(j) < \bar{\omega}^n_{t+1}(j)$ will default and will pay $\omega^n_{t+1}(j)R^n_{t+1}q^n_t K^n_{t+1}(j)$
- To receive the payment from default loans, the shadow bank should pay the monitoring cost, $\Pi_t m^{sb}_t = \mu^n \omega^n_t(j) R^n_t q^n_{t-1} K^n_t(j)$, which is the fraction μ^n of the return from default startups.

- Given the contract, the payment fraction Γ^n_{t+1} is determined as follows:

$$
\begin{aligned}
&\Gamma^n_{t+1} = \Gamma^n\left(\bar{\omega}^n(j)\right) \\
&= \int_0^{\bar{\omega}^n_{t+1}(j)} \omega^n_{t+1}(j) f^n\left(\omega^n_{t+1}(j)\right) \mathrm{d}\omega^n_{t+1}(j) + \int_{\bar{\omega}^n_{t+1}(j)}^{\infty} \bar{\omega}^n_{t+1}(j) f^n\left(\omega^n_{t+1}(j)\right) \mathrm{d}\omega^n_{t+1}(j) \\
&= \int_0^{\bar{\omega}^n_{t+1}(j)} \omega^n_{t+1}(j) f^n\left(\omega^n_{t+1}(j)\right) \mathrm{d}\omega^n_{t+1}(j) + \left[1 - F^n\left(\bar{\omega}^n_{t+1}(j)\right)\right] \bar{\omega}^n_{t+1}(j)
\end{aligned}
$$

  where the default rate F^n_{t+1} is defined as:

$$
F^n_{t+1} = F^n\left(\bar{\omega}^{nj}_{t+1}\right) = \int_0^{\bar{\omega}^{nj}_{t+1}} f^n\left(\omega^{nj}_{t+1}\right) \mathrm{d}\omega^{nj}_{t+1}
$$

- Participation constraint of shadow bank.
  - Considering the chance of default and monitoring costs accompanied with lending to startups, the shadow bank requires the expected return to be the same as the return, R^{fn}_{t+1}, from the same

amount of riskless loans to fictitious firms.

$$\mathbb{E}_t\left[\left(\Gamma^n_{t+1}-\mu^n G^n_{t+1}\right)R^n_{t+1}q^n_t K^n_{t+1}(j)\right]\geq \mathbb{E}_t R^{fn}_{t+1}b^n_t$$

where G^n_{t+1} is the expectation of the shock process $\omega^n_{t+1}(j)$ of default startups:

$$G^n_{t+1}=G^n_{t+1}\left(\bar{\omega}^n(j)\right)\equiv\int_0^{\bar{\omega}^n_{t+1}(j)}\omega^n_{t+1}(j)f^n\left(\omega^n_{t+1}(j)\right)\mathrm{d}\omega^n_{t+1}(j)$$

- In sum, the startup j maximizes its wealth $\mathcal{W}^n_{t+1}(j)$ subject to the participation constraint of the shadow bank.
  - Consider the contractual repayment rate, $Z^n_{t+1}(j)$. For the startups who do not default, the following should hold:

$$\bar{\omega}^n_{t+1}(j)R^n_{t+1}q^n_t K^n_{t+1}(j)=Z^n_{t+1}(j)b^n_t(j)$$

  - Define the loan-to-value ratio $x^n_t(j)$ as follows:

$$x^n_t(j)\equiv\frac{Z^n_t(j)b^n_t(j)}{q^n_t K^n_{t+1}(j)}$$

  - From the contractual obligation identity, we have:

$$\bar{\omega}^n_{t+1}(j)=\frac{x^n_t(j)}{R^n_{t+1}}$$

- In the optimization problem, a startup j chooses $K^n_{t+1}(j)$ and, instead of $b^n_t(j)$, it chooses $x^n_t(j)$ to maximize its wealth.

D.8.2 Lagrangean

$$
\begin{aligned}
\max_{x_t^n(j), k_t(j)} \mathbb{E}_t \Bigg\{ & \left[1 - \Gamma^n\left(\frac{x_t^n(j)}{R_{t+1}^n}\right)\right] R_{t+1}^n q_t K_{t+1}^n(j) \\
& + \xi_t^n(j)\left[\left(\Gamma^n\left(\frac{x_t^n(j)}{R_{t+1}^n}\right) - \mu^n G^n\left(\frac{x_t^n(j)}{R_{t+1}^n}\right)\right) R_{t+1}^n q_t^n K_{t+1}^n(j) \right. \\
& \left. - R_{t+1}^{fn}\left(q_t^n \int_0^1 K_{t+1}^n(j)\mathrm{d}j - n_t^n\right)\right]\Bigg\}
\end{aligned}
$$

D.8.3 First-Order Conditions

- I drop the index j in the following FOCs.
- FOC for loan-to-value ratio $x_t^n(j)$:

$$
\mathbb{E}_t\left\{\left[-\Gamma_{t+1}^{n\prime} + \xi_t^n\left(\Gamma_{t+1}^{n\prime} - \mu^n G_{t+1}^{n\prime}\right)\right]\right\} = 0
$$

- FOC for capital demand $K_{t+1}^n(j)$:

$$
\mathbb{E}_t\left\{\left[1 - \Gamma_{t+1}^n\right] R_{t+1}^n + \xi_t^n\left[\Gamma_{t+1}^n - \mu^n G_{t+1}^n R_{t+1}^n - R_{t+1}^{fn}\right]\right\} = 0
$$

D.9 Central Bank

D.9.1 Monetary Policy

$$
R_t = \bar{R}\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{m_\pi}\left(\frac{y_t}{\bar{y}}\right)^{m_y} S_t^i
$$

where

$$
\log(S_t^i) = \rho^i \log(S_{t-1}^i) + u_t^i
$$

D.9.2 Asset Purchases Policy

- The central bank supplies reserves to the wholesale bank and lends to intermediate good firms' debt:

$$\tilde{\ell}_t^{f,cb} = re_t$$

- The central bank transfers its operating profit to the household:

$$\Pi_t T_t^{cb} = r_{t-1}^{f} \tilde{\ell}_{t-1}^{f,cb} - R_{t-1} re_{t-1}$$

- The reserve policy responds to deviations in inflation and credit line limit from their steady states respectively:

$$re_t = \bar{re} \left(\frac{\Pi_t}{\bar{\Pi}} \right)^{-q_\pi} \left(\frac{\mathbb{E}_t \ell_{t+1}^{f,b}}{\bar{\ell}^{f,b}} \right)^{-q_\ell} S_t^q$$

where

$$\log(S_t^q) = \rho^q \log(S_{t-1}^q) + u_t^q$$

D.9.3 Macroprudential Policies

- Macroprudential policy for banker's leverage ratio:

$$\nu_t^{bhc} = \left(1 - \rho^{bhc}\right) \bar{\nu}^{bhc} + \left(1 - \rho^{bhc}\right) \left[\chi^{bhc} \left(\frac{e_t + b_t^b}{y_t} - \frac{\bar{e} + \bar{b}^b}{\bar{y}} \right) \right] + \rho^{bhc} \nu_{t-1}^{bhc}$$

- Angelini et al. (2014) Macroprudential policy for wholesale bank's capital-asset ratio:

$$\nu_t^{k} = \left(1 - \rho^{k}\right) \bar{\nu}^{k} + \left(1 - \rho^{k}\right) \left[\chi^{k} \left(\frac{\tilde{\ell}_t^{f,b} + b_t^{sb}}{y_t} - \frac{\bar{\tilde{\ell}}^{f,b} + \bar{b}^{sb}}{\bar{y}} \right) \right] + \rho^{k} \nu_{t-1}^{k}$$

D.10 Resource Constraints and GDP

$$
\begin{aligned}
y_t = {} & c_t^b + c_t^h + I_t + I_t^n + d_t^h \Phi(s_t) + G_{P,t} + G_{I,t} + G_{I,t}^n + \varphi_t \\
& + \left(\mathcal{C}_{t-1}^{bhc} + \mathcal{C}_{t-1}^{bhc,b} + \mathcal{C}_{t-1}^{b} + \mathcal{C}_{t-1}^{b,f} + \mathcal{C}_{t-1}^{b,sb} + \mathcal{C}_{t-1}^{sb,n} \right) \Pi_t^{-1} \\
& + m_t^{sb}
\end{aligned}
$$

Appendix E. Methodology

E.1 Data

- The following data were retrieved from the Federal Reserve Economic Data (FRED) database:
  - Z.1 Financial Accounts of the United States of Federal Reserve Board of Board from Governors of the Federal Reserve System.
  - Personal consumption expenditures (implicit price deflator) from U.S. Bureau of Economic Analysis.
  - National rates from Federal Deposit Insurance Corporation.
  - Treasury bill rates of U.S. from Board of Governors of the Federal Reserve System.
- The Wu-Xia shadow rates are obtained from Federal Reserve Bank of Atlanta.
- The P-Fin index is obtained from the Teachers Insurance and Annuity Association of America (TIAA).
- The following data is retrieved from Statista.

– Stock market participation rate from Gallup.

– Number of active mobile banking customers from JPMorgan Chase and Bank of America's annual reports.

E.2 Software

I used Matlab 2025a and Dynare 6.4 for solving and estimating the model.

E.3 Solution Methods

I solved the model using the first-order perturbation method around the non-stochastic steady state. The precision of the solution was verified by comparing results from the first-order perturbation method with those from the second-order perturbation method. For the latter, the pruning algorithm provided by Kim et al. (2008) was employed. The following figures present the comparison results for the financial distress shocks. For the selected variables, the responses from the first-order and second-order perturbation methods exhibit similar patterns.

However, the responses of remuneration costs show significant differences between the two methods. In particular, the responses of the capital-asset ratio and banker's leverage ratio adjustment costs are notable, as shown in Figure 27 and ??. Under the first-order perturbation method, the responses of both adjustment costs are negligible. In contrast, under the second-order perturbation method, both adjustment costs respond significantly to the financial distress shocks. Additionally, the marginal cost of intermediate good production decreases more under the second-order perturbation method as the second-order effects on adjustment costs are captured. Investigation of adjustment costs under the second-order perturbation method is left for future research.

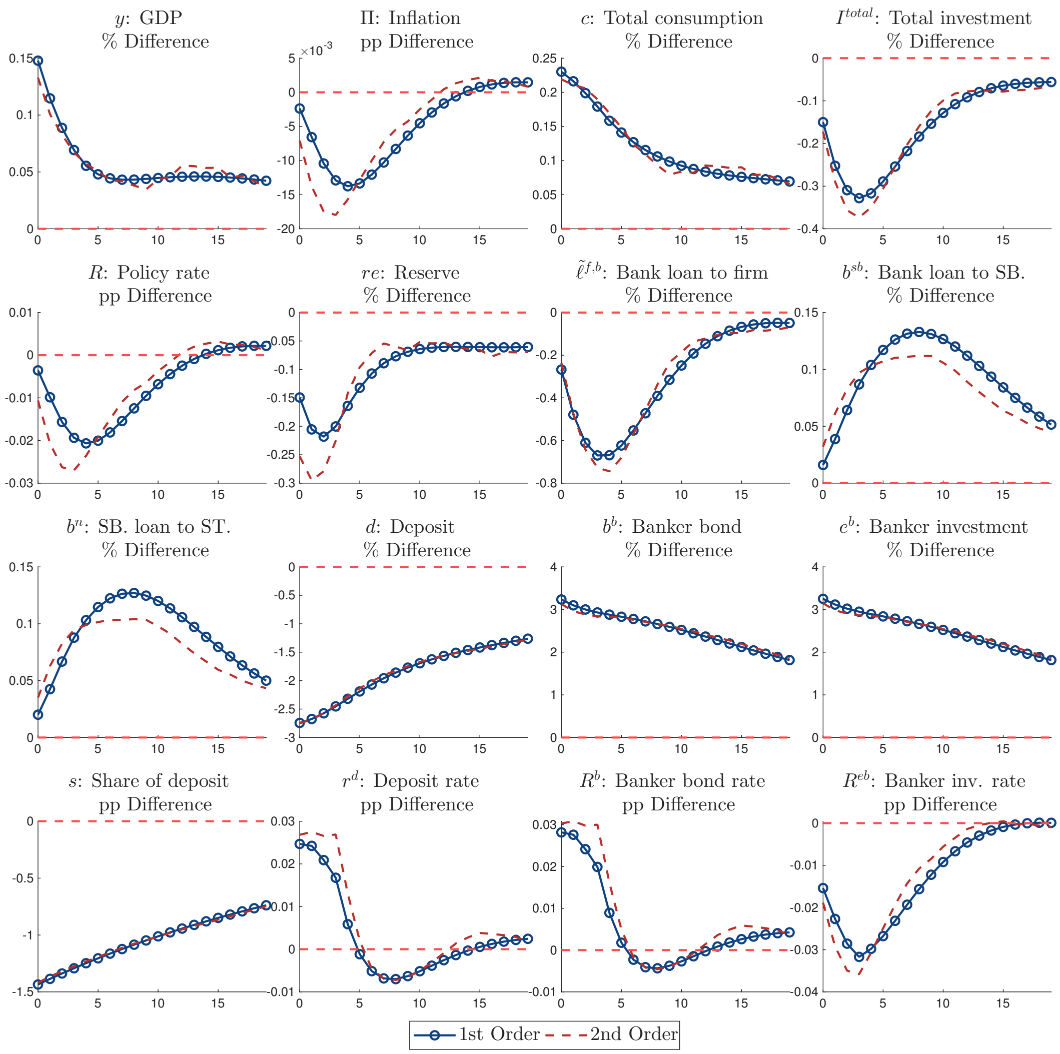

Figure 24: Financial distress shock 1

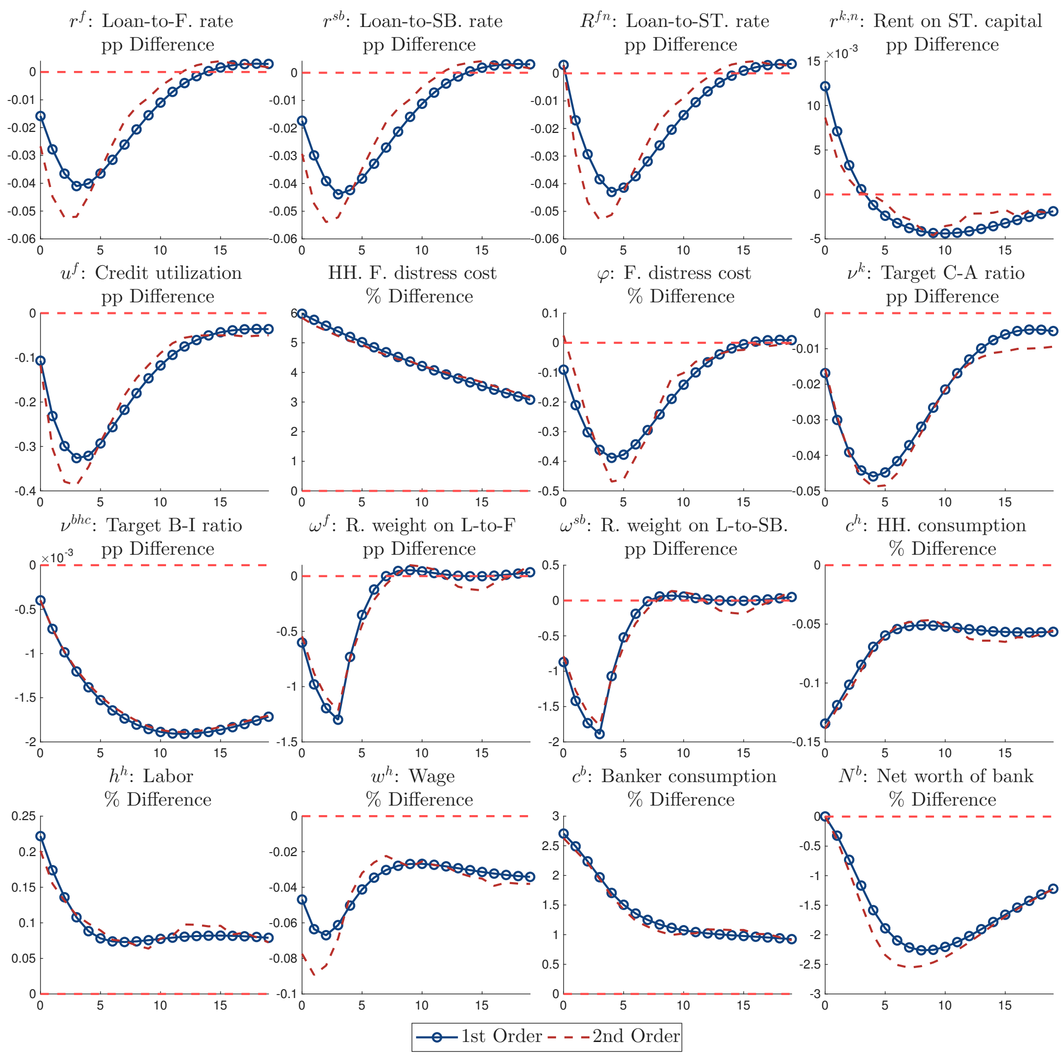

Figure 25: Financial distress shock 2

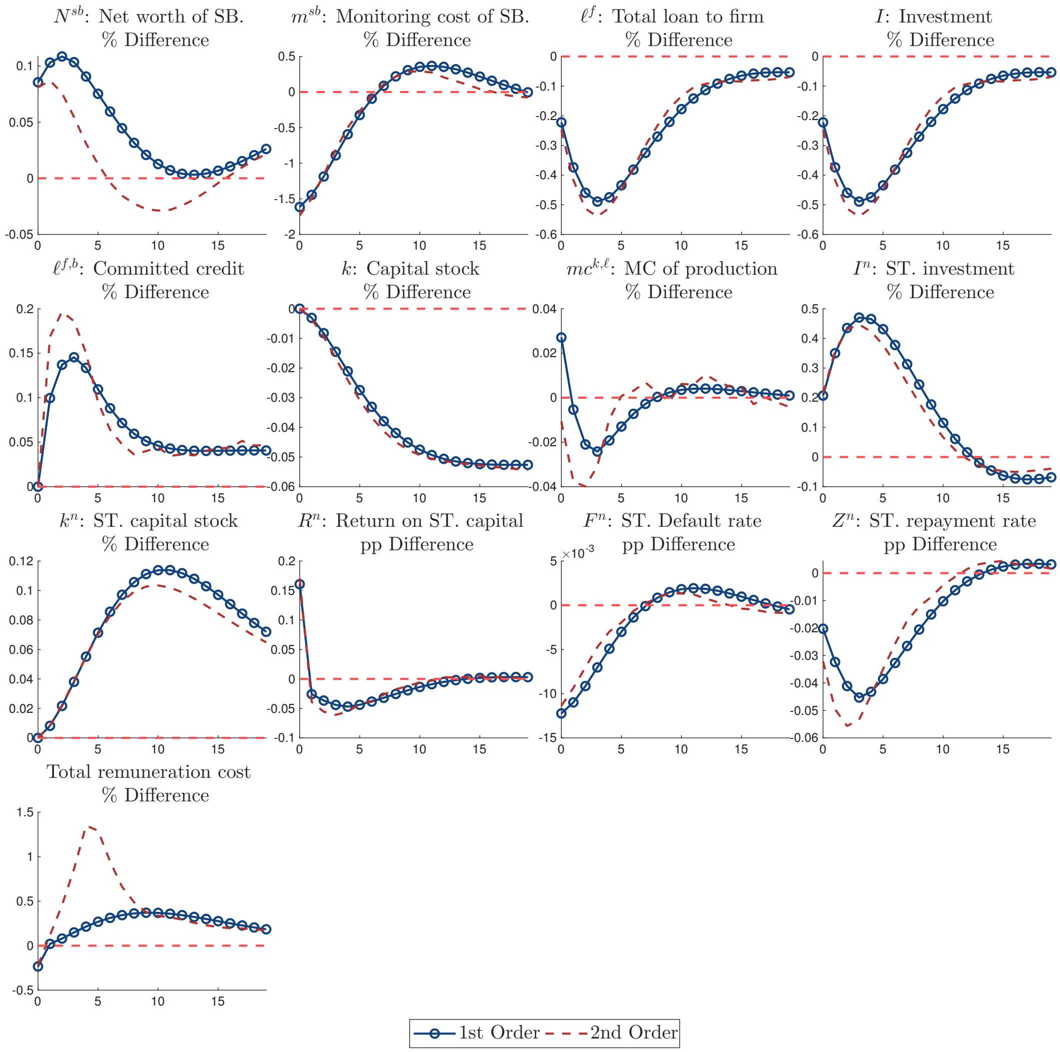

Figure 26: Financial distress shock 3

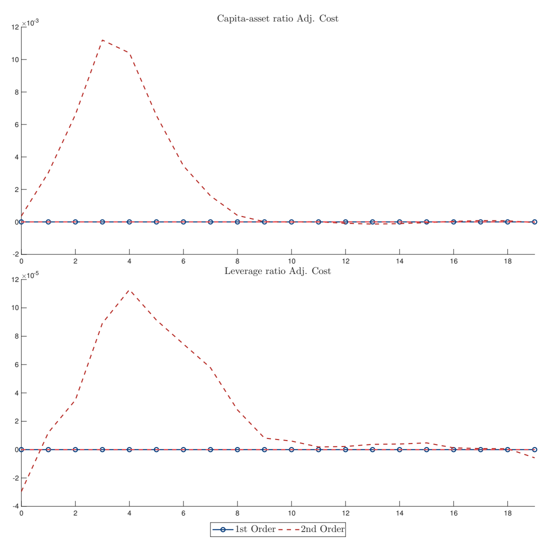

Figure 27: Financial distress shock to adjustment costs

Appendix F. Calibration

The model was calibrated using parameters from different sources. First, the parameters obtained from the literature are organized by model sectors in Table 4. Second, the prior distributions and posterior statistics are provided in Table 5. Finally, the parameters estimated through Bayesian estimation are reported in Table 6.

Table 4: Calibration Parameters

Parameter	Value	Target	Description	Source
Households				
β_h	0.995	SS retail deposit rate, $\bar{r}^d = 1 + 0.02/4$	Time preference	KW (2021)
γ_h	0.5		Intertemporal elasticity of consumption	KW (2021)
χ_h	0.483	SS Labor supply, $\bar{h}^h = 1$	Coefficient of labor disutility	KW (2021)
ζ_h	1		Elasticity of labor supply	KW (2021)
$\bar{\vartheta}$	0.60	SS Share of deposits, $\bar{s}$	Elasticity of financial distress cost	
$\bar{\chi}_1$	0.0007		Coefficient of financial distress cost	
Banker				
β_b	0.993	SS policy rate, $\bar{R} = 1 + 0.03/4$	Time preference	
$\kappa_{bhc,b}$	0.001	Moody's Saa bond yield spread	Coefficient of borrowing adjustment cost	
$\theta^{bhc,b}$	2		Elasticity of borrowing adjustment cost	KW (2021)
$\kappa_{bhc,e}$	0.001	$\kappa_{bhc,b}$	Coefficient of equity investment cost	
$\theta^{bhc,e}$	1		Elasticity of equity investment adjustment cost	KW (2021)
Wholesale Bank				
ν^b	0.079	SS balance sheet condition	Fixed dividend rate	
ρ_e	0.197	Basel III capital requirement	Weight for equity investment in capital	Basel III
$\bar{\omega}^f$	1.2		SS risk weight of loans to firms in asset	Basel III
$\bar{\omega}^{sb}$	1.2		SS risk weight of loans to shadow bank in asset	Basel III
Retail Bank				
$\varepsilon^{b,f}$	2.714	Annual C&I loan spread= $175bp$	SS markup for firm lending	Pandolfo (2025)
$\varepsilon^{b,sb}$	2.563	Annual Private Debt Funds spread= $192bp$	SS markup for SB lending	BCLZ (2025)
$\bar{\varepsilon}^{b,d}$	-2.03	SS retail deposit rate, $\bar{r}^d = 1 + 0.02/4$	SS markdown for HH deposit	
$\rho^{b,d}$	0.5		Persistence of markdown process	
$\chi^{b,d}$	120		Strength of response to policy rate change	
Final & Intermediate Good Producer				
θ	11	Markup in the SS, $\mu = \theta/(\theta - 1) = 1.1$	Final good aggregation technology	KW (2021)
α	0.333		Share of capital in intermediate good production	KW (2021)
ζ	0.21	$\delta^n \in [0.15, 0.20]$	Share of startups' capital in total capital	
$\bar{\theta}^\pi$	1.211	SS firms' loan from bank to GDP ratio= 0.04	SS multiplier of credit line limit constraint	
δ	0.014	SS investment-to-GDP ratio, $\bar{I}/\bar{y} = 0.18$	Depreciation rate of capital	KW (2021)
$\bar{u}^f$	0.4		SS utilization rate of credit line	GKP (2023)
ϕ_p	200		Degree of stickiness in inflation	KW (2021)
ϕ_I	2.5		Degree of stickiness in investment	KW (2021)
θ_u	2		Firm curvature of financial distress cost	
$\bar{\psi}^L$	1.45		SS multilplier of debt-investment ratio	
Capital Good Producer & Startups				
χ^n	0.035	SS Capital-to-net value, $\bar{q}^n\bar{K}^n/\bar{n}^n = 2$	Startups exit rate	GLMV (2024)
ι	0.002		Startups portion of starting funds	GLMV (2024), GK (2010)
ϕ_I^n	2.5		Degree of stickiness in investment	KW (2021)
δ^n	0.04		Depreciation rate of startups' capital	LH(2018)
$\bar{\sigma}^n$	0.272	SS startups default rate $\bar{F} = 0.03$	SS dispersion in the dist. of return shock	GKP (2023)
μ^n	0.173	Annual return spread= $900bp$	SS share of monitoring cost	Koch (2014)
Shadow Banking				
$\kappa^{sb,n}$	0.010	Annual spread of private credit loan= $600bp$	SB coeff. of borrowing adj. cost	Pandolfo (2025)
$\theta^{sb,n}$	2		Elasticity of borrowing adjustment cost	KW (2021)
Monetary Policy				
m_y	0		Strength of MP response to output gap	SWZ (2023)
$\bar{re}/\bar{y}$	0.10		SS reserve-to-GDP ratio	SWZ (2023)
q_π	0		Strength of AP response to inflation gap	SWZ (2023)
Macroprudential Policy				
$\bar{\nu}^k$	0.105		SS target capital-asset ratio for wholesale bank	Basel III
$\bar{\nu}^{bhc}$	1.2		SS target leverage ratio for banker	RF (2020)
Inflation				
$\bar{\Pi}$	1		SS inflation rate	

Note: Parameters are calibrated from various sources as listed. SS refers to steady state.

Table 5: Prior Distributions for Bayesian Estimation

Parameter	Description	Dist.	Mean	Std.
Policy Parameters				
m_π	Strength of MP response to inflation gap	Gamma	1.5	0.01
q_ℓ	Strength of AP response to credit gap	Gamma	1.5	0.01
χ^{bhc}	Cyclicity of macroprudential policy for banker	Normal	0	0.15
χ^k	Cyclicity of macroprudential policy for bank	Gamma	0.5	0.05
Adjustment Cost Parameters				
κ_{bhc}	Banker leverage	Gamma	10	2.5
κ_{Kb}	Bank capital	Gamma	15	2.5
$\kappa_{b,f}$	Retail bank loan to firm	Gamma	3	2.5
$\kappa_{b,sb}$	Retail bank loan to shadow bank	Gamma	3	2.5
κ_f	Firm financial distress	Gamma	0.02	0.01
Risk Weight Parameters				
χ^f	Strength of loan to firm	Normal	-10	2.5
χ^{sb}	Strength of loan to shadow bank	Normal	-15	2.5
ρ^f	Persistence of loan to firm	Beta	0.8	0.1
ρ^{sb}	Persistence of loan to shadow bank	Beta	0.8	0.1
Macroprudential Policy Persistence				
ρ^k	Policy for wholesale bank	Beta	0.8	0.1
ρ^{bhc}	Policy for banker	Beta	0.8	0.1
Shock Persistence Parameters				
ρ^a	Technology shock	Beta	0.8	0.1
ρ^i	Monetary policy shock	Beta	0.8	0.1
ρ^q	Asset purchase policy	Beta	0.8	0.1
ρ^π	Credit shock	Beta	0.8	0.1
ρ^n	Return shock	Beta	0.8	0.1
ρ^u	Debt-Investment shock	Beta	0.8	0.1
ρ^ϑ	HH financial distress cost shock	Beta	0.8	0.1
Shock Standard Deviations				
σ_{u^a}	Technology shock	Inv. Gamma	0.01	0.05
σ_{u^i}	Monetary policy shock	Inv. Gamma	0.01	0.05
σ_{u^q}	Asset purchase policy	Inv. Gamma	0.01	0.05
σ_{u^π}	Credit line shock	Inv. Gamma	0.01	0.05
σ_{u^n}	Return shock	Inv. Gamma	0.01	0.05
σ_{u^u}	Debt-Investment shock	Inv. Gamma	0.01	0.05
σ_{u^ϑ}	HH financial distress cost shock	Inv. Gamma	0.01	0.05
Other Parameters				
ν^{sb}	SB fixed dividend rate	Beta	0.05	0.01

Note: Prior distributions for Bayesian estimation using U.S. quarterly data from 2009:Q3 to 2025:Q2.
MP = Monetary Policy; AP = Asset Purchase; HH = Household.

Table 6: Posterior Statistics for Bayesian Estimation

Parameter	**Mode**	**Mean**	**2.5%**	**Median**	**97.5%**
Policy Parameters					
m_π	1.501	1.502	1.482	1.501	1.521
q_ℓ	1.500	1.500	1.480	1.500	1.519
χ^{bhc}	-0.002	0.005	-0.282	0.004	0.300
χ^k	0.529	0.524	0.425	0.523	0.630
Adjustment Cost Parameters					
κ_{bhc}	9.373	9.944	5.704	9.690	15.510
κ_{Kb}	15.778	15.255	10.647	15.103	20.618
$\kappa_{b,f}$	1.054	3.201	0.207	2.531	10.105
$\kappa_{b,sb}$	0.5014	1.781	0.104	1.337	5.895
κ_f	0.009	0.011	0.003	0.010	0.023
Risk Weight Parameters					
χ^f	-9.753	-9.673	-14.477	-9.724	-4.739
χ^{sb}	-14.346	-14.260	-19.094	-14.265	-9.348
ρ^f	0.847	0.804	0.578	0.817	0.957
ρ^{sb}	0.849	0.817	0.605	0.829	0.962
Policy Persistence Parameters					
ρ^k	0.741	0.724	0.521	0.732	0.874
ρ^{bhc}	0.846	0.803	0.578	0.817	0.954
Shock Persistence Parameters					
ρ^a	0.947	0.940	0.896	0.942	0.973
ρ^i	0.756	0.750	0.693	0.752	0.802
ρ^q	0.846	0.798	0.570	0.812	0.952
ρ^π	0.846	0.800	0.569	0.814	0.954
ρ^n	0.846	0.801	0.572	0.814	0.953
ρ^u	0.940	0.903	0.780	0.913	0.969
ρ^ϑ	0.966	0.946	0.890	0.950	0.981
Shock Standard Deviations					
σ_{u^a}	0.019	0.020	0.015	0.019	0.028
σ_{u^i}	0.007	0.007	0.006	0.007	0.008
σ_{u^q}	0.005	0.009	0.003	0.007	0.034
σ_{u^π}	0.005	0.009	0.003	0.007	0.027
σ_{u^n}	0.005	0.009	0.003	0.007	0.030
σ_{u^u}	0.191	0.280	0.101	0.262	0.566
σ_{u^ϑ}	0.024	0.025	0.021	0.024	0.029
Other Parameters					
ν^{sb}	0.047	0.046	0.041	0.046	0.052

Note: Posterior statistics from Bayesian estimation using U.S. quarterly data from 2009:Q3 to 2025:Q2. All values are rounded to three decimal places.

Table 7: Sources and Abbreviations

Abbreviation	Full Reference
AENPQ (2011)	Angelini et al. (2010)
ANP (2014)	Angelini et al. (2014)
BCLZ (2025)	Berrospide et al. (2025)
GLMV (2024)	Gasparini et al. (2024)
GNSS (2010)	Gerali et al. (2010)
GK (2010)	Gertler and Karadi (2011)
GK (2016)	Gambacorta and Karmakar (2018)
GKP (2023)	Greenwald et al. (2020)
KW (2021)	Kumhof and Wang (2021)
LH (2018)	Li and Hall (2020)
SWZ (2023)	Sims et al. (2023)
RF (2020)	Federal Reserve Bank of Richmond (2020)

Appendix G. Additional Robustness Checks

G.1 The Role of Leverage Ratio Regulation

One of the macroprudential policies in the model is the regulation of the banker's leverage ratio. As explained in the main text, the negative value of χ^{bhc} in equation (59) prevents intensive expansion of the banker's assets. Specifically, the target ratio decreases when the balance sheet of the banker expands relative to GDP. The decrease in the ratio increases the banker's leverage ratio adjustment cost, and the banker reduces its equity investment or increases its borrowing to minimize the adjustment costs.

To illustrate the role of leverage ratio regulation, I conducted a sensitivity analysis by varying the value of χ^{bhc}. Figure (28) shows the IRFs to a contractionary monetary policy shock when χ^{bhc} is set to -1.0, 0, and 1.0. The shock results in the hikes of the interest rates in the model. Then the household saving increases, which also induces an increase in banker's bonds. With the increase of its funding, the banker invests more in the wholesale bank. Different responses of macroprudential policy to the expansion in the banker's balance sheet are summarized in panel (d) of Figure (28). Additionally, panel (c) shows that the banker's investment in the wholesale bank is dampened when the macroprudential policy is designed to suppress the expansion of the banker's assets ($\chi^{bhc} = -1$). In panel (b), it is evident that the banker needs to borrow more from the household under this policy regime.

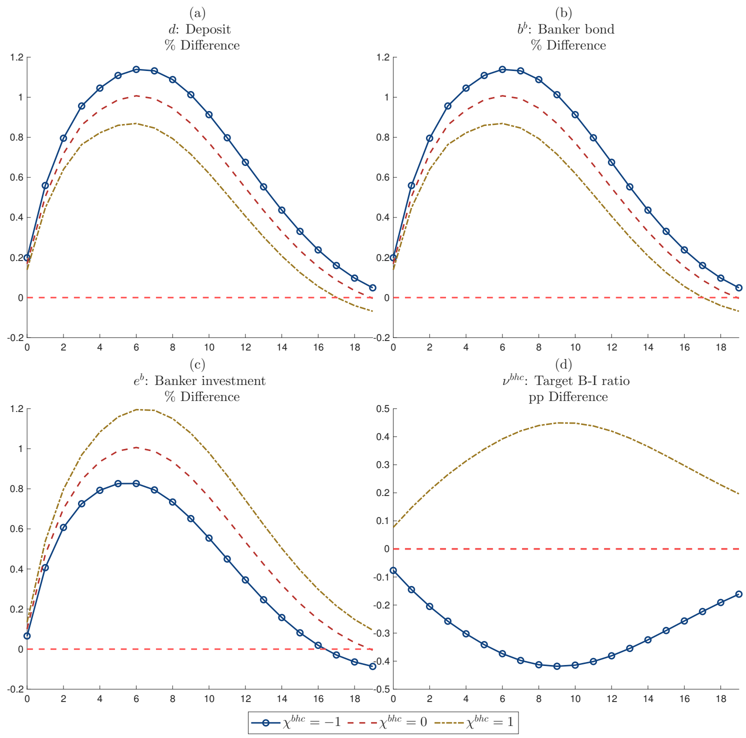

Figure 28: IRFs to contractionary monetary policy shock with different χ^{bhc}

G.2 The Role of Sticky Retail Deposit Rates

One feature implemented in the model is the stickiness of retail deposit rates. By assumption, only a limited share of policy rate changes is reflected in retail deposit rates when the policy rate changes. This is captured by the parameter $\chi^{b,d}$ in equation (27). The estimation of this parameter is summarized in Appendix C.1. In this section, I illustrate the role of retail deposit rate stickiness by conducting a sensitivity analysis.

Figure (29) shows the IRFs to a monetary policy shock when $\chi^{b,d}$ is set to 0 and 500; these values are selected for an illustrative purpose. A larger value of $\chi^{b,d}$ indicates that the markdown, $\varepsilon_t^{b,d}$, responds more actively to changes in the policy rate. For instance, when the policy rate increases, the markdown increases more with a larger value of $\chi^{b,d}$. An intuitive way to understand this is to examine the degree of transmission of policy rate changes to the retail deposit rate. From the first-order condition of retail banks, one can derive the relationship between the retail deposit rate r_t^d and the wholesale deposit rate R_t^d as follows:

$$r_t^d = 1 + \left(\frac{-\varepsilon_t^{b,d}}{1 - \varepsilon_t^{b,d}} \right) (R_t^d - 1).$$

The first-order condition of the wholesale bank with respect to reserve demand suggests that the policy rate, R_t and the wholesale deposit rate, R_t^d comove in equilibrium. Conclusively, the term $\frac{-\varepsilon_t^{b,d}}{1-\varepsilon_t^{b,d}}$ captures the degree of transmission from the policy rate to the retail deposit rate in equilibrium. In panel (i) of Figure (29), the degree of transmission drops significantly when $\chi^{b,d} = 500$ whereas it does not change when $\chi^{b,d} = 0$. The response of the deposit rate, r_t^d, becomes smaller when the shock hits, and the rate moves more slowly with $\chi^{b,d} = 500$, as shown in panel (b). However, to bring about a significant change in the transmission degree, a substantial value of $\chi^{b,d}$ is required.

One caveat of the model is that the response of the interest rate on banker's bonds, R_t^b, cannot be separated from that of the retail deposit rate, r_t^d, as observed in panels (b) and (c). Without additional assumptions regarding the household's problem, the two rates move together in the model. As remarked in the main text, this is relevant to the limited effect of macroeconomic policies on the share of deposits in the model. The share barely moves in response to shocks, which is related to a comovement of household deposits and banker's bond holdings, as shown in panels (d) and (e).

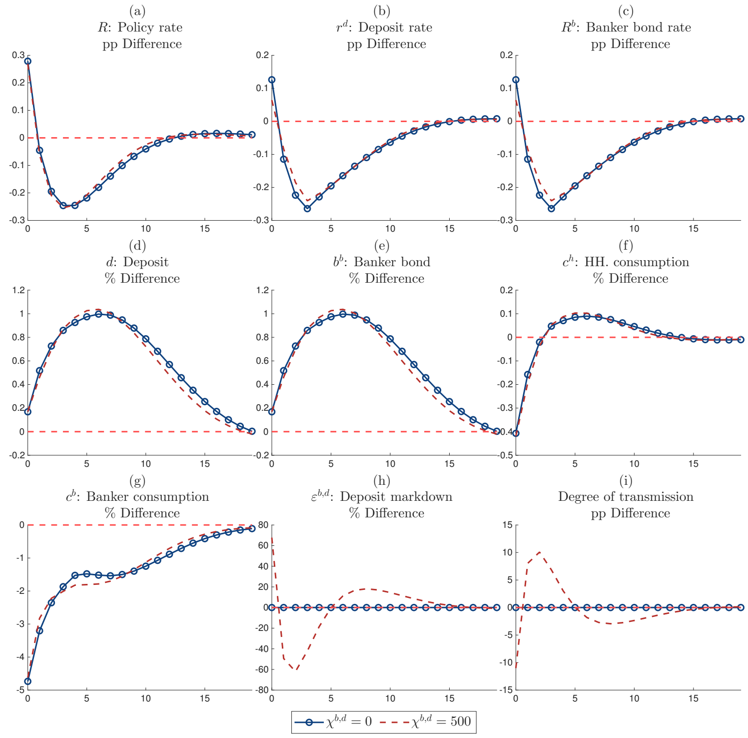

Figure 29: IRFs to Monetary policy shock with different $\chi^{b,d}$

G.3 The Financial Distress Cost of Intermediate Good Producers and the Credit Utilization Rate

The coefficient of the financial distress cost function of intermediate good producers, κ^f, is a key parameter of the model that governs the borrowing behavior of intermediate good producers. It is one of the determinants of the reallocation of credit between the producers and startups in response to the shocks.

Additionally, κ^f is crucial for guaranteeing the existence of the steady state equilibrium of the model and is sensitive to the value of the steady state credit utilization rate, $\bar{u}^f$. Figure 30 shows the existence of the steady state equilibrium according to changes in $\bar{u}^f$ and κ^f, given the baseline calibration and posterior modes of parameters. The shaded area represents the non-existence of the equilibrium. In the diagram, κ^f greater than 3.3 does not allow for the existence of the steady state equilibrium for any value of $\bar{u}^f$. Additionally, when κ^f is greater than 1.5 and is accompanied by a value of $\bar{u}^f$ below 0.8, the system of steady state equilibrium equations becomes unstable and no solution exists in some cases. Given the steady state utilization rate of 0.4 in the baseline calibration, I set the prior mean of κ^f to be 0.02, which guarantees the existence of the steady state equilibrium.

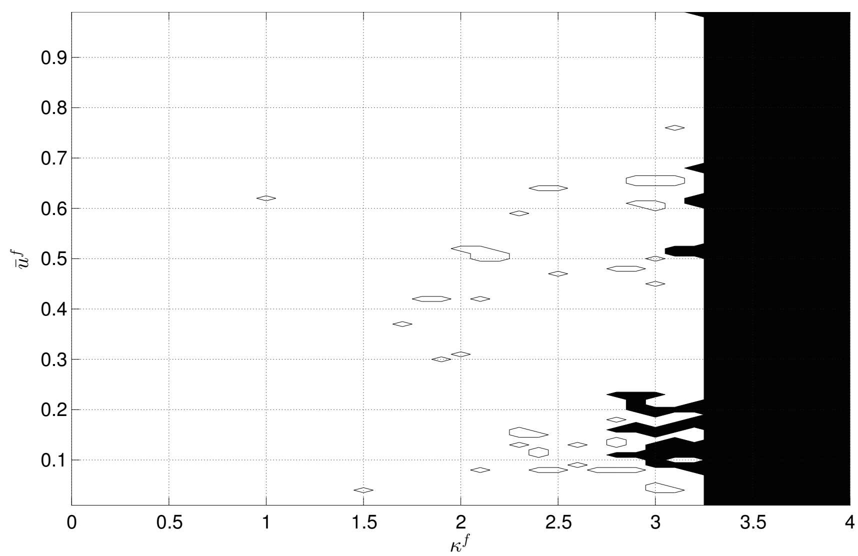

Figure 30: Determinacy as a function of the steady state utilization rate and κ^f

Notes: The figure shows the existence of steady state equilibrium according to changes in the steady state utilization rate, $\bar{u}^f$, and the coefficient of the financial distress cost function of intermediate good producers, κ^f, given the baseline calibration. The shaded area represents the non-existence of the steady state equilibrium.

Appendix H. Impulse Response Functions

The following are the impulse response functions (IRFs) to various shocks in the model. They encompass the responses of selected macroeconomic variables to technology shocks, monetary policy shocks, asset purchase policy shocks, committed credit line shocks, startups' return shocks, debt-investment shocks, and household financial distress cost shocks. The variables are in real terms. Each set of IRFs contains identical responses under three different steady state shares of depositors in the household: 55%, 60%, and 65%. The names of the variables are listed at the top of each panel, and the following abbreviations are used in the figures:

- SB.: Shadow bank.
- ST.: Startups.
- inv.: Investment.
- HH.: Households.
- F.: Intermediate good producers.
- invest.: Investment.
- Target C-A ratio: Target capital-asset ratio of wholesale bank.
- Target B-I: Target leverage ratio of banker.
- HH. F. distress cost: Household financial distress cost.
- R. weight on L-to-F: Risk weight on loan to intermediate good producers.
- R. weight on L-to-SB: Risk weight on loan to shadow bank.
- MC of production: Marginal cost of production.

A one standard deviation shock is applied to the economy and the standard deviation is set to be the same as the estimated value in Table 6.

H.1 IRFs for Technology Shocks

The following figures present the impulse response functions (IRFs) for a positive shock to the technology.

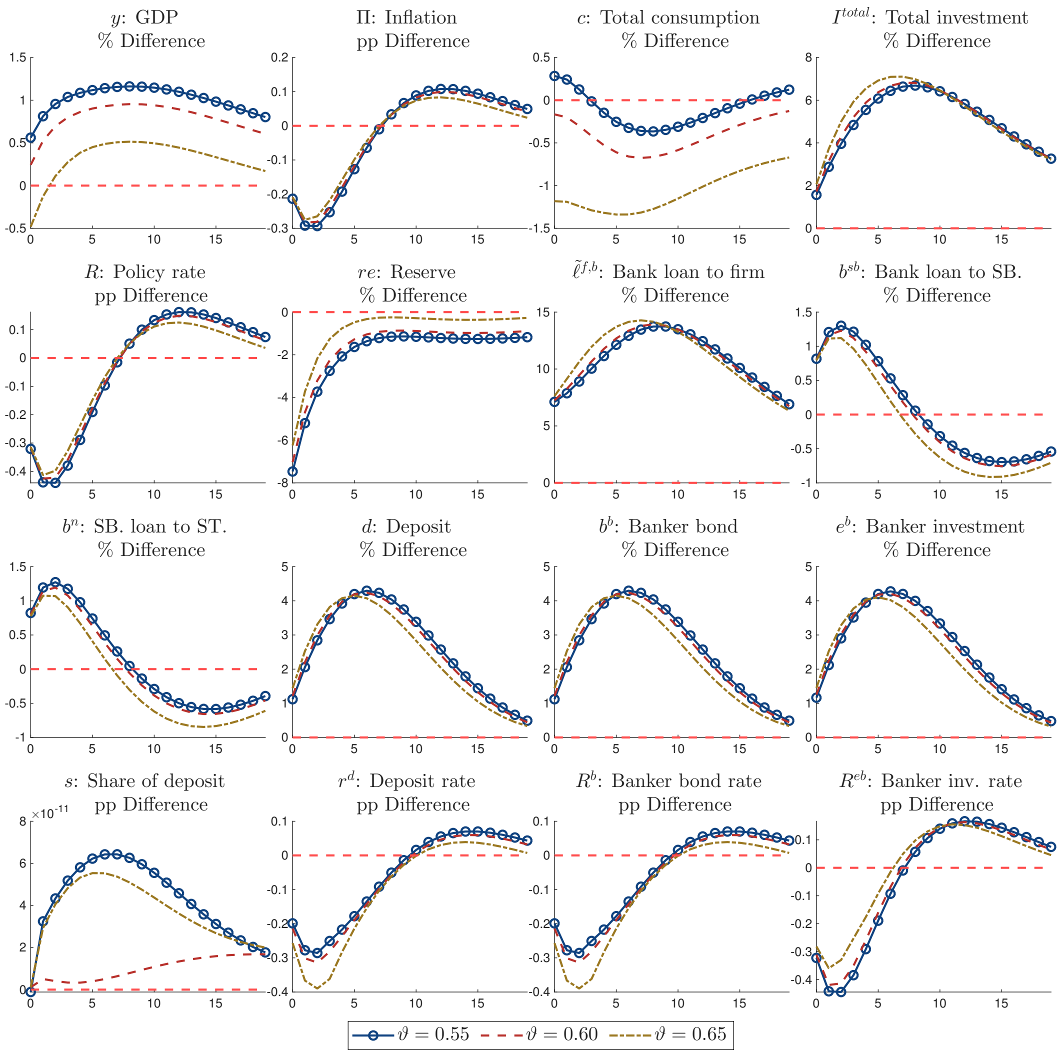

Figure 31: Technology shock 1

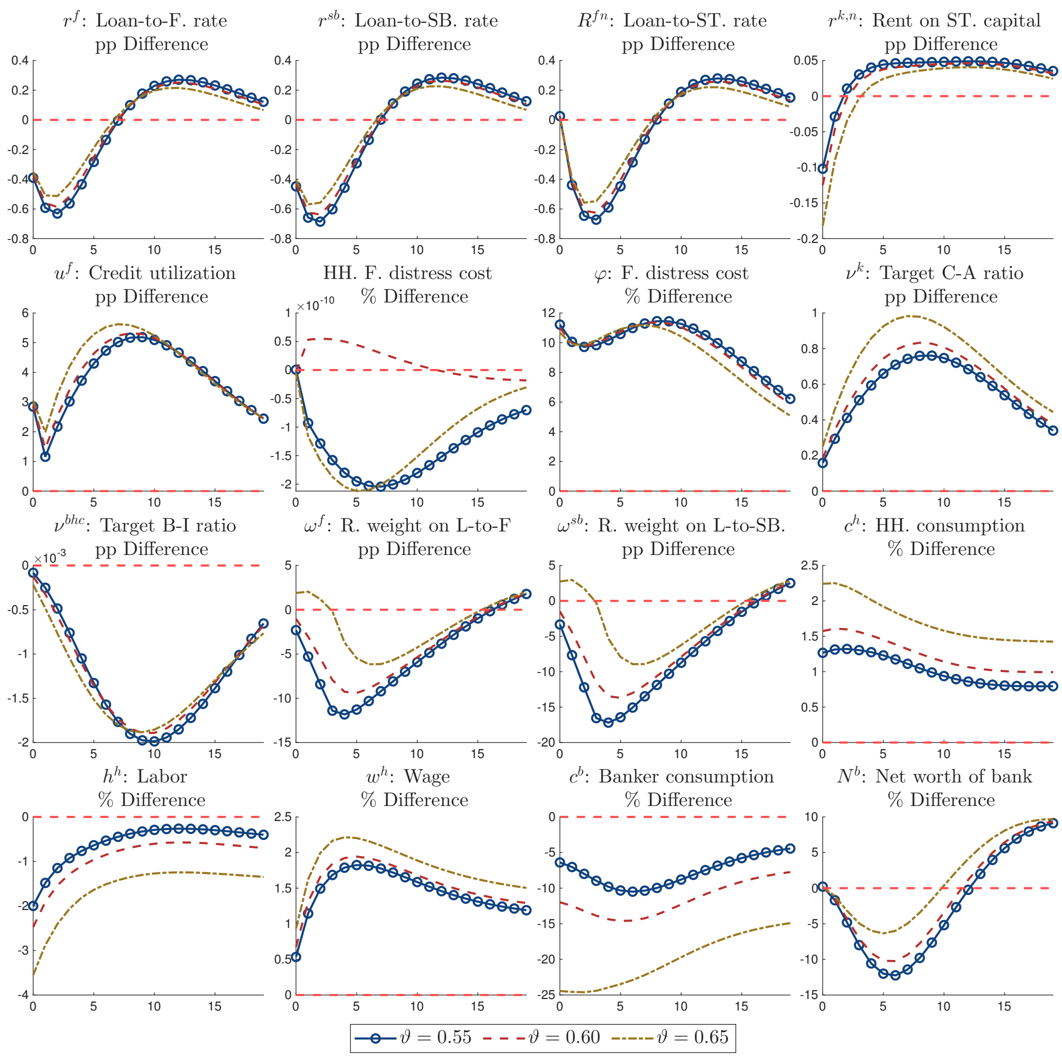

Figure 32: Technology shock 2

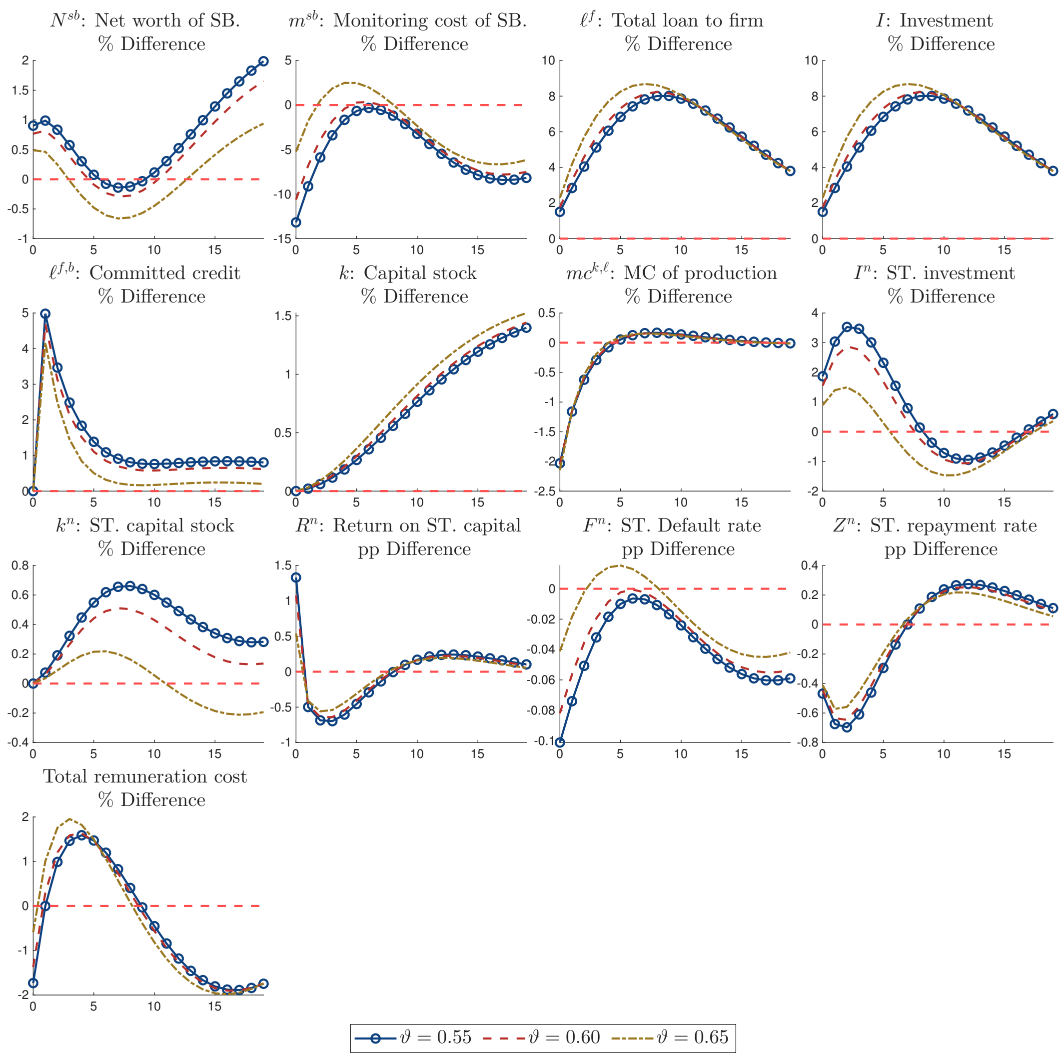

Figure 33: Technology shock 3

H.2 IRFs for Monetary Policy Shocks

The following figures present the impulse response functions (IRFs) for a positive shock to the policy rate.

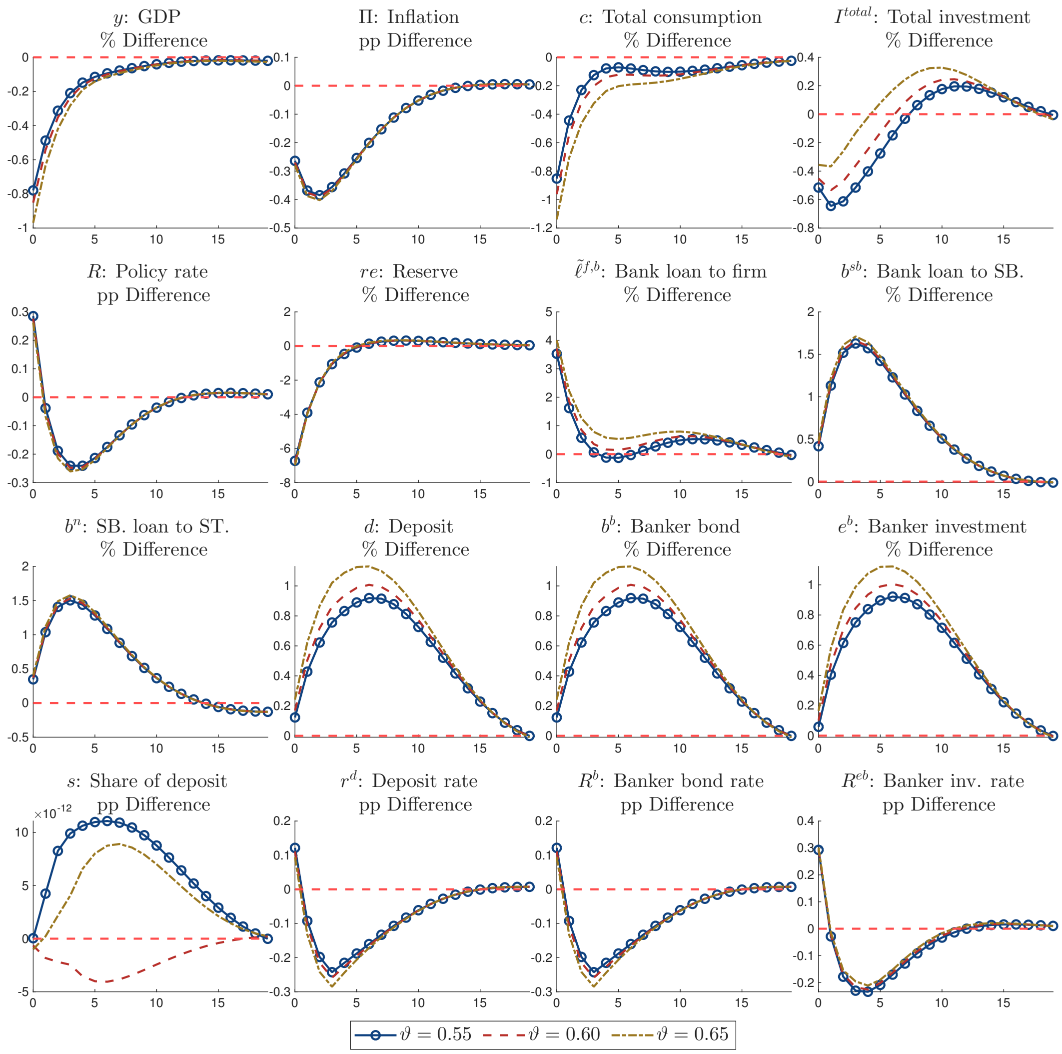

Figure 34: Monetary policy shock 1

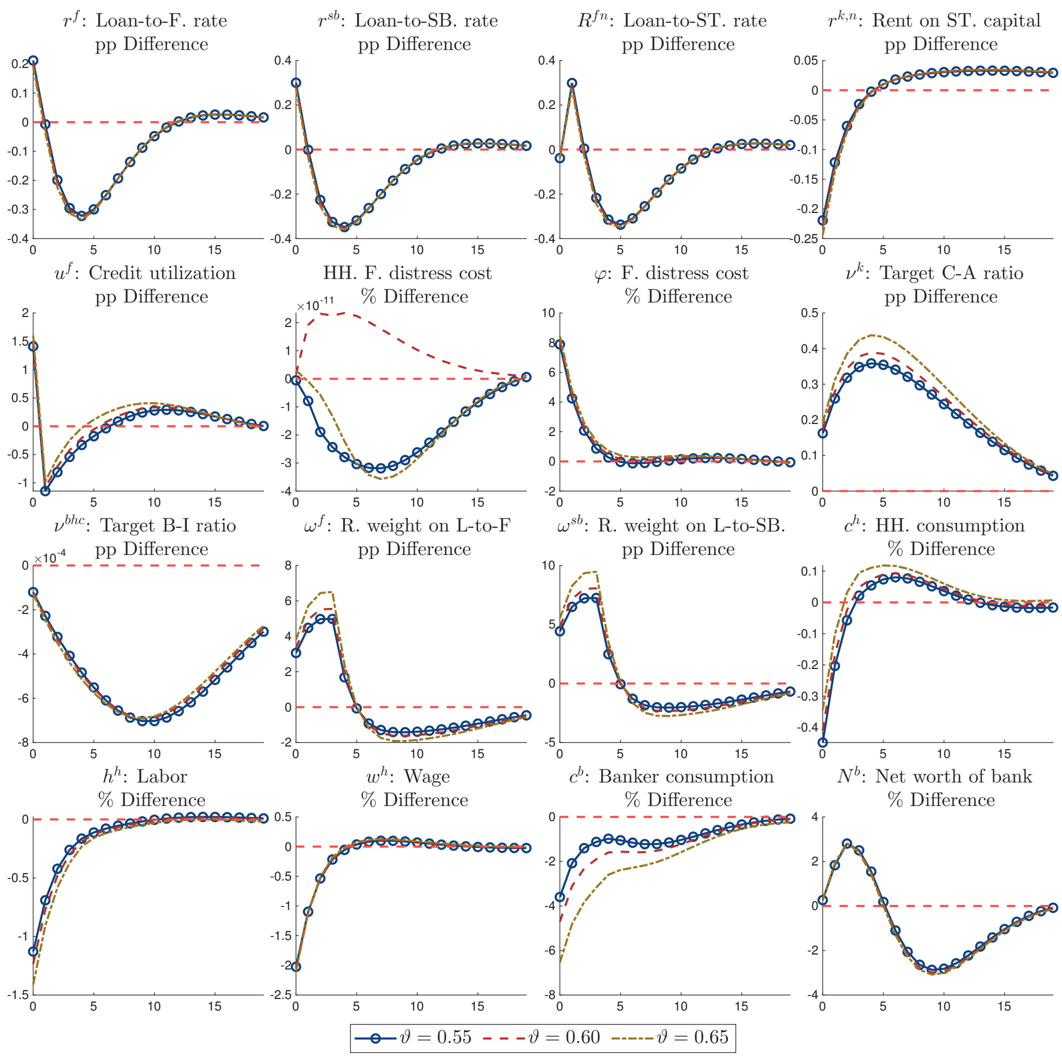

Figure 35: Monetary policy shock 2

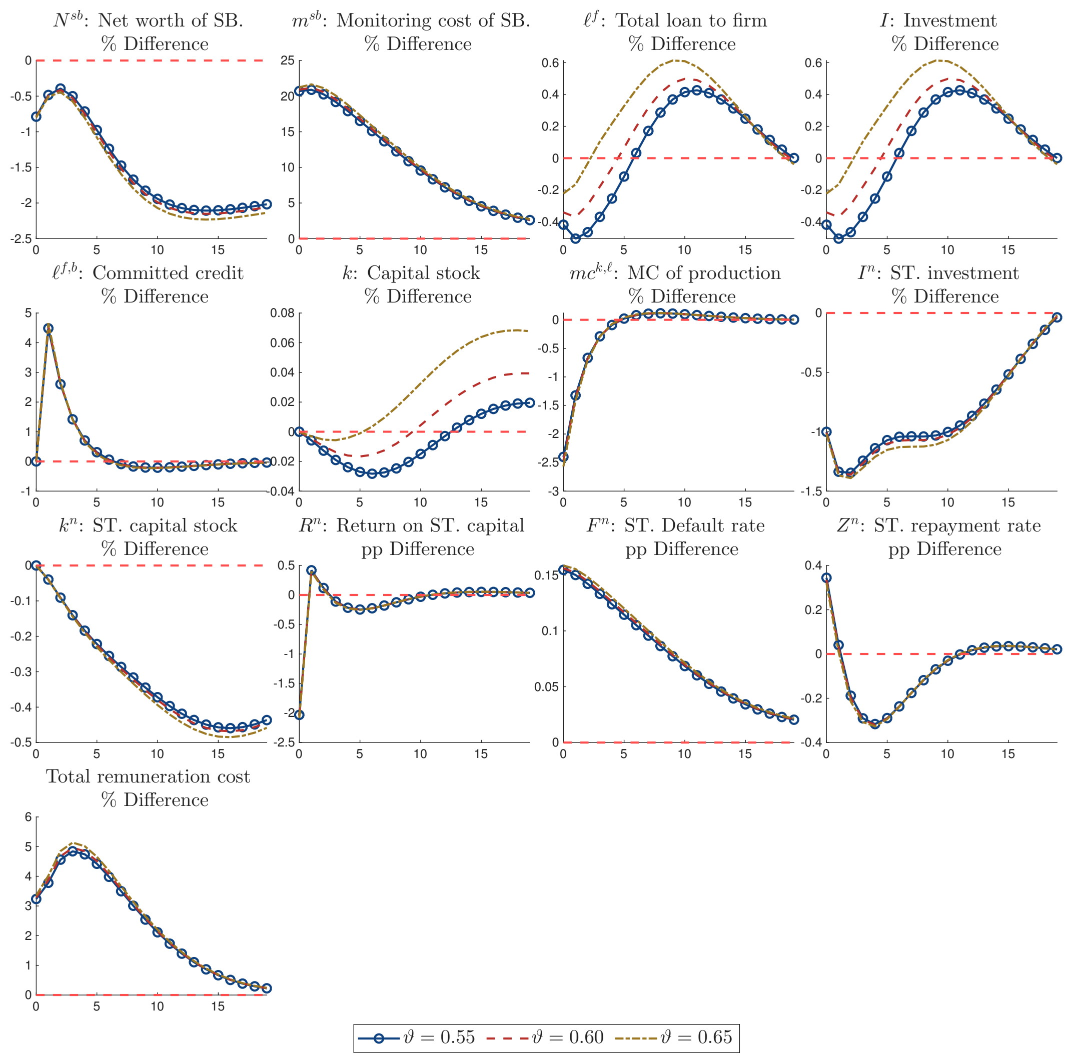

Figure 36: Monetary policy shock 3

H.3 IRFs for Asset purchase policy Shocks

The following figures present the impulse response functions (IRFs) for a positive shock to the asset purchase policy.

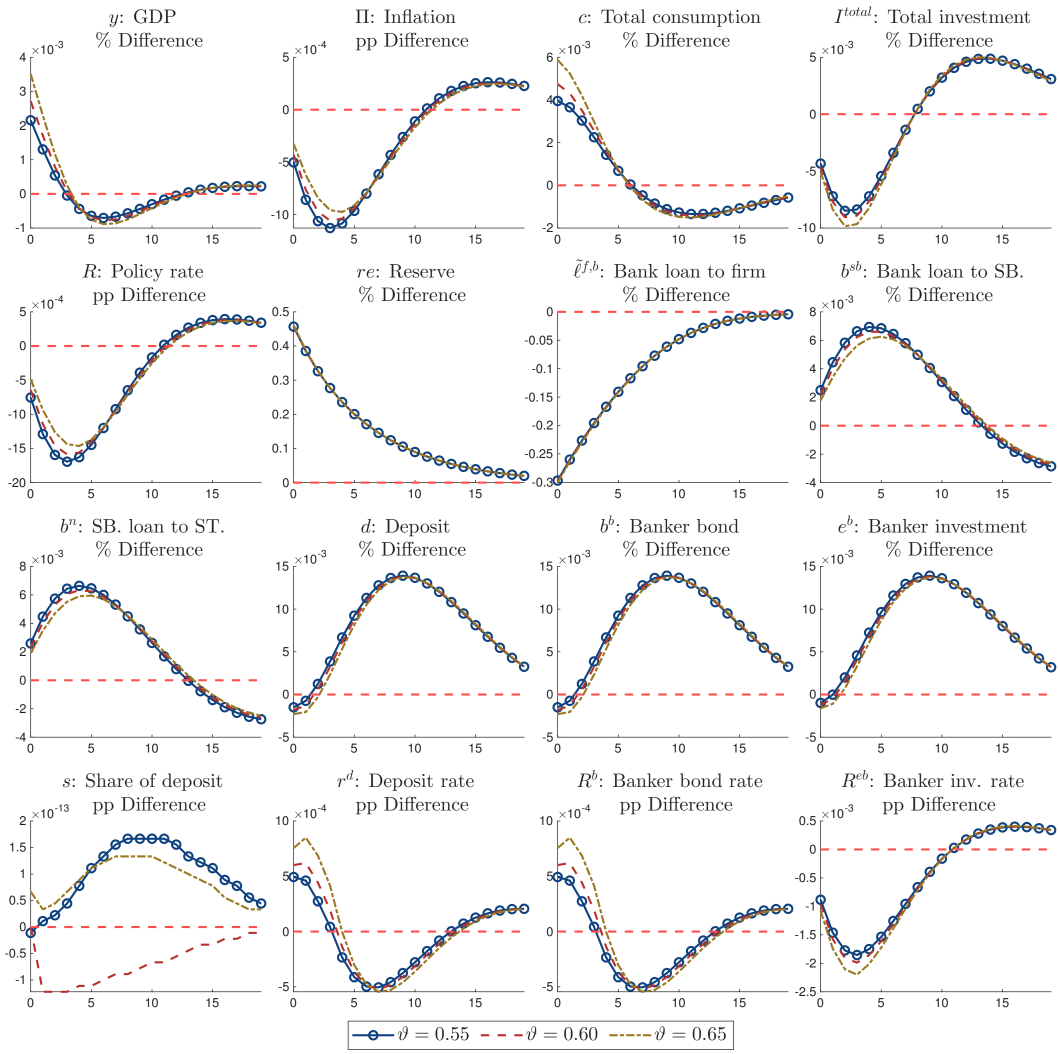

Figure 37: Asset purchase policy shock 1

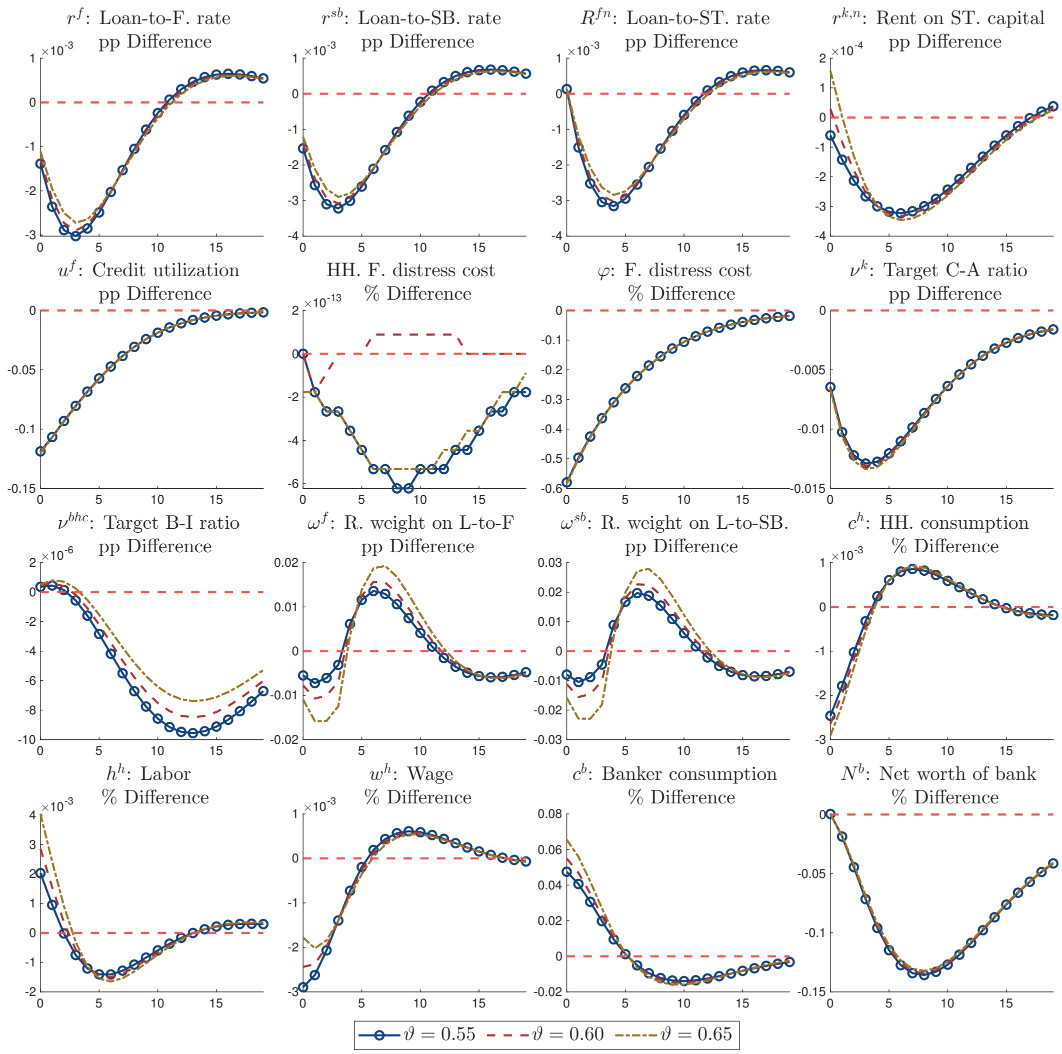

Figure 38: Asset purchase policy shock 2

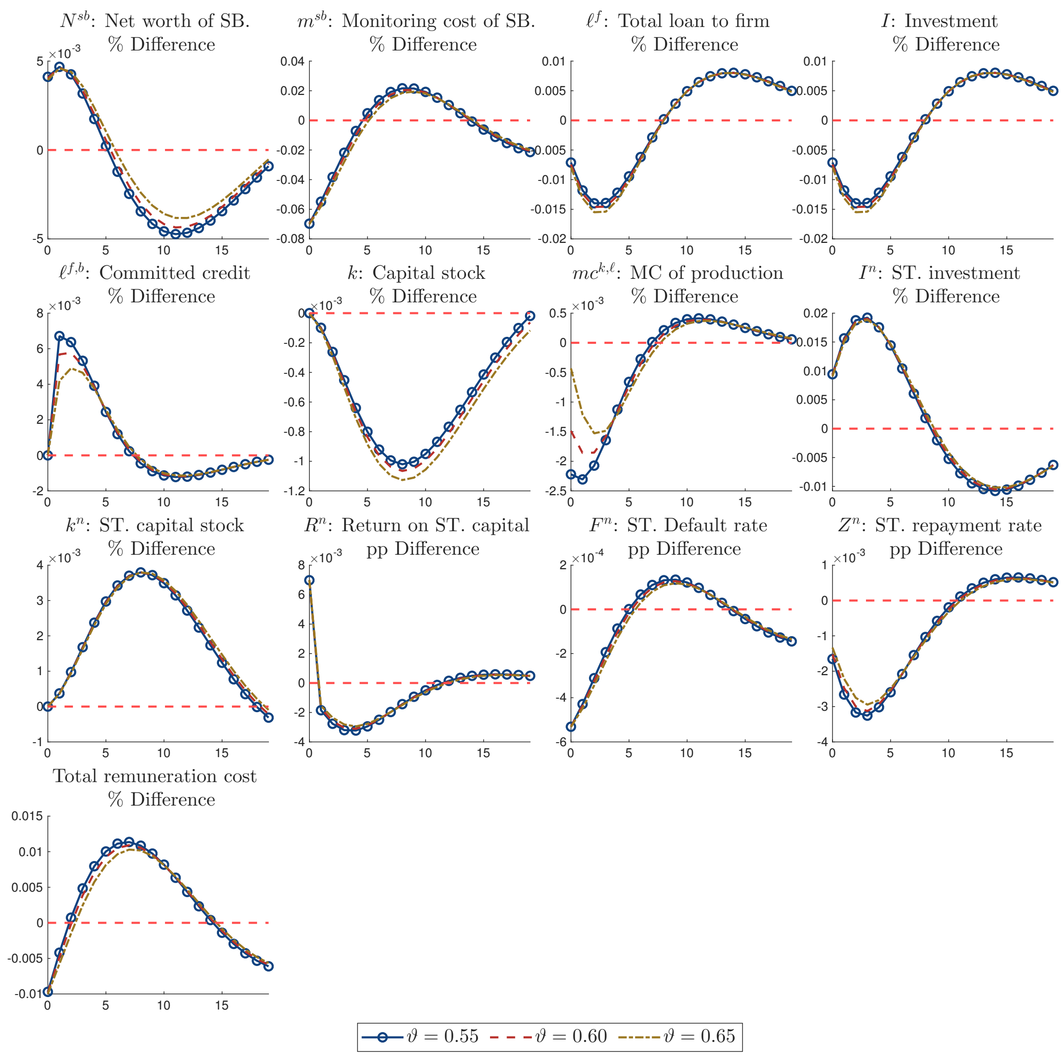

Figure 39: Asset purchase policy shock 3

H.4 IRFs for Credit Limit Shocks

The following figures present the impulse response functions (IRFs) for a positive shock to the credit line commitment.

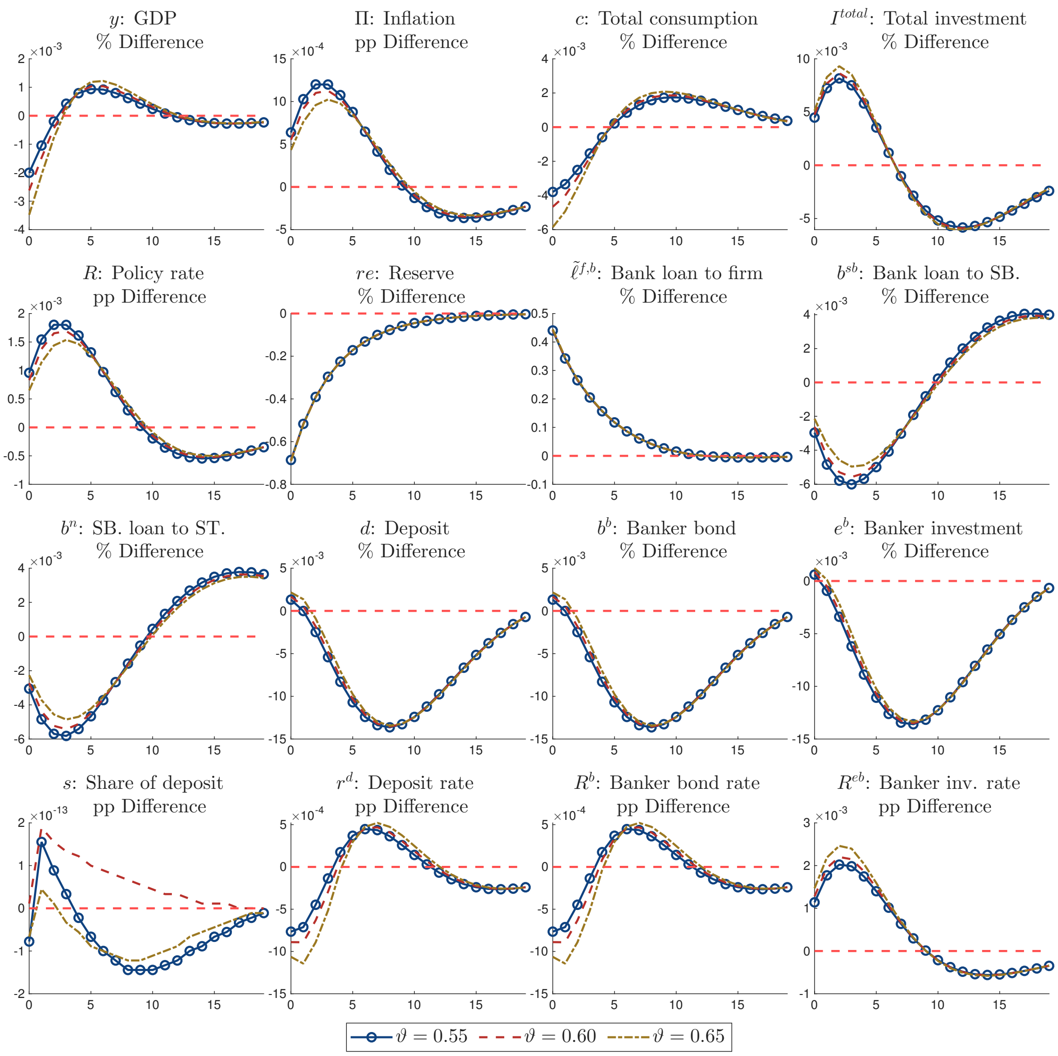

Figure 40: Credit limit shock 1

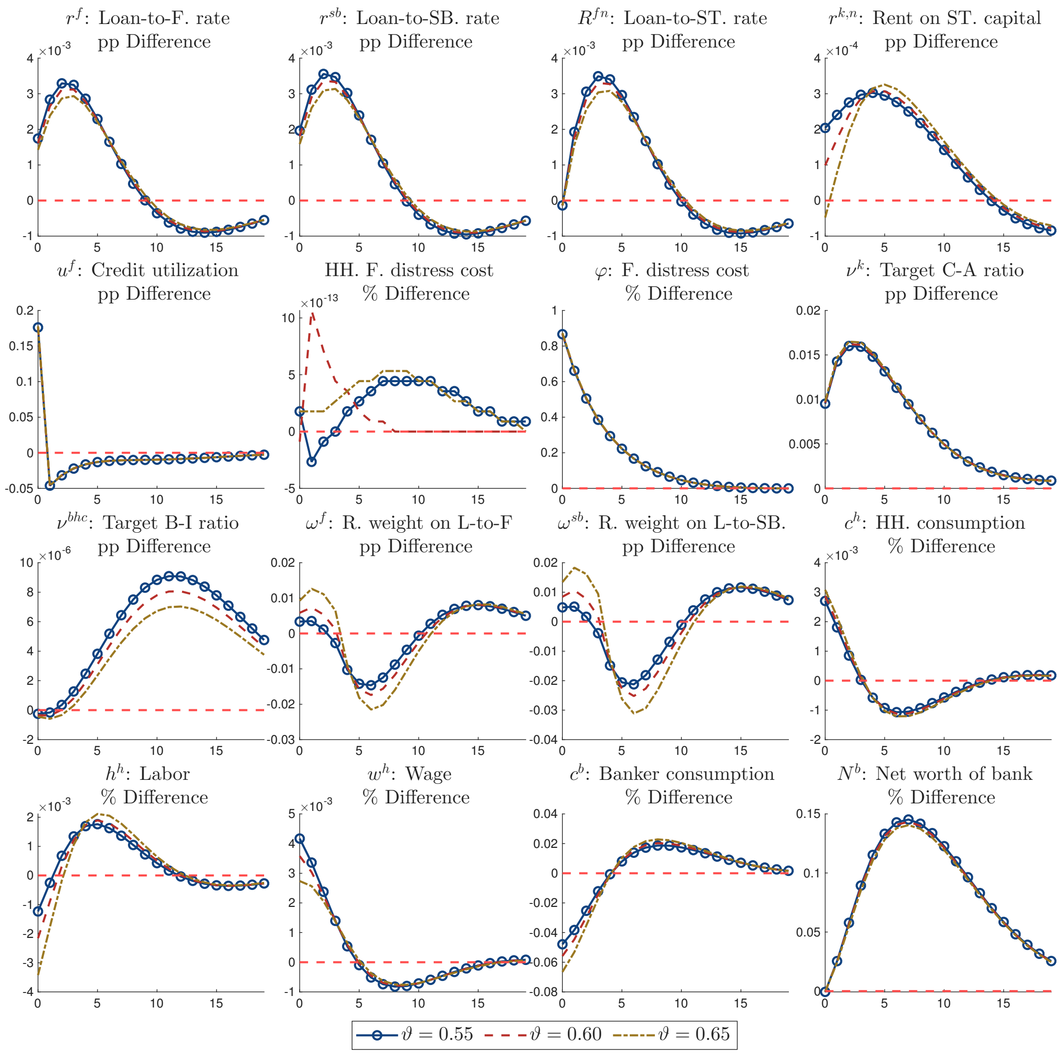

Figure 41: Credit limit shock 2

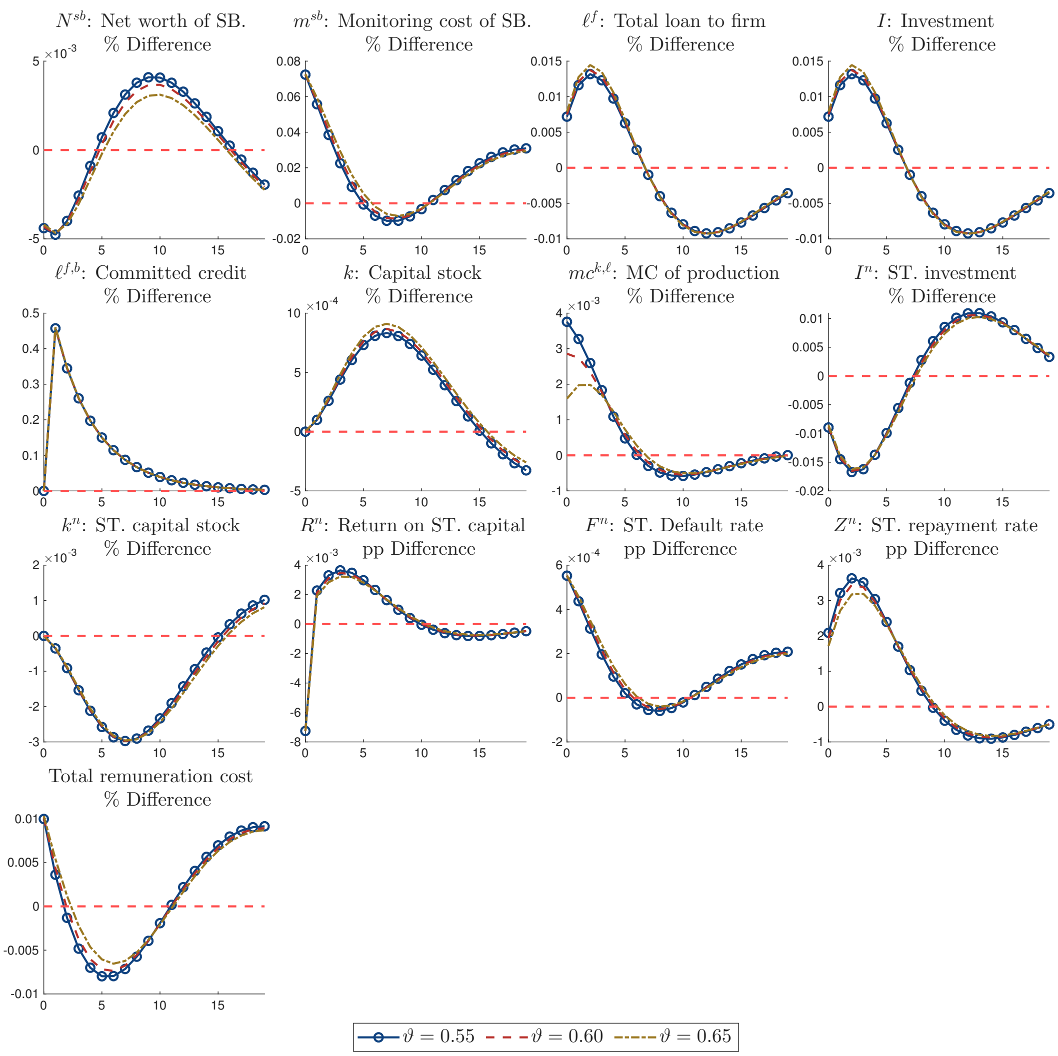

Figure 42: Credit limit shock 3

H.5 IRFs for Return Shocks

The following figures present the impulse response functions (IRFs) for a positive shock to the startups' return.

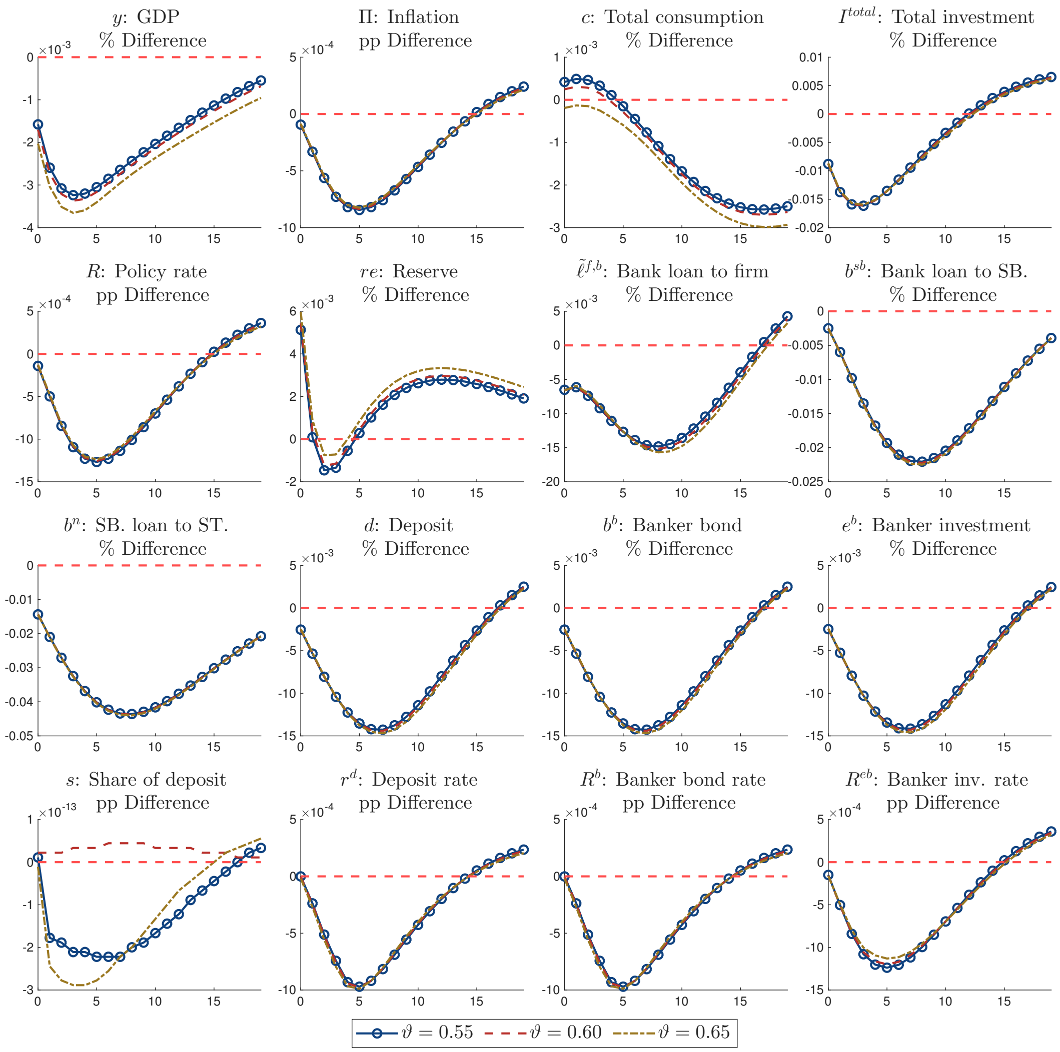

Figure 43: Return shock 1

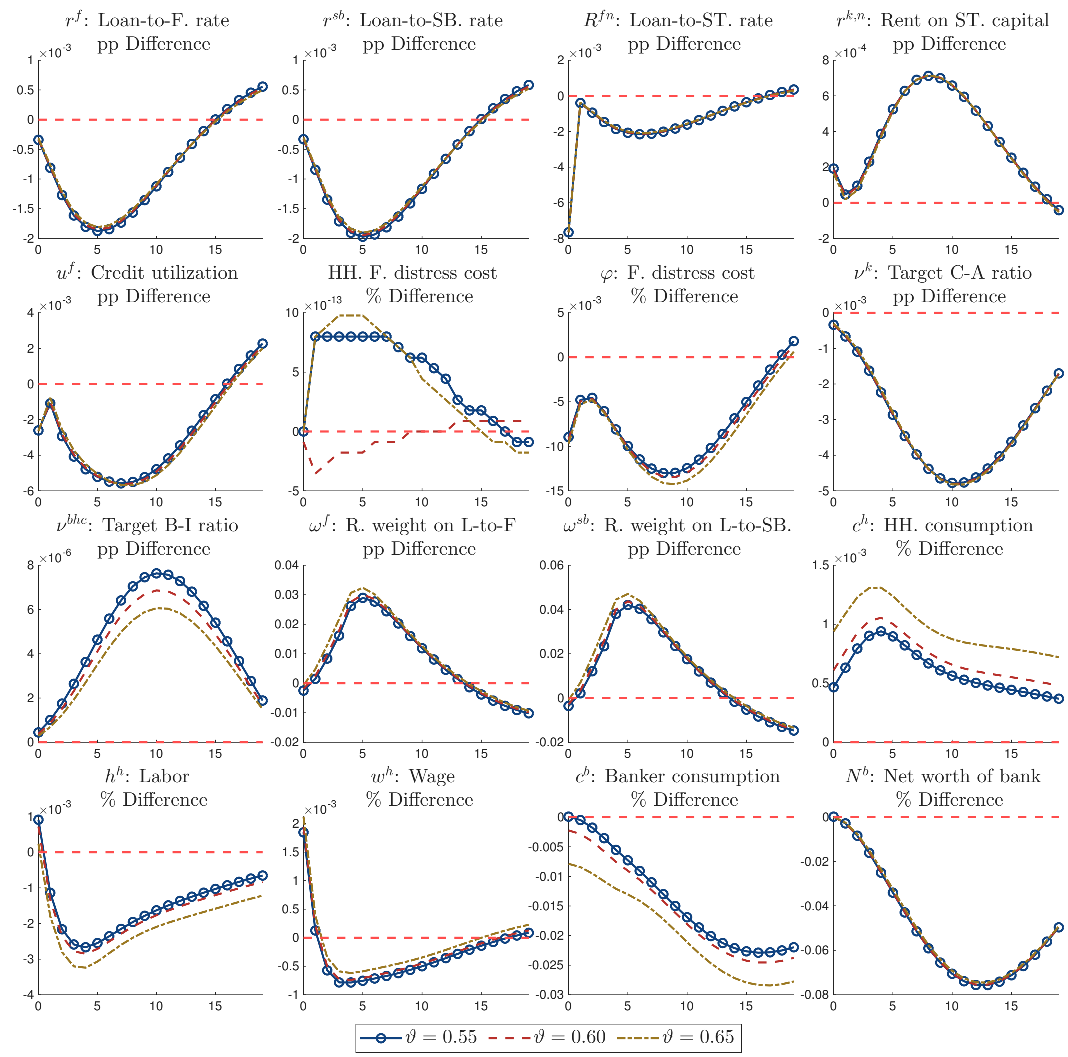

Figure 44: Return shock 2

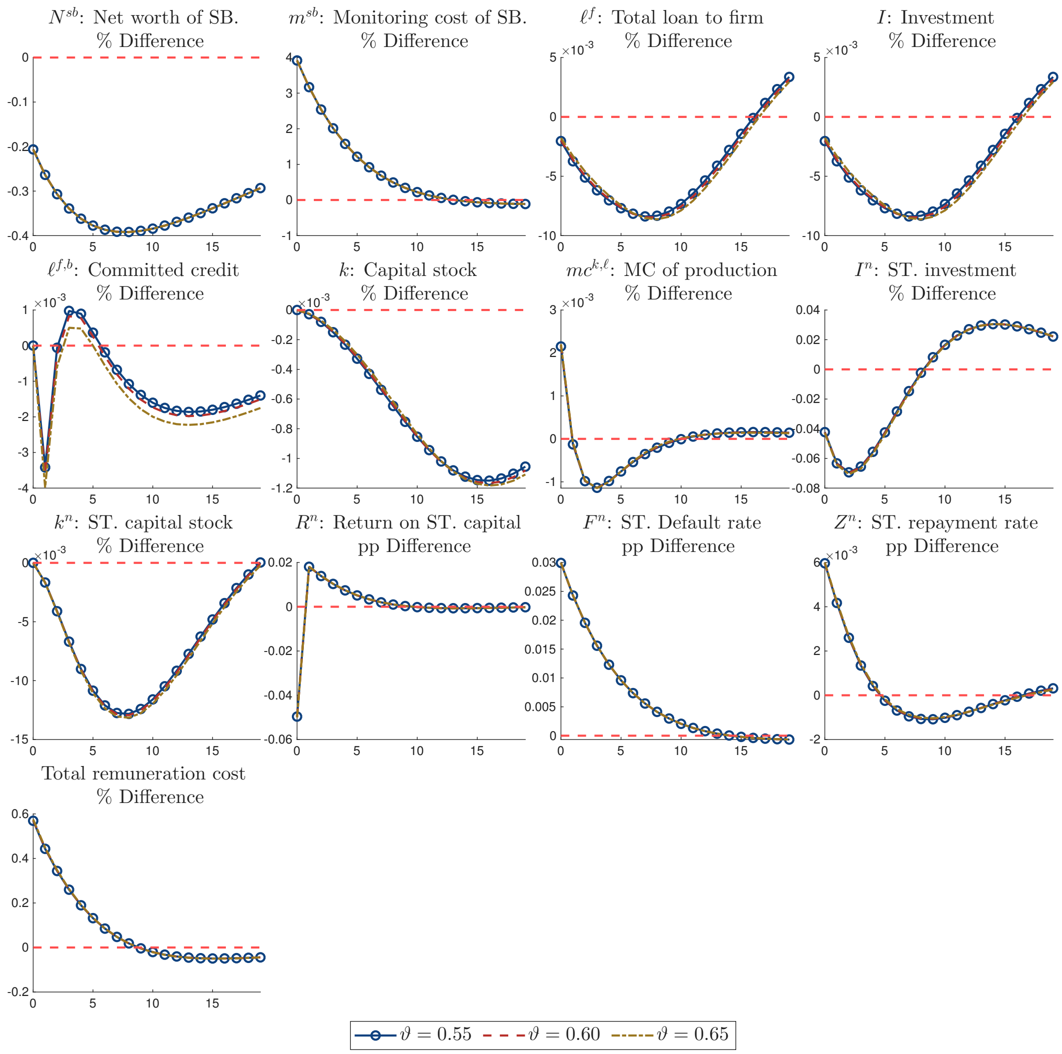

Figure 45: Return shock 3

H.6 IRFs for Debt-Investment Shocks

The following figures present the impulse response functions (IRFs) for a positive shock to the intermediate good producers' debt-investment multiplier.

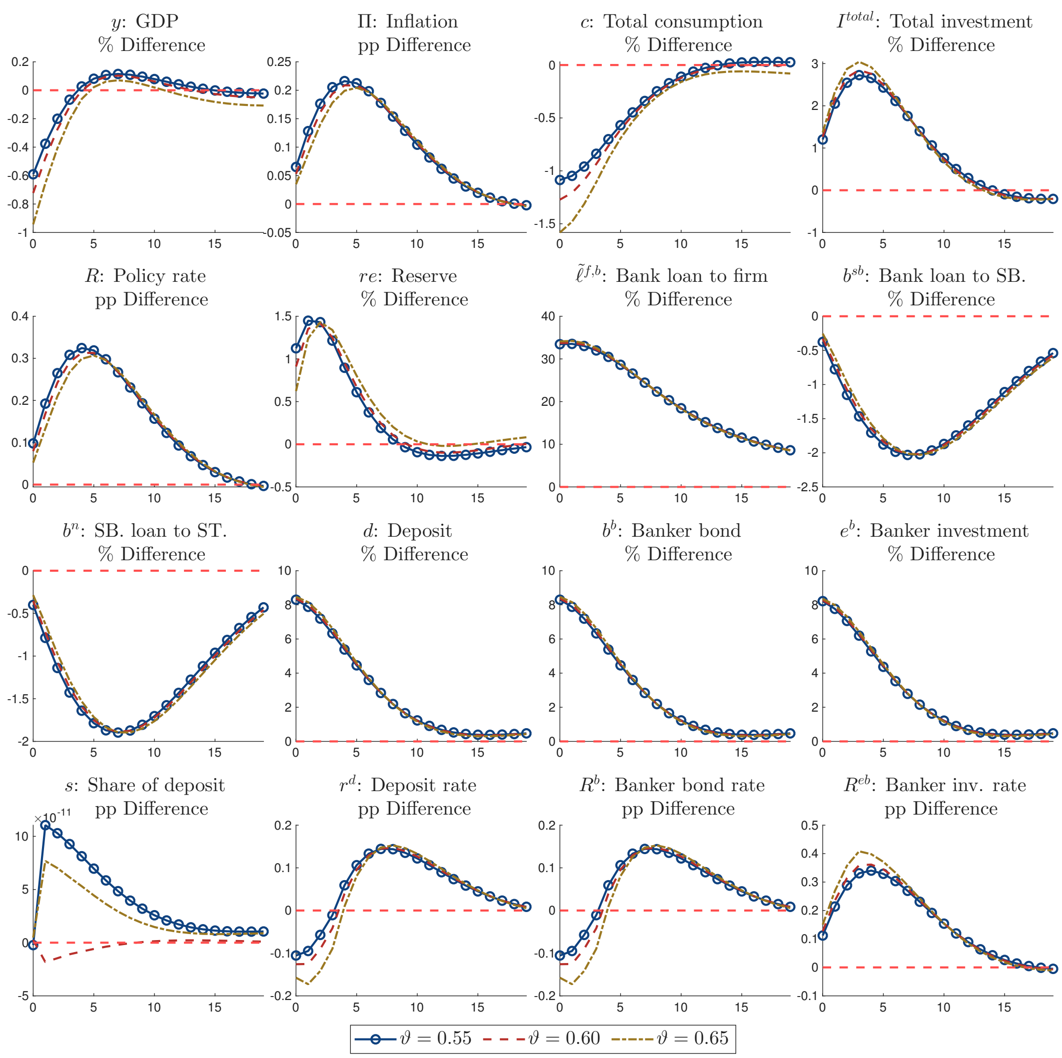

Figure 46: Debt-investment shock 1

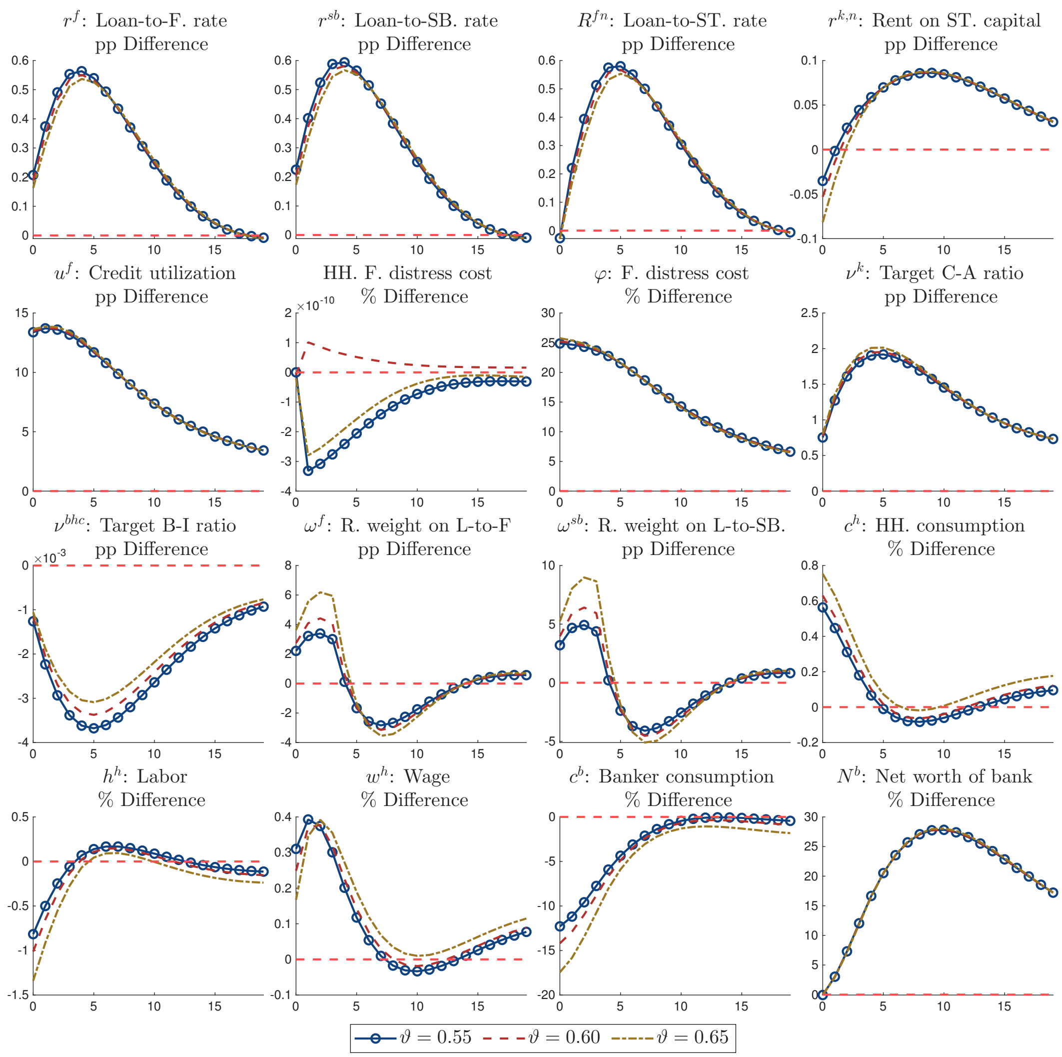

Figure 47: Debt-investment shock 2

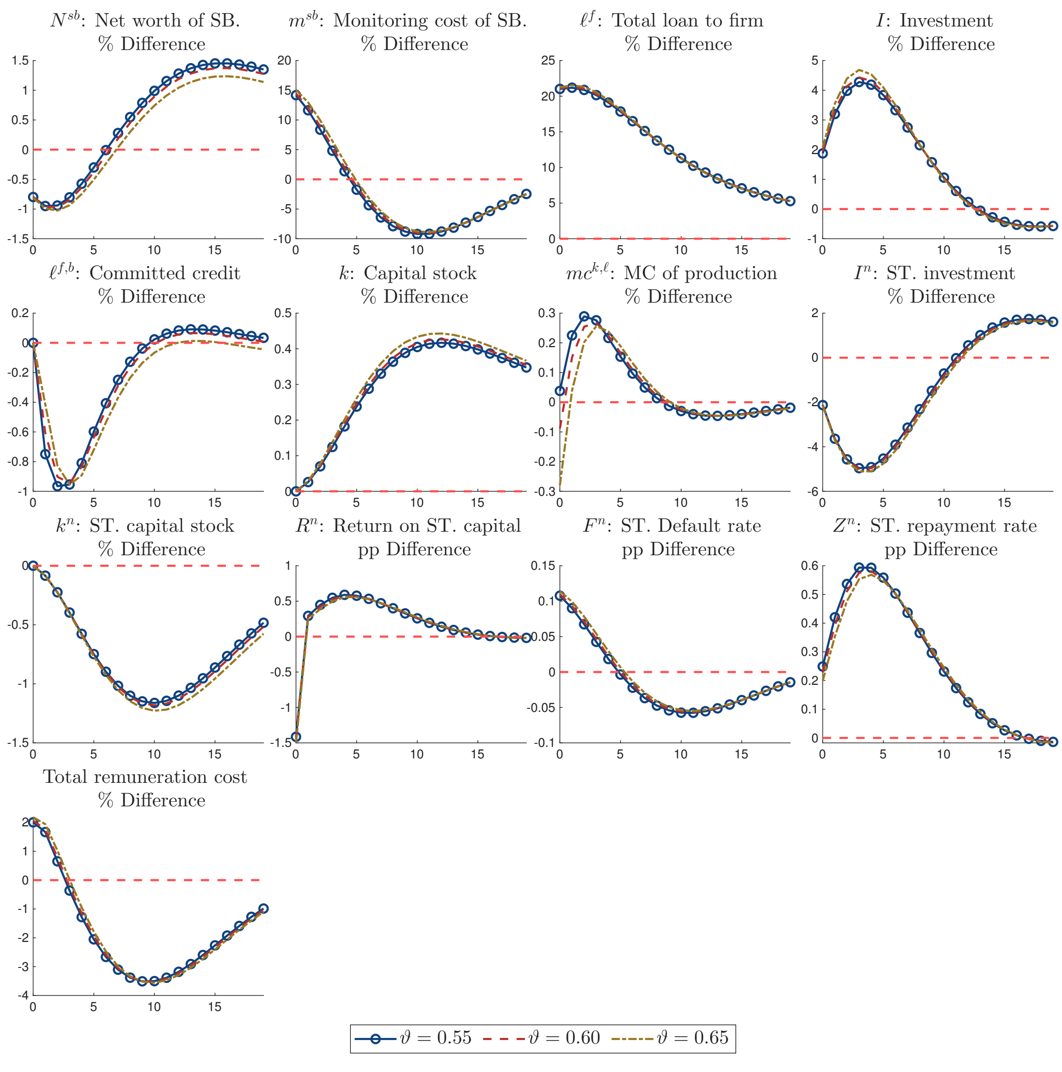

Figure 48: Debt-investment shock 3

H.7 IRFs for Financial Distress Shocks

The following figures present the impulse response functions (IRFs) for a negative shock to the household financial distress cost.

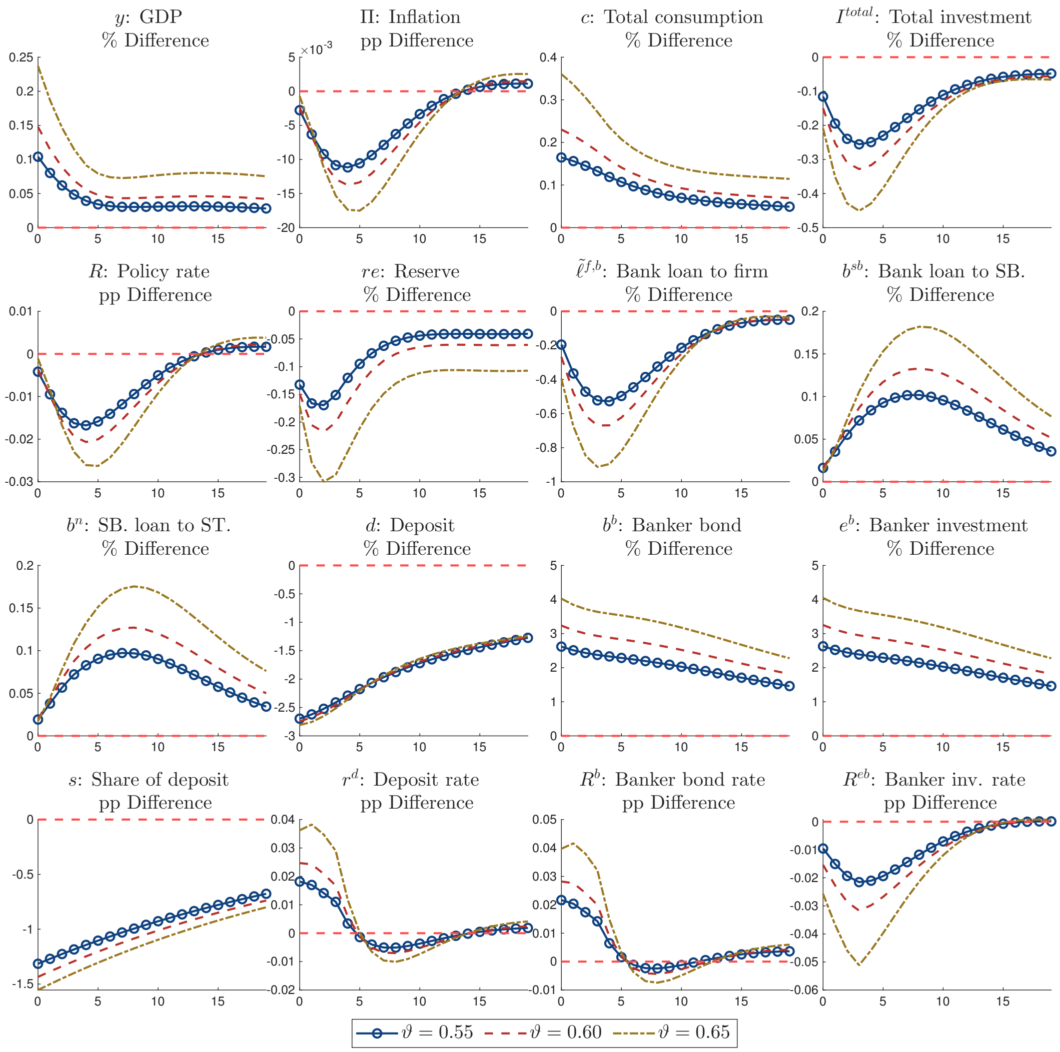

Figure 49: Financial distress shock 1

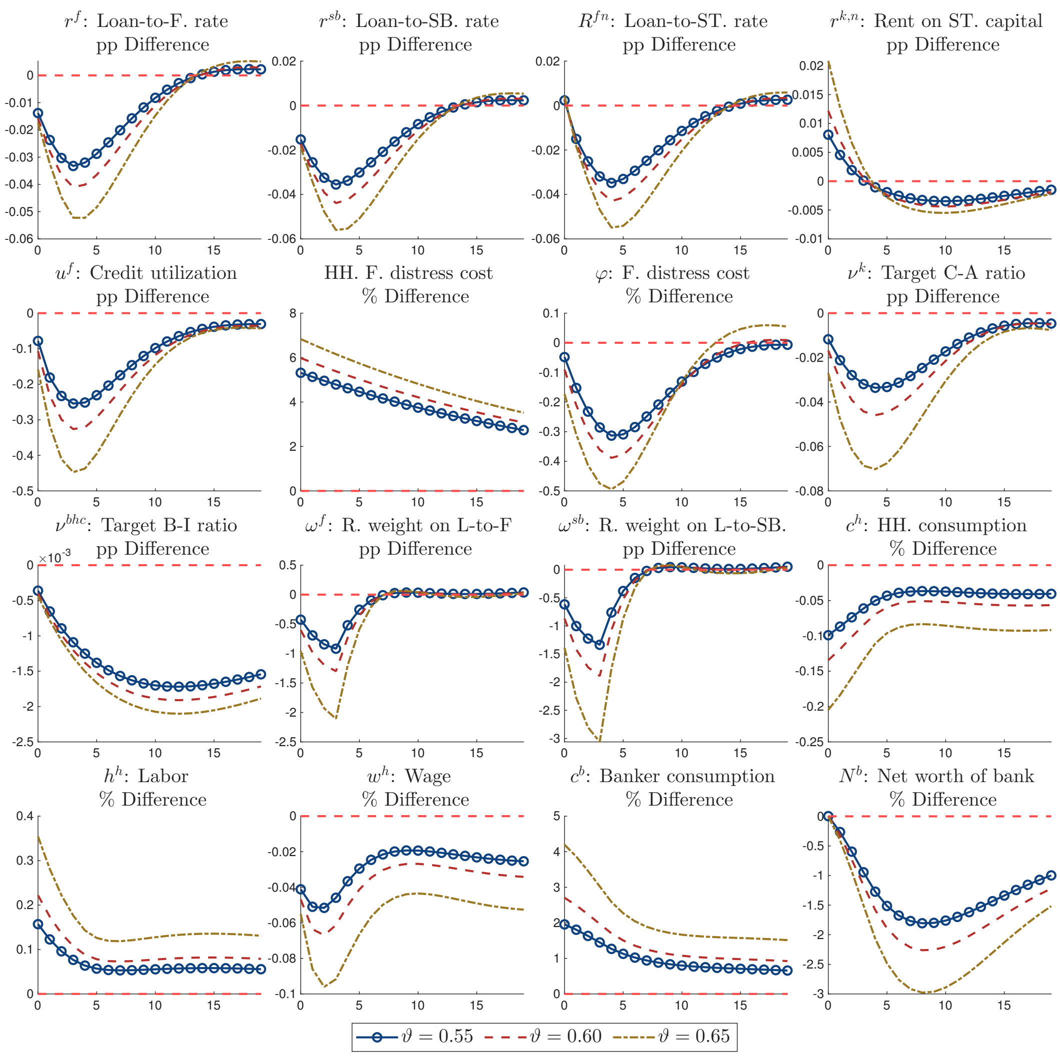

Figure 50: Financial distress shock 2

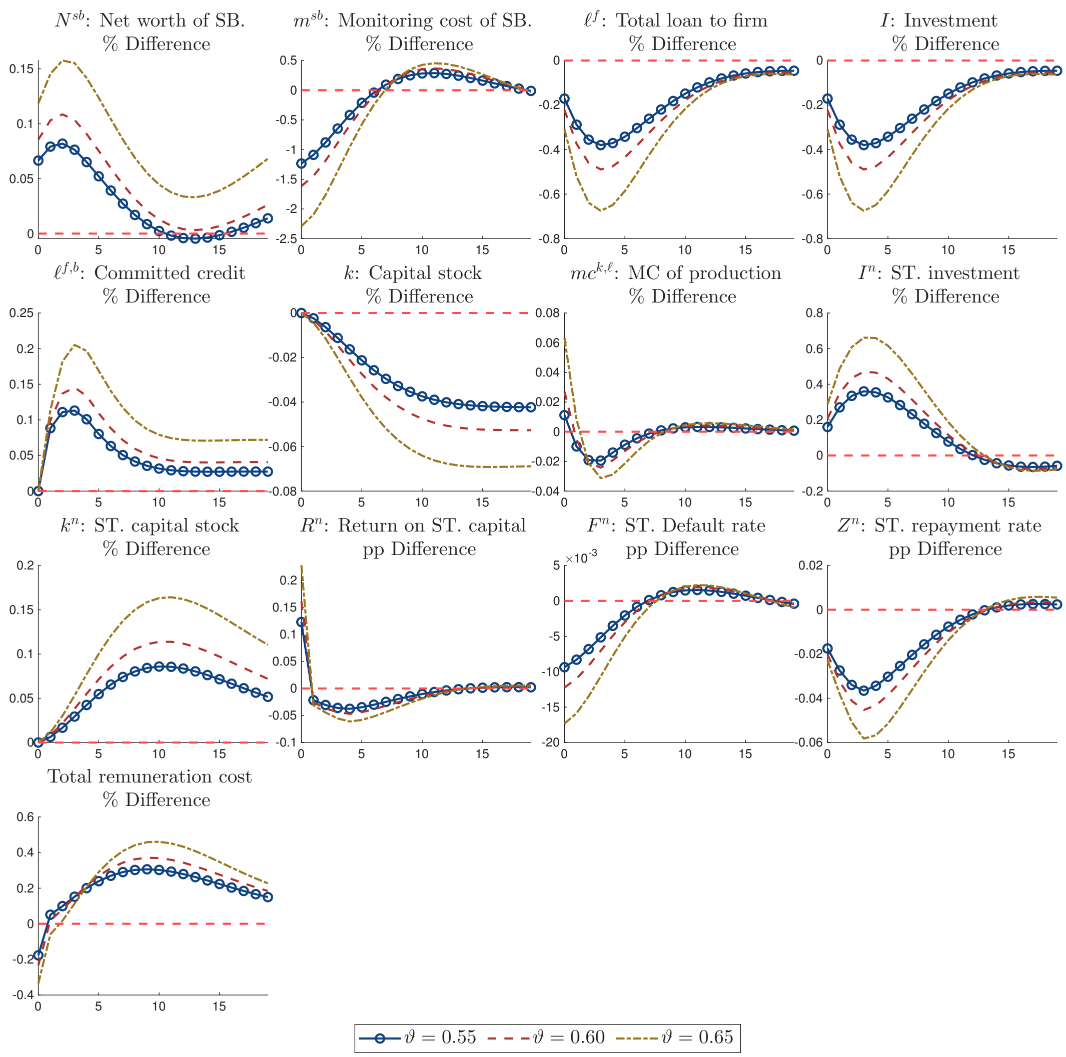

Figure 51: Financial distress shock 3