Banks' Maturity Choices and the Transmission of Interest-Rate Risk*

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Abstract

This paper develops a quantitative heterogeneous-bank model to study how interest-rate risk transmits through the financial sector. Banks optimally choose their leverage and maturity structure in the presence of limited equity issuance, default risk, and partial deposit insurance. Long-maturity assets carry a premium because they expose banks to valuation losses when interest rates rise. To preserve their franchise value, banks with low net worth relative to risky assets take on less interest-rate risk, despite the presence of risk-shifting incentives associated with deposit insurance. Applying the model to the 2022–2023 monetary tightening, I show that a rapid increase in interest rates can generate large declines in asset prices and equity values even though banks have access to short-term assets that provide insurance against interest-rate risk. Under the lens of the model a substantial share of the losses in 2022 was predictable, whereas the losses in 2023 were largely unexpected. A shift toward long-term assets during a period of unusually low rates amplified the initial tightening, but a rebalancing toward shorter maturities dampened the transmission of later hikes.

Keywords: Interest-rate risk, heterogeneous banks, aggregate uncertainty, maturity mismatch, leverage.

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1. Introduction

Financial intermediaries play a crucial role in the economy by providing long-term credit funded with short-term, callable liabilities. This process, known as maturity transformation, earns banks a premium but it also exposes them to monetary policy. Due to the mismatch between the maturity of assets and liabilities, unexpected increases in interest rates can result in balance-sheet losses, potentially disrupting financial intermediation. Banks' exposure to interest-rate risk gained renewed attention with the monetary tightening of 2022-2023. The rapid sequence of policy hikes caused sharp declines in the value of long-term assets, culminating in a number of bank failures, exemplified by the case of the Silicon Valley Bank (SVB). These recent events challenged the view that banks are immune to interest-rate risk, and sparked interest in reassessing the role of the financial sector in the transmission of monetary policy.

In this paper, I provide a quantitative framework to study the propagation of interest-rate shocks through the balance sheets of financial intermediaries. I begin by developing a novel macro-finance model in which banks invest in assets of different maturities, subject to financial frictions. The economy features a short-term asset, that is risk-free, and a long-term asset that yields higher average returns but makes bank networth sensitive to changes in interest rates. A key feature of the model is that the optimal portfolio allocation between these two assets depends on the bank's level of capitalization. Intermediaries with low networth relative to risky assets operate with higher leverage, demand a larger premium to hold long-term assets, and choose portfolios with shorter maturities. Shocks to the interest rate affect bank networth and trigger portfolio rebalancing across maturities. Specifically, the model predicts that a sudden increase in interest rates depresses the price of long-term asset, generate capital losses, and makes it optimal for banks—especially low-net-worth ones—to shift investment toward short-term assets.

Using bank-level regulatory data for the US and identified monetary policy shocks from the literature, I provide empirical evidence that supports these model predictions. I then conduct an application to the 2022–2023 tightening episode. I quantify the asset-price declines and bank equity losses during this period and use the model to compute the share of these losses that could have been anticipated given the information available at the time. Additionally, I assess the role of banks' portfolio adjustments across maturities both before and during the tightening episode. I find that the low interest rates in the two years leading up to the tightening induced banks to accumulate interest rate risk by increasing their exposure to long-term assets. However, portfolio adjustments following the first wave of policy rate hikes in 2022 partially shielded banks from the subsequent tightening in 2023.

The paper begins by laying out an economy populated by infinitely lived, heterogeneous banks that choose, in each period, the size and composition of their balance sheets as well as their leverage, subject to financial constraints. Agents face aggregate risk stemming from shocks to the household's discount factor, which generate exogenous fluctuations in the real interest rate. Banks additionally face idiosyncratic shocks, making them ex post heterogeneous. The model builds on two key features. First, banks can invest in two types of assets: short-term government bonds and long-term financial securities issued by non-financial firms and backed by the physical capital stock, as in Gertler and Karadi (2011). The price of the long-term asset is endogenous and moves inversely with the level of the interest rate. As a result, investing in long-term securities induces a duration mismatch between assets and liabilities, exposing banks to interest rates through fluctuations in long-term asset prices. Relative to models with only long-term claims, the availability of a short-term safe asset enhances banks' ability to self-insure against aggregate and idiosyncratic risk, allowing them to reduce their interest-rate-risk exposure without scaling down their balance sheets.

The second key feature is that banks face financial constraints and value long-term assets not only based on their expected excess returns relative to short-term bonds but also on the covariance between those returns and the shadow value of networth. This covariance generates a bank-specific intermediation premium. Balance-sheet frictions arise because banks cannot issue new equity and must rely on retained earnings and household deposits to finance investment. In addition, banks lack commitment and can default on their obligations. I allow bank debt to be partially insured by the government, which gives rise to risk-shifting incentives in addition to default risk. I show that in the model banks that are closer to default choose portfolios that are less exposed to interest-rate risk, contrary to what would be expected under risk-shifting behavior. This suggests that risk-mitigating incentives dominate, as low-net-worth banks seek to preserve their franchise value rather than gamble on the higher upside of long-term assets under limited liability.

A key mechanism of the model is that changes in interest rates affect banks' portfolio choices not only through variations in expected excess returns but also through their impact on bank networth and intermediation premia. When the economy experiences a sudden increase in interest rates, asset prices decline and bank networth deteriorates. The resulting capital losses tighten balance sheet constraints, making banks more averse to taking on aggregate and idiosyncratic risk. Consequently, banks shift toward short-term assets and reduce long-term lending to non-financial firms. The effects of an interest rate shock on bank networth and investment are further amplified by a financial accelerator mechanism: the initial decline in investment lowers the price of long-term assets, and the resulting fall in asset values generates additional balance-sheet losses, forcing banks to cut investment further and reinforcing the downward adjustment in asset prices.

To understand whether empirical evidence supports the prediction of the model, I conduct an empirical analysis based on bank-level data from the Reports of Condition and Income, also known as Call Reports. The advantage of this data is that it includes information on the composition of assets and liabilities by maturity, allowing me to compute a bank's maturity gap following English *et al.* (2018). I first document a negative cross-sectional relationship between the deposit-to-asset ratio and the maturity gap, suggesting that banks with higher deposit funding tend to invest in shorter-maturity portfolios. I then exploit identified monetary policy shocks to study how banks adjust their maturity profile following an unexpected increase in interest rates, and how these responses vary across banks with different balance-sheet conditions. Using local projections in the spirit of Jorda (2005), I find that the effect of a surprise increase in interest rates on the maturity gap is negative on average, and larger in magnitude for banks with higher deposit-to-asset ratios at the time of the shock.

With supporting evidence at hand, I calibrate the quantitative model at the annual frequency to match key banking moments, including the average maturity gap and its cross-sectional standard deviation. I solve for the competitive equilibrium under aggregate uncertainty using global methods, implementing a numerical algorithm in the spirit of Krusell and Smith (1998). Consistent with the empirical evidence, the model predicts that more leveraged banks choose portfolios with shorter maturities. In addition, the model reproduces the untargeted negative response of banks' maturity gaps to an unexpected increase in interest rates — as well as the observed heterogeneity in this response. Following the shock, banks reduce their maturity gaps and, as in the data, this portfolio rebalancing toward short-term assets is more pronounced for banks with higher deposit-to-asset ratios, which face tighter balance-sheet constraints.

In the final part of the paper, I apply the model to the 2022–2023 hiking cycle, which had significant repercussions for the U.S financial sector. The exercise consists of feeding into the model the sequence of aggregate shocks that replicates the historical path of the long-term real interest rate from 1997 to 2023, and then tracking the dynamics of aggregate variables over this period — with particular attention to the recent tightening episode. The model generates a cumulative decline in asset prices of approximately 5% between 2020 and 2023 and losses in bank equity values of around 10%, consistent with empirical evidence. Given the large losses predicted by the model, I then ask what share of these losses would have occurred if interest rates in 2022 and 2023 had followed the expected path implied by the information available at the time. I find that a large share of the losses in 2022—around 43% for asset prices and 33%

for market equity—was predictable, whereas only about 18% of the losses that materialized in 2023 could have been anticipated given the information available at the beginning of that year.

In terms of portfolio adjustments, the model predicts an increase in the average maturity gap in the two years preceding the tightening, driven by an extraordinarily accommodative monetary policy in the wake of the COVID-19 pandemic. This is consistent with the narrative that a period of unusually low interest rates led financial intermediaries to take on greater interest-rate risk. After the initial rate increases, however, banks in the model rebalance their portfolios and substantially reduce their maturity gaps, shielding their balance sheets from further hikes. To assess the quantitative importance of these portfolio adjustments, I compare the baseline results with two alternative model specifications: one in which banks have access only to long-term assets, and another in which they can also hold short-term bonds but portfolio shares are fixed exogenously—both over time and across banks—at their baseline averages. In the model without short-term bonds, both the initial and subsequent declines in asset prices and equity values are substantially steeper, reflecting greater exposure to interest-rate fluctuations. Between 2020 and 2023, asset prices fall by nearly twice as much as in the baseline, and equity values by about 1.75 times more. In the fixed-share model, the initial drops are about 10% smaller than in the baseline, but the continued tightening leads to a cumulative decline in equity values that is 47% larger, as banks cannot rebalance their portfolios following the initial hike.

Lastly, I use the model to study whether liquidity requirements can mitigate aggregate fluctuations stemming from interest-rate risk. I consider a policy that mandates banks to maintain a minimum share of short-term assets in their portfolios. A tighter requirement reduces maturity gaps but also raises leverage, as banks comply by expanding their balance sheets rather than solely rebalancing their portfolios. Quantitatively, the policy dampens the transmission of interest-rate shocks to asset prices and bank equity values, consistent with a stabilization role for liquidity regulation. Importantly, these effects are heterogeneous across the distribution of bank networth: high–networth institutions are directly constrained and reduce their exposure to long-term assets while increasing leverage, whereas low–networth banks are not constrained and, facing more stable asset prices, instead shift their portfolios toward longer-maturity positions.

2. Literature Review

This paper contributes to an extensive line of work studying the role of financial frictions in the transmission of aggregate shocks. Starting with the seminal contributions by Kiyotaki and

Moore (1997) and Bernanke *et al.* (1999), the financial accelerator literature has highlighted the ability of models with balance-sheet constraints to generate substantial amplification of shocks. Motivated by the Great Financial Crisis, later contributions applied the financial accelerator logic to the financial sector (Gertler and Karadi (2011), He and Krishnamurthy (2013), Brunnermeier and Sannikov (2014) and Gertler and Kiyotaki (2015)). The focus of these papers, however, has been mostly on intermediary leverage.[1] I contribute to this literature by developing a framework where financial fragility arises from both leverage and maturity choices, providing a lens to understand intermediaries' risk exposure beyond leverage. Incorporating additional margins of risk-taking is crucial to understand the transmission of shocks through the financial sector, especially in a regulatory environment that heavily constrains leverage.

Second, this paper contributes to a large literature studying the interaction between banks and interest rates.[2] The closest paper in this regard is Di Tella and Kurlat (2021), who study optimal maturity mismatch in a frictionless economy where deposits provide liquidity services. In their model, banks optimally expose themselves to interest-rate risk because in periods of high interest rates they face better investment opportunities. Schneider (2023) extends Di Tella and Kurlat (2021) to account for a zero-lower bound on nominal interest rates. He shows that the presence of the ZLB reinforces banks' incentives to take up interest rate exposure in periods of loose monetary policy. Both papers consider a complete-markets setting where risk-taking is efficient. My key contribution to this literature is to embed an endogenous maturity choice in a model with financial frictions, bridging the work of Di Tella and Kurlat (2021) and Schneider (2023) with the financial accelerator literature. Like their framework, my model is able to generate a negative correlation between interest rates and maturity mismatch, as in the data. However, it does so through a feedback look between asset prices, balance-sheet constraints, and risk-premia. In addition my model features several inefficiencies that create scope for policy interventions.

Third, my paper contributes to a recent literature that incorporates heterogeneous financial intermediaries in quantitative general-equilibrium models. Coimbra and Rey (2023) develop a framework where intermediaries face heterogeneous VaRs constraints, reflecting differences in risk attitudes or in regulatory constraints. Jamilov and Monacelli (2023) study a model with both permanent and transitory heterogeneity to study the macroeconomic implications of imperfect competition in the banking sector. Bianchi and Bigio (2022) study monetary-policy transmission in a setting where banks experience idiosyncratic deposit withdrawals. I contribute

[1] Examples include Adrian and Shin (2014), Gorton and Ordoñez (2014), Nuño and Thomas (2017) and Morelli *et al.* (2022), among others.

[2] See, e.g., Dell'ariccia *et al.* (2017), Wu and Xia (2016), Drechsler *et al.* (2017), Drechsler *et al.* (2021), Whited *et al.* (2021), Wang *et al.* (2022), Wang (2022), Jermann and Xiang (2023) and Drechsler *et al.* (2025))

to this literature by developing a model that generates a distribution of maturity gaps, leading to heterogeneous exposures to interest-rate risk on the asset side of the balance sheet. I leverage this heterogeneity to validate the model against empirical cross-sectional patterns related to banks' maturity mismatch.

Fourth, this paper contributes to a strand of literature studying the effect of monetary policy on asset prices. Bernanke and Kuttner (2005) provide evidence of substantial effects of surprises rate changes on equity prices. Following their work, a large number of contributions have provided evidence that the values of long-term assets respond to monetary policy (Hanson and Stein (2015), Gertler and Karadi (2015), Gilchrist *et al.* (2015), Lagos and Zhang (2020), Bianchi *et al.* (2022) and Kekre and Lenel (2022)). I contribute to this literature by incorporating the link between asset-price dynamics and interest rates into a quantitative model where banks choose endogenously the exposure of their balance sheets to asset-price fluctuations. Related to this paper is also a literature that emphasizes the role of risk premia for bank risk-taking and the transmission of monetary policy. Martinez-Miera and Repullo (2017) study an economy in which low interest rates shift activity toward non-monitoring banks, generating endogenous boom–bust cycles and countercyclical risk premia. Kekre *et al.* (2025) develop a segmented-markets model in which an unexpected short-rate hike reduces the wealth of arbitrageurs with positive duration gaps, leading—through this channel—to an increase in term premia.

Finally, the paper contributes to a recent literature studying the macroeconomics effects and welfare implications of bank regulation. Most related to my paper is work by Begenau (2020), Corbae and D'Erasmo (2021) and Begenau and Landvoigt (2022), who study optimal capital requirements in quantitative models of the financial sector. I contribute to this literature by studying the effects of banking policies in a model where the portfolio composition is endogenous.

The rest of the paper is organized as follows. Section 3 lays out the model, and Section 4 discusses its key mechanisms and defines the equilibrium. Section 5 presents supporting empirical evidence. Section 6 describes the model calibration, validates it against untargeted moments, and studies its aggregate implications, including an application to the 2022–2023 tightening episode. Section 7 concludes.

3. Model

I consider a discrete-time, infinite-horizon economy populated by a representative household, a set of heterogeneous non-financial firms and banks, a representative final good producer, a representative capital good producer and a government. Banks are the focus of the model. They can invest in short-term government bonds and long-term securities issued by non-financial firms. Banks cannot issue equity and finance investment using own networth and borrowing from households subject to endogenous default risk.

3.1. Households

The economy features a representative, risk-neutral household whose life-time utility is given by

$$\mathbb{E}_0 \sum_{t\geq 0} \left[\prod_{h=0}^{t} \beta_h \right] C_{i,t}$$

with $\beta_0 = 1$. The discount rate at time t is given by $\beta_t = \beta e^{Z_t}$, where Z_t is an intertemporal preference shock that alters the weight of utility at $t+1$ relative to utility at time t. Shocks to the household's discount factor give rise to exogenous fluctuations in the economy's real risk-free rate, and are the only source of aggregate uncertainty in the model.

Households supply one unit of labor inelastically, own banks and all other firms in the economy, and price bank deposits competitively. In addition to deposits, households can also invest in risk-free, short-term government bonds that pay off one unit of consumption with certainty in the following period. Households' optimality implies that the price of government bonds is simply the inverse of the economy's risk-free rate: $\beta e^{Z_t} = \frac{1}{R_t^f}$.

3.2. Non-financial Firms

There exists a continuum of islands indexed by $i \in [0, 1]$. In each island there is a representative bank and a representative non-financial firm. The non-financial firm purchases capital from capital good producers and rents it to final good producers, earning a rental return R_t^K. Capital depreciates geometrically at a rate $\delta \in (0, 1)$. After purchasing capital, firms experience an island-idiosyncratic capital quality shock, $\omega_{i,t} \in \Omega = \{\omega_1, ...\omega_{N_\omega}\}$.[3] I assume that this shock is i.i.d. across time and islands, and that each realization $\omega \in \Omega$ occurs with probability π_ω.

Each firm finances its capital purchases each period by obtaining funds from banks. To acquire these funds, the firm issues $A_{i,t+1}^l$ claims equal to the number of units of capital acquired $K_{i,t+1}$ and prices each claim at the price of a unit of capital Q_t, determined by the capital production block. I normalize one unit of issued securities to be a claim to the stream of future

[3] The capital quality shock, $\omega_{i,t}$, helps me generate cross-sectional heterogeneity in banks' capital structures. It is also helpful to match the default rates observed in the data (Ottonello and Winberry (2020)).

returns of one unit of capital, $\omega_{i,t+1}R^K_{t+1},\ \omega_{i,t+1}\omega_{i,t+2}(1-\delta)R^K_{t+2},\ \ldots$.[4]

3.3. Banks

Assets. Banks are owned by households and cannot diversify lending across islands. This implies that the return of bank i depends on the realization of the idiosyncratic quality shock $\omega_{i,t}$ in island i. The objective of each bank is to maximize its value:

$$V_{i,t} = \mathbb{E}_t \sum_{s\geq t} \left[\prod_{h=t}^{s} \beta_h\right] DIV_{i,s}$$

where β_t is the discount factor of the household at time t and $DIV_{i,t}$ are dividends issued by bank i in period t. In addition to long-term securities, $A^l_{i,t}$, banks can also invest in short-term government bonds, $A^s_{i,t}$. Given a portfolio, $(A^s_{i,t}, A^l_{i,t})$, the per-period payoff to the bank is given by

$$\Pi_t(A^s_{i,t}, A^l_{i,t}) = A^s_{i,t} + \omega_{i,t}\left[R^K_t + (1-\delta)Q_t\right] A^l_{i,t} \tag{1}$$

The return on long-term securities depends on the rental rate, R^K_t, and the price of capital, Q_t. Both are endogenous variables, but only the price of capital responds contemporaneously to aggregate shocks. The rental rate, R^K_t, is predetermined, given the stock of capital carried over from the previous period. The effect of a change in the aggregate shock, Z_t, on a bank's payoff is therefore given by

$$\frac{\partial \Pi_t(A^s_{i,t}, A^l_{i,t})}{\partial Z_t} = \omega_{i,t}(1-\delta)\frac{\partial Q_t}{\partial Z_t} A^l_{i,t}. \tag{2}$$

This equation highlights the key source of interest-rate risk in the model. As long as the price of long-term securities responds to changes in the interest rate, banks holding such assets are exposed to fluctuations in their valuations. In contrast, short-term bonds are risk-free. Hence, the extent of banks' exposure to interest-rate risk on the asset side is determined by their investment in long-term assets.

Balance Sheet. Bank i enters the period with a portfolio, $(A^s_{i,t}, A^l_{i,t})$, and networth, $N_{i,t}$, and chooses how to allocate its funds for the next period, $(A^s_{i,t+1}, A^l_{i,t+1})$. The bank finances

[4] As in Kiyotaki and Moore (2019), I assume that there is a claim to the future return of every unit of short- and long-term capital. I normalize such claims such that they depreciate at the same rate as the underlying capital. I abstract from frictions between non-financial firms and bank, following the approach of Gertler and Karadi (2011), He and Krishnamurthy (2013), Gertler and Kiyotaki (2015), Begenau (2020) and Begenau and Landvoigt (2022)

investment with own networth, $N_{i,t}$, and by issuing one-period, defaultable deposits, $B_{i,t+1}$.[5] The bank's networth is given by

$$N_{i,t} = \Pi_t(A^s_{i,t}, A^l_{i,t}) - B_{i,t} \tag{3}$$

where $B_{i,t}$ is debt from the previous period and $\Pi_t(B_{i,t}, k_{i,t})$ is defined in equation (1).

Let $q_{i,t}(A^s_{i,t+1}, A^l_{i,t+1}, B_{i,t+1})$ denote the endogenous debt price offered by creditors to a bank that chooses a portfolio, $(A^s_{i,t+1}, A^l_{i,t+1})$, and issues debt, $B_{i,t+1}$. The bank's flow of fund constraint is given by

$$DIV_{i,t} + \beta e^{Z_t} A^s_{i,t+1} + Q_t A^l_{i,t+1} + \psi(A_{i,t+1}, \omega_{i,t} A^l_{i,t}) = N_{i,t} + q_{i,t}(A^s_{i,t+1}, A^l_{i,t+1}, B_{i,t+1}) B_{i,t+1} \tag{4}$$

where $\psi(A_{i,t+1}, \omega_{i,t} A^l_{i,t})$ is a balance-sheet adjustment cost function which depends on next-period total assets, $A_{i,t+1} = A^s_{i,t+1} + A^l_{i,t+1}$. I assume the adjustment cost function is homogeneous of degree one in its first argument, i.e. $\psi(A_{i,t+1},\, \omega_{i,t} A^l_{i,t}) = \psi\left(\frac{A_{i,t+1}}{\omega_{i,t} A^l_{i,t}}\right) \omega_{i,t} A^l_{i,t}$, and satisfies the following properties: $\psi(1) = \psi'(1) = 0$, and $\psi''\left(\frac{A_{i,t+1}}{\omega_{i,t} A^l_{i,t}}\right) \geq 0$.[6]

Banks cannot issue new equity, $DIV_{i,t} \geq 0$, and face an exogenous leverage constraint that bounds leverage, $\frac{B'}{A'} \leq \bar{l}$. Although the leverage constraint does not play a major role in the analysis, its presence is necessary: without it, as long as bank debt is not fully uninsured, banks would borrow infinitely, default, and immediately exit the economy.

Entry and Exit. As in Gertler and Karadi (2011), at the beginning of each period banks receive an exogenous exit shock with probability $\sigma \in [0, 1]$, which forces them to exit the economy. This standard assumption makes it harder for banks to overcome financial frictions. After all shocks and payoffs are realized, banks can endogenously choose to default on their debt, in which case they immediately exit the economy. Similar to Begenau and Landvoigt (2022), I assume that failure to repay causes banks to incur a default penalty proportional to long-term assets, i.e. $V^{def}_{i,t} = -\zeta \omega_{i,t} A^l_{i,t}$.

[5] I assume that deposits are generally risky for households. However, each period the government may intervene, bailing out the defaulting bank and repays depositors in full.

[6] These assumptions imply that the adjustment cost function is downward-sloping to the left of one and upward-sloping to the right of one. The upward-sloping segment constrains banks' ability to expand their balance sheets, reflecting the increasing marginal costs associated with rapid balance-sheet growth. Conversely, the downward-sloping segment captures the idea that it is costly for banks to contract their balance sheets quickly, for instance because doing so would require them to shed deposits abruptly or restrict funding access—actions that are both operationally and reputationally costly.

I assume that bank debt is partially insured by the government. In particular, if a bank defaults, the government intervenes with probability π_b and fully repays depositors. If instead the government does not bail out the bank, depositors recover only a fraction γ of outstanding long-term claims, $\gamma(1-\delta)Q_t\omega_{i,t}A^l_{i,t}$. The remaining of a defaulting bank's value is seized by the government and rebated lump-sum to the household.[7]

In terms of entry, I assume that the mass of entrant banks in each period is equal to the mass of exiting banks, $\bar{\mu}_t$. Furthermore, I assume that new entrants are endowed with equal shares of long-term assets left by exiting banks. Therefore, the initial endowment of long-term securities for an entrant bank, $A^l_{0,t}$, is time-varying and given by

$$A^l_{0,t} = \frac{1}{\bar{\mu}_t}\int_{i\in\mathcal{E}_t}(1-\delta)\omega_{i,t}A^l_{i,t}di \tag{5}$$

where $\mathcal{E}_t$ denotes the set of banks that exits the economy at time t, either because they are hit by the exit shock or because they optimally choose to default. Banks enter with initial deposits $B_{0,t} = l_0 \cdot A^l_{0.t}$ where l_0 is a parameter that governs the leverage of new entrants.

Timing. The timing of the model can be summarized as follows.

1. A mass $\bar{\mu}_t$ of new banks enters the economy;

2. The aggregate shock and idiosyncratic capital quality shocks are realized; the payoff from capital accrues;

3. Banks draw the exogenous exit shock. Upon exit they decide whether to default and exit or repay and exit;

4. Banks that do not exit exogenously decide whether to default and exit or continue;

5. Government bails-out defaulting banks with probability π_b; if the government does not bail-out a bank, creditors recover a fraction γ of outstanding long-term claims;

6. Continuing banks choose next-period holdings of bonds and long-term securities, and issue new deposits at the price $q_{i,t}(A^s_{i,t+1}, A^l_{i,t+1}, B_{i,t+1})$;

[7] The assumption that the value not recovered by creditors is rebated to households implies that bankruptcy does not give rise to dead-weight losses in this economy.

3.4. Final Good Producers

There is a continuum of perfectly competitive firms that produce the final good by combining labor, supplied by households, and capital, rented each period from non-financial firms, according to a constant returns to scale Cobb-Douglas production function:

$$Y_t = K_t^{\alpha} L_t^{1-\alpha}, \; \alpha \in (0;1)$$

3.5. Capital Good Producers

There is a representative capital good producer who produces new investment goods subject the following adjustment costs

$$\Phi(I_t, K_t) = I_t + \frac{\phi}{2}\left(\frac{I_t}{K_t} - \hat{\delta}\right)^2 K_t$$

where I_t denotes investment and $\hat{\delta}$ is the steady-state investment rate in the absence of aggregate uncertainty.[8] The profit maximization problem of the capital good producer is

$$\max_{I_t} \{QI_t - \Phi(I_t, K_t)\} \tag{6}$$

The first-order condition pins down the prices of capital as follows:

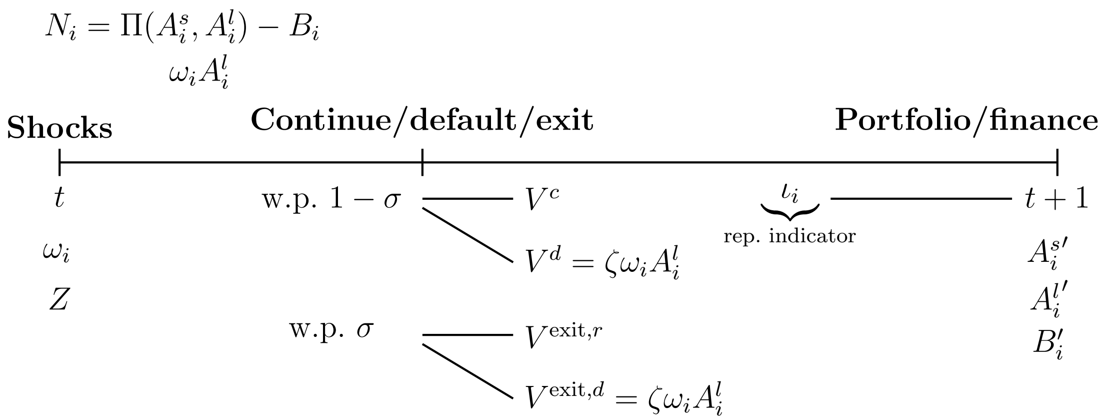
$$Q_t = 1 + \phi\left(\frac{I_t}{K_t} - \hat{\delta}\right) \tag{7}$$

3.6. Government

The government issues government bonds, A_{t+1}^s, elastically to fulfill the demand of financial intermediaries. In addition, the government levies a lump-sum tax (or transfer), T_t, from the household and repays deposits in case of bailout following a bank failure. The government

[8] Assuming an imperfectly elastic supply of capital is key to generate endogenous fluctuations in the price of capital. Without this crucial ingredient interest-rate changes would not affect intermediaries' balance sheets and would only impact investment via a standard, present-value effect. In the presence of aggregate adjustment costs, a financial accelerator emerges. The initial drop in investment following an unexpected increase in interest rates causes a deterioration in asset prices. In turn, falling asset values lead to balance-sheet losses, forcing banks to further reduce investment. See Kilic and Zhang (2023) for a discussion on the role of inelastic factor demand in the transmission of interest-rate shocks.

Figure 1: Timing of the Banks's Problem



budget constraint then is simply

$$T_t + \beta e^{Z_t} A_{t+1}^s = \pi_b \int_{i \in \mathcal{D}_t} B_{i,t} di + A_t^s$$

where $\mathcal{D}_t$ denotes the set of defaulting banks at time t and π_b is the probability of government intervention.

4. Bank Problem and Equilibrium

In this section, I present a recursive formulation of the bank's problem, illustrate the key channels that drive banks' portfolio and leverage decisions, and define the competitive equilibrium.

4.1. Recursive Bank Problem

A bank's state space is summarized by $(\mathbf{s}, \mathbf{S})$, where $\mathbf{s} = (N, \omega A^l)$ is the idiosyncratic state, which includes networth, N, and outstanding long-term securities, ωA^l. $\mathbf{S}$ denotes the aggregate state, which includes the exogenous aggregate shock, Z, and the endogenous bank distribution, μ. Let $\theta' = \frac{A^{l\prime}}{A'}$ denote the share of a bank's portfolio invested in the long-term asset. Conditional on repaying, the bank chooses dividends, DIV, next-period's total assets, A', long-term portfolio share, θ', and debt, B', to solve the following problem:

$$V^c(\mathbf{s}, \mathbf{S}) = \max_{DIV, A' \geq 0, \theta' \in [0,1], B'} DIV + \beta e^Z \mathbb{E}_{\omega', \mathbf{S}' | \mathbf{S}} V(N', \omega' \theta' A', \mathbf{S}') \tag{8}$$

s.t.

$$N' = \left\{1 - \theta' + \omega' \left[R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}')\right]\theta'\right\} A' - B'$$

$$DIV + \left\{\beta e^Z(1-\theta') + Q(\mathbf{S})\theta'\right\} A' + \psi(A', \omega A^l) = N + q(A', \theta', B', \mathbf{S})B'$$

$$DIV \geq 0, \quad \frac{B'}{A'} \leq \bar{l}, \quad \mathbf{S}' = \Gamma(\mathbf{S})$$

where $\Gamma(\mathbf{S})$ is the conjectured law of motion of the aggregate state. The set of constraints includes the law of motion of bank's networth, the flow-of-funds constraint, the no-equity-issuance condition, the leverage constraint and the law of motion of the aggregate state.

The bank's continuation value function is given by

$$V(\mathbf{s}, \mathbf{S}) = (1-\sigma)\left[\iota(\mathbf{s}, \mathbf{S})V^c(\mathbf{s}, \mathbf{S}) - (1 - \iota(\mathbf{s}, \mathbf{S}))\zeta\omega A^l\right] + \sigma V^{\text{exit}}(\mathbf{s}, \mathbf{S})$$

where $\iota(\mathbf{s}, \mathbf{S})$ is a repayment indicator which is equal to one if the bank repays, and $V^{\text{exit}}(\mathbf{s}, \mathbf{S})$ is the value upon exogenously exiting the economy. When hit by an exit shock, a bank optimally decides whether to repay or default. Only after this choice is made, the bank exits the economy. Therefore, the value function upon exit is

$$V^{\text{exit}}(\mathbf{s}) = \max\{N - \psi(0, \omega A^l), 0\} - \zeta\omega A^l \mathbb{1}_{N - \psi(0, \omega A^l) < 0}$$

In Appendix A.1 I show that the bank problem is homogeneous in ωA^l. This implies that the value functions take the form $V(N, \omega A^l, \mathbf{S}) = \nu(n, \mathbf{S})\,\omega A^l$ and $V^c(N, \omega A^l, \mathbf{S}) = \nu^c(n, \mathbf{S})\,\omega A^l$ for some functions ν and ν^c, where $n = \frac{N}{\omega A^l}$ is the ratio of bank networth to long-term assets. The Bellman equation then becomes, using the notation $g' = \frac{A'}{\omega A^l}$, $l' = \frac{B'}{A'}$ and $div = \frac{DIV}{\omega A^l}$.

$$\nu^c(n, \mathbf{S}) = \max_{div, g' \geq 0, \theta' \in [0,1] l' \leq \bar{l}} div + \beta e^Z \mathbb{E}_{\omega, \mathbf{S}'|\mathbf{S}}\left[\nu(n', \mathbf{S}')\omega'\right]\theta' g' \tag{9}$$

s.t.

$$n' = R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') + \frac{(1-\theta') - l'}{\omega'\theta'}$$

$$div + \left[\beta e^Z(1-\theta') + Q(\mathbf{S})\theta'\right] g' + \psi(g') = n + q(\theta', l', \mathbf{S})l'g'$$

$$div \geq 0, \quad \mathbf{S}' = \Gamma(\mathbf{S})$$

The expression for the debt price schedule, $q(\theta', l', \mathbf{S})$, is provided in Section 4.3. Similarly, the value of exit can be expressed as $V^{\text{exit}}(N, \omega A^l) = \nu^{exit}(n)\omega A^l$.

4.2. Model Mechanisms

In this section, I provide a characterization of the bank problem. For simplicity, I focus on a special case without exogenous exit i.e. $\sigma = 0$ and without default penalty, i.e. $\zeta = 0$. While these features are quantitatively useful, they are not essential for the main mechanism of the model. In Appendix A.2, I prove the following result:

***Proposition* 1.** *Consider a bank with ratio of networth to long-term asset n. The bank's optimal decision is characterized by one of the following three cases.*

1. ***Default**: There exists a threshold $\underline{n}(\boldsymbol{S})$ such that the bank defaults if $n \leq \underline{n}(\boldsymbol{S})$.*
2. ***Unconstrained**: There exists a threshold $\overline{n}(\boldsymbol{S})$ such that the bank is financially unconstrained if $n \geq \overline{n}(\boldsymbol{S})$. Unconstrained banks are indifferent over any combination of l' and div such that they remain unconstrained for every period with probability one. In addition, let $g^*(\boldsymbol{S})$ and $\theta^*(\boldsymbol{S})$ be the solution to the unconstrained bank problem. If $g^*(\boldsymbol{S}) > 1$, then it is optimal for the bank to invest only in long-term assets, i.e. $\theta^*(\boldsymbol{S}) = 1$.*
3. ***Constrained**: Banks with $n \in [\underline{n}(\boldsymbol{S}), \overline{n}(\boldsymbol{S})]$ are financially constrained. Constrained banks pay zero dividends and their optimal policies, $g'(n, \boldsymbol{S})$, $\theta'(n, \boldsymbol{S})$ and $l'(n, \boldsymbol{S})$ solve the Bellman equation (9).*

Default threshold. Proposition 1 establishes the existence of a threshold $\underline{n}(\mathbf{S})$, which only depends on the aggregate state, such that a bank defaults if and only if $n < \underline{n}(\mathbf{S})$.[9] Define $\underline{\omega}(\theta, b, \mathbf{S})$ as the realization of the capital quality shock such that

$$n(\omega(\theta, b, \mathbf{S})) \equiv R^K(\mathbf{S}) + (1-\delta)Q(\mathbf{S}') + \frac{(1-\theta) - l}{\omega(\theta, b, \mathbf{S})\theta} = \underline{n}(\mathbf{S}).$$

Using the fact that the capital quality shock is i.i.d., the default probability, given the realization of the aggregate state, can be written as

$$d(\theta, l, \mathbf{S}) = \begin{cases} 0, & \text{if } l \leq (1-\theta) + \omega_1 \left[R^K(\mathbf{S}) + (1-\delta)Q(\mathbf{S})\right]\theta \\ 1 - \mathbb{E}_\omega\big[\mathbf{1}_{\{\omega \geq \underline{\omega}(\theta, l, \mathbf{S})\}}\big], & \text{otherwise.} \end{cases} \tag{10}$$

Optimality conditions. I am now ready to derive the optimality conditions of the bank problem. I focus on the case where the choice of θ' is interior to the interval $[0, 1]$ and the

[9] This follows from the assumption that the capital quality shock is i.i.d. across banks and time.

leverage constraint $l' \leq \bar{l}$ is not binding. Combining the first-order conditions with respect to θ' and b', I obtain the following expression:

$$\begin{aligned}
&\left(Q(\mathbf{S}) - \beta e^{Z} - q_{\theta}(\theta', l', \mathbf{S})b'\right) \frac{\beta e^{Z}/q(\theta', l', \mathbf{S})}{1 + q_{l}(\theta', l', \mathbf{S})l'/q(\theta', l', \mathbf{S})} = \\
&\qquad \beta e^{Z} \tilde{\mathbb{E}}_{\omega', \mathbf{S}'|\mathbf{S}}\left(\omega' \left[R^{K}(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') - \psi_2'\right] - 1\right) \\
&\qquad + \beta e^{Z} \frac{\widetilde{\mathrm{Cov}}_{\omega', \mathbf{S}'|\mathbf{S}}\left(\omega' \left[R^{K}(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') - \psi_2'\right] - 1,\ 1 + \lambda(n', \mathbf{S}')\right)}{\tilde{\mathbb{E}}_{\omega', \mathbf{S}'|\mathbf{S}}\left[1 + \lambda(n', \mathbf{S}')\right]} \qquad (11)
\end{aligned}$$

where $\lambda(n, \mathbf{S})$ denotes the Lagrange multiplier on the non-negativity constraint on dividends, $\psi_2' = \psi_2(A'', \omega'\theta' A')$, and

$$\tilde{\mathbb{E}}_{\omega', \mathbf{S}'|\mathbf{S}}(X(\mathbf{S}')) = \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}}\left[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S}')\}} X(\mathbf{S}')\right]$$

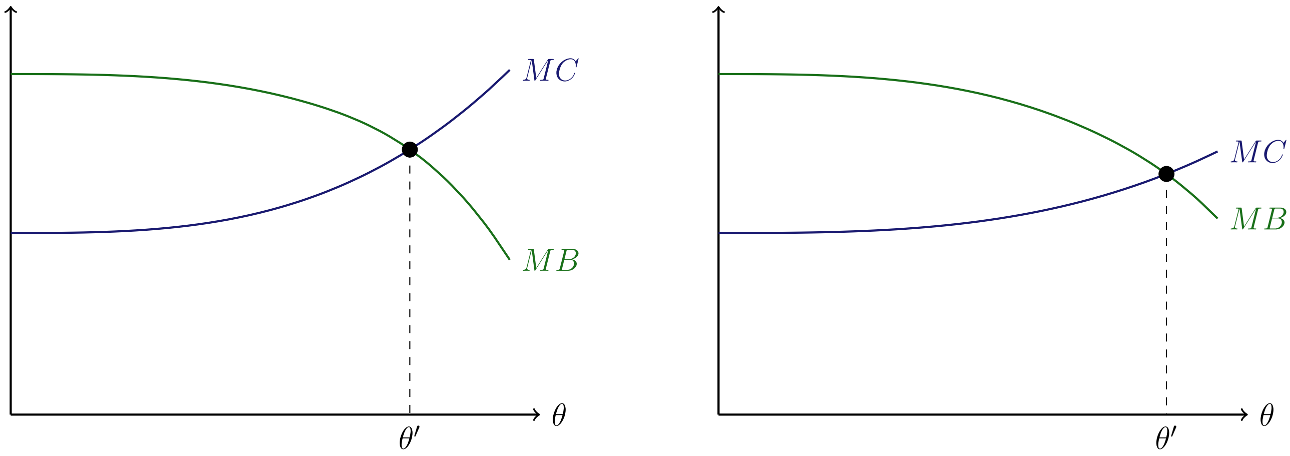
$$\widetilde{\mathrm{Cov}}_{\omega', \mathbf{S}'|\mathbf{S}}(X(\mathbf{S}'), Y(\mathbf{S}')) = \mathrm{Cov}_{\omega', \mathbf{S}'|\mathbf{S}}\left[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S}')\}} X(\mathbf{S}'), \mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S}')\}} Y(\mathbf{S}')\right]$$

To interpret this equation, it is useful to think of the left-hand side as the marginal cost of increasing the portfolio share invested in long-term assets, and the right-hand side as the marginal benefit. The marginal cost consists of two components. The term inside the brackets captures the price difference between long- and short-term assets, $Q(\mathbf{S}) - \beta e^{Z}$, and also includes $q_{\theta}(\cdot, \mathbf{S})\, l'$, which reflects how changes in the next-period portfolio composition affect the price of debt. The term outside the brackets depends on $\beta e^{Z}/q(\theta', l', \mathbf{S})$, which is a measures of the borrowing spread, and on $q_{l}(\theta', l', \mathbf{S})\, l'/q(\theta', l', \mathbf{S})$, which is the elasticity of the debt price schedule with respect to leverage.

The marginal benefit has two components: the expected payoff difference between long- and short-term assets, which corresponds to the second line of Equation (11), and the covariance between this difference and the bank's shadow value of networth, $1 + \lambda(n', \mathbf{S}')$, shown in the last line of the same equation. The latter term captures the bank-specific intermediation premium arising from financial frictions. The covariance is negative because periods of low asset prices—and thus low payoffs from long-term assets—coincide with periods in which the shadow value of bank networth is higher. Importantly, both expectations and covariances are computed only over states in which the bank does not default.

The key aspect of the above equation is that the optimal choice of θ' depends on a bank's idiosyncratic state, particularly its ratio of networth to long-term assets. To build intuition, let us first consider the marginal cost. Given a leverage choice l', the marginal cost is initially flat for values of θ' so low that the bank avoids default risk for any realization of aggregate and

Figure 2: Marginal cost and benefit under different networth levels



(a) Low Networth Relative to L-T Assets

(b) High Networth Relative to L-T Assets

idiosyncratic shocks. As θ' increases, the bank begins to face default risk, and the marginal cost curve becomes upward sloping, provided that bank debt is not fully insured. Notice now that a bank with low networth relative to long-term assets must take on more leverage, compared to a high-net-worth bank, to achieve the same level of investment; higher leverage, in turn, exposes the bank to greater default risk, and investing more in long-term assets amplifies this risk further. As a result, low-net-worth banks face a steeper marginal cost curve that remains upward sloping over a larger range of θ'.

Consider next the marginal benefit of increasing the share of long-term assets. For a risk-free bank, this marginal benefit is flat, as the bank always repays and requires no intermediation premium. By contrast, for a risky bank, the relationship between the marginal benefit and the portfolio share depends on how the latter affects the expectation and covariance terms on the right-hand side of Equation (11). Focusing first on the expected payoff component, the sign of this effect is ambiguous because the bank only values payoffs in states where it remains solvent. When a bank's networth is low relative to its long-term assets, the default threshold is high. This implies that a larger set of low-payoff states is excluded from the computation of the expected payoff, but also that the relative weight assigned to high-payoff states in which the bank remains solvent is higher.

Turning to the covariance component, banks with low networth relative to assets face a higher risk of default and therefore place greater value on preserving their franchise value. For these banks, an increase in the share of long-term assets amplifies the negative covariance between portfolio payoffs and the shadow value of networth, as it makes bank payoffs more sensitive to the realization of both aggregate and idiosyncratic shocks. This mechanism—unless offset by the expected payoff component—makes the marginal benefit curve downward sloping and particularly steep for banks with low networth relative to long-term assets.

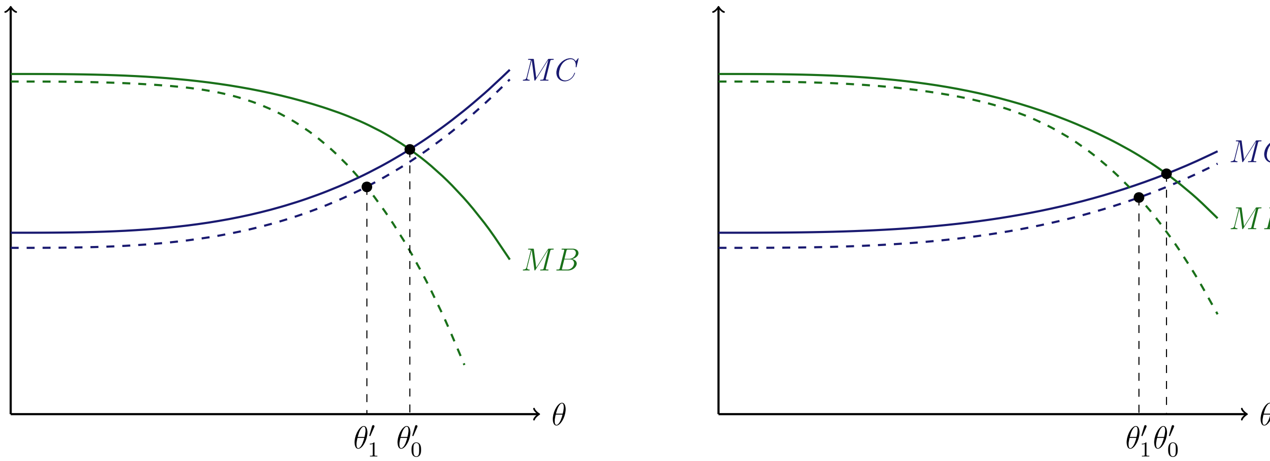
Figure 2 shows how the optimal share θ' is determined for banks with different levels of networth relative to long-term assets. The low-net-worth bank operates under tight financial constraints and demands a higher intermediation premium for bearing aggregate and idiosyncratic risk. As a result, it faces steeper marginal cost and benefit curves and, while leveraging more, chooses a lower value of θ'.

Effect of interest-rate shock. Let us now consider the effect of an increase in the interest rate on the optimal portfolio choice. Specifically, suppose that the economy is in the ergodic steady state and is then hit by a negative shock to Z that mean-reverts over time with some persistence. In terms of marginal cost, if the long-term asset becomes sufficiently cheaper in response to the shock—i.e. if $\frac{\partial Q(\mathbf{S})}{\partial Z}$ is sufficiently negative—then the interest-rate increase will shift the marginal-cost curve downward. Moreover, by depressing the long-term asset price, a higher interest rate will reduce bank networth and increase leverage. If the bank faces some degree of default risk, this will steepen the upward-sloping portion of the marginal-cost curve, as illustrated in Figure 3.

Turning to the marginal benefit, since the shock mean-reverts toward its steady-state level, banks will expect the asset price to recover over time. Nonetheless, as long as the shock is persistent, they will still expect the price to remain below its initial level. This force tends to reduce the expected payoff difference between the long- and short-term assets—i.e. the second line of Equation (11). In addition, as discussed above, the higher interest rate will lower networth and induce banks to increase their leverage. While this has an ambiguous effect on expected payoffs, it will generally tend to raise the intermediation premium, making the marginal-benefit curve steeper. If the effect operating through the intermediation premium is sufficiently strong, this will lead banks to reduce their exposure to the long-term asset. This case is illustrated in Figure 3, which also shows that the effect is likely to be stronger for banks starting with low networth relative to long-term assets.

It is worth mentioning that, while the case illustrated in Figure 3 is consistent with the effects I find in the numerically solved version of the model, in general, the effect of an increase in the interest rate could be different. In particular, it is possible that, following the shock, the intersection between the marginal-cost and marginal-benefit curves occurs at a higher value of θ' than in the absence of the shock, resulting in a higher exposure to long-term assets rather than a lower one.

Figure 3: Shifted marginal cost and benefit under different networth levels



(a) Low Networth Relative to L-T Assets **(b)** High Networth Relative to L-T Assets

To get some further intuition in Appendix A.3, I prove the following result

***Proposition* 2.** *Consider a bank with ratio of networth to long-term asset* n*. If* $\theta'(n, \boldsymbol{S}) \in (0, 1)$ *the following condition holds*

$$\tilde{\mathbb{E}}_{\omega',\boldsymbol{S'}|\boldsymbol{S}}\left[R^l(n, \boldsymbol{S}, \boldsymbol{S'}) - R^s(n, \boldsymbol{S})\right] = \frac{\widetilde{\text{Cov}}_{\omega',\boldsymbol{S'}|\boldsymbol{S}}\left(R^l(n, \boldsymbol{S}, \boldsymbol{S'}), 1 + \lambda(n', \boldsymbol{S'})\right)}{\tilde{\mathbb{E}}_{\omega',\boldsymbol{S'}|\boldsymbol{S}}\left[1 + \lambda(n', \boldsymbol{S'})\right]} \tag{12}$$

where

$$R^l(n, \boldsymbol{S}, \boldsymbol{S'}) = \frac{\omega'\left(R^K(\boldsymbol{S'}) + (1-\delta)Q(\boldsymbol{S'}) - \psi_2'\right) - l'(n, \boldsymbol{S})}{Q(\boldsymbol{S}) + \psi'(g') - \left[q(., \boldsymbol{S}) + (1 - \theta'(n, \boldsymbol{S}))q_\theta(., \boldsymbol{S})\right] l'(n, \boldsymbol{S})}$$

$$R^s(n, \boldsymbol{S}) = \frac{1 - l'(n, \boldsymbol{S})}{\beta e^Z + \psi'(g') - \left[q(., \boldsymbol{S}) - \theta'(n, \boldsymbol{S})q_\theta(., \boldsymbol{S})\right] l'(n, \boldsymbol{S})}$$

Equation (12) shows that if a bank invests in both long- and short-term assets, the expected excess levered return on long-term securities relative to short-term bonds must equal the covariance between the return on those long-term securities and the bank's shadow value of networth. This condition highlights two channels through which changes in the interest rate influence banks' portfolio choices. On the one hand, an increase in the interest rate tends to raise expected excess returns, as banks anticipate future capital gains on their long-term assets when asset prices recover. Moreover, as aggregate capital declines, the rental rate on capital rises, further increasing expected returns. On the other hand, a higher interest rate generates capital losses on banks' existing long-term assets, weakening their balance sheets and raising the intermediation premium. While the rise in expected excess returns encourages investment in long-term assets, the tightening of financial constraints exerts the opposite effect. Which force dominates is therefore a quantitative question.

4.3. Debt Price

Households supply funds competitively to banks at the price schedule $q(\theta', l', \mathbf{S})$. As discussed above, if a bank defaults, the government repays depositors in full with probability π_b. Otherwise, creditors recover only a fraction γ of outstanding long-term claims, i.e. $\gamma(1-\delta)Q(\mathbf{S})\omega\theta A$. Let $\iota_i(\theta', l', \mathbf{S}')$ and $\iota_i^e(\theta', l', \mathbf{S}')$ denote, respectively, the repayment indicator when the bank does not exit exogenously and when it exits exogenously. Then the equilibrium debt price is

$$q(\theta', l', \mathbf{S}) = \beta e^Z \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}} \Bigg\{ 1 - [1 - [(1-\sigma)\iota_i(\theta', l', \mathbf{S}') + \sigma \iota_i^e(\theta', l', \mathbf{S}')]] \\ (1-\pi_b)\left[1 - \min\left\{\frac{\gamma(1-\delta)Q(\mathbf{S}')\omega'\theta'}{l'}, 1\right\}\right] \Bigg\} \quad (13)$$

4.4. Equilibrium

Before defining the equilibrium, I need to characterize the law of motion of the distribution of banks. Let $\mu_t(n, \omega A^l)$ denote the distribution of banks across idiosyncratic states $(n, \omega A^l)$ at time t. Since the mass of entering banks is equal to the mass of exiting firms, the distribution of banks has a constant mass of one. Let $\mu_t^i(n, \omega A^l)$ denote the distribution of incumbent banks that do not default and let $\mu_t^e(n, \omega A^l)$ denote the distribution of new entrants.

The law of motion of $\mu_t^i(n, \omega A^l)$ is

$$\mu_{t+1}^i(n', A^{l'}) = \int \sum_{\omega' \in \Omega} \iota_t(n) \mathbb{1}\{n' = n_{t+1}(l_t'(n), \theta_t'(n), \omega')\} \mathbb{1}\{A^{l'} = \omega' g_t'(n) \omega A^l\} \pi_{\omega'} d\mu_t(n, \omega A^l) \quad (14)$$

where $n_{t+1}(l_t'(n), \theta_t'(n), \omega') \equiv R_{t+1}^K + (1-\delta)Q_{t+1} + \frac{(1-\theta_t'(n)) - l_t'(n)}{\omega' \theta_t'(n)}$, and $l_t'(n)$, $\theta_t'(n)$ and $g_t'(n)$ are the policy functions that solve the bank problem.

The distribution of new entrants is

$$\mu^e_{t+1}(n', A^{l'}) = \bar{\mu}_t \int \sum_{\omega' \in \Omega} \mathbb{1}\{n' = n_{t+1}(l_0, 1, \omega')\}\mathbb{1}\{A^{l'} = \omega' A^l_{0,t}\}\pi_{\omega'} \tag{15}$$

where l_0 is the exogenous leverage of entering banks, $A^l_{0,t}$ is defined in equation (5) and $\bar{\mu}_t$ is the measure of exiting firms:

$$\bar{\mu}_t = \int \left[(1-\sigma)\left(1-\iota_t(n)\right) + \sigma\right] d\mu_t(n, \omega A^l) \tag{16}$$

Finally, the distribution of banks, $\mu_{t+1}(n, \omega A^l)$, is given by

$$\mu_{t+1}(n', A^{l'}) = (1-\sigma)\mu^i_{t+1}(n', A^{l'}) + \mu^e_{t+1}(n', A^{l'}) \tag{17}$$

With the law of motion of the distribution at hand I am now ready to define a recursive competitive equilibrium in this economy

***Definition* 1.** *Let $\boldsymbol{S} = (Z, \mu)$ denote the aggregate state, where Z is the shock to the household's stochastic discount factor and μ the distribution of banks' across the idiosyncratic state, $\boldsymbol{s} = (n, \omega A^l)$. Let μ^i denote the distribution of incumbent banks that do not default, and let μ^d be the distribution of incumbent banks that default. A recursive competitive equilibrium is a set of*

1. *Value functions for banks $\{\nu(n, \boldsymbol{S}), \nu^c(n, \boldsymbol{S}), \nu^{exit}(n)\}$,*
2. *Policy functions $\{g'(n, \boldsymbol{S}), \theta'(n, \boldsymbol{S}), l'(n, \boldsymbol{S})\}$,*
3. *A debt price $q(\theta, l, \boldsymbol{S})$,*
4. *A rental rate $R^K(\boldsymbol{S}) = \alpha K(\boldsymbol{S})^{\alpha-1}$ and a price of capital $Q(\boldsymbol{S})$ given by (7),*
5. *Distributions $\{\mu(\boldsymbol{s}, \boldsymbol{S}), \mu^i(\boldsymbol{s}, \boldsymbol{S}), \mu^e(\boldsymbol{s}, \boldsymbol{S})\}$, and*
6. *A conjectured law of motion for the aggregate state $\Gamma(\boldsymbol{S})$,*

such that

1. *Given prices $\{q(\theta, l, \boldsymbol{S}), R^K(\boldsymbol{S}), Q(\boldsymbol{S})\}$ and the perceived law of motion $\Gamma(\boldsymbol{S})$, the policy functions $\{g'(n, \boldsymbol{S}), \theta'(n, \boldsymbol{S}), l'(n, \boldsymbol{S})\}$ solve the bank problem (9) and $\{\nu(n, \boldsymbol{S}), \nu^c(n, \boldsymbol{S}), \nu^{exit}(n)\}$ are the associated value functions.*
2. *The debt price $q(\theta, l, \boldsymbol{S})$ solves (13).*

3. *The conjectured law of motion* $\Gamma(\boldsymbol{S})$ *is consistent with agents' policies.*

4. *Distributions* $\{\mu(\boldsymbol{s},\boldsymbol{S}),\mu^i(\boldsymbol{s},\boldsymbol{S}),\mu^e(\boldsymbol{s},\boldsymbol{S})\}$ *satisfy (14), (15) and (17).*

5. *Markets clear*

$$Y(\boldsymbol{S}) = C(\boldsymbol{S}) + I(\boldsymbol{S}) - \Phi(I(\boldsymbol{S}), K(\boldsymbol{S})) - \Psi(\boldsymbol{S}) \tag{18}$$

The term $Y(\boldsymbol{S})$ *denotes aggregate output, which is given by* $Y(\boldsymbol{S}) = K(\boldsymbol{S})^\alpha$ *with* $K(\boldsymbol{S}) = \int \omega A^l d\mu(\boldsymbol{s},\boldsymbol{S})$. *The term* $I(\boldsymbol{S})$ *denotes aggregate investment, which is given by* $I(\boldsymbol{S}) = \int \theta'(n,\boldsymbol{S})g'(n,\boldsymbol{S})\omega A^l d\mu^i(\boldsymbol{s},\boldsymbol{S}) - (1-\delta)\int \omega A^l d\mu(\boldsymbol{s},\boldsymbol{S})$. *The term* $\Psi(\boldsymbol{S})$ *denotes the aggregate bank-level adjustment cost which is given by* $\Psi(\boldsymbol{S}) = (1-\sigma)\int \psi(g'(n,\boldsymbol{S}))\omega A^l d\mu^i(\boldsymbol{s},\boldsymbol{S}) + \sigma \int \psi(0)\omega A^l d\mu^i(\boldsymbol{s},\boldsymbol{S}) + \int \psi(0)\omega A^l d\mu^d(\boldsymbol{s},\boldsymbol{S})$.

5. Supporting Empirical Evidence

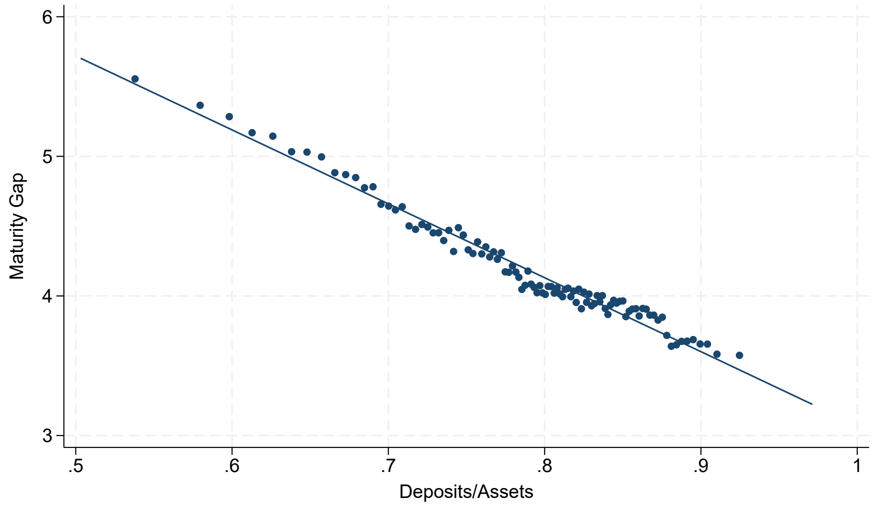
In this section, I present supporting empirical evidence that I will later use to validate the quantitative model.

Data and measurement. My analysis relies on bank-level data obtained from U.S Call Reports. I collect balance-sheet and income information for all U.S commercial banks and aggregate it at the level of the ultimate parent institution. Starting in 1997, banks have been required by regulation to report a breakdown of assets and liabilities by maturity. Using this information on repricing maturity, I compute each bank's maturity gap following English *et al.* (2018).[10] I use the midpoint of each range as the maturity of the corresponding category. Furthermore, following Drechsler *et al.* (2021), I assign a maturity of five years to subordinated debt and zero maturity to cash, Fed funds, and transaction and savings deposits. Appendix B.1 provides additional details on the data used in the empirical analysis.

Maturity gap and deposit-to-asset ratio. According to the model, more constrained banks tend to rely more on leverage while holding shorter-maturity portfolios. Consequently, one would expect a negative cross-sectional correlation between banks' deposit-to-asset ratios and their maturity gaps. To see whether this prediction is supported by the data, Figure 4 presents a binned scatterplot of maturity gaps against the deposit-to-asset ratio. Following Di Tella and

[10] English *et al.* (2018) argue that repricing maturity is a good proxy for banks' exposure to interest rate risk because it distinguishes between long-term fixed-rate assets and short-term floating-rate assets. The set of assets for which maturity information is available covers approximately 83% of total assets.

Figure 4: Maturity Gap and Deposit-to-Asset Ratio



Notes: Cross-sectional binned scatterplot of the maturity gap on the deposit-to-asset ratio, where deposits are given by the sum of checking and savings deposits. The plot residualizes the maturity gap on bank size, share of wholesale funding in total liabilities, lagged ROA, lagged nonperforming loan ratio, and bank- and time-fixed effects, and then adds back the mean of the maturity gap to maintain centering. Data are from U.S Call Reports.

Kurlat (2021), deposits are defined as the sum of checking and savings deposits. The plot controls for bank size, the ratio of wholesale funding to total liabilities, and two measures of past performance, namely the return on assets (ROA) and the share of nonperforming loans, as well as bank and time fixed effects.[11] Figure 4 reveals a stark negative correlation between maturity gaps and deposit-to-asset ratios. One concern is that this correlation may be driven by the inherent short-term nature of bank deposits. To address this concern, in Figures B.1 and B.2 I separately plot the average maturity of assets and liabilities against the deposit-to-asset ratio. The figures show that most of the variation in banks' maturity profiles stems from the asset side of the balance sheet. Instead the maturity of liabilities is relatively constant across the distribution of deposit-to-asset ratios. In Appendix B.3, I show that this result remains robust when using total deposits, including time deposits (see Figure B.3), and when weighting each bank by its share of total assets or total deposits (see Figures B.4 and B.5).

Response of maturity gap to interest rate shocks. To study how banks adjust their maturity profile in response to changes in the interest rate, I exploit identified monetary policy shocks following Gorodnichenko and Weber (2016) and Ottonello and Winberry (2020). To

[11] Wholesale funding is defined as the sum of large time deposits and fed funds acquired from other financial institutions as in Drechsler *et al.* (2021).

construct a quarterly measure of monetary policy shocks, ϵ_t^m, I compute the average of the daily shocks within each quarter, weighting them by the number of days remaining in the quarter after each shock occurs. Since ϵ_t^m is potentially a noisy measure of true monetary policy shocks, I follow Stock and Watson (2018) and use ϵ_t^m as an instrument for the change in the policy rate, ΔR_t, in an IV regression.[12] As a robustness check, I also consider the monetary policy shocks constructed by Nakamura and Steinsson (2018). Finally, to focus on conventional monetary policy, I restrict the estimation sample to end in the last quarter of 2007.

First, I explore whether banks adjust their maturity gaps differently in response to monetary policy shocks depending on their balance-sheet conditions. In particular, I focus on heterogeneity with respect to the deposit-to-asset ratio. To this end, I estimate the following empirical specification:

$$\Delta \log \text{ Maturity Gap}_{i,t+h} = \beta^h (l_{i,t-1} - \mathbb{E}_i [l_{i,t}]) \Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \alpha_i^h + \alpha_t^h + \epsilon_{i,t} \tag{19}$$

where $\Delta \log$ Maturity $\text{Gap}_{i,t+h}$ is the change in bank i's maturity gap between t and $t+h$, ΔR_t is the change in the interest rate, $l_{i,t-1}$ is bank i's deposit-to-asset ratio at time $t-1$, $\mathbb{E}_i [l_{i,t}]$ is the average deposit-to-asset ratio of bank i over the time period, $\mathbf{X}_{i,t-1}$ is a vector of additional bank-level controls, α_i^h is a bank fixed effect and α_t^h a time fixed effect.[13] To make coefficients easier to interpret, I normalize the banks' demeaned deposit-to-asset ratio, $l_{i,t-1} - \mathbb{E}_i [l_{i,t}]$, so their units are standard deviations in our sample.

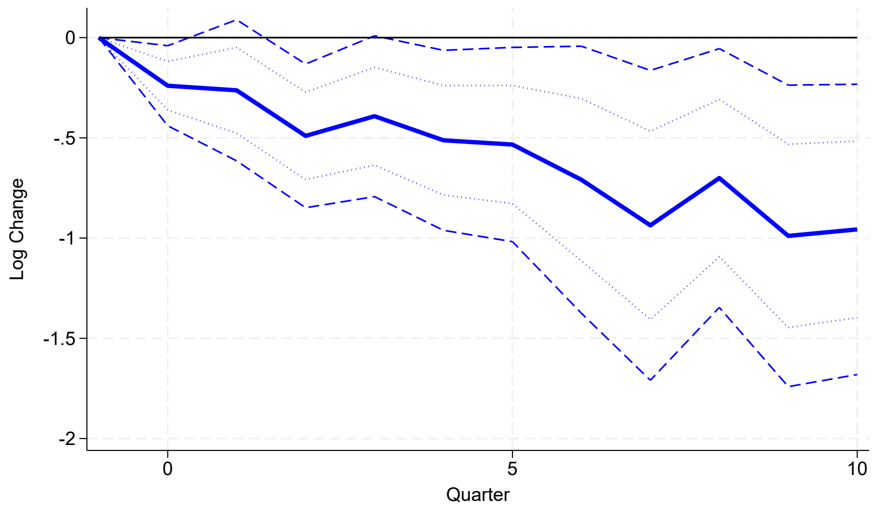
The coefficient of interest, β^h, captures how a given bank adjusts its maturity gap in response to a monetary policy shock when its deposit-to-asset ratio is higher than its historical average. Figure 5 illustrates the dynamics of this coefficient across different horizons. The estimated values are negative, indicating that banks with above-average deposit-to-asset ratios are relatively more responsive to unexpected changes in interest rates. At the one-year horizon, the point estimate is approximately -0.5, implying that a bank whose deposit-to-asset ratio is one standard deviation above its mean exhibits a 0.5-unit lower semi-elasticity of the maturity gap with respect to a monetary policy shock.

Figure B.6 shows the results from a specification that also includes an interaction term between the monetary policy shock and total assets, controlling for potential heterogeneity in

[12] As in Stock and Watson (2018), ΔR_t is the change in the interest rate on one-year U.S Treasury bonds.

[13] Following Ottonello and Winberry (2020), I focus on the interaction between the monetary policy shock and $l_{i,t-1} - \mathbb{E}_i [l_{i,t}]$ to account for the fact that banks may be ex-ante heterogeneous in their response to monetary policy depending on their deposit-to-asset ratios. The set of bank-level controls at time $t-1$ includes the deposit-to-asset ratio, the logarithm of total assets, wholesale funding as a share of total liabilities, the ROA and the nonperforming loan ratio. Including bank fixed-effects, α_i^h, allows me to control for permanent heterogeneity in banks' maturity profiles, for example stemming from specialization or different business models.

Figure 5: Heterogeneous Dynamic Response of Maturity Gap to Monetary Shocks



Notes: Dynamics of the coefficient on the interaction term between monetary shocks and deposit-to-asset ratio. The figure reports the point estimates, 90% confidence intervals (dashed lines), and one-standard-error bands (dotted lines) for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h(l_{i,t-1} - \mathbb{E}_i[l_{i,t}])\Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \alpha_i^h + \alpha_t^h + \epsilon_{i,t}$. Covariates included in $\mathbf{X}_{i,t-1}$ are log of total assets, deposit-to-asset ratio, wholesale funding as a share of total liabilities, ROA and the nonperforming ratio. Confidence intervals based on two-way clustered standard errors at bank and time levels.

responses by bank size. Figure B.7 confirms that the findings are robust to using the series of Nakamura–Steinsson shocks, while Figure B.8, which also relies on these shocks, shows that estimating specification (19) over the full sample (from the second quarter of 1997 to the last quarter of 2020) yields very similar results. Finally, Figure B.9 plots the dynamic response of the average effect of monetary policy shocks on banks' maturity gaps, obtained by estimating the following specification:

$$\begin{aligned}\Delta \log \text{ Maturity Gap}_{i,t+h} &= \beta_0^h \Delta R_t + \beta_1^h (l_{i,t-1} - \mathbb{E}_i[l_{i,t}])\Delta R_t \\ &+ \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \sum_{\tau=1}^{4} \mathbf{\Gamma}_{2,\tau}^h \mathbf{Y}_{t-\tau} + \alpha_i^h + \epsilon_{i,t} \quad (20)\end{aligned}$$

where $\sum_{\tau=1}^{4} \mathbf{\Gamma}_{2,\tau}^h \mathbf{Y}_{t-\tau}$ is a vector of aggregate controls which includes lags of GDP growth, the unemployment rate, inflation and the change in VIX index. The negative estimated effect indicates that, on average, banks reduce their maturity gaps in response to a unexpected increase in the interest rate.[14]

6. Quantitative Analysis

In this section, I use the above empirical evidence, together with additional data moments from U.S Call Reports, to discipline the quantitative model. Section 6.1 presents the calibration strategy. Section 6.2 conducts a series of validates exercises against untargeted empirical patters. Section 6.3 discusses the model reposnse to interest rate shocks. Section 6.3 discusses the model's response to interest rate shocks. Section 6.4 presents the quantitative application to the 2022-2023 tightening episode, while Section 6.5 studies the effects of introducing a liquidity requirement.

6.1. Calibration

I calibrate the model at the annual frequency to match banking moments between 1997 and 2020. The combination of heterogeneity and aggregate uncertainty implies that the distribution of banks, an infinite-dimensional object, is an endogenous state variable. To solve the model in general equilibrium, I follow Krusell and Smith (1998) and assume that agents form forecasts based on a small set of moments of the distribution. The numerical algorithm is described in detail in Appendix A.4

In terms of functional forms, I assume that the shock to the household's discount factor follows an AR(1) process:

$$Z_{t+1} = \rho_Z Z_t + \sigma_Z \epsilon_{Z,t},\ \ \epsilon_t \sim N(0,1)$$

Recall from Section 3, that the capital quality shock is i.i.d. across banks and time. I assume that it follows the process $\log \omega_t = \sigma_\omega \epsilon_{\omega,t},\ \ \epsilon_{\omega,t} \sim N(0,1)$, which I discretize over a finite grid, $\Omega = \{\omega_1, ..., \omega_{N_\omega}\}$. For bank-level adjustment costs, I assume a standard quadratic function: $\psi(g') = \frac{\psi}{2}(g'-1)^2$.

Given these functional forms, the calibration is done in two steps. The first step consists of exogenously fixing the value of parameters that either have standard values or can be estimated directly from the data. These parameters are reported in Panel (a) of Table 1. I set the capital share in the production function, $\alpha = 0.33$, and the exogenous exit parameter, $\sigma = 0.1$, as

[14] Coulier *et al.* (2024) provide evidence consistent with my findings for the euro area. Using granular supervisory data, they show that periods of low interest rates induce banks to increase their duration gaps. By contrast, when rates rise, banks reduce their exposure by shifting away from long-term lending and by curtailing credit to non-financial firms.

Table 1: Parameter Values

Panel (a): Fixed and Estimated Parameters			Panel (b): Calibrated Parameters		
Param.	Description	Value	Param.	Description	Value
α	Share of capital	0.33	π_b	Bailout probability	0.93
δ	Depreciation	0.15	γ	Recovery rate	0.5
σ	Exogenous exit rate	0.1	ψ	Bank-level adj. cost	0.35
l_0	Leverage of new entrants	0.9	σ_ω	Volatility of quality shock	0.15
$\bar{l}$	Minimum capital requirement	0.94	ζ	Default penalty	1.2
β	Discount factor, mean	0.99	ϕ	Aggregate adj. cost	5.0
σ_Z	Discount factor, volatility	0.01			
ρ_Z	Discount factor, correlation	0.8			

Notes: Panel (a) shows the parameters that are exogenously fixed $\alpha, \delta, \sigma, l_0, \bar{l}$ or directly estimated from the data β, σ_Z, ρ_Z. Panel (b) shows the parameters that are calibrated to match relevant data moments.

in Gertler and Karadi (2011). For the depreciation rate of long-term capital, I pick a value $\delta = 0.15$, which is consistent with the average duration of assets with maturity greater than one year in the data. I fix the leverage of new entrants, $l_0 = 0.9$, in line with evidence from Call Reports. Finally, I set $\bar{b} = 0.94$, a value that is broadly consistent with capital requirements faced by U.S banks. A second subset of parameters (β, σ_Z and ρ_Z) is related to the stochastic process for the household's discount factor. I fit an AR(1) process to the 10-years real interest rate in the data and set these parameters so that the process for the 10-year rate in the model closely approximate the empirical counterpart.

I calibrate the remaining parameters, shown in Panel (b) of Table 1, to match balance-sheet and default moments obtained from Call Reports or computed in other papers. I set the probability of government intervention in case of default to match the average deposit-to-asset ratio in the data.[15] A high value, $\pi_b = 0.93$, is needed under the lens of the model to match an average deposit-to-asset ratio of 0.68 in the data. I calibrate the standard deviation of the capital quality shock, $\sigma_\omega = 0.15$, to match the median age at default from Coimbra and Rey (2023). Using FDIC data on bank failures, they find that failing banks have a median age of 20.5 years. To discipline the recovery rate on capital, $\gamma = 0.5$, I follow Begenau and Landvoigt (2022) and target the net recovery value of secured corporate debt assessed by Moody's, after deducting resolution expenses incurred from transferring bank assets into FDIC receivership. Finally, I

[15] In the data I define deposits as the sum of checking and savings deposits.

Table 2: Targeted Bank Moments

Statistic	Data	Model	Source
Duration (Aggregate)			
Avg. Duration Gap	4.93	5.16	Call Reports
Duration (Heterogeneity)			
CS Sd. of Duration Gap	0.96	1.11	Call Reports
Balance Sheet and Default			
Avg. Deposit/Assets	68%	64.75%	Call Reports
Avg. Age at Default	20.5	25.53	Coimbra and Rey (2023)
Avg. Recovery Value	48%	45.58%	Begenau and Landvoigt (2022)
Vol. Market Leverage	0.02	0.02	Call Reports

Notes: This table shows the set of data moments targeted in my calibration and their model counterparts computed by simulating a panel of banks from the calibrated model.

calibrate the parameter $\phi = 5$ in the adjustment cost function of capital good producers to match the volatility of banks' market leverage in the data.

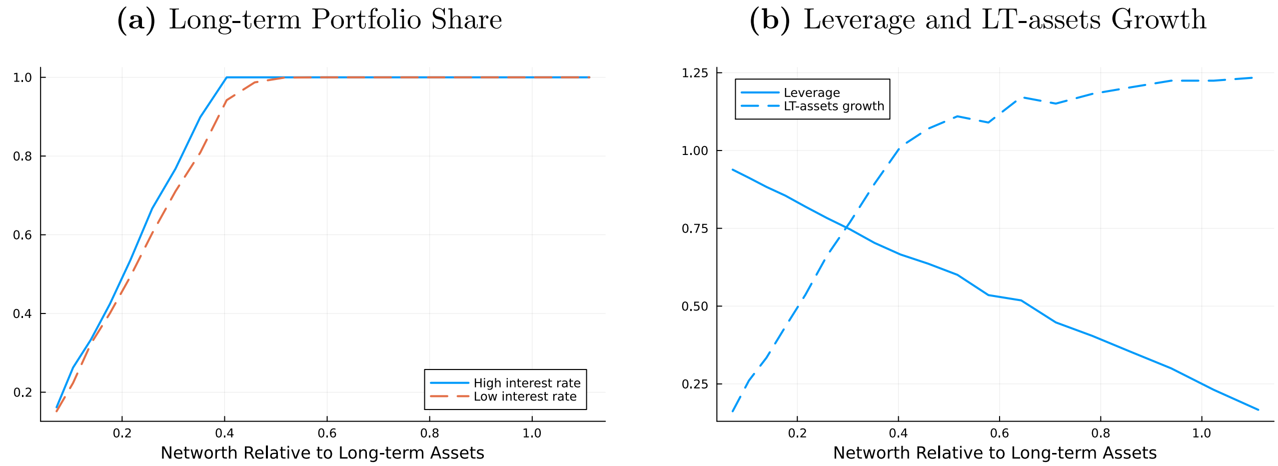
The remaining parameters are ζ and ψ, which refer respectively to the default penalty and to bank-level adjustment costs. The parameter ζ mostly governs the average share banks allocate to long-term securities. I therefore calibrate $\zeta = 1.2$ to match the average maturity gap in Call Reports data. Meanwhile, ψ captures the heterogeneity in banks' portfolios. I therefore set $\psi = 0.35$ to match the cross-sectional dispersion of maturity gaps. It is noteworthy that the model doesn't inherently incorporate ex-ante heterogeneity among banks, which, nevertheless, is a significant determinant of maturity gaps in the data. To address this concern, I residualize maturity gaps in the data using bank fixed effects and use the standard deviation of the residualized variable as target in my calibration.[16]

Figure 6 plots the policy functions of the bank. The left panel shows the policy function for the long-term asset share, $\theta'(n, \mathbf{S})$, as a function of the ratio of networth to long-term assets, for both a high-interest-rate state and a low-interest-rate state. The right panel focuses on the high-interest-rate state and plots the policy functions for the deposit-to-asset ratio, $l'(n, \mathbf{S})$, and the growth rate of long-term assets, given by $\theta'(n, \mathbf{S})g'(n, \mathbf{S})$.[17] In the left panel, the policy function is initially upward sloping and eventually reaches one as the bank's networth increases.

[16] Table C.1 shows that the model match reasonably well other untargeted cross-sectional moments.

[17] Figure C.1 plots the policy function for the deposit-to-asset ratio, $l'(n, \mathbf{S})$, and the growth rate of long-term assets, given by $\theta'(n, \mathbf{S})g'(n, \mathbf{S})$ for both a high-interest-rate state and a low-interest-rate state.

Figure 6: Bank Policy functions



Notes: Panel (a) plots the policy function for the long-term-asset portfolio share, $\theta'(n, \mathbf{S})$, as a function of the ratio of networth to long-term assets for high (solid line) and low (dashed line) interest rate states. Panel (b) plots the policy function for leverage, $l'(n, \mathbf{S})$ (solid line), and for the growth rate of long-term assets, $\theta'(n, \mathbf{S})g'(n, \mathbf{S})$ (dashed line).

This indicates that, beyond a certain level of networth, banks invest exclusively in long-term assets. The right panel shows that low-net-worth banks choose significantly higher leverage and scale down their long-term asset holdings, while high-net-worth banks expand the size of their balance sheets and increase their investment in long-term assets. Going back to the left panel, one can notice that the policy function for the long-term–asset share in the low–interest-rate state always lies below that of the high–interest-rate state. This implies that, for a given level of networth relative to long-term assets, a bank optimally allocates a smaller fraction of its portfolio to long-term securities in low-interest-rate states, reflecting the lower expected returns characterizing such states.

6.2. Model Validation

In this section, I demonstrate that the model is consistent with the empirical findings documented in Section 5.

Maturity gap and deposit-to-asset ratio. I first show that the model captures the negative relationship between maturity gap and deposit-to-asset ratio in the cross-section of banks. I estimate a simple regression of maturity gap on the deposit-to-asset ratio, $l_{i,t}$, and total assets

Table 3: Maturity Gap and Deposit-to-Asset Ratio: Model vs Data

	Maturity Gap$_{i,t}$	
	Data	Model
dep/asset	-0.03	-0.11
	(0.00)	
logassets	0.02	0.03
	(0.01)	
Bank FE	yes	no
Time FE	yes	yes
Bank Controls	yes	no

Notes: This table reports the estimated coefficients from regression (21). The data regression includes additional controls, time and year fixed effects. In the model, I include aggregate state variables as controls in the regression. In the data standard errors are clustered at the bank level.

(logged), $\log(A_{i,t})$, including time fixed effects, α_t. The specification is

$$\text{Maturity Gap}_{i,t} = \beta_0 + \beta_1 l_{i,t} + \beta_2 \log(A_{i,t}) + \alpha_t + \epsilon_{i,t} \tag{21}$$

The results are reported in Table 3, which compares the model estimates for β_1 and β_2 with the empirical counterparts.[18] Consistent with the data, the estimated coefficient on deposit-to-asset ratio is negative.

I also examine the non-linear relationship between maturity and deposit-to-asset ratio both in the data and in the model. To this end, I divide banks into deciles based on their deposit-to-asset ratio and I run the following regression on model-simulated data:

$$\text{Maturity Gap}_{i,t} = \beta_0 + \sum_{d\in\{2:10\}} \beta_{1,d} 1_{d(i)=d} + \beta_2 \log(A_{i,t}) + \alpha_t + \epsilon_{i,t} \tag{22}$$

where $d(i)$ is the decile of bank i and $1_{d(i)=d}$ is an indicator function that is equal to one if bank i belongs to decile d of the distribution of deposit-to-asset ratios.[19] The results are shown in Figure C.2 which illustrates the coefficients $\beta_{1,d}$ in the data (red) and in the model (blue). The figure shows a clear negative relationship which is consistent throughout the distribution.

[18] The empirical equivalent of regression (21) is: $\text{Maturity Gap}_{i,t} = \beta_1 l_{i,t} + \beta_2 \log(A_{i,t}) + \mathbf{\Gamma X}_{i,t} + \alpha_t + \alpha_i + \epsilon_{i,t}$, where $\mathbf{X}_{i,t}$ includes additional controls, and α_t and α_i are respectively time and bank fixed effects.

[19] The empirical equivalent of regression (22) is: $\text{Duration Gap}_{i,t} = \sum_{d\in\{2:10\}} \beta_{1,d} 1_{d(i)=d} + \beta_2 \log(k_{i,t}) + \mathbf{\Gamma X}_{i,t} + \alpha_t + \alpha_i + \epsilon_{i,t}$, where $\mathbf{X}_{i,t}$ includes additional controls, and α_t and α_i are respectively time and bank fixed effects.

Response of maturity gap to interest rate shocks. I explore next whether the model can reproduce the differential responses to interest-rate shocks. To do so, I estimate the model equivalent of equation (19) focusing of the effect one year ahead:

$$\Delta \log \text{ Maturity Gap}_{i,t+1} = \beta l_{i,t-1} \Delta R_t + \gamma l_{i,t-1} + \alpha_t + \alpha + \epsilon_{i,t} \tag{23}$$

I regress the change in duration gaps between t and $t+1$ on the interaction between the interest-rate change at time t and bank i's deposit-to-asset ratio at $t-1$, including time fixed effects and a constant. Both in the data and in the model, I normalize the banks' deposit-to-asset ratios to express them as standard deviations from their respective means.[20] The coefficient of interest is β which captures how the response of maturity gaps to the interest-rate shock varies across banks with different levels of deposit-to-asset ratios. Column (1) of Table 4 presents the results for this specification. The coefficient β is negative both in the data and in the model, indicating that banks with higher deposit funding reduce their maturity gaps more sharply in response to an interest-rate increase.

Table 4 also presents results from alternative regression specifications. Column (2) includes an additional interaction term between the interest-rate change and the log of total assets at time $t-1$:

$$\begin{aligned}\Delta \log \text{ Maturity Gap}_{i,t+1} = {} & \beta_1 l_{i,t-1} \Delta R_t + \beta_2 \log(A_{i,t-1}) \Delta R_t \\ & + \gamma_1 l_{i,t-1} + \gamma_2 \log(A_{i,t-1}) + \alpha_t + \alpha + \epsilon_{i,t} \end{aligned} \tag{24}$$

In column (3) I remove time fixed effects to estimate the average response of maturity gaps to the interest rate change:[21]

$$\begin{aligned}\Delta \log \text{ Maturity Gap}_{i,t+1} = {} & \beta_0 \Delta R_t + \beta_1 l_{i,t-1} \Delta R_t \\ & + \gamma_1 l_{i,t-1} + \gamma_2 \log(A_{i,t-1}) + K_t + \alpha + \epsilon_{i,t} \end{aligned} \tag{25}$$

Across all specifications, the model coefficients on the interaction between deposit-to-asset ratio and interest-rate shock have the same sign and similar magnitudes to those estimated in the data. The average effect is also negative, although its magnitude is smaller than the empirical

[20] Since the model does not incorporate permanent heterogeneity across banks, I do not include bank fixed effects in the regression. In addition, because banks are ex-ante identical, I obtain nearly the same results if I demean the deposit-to-asset ratio as in the data and include $l_{i,t-1} - \mathbb{E}_t[l_{i,t}]$ in the regression instead of $l_{i,t-1}$.

[21] Here I control for the aggregate capital stock in the economy.

Table 4: Responses of Duration Gap to Interest-Rate Shock: Model vs Data

	(1)		(2)		(3)	
	Data	Model	Data	Model	Data	Model
dep/asset	0.05	0.05	0.05	0.05	0.04	0.05
	(0.01)		(0.01)		(0.01))	
dep/asset × mp shock	−0.51	−0.38	−0.33	−0.37	−0.47	−0.38
	(0.27)		(0.25)		(0.37)	
logassets × mp shock			1.27	0.11		
			(0.51)			
mp shock					−2.32	−0.81
					(1.11)	
Bank controls	yes	yes	yes	yes	yes	yes
Bank FE	yes	no	yes	no	yes	no
Time FE	yes	yes	yes	yes	no	no
Aggregate controls	no	no	no	no	yes	yes

Notes: This table reports the estimated coefficients from regressions (23), (24) and (25). The empirical regressions always include bank fixed effects and additional bank-level controls that are outside the model. Standard errors (in brackets) are two-way clustered by bank and time.

counterpart.[22]

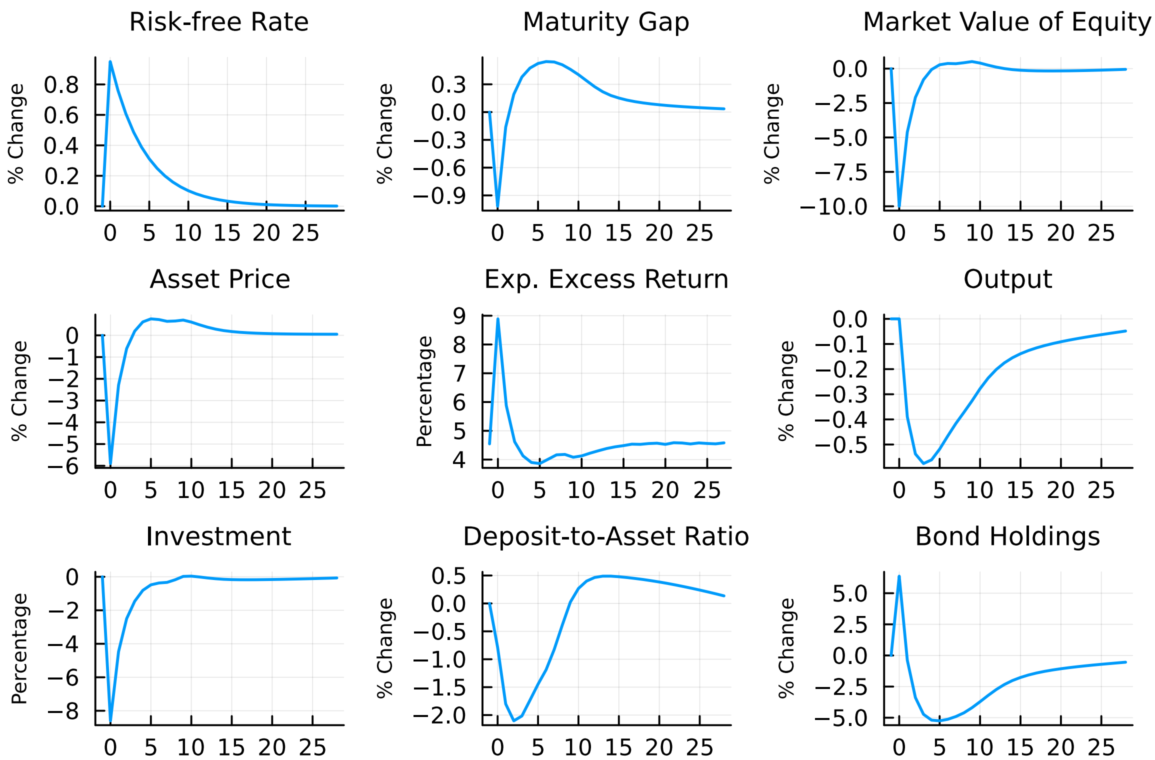
6.3. Aggregate Dynamics

Figure 7 illustrates the aggregate responses to a one–standard deviation increase in the interest rate. Following the shock, the price of long-term assets and the market value of bank equity fall sharply, eroding balance sheet strength and tightening financial constraints. As banks' networth deteriorates, they respond by contracting investment and rebalancing their portfolios toward shorter-term assets, as reflected in the decline of the maturity gap and the increase in bond holdings. The tightening of financial conditions raises the intermediation premium and leads to a sharp spike in expected excess returns. Losses in the banking sector propagate to the real economy: investment declines significantly, and output contracts persistently before gradually recovering as financial conditions normalize.

Figure 7 also shows the dynamics of the deposit-to-asset ratio. The effect of interest rates on leverage reflects two opposite forces. On one hand, rising interest rates lead to capital losses

[22] These results seem to rule out a significant role for risk-shifting in driving bank portfolio choices. Given the presence of deposit insurance, one might expect that, following an increase in interest rates, low-net-worth banks, becoming even closer to default, would find it optimal to take on greater risk. However, this does not appear to be the case in the model.

Figure 7: Impulse Response Function to One-Standard-Deviation Increase in the Interest Rate

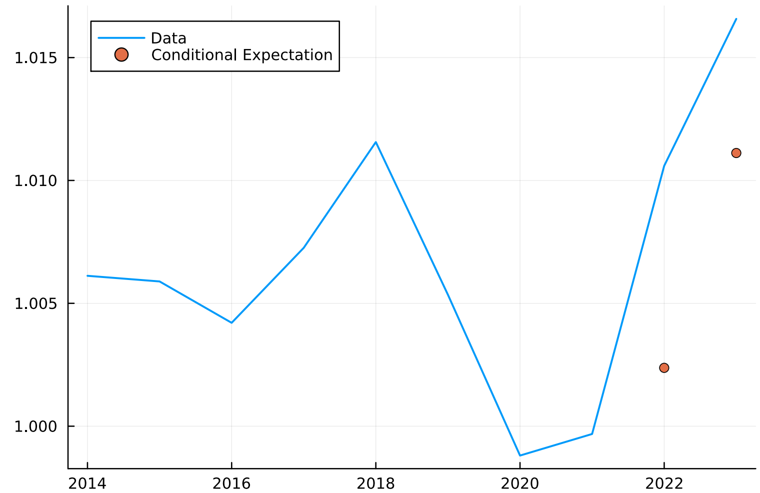


Notes: This figure plots the impulse response function to a one-standard-deviation increase in the interest rate. All variables but excess returns are expressed as percentage deviations from their ergodic means. Expected excess returns are in percentage points.

and weaker bank balance sheets, increasing banks' reliance on deposits to finance investment. On the other hand, higher interest rates make debt financing more expensive, both directly and by increasing default probabilities. Consistent with the latter effect being stronger, Figure 7 shows that the deposit-to-asset ratio declines following the shock, as banks reduce leverage and scale down their balance sheets.

The large effects of the interest-rate shock on bank equity values and investment reflect a powerful financial accelerator mechanism arising from the interaction between balance-sheet constraints and asset-price dynamics. Following an unexpected increase in interest rates, the value of long-term assets declines, eroding banks' equity capital. As balance-sheet losses compel banks to reduce investment, asset prices fall further, amplifying the deterioration of bank networth.

Figure 8: Path of the Long-Term Interest Rate and Conditional Expectations in 2022–2023



Notes: The blue solid line plots the path of 10-year real Treasury rate observed in the data. The red dots represnt the model-implied counterfactual long-term real rates in 2022–2023, computed under the assumption that the realized aggregate shock equals the conditional expectation given its past realizations.

6.4. Quantifying the Effects of the 2022–2023 Tightening Episode

In this section, I use the model to quantify the effects of the 2022-2023 hiking cycle on the US financial sector, focusing on its impact on long-term asset prices and bank equity values. I start by backing out the sequence of shocks, $[\epsilon_{1997}, \epsilon_{1998}, ..., \epsilon_{2023}]$, such that the model's 10-year real interest rate precisely tracks its historical path from 1997 to 2023. Figure C.3 and C.4 plot respectively the time-series of the long-term risk-free rate in the data, which the model matches by construction, and the corresponding sequence of shocks.[23] It is clear that the recent hiking cycle was characterized by a rapid shift from a period of exceptionally low interest rates to a historically steep tightening phase. From these shocks, I construct the path for the state variable Z, $[Z_{1997}, Z_{1998}, \ldots, Z_{2023}]$, feed it into the model, and compute the dynamic responses of the relevant aggregate variables.[24]

The first column of Table 5 reports the percentage changes in the price of long-term assets and in the market value of bank equity predicted by the model over the tightening episode. Between 2021 and 2022, asset prices in the model fall by 1.79% and banks' market equity declines by 4.37%, while the losses between 2022 and 2023 amount to 2.1% and 4.36%,

[23] The long-term rate is measured as the inflation-adjusted interest rate on 10-year Treasury securities with a constant maturity.

[24] Figure C.5 displays the dynamic response over the entire period, while Figure C.6 focuses on a window around the recent tightening episode.

respectively. The magnitude of the capital losses on long-term assets predicted by the model is in line those documented by Jiang *et al.* (2023).[25] Although banks in the model can hedge against interest-rate risk by investing in short-term bonds, the results suggest that they remain highly exposed.

Given this large exposure, it is natural to ask to what extent these losses could have been anticipated. To address this question, I focus on a specific date of interest, T, which in this context corresponds to either 2022 or 2023. I feed into the model an alternative sequence of shocks that matches the observed sequence up to period $T-1$, but replaces the realization at time T with its expected value. Formally, I construct a counterfactual path $\hat{Z}_t$ such that $\hat{Z}_t = Z_t$ for all $t \leq T-1$, and $\hat{Z}_T = \mathbb{E}_{T-1}[Z_T] = \rho_z Z_{T-1}$. In this way, the economy follows the same history as in the data up to period $T-1$, but at time T it experiences the level of the aggregate state—and thus the interest rate—that banks would have anticipated one period earlier. I implement this counterfactual separately for $T = 2022$ and $T = 2023$. The values of the interest rate implied by the counterfactual are illustrated in Figure 8. The second column of Table 5 shows the share of the observed decline in asset prices and market equity that would have occurred had interest rates evolved as expected. The results indicate that a large share of the losses in 2022—around 43% for asset prices and 33% for market equity—was predictable based on information available one period in advance, whereas only 18% of the losses materializing in 2023 could have been anticipated.

Next, I examine whether banks' portfolio adjustments play a quantitatively important role in the transmission of the rate hike to asset prices and bank equity values. As shown in Figure C.6, the model predicts a rise of about 1.9% in the average maturity gap during the two years leading up to the policy-rate hike, a period characterized by exceptionally accommodative monetary policy. This finding supports the narrative that a period of unusually low interest rates following the COVID-19 pandemic encouraged banks to take on greater interest-rate risk.[26] Moreover, the figure shows that, following the initial rate increase, banks rebalanced their portfolios and reduced significantly their maturity gap, shielding their balance sheets from further rate increases.

To assess the quantitative importance of these portfolio adjustments, I compare the baseline results with two alternative model specifications: one in which banks have access only to long-

[25] Jiang *et al.* (2023) use prices of exchange-traded funds (ETFs) across various asset classes to quantify the impact of the recent monetary tightening on US banks' asset portfolios, documenting a sizable fall in the market value of long-term fixed-income securities.

[26] Using confidential regulatory data, Greenwald *et al.* (2023) document that banks considerably increased holdings of long-term securities in the years leading up to the tightening. Consistent with this finding, publicly available data from Call Reports reveal that the average duration gap in banks' balance sheets jumped in the two years prior to the tightening from 4.3 years in 2020 to 5.6 years at the beginning of 2022.

Table 5: Asset and Equity Losses: Baseline and Expected Losses

	Baseline (%)	Expected Losses (rel. to baseline)
$\Delta_{2021,2022}$		Conditional on $[Z_{1997},\ldots,Z_{2021}]$
Asset Price	-1.79%	0.428
Market Value of Equity	-4.73%	0.333
$\Delta_{2022,2023}$		Conditional on $[Z_{1997},\ldots,Z_{2022}]$
Asset Price	-2.1%	0.127
Market Value of Equity	-4.36%	0.179

Notes: The table reports the actual and expected losses in asset prices and market equity under the baseline model, alongside two counterfactual scenarios: one without short-term bonds and another with fixed portfolio shares. Values under the counterfactual models are expressed relative to the baseline. Expected losses are shown as a fraction of the losses in the baseline model.

Table 6: Counterfactuals: Baseline, No Short-Term Bonds and Fixed Share

	Baseline (%)	No S-T Bonds (rel. to baseline)	Fixed Share (rel. to baseline)
$\Delta_{2020,2022}$			
Asset Price	-2.77	1.901	0.895
Market Value of Equity	-5.78	1.705	0.964
$\Delta_{2020,2023}$			
Asset Price	-4.87	1.851	1.536
Market Value of Equity	-10.15	1.750	1.474

Notes: The table reports the actual and expected losses in asset prices and market equity under the baseline model, alongside two counterfactual scenarios: one without short-term bonds and another with fixed portfolio shares. Values under the counterfactual models are expressed relative to the baseline. Expected losses are shown as a fraction of the losses in the baseline model.

term assets, and another in which banks can also hold short-term bonds but portfolio shares are fixed exogenously—both over time and across banks—at their average levels under the baseline calibration. In both counterfactuals, banks optimally choose the size of their balance sheets and leverage, but not their portfolio composition. I then feed the same sequence of shocks into these alternative models and compute the model-implied dynamics.[27]

[27] Figure C.8 compares the response to the same sequence of shocks, $[\epsilon_{1997}, \epsilon_{1998}, ..., \epsilon_{2023}]$, in the baseline and in the model without short-term bonds. Figure C.7 compare the response in the baseline and in the model with fixed portfolio shares.

Table 7: Effects of Liquidity Requirement

	5% Liquidity Requirement (relative to baseline)	10% Liquidity Requirement (relative to baseline)
Avg. Maturity Gap	0.968	0.932
Avg. Deposit-to-Asset Ratio	1.02	1.028
Avg. Bond Holdings	1.62	2.342
Avg. Bank Failure Rate	0.996	1.025
Avg. Default Penalty	0.981	0.959
Vol. Asset Price	0.906	0.93
Vol. Market Value of Equity	0.925	0.926
Capital	0.982	0.959
Output	0.994	0.986

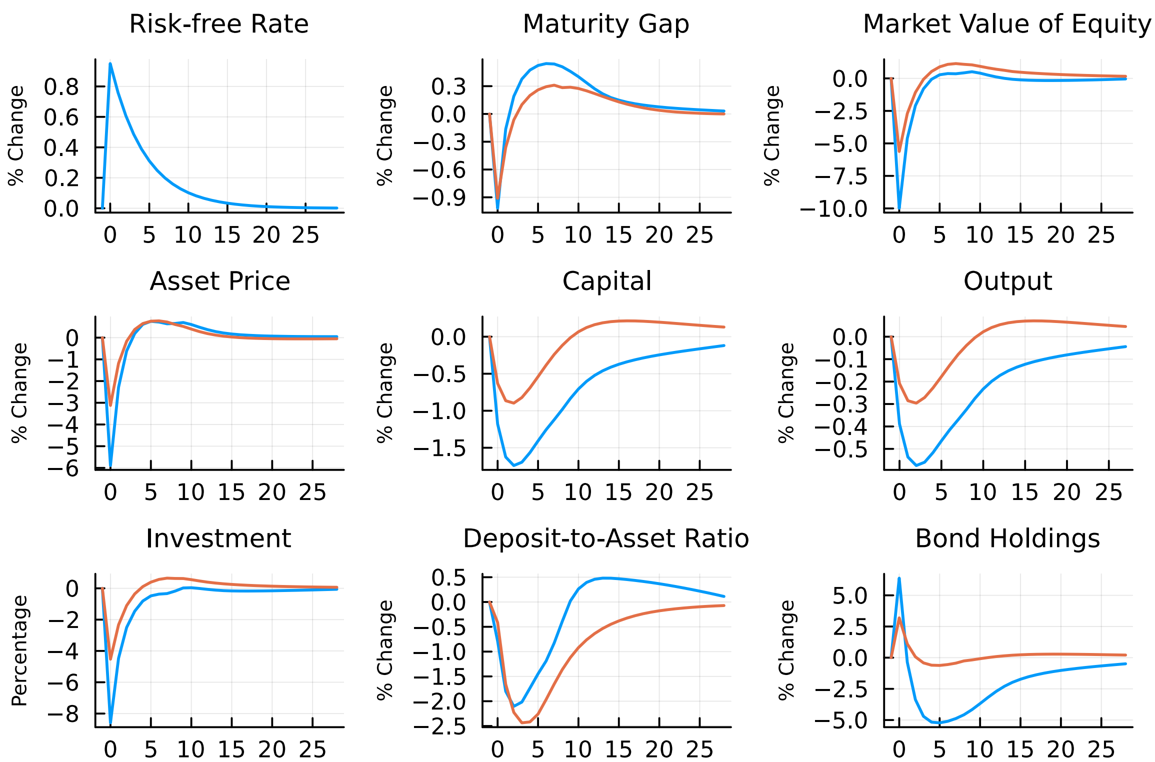
Notes: This table compares the baseline model with two counterfactual scenarios: one with a liquidity requirement $1 - \overline{\theta} = 0.5$ and another with a liquidity requirement $1 - \overline{\theta} = 0.10$. All values under the counterfactual models are expressed relative to the baseline.

Table 6 shows that the model predicts a cumulative fall between 2020 and 2023 of 4.87% for the price of the long-term asset and of 10.15% for bank equity values. In the version without short-term bonds, both the initial and subsequent declines are substantially steeper, reflecting even greater exposure to interest-rate fluctuations relative to the baseline. The drop in asset prices over 2020–2023 is nearly twice as large as in the baseline, while the decline in equity values is about 1.75 times larger. In the model with fixed portfolio shares, the magnitude of the initial drops is smaller, with asset prices and equity values falling by roughly 10% less than in the baseline during the initial phase of the tightening. This difference arises because, in the baseline model, banks endogenously widen their maturity gaps when interest rates are low and become more exposed to a potential tightening. By contrast, the effects of the subsequent tightening in 2023 are more severe in the fixed-share model, with a cumulative decline in equity values that is 47% larger than in the baseline. Facing tighter financial constraints, banks in the baseline optimally adjust their portfolios toward short-term assets following the initial hike. When portfolio shares are fixed, this reallocation is precluded, making a prolonged tightening cycle more detrimental to bank balance sheets.

6.5. Liquidity Regulation

The potentially severe consequences of steep rate hikes for financial stability highlight the need for policies that mitigate banks' exposure to interest-rate risk. Within my framework there are two motives for such policies. First, the combination of limited liability and deposit

Figure 9: Liquidity Requirement Counterfactual



Notes: This figure compares the dynamics of duration gap, asset price, market value of equity and output in the baseline model (solid blue line) and in the counterfactual economy with a liquidity requirement. (red dashed line)

insurance gives rise to a standard risk-shifting problem. When investing, banks only value assets based on their payoff in no-default states. Second, there exist pecuniary externalities that lead banks to take excessively risky position, a standard feature of financial-accelerator models. In particular, banks do not internalize that reducing maturity mismatches or leverage would dampen asset-price fluctuations and make the financial sector more resilient to aggregate shocks. From the perspective of a social planner, the presence of a risk-shifting motive and of pecuniary externalities leads banks to choose suboptimal balance-sheet structures.

While a comprehensive welfare analysis is beyond the scope of this paper, I use the model to assess the effects of a liquidity requirement that restricts intermediaries' ability to take interest-rate risk on the asset side of their balance sheets. Specifically, I assume that banks are required to hold a fraction $1 - \overline{\theta}$ of their assets in the form of short-term bonds. Under this policy, the recursive problem of the bank becomes

$$\nu^c(n,\mathbf{S}) = \max_{div, g' \geq 0, \theta' \in [0,1] l' \leq \bar{l}} div + \beta e^Z \mathbb{E}_{\omega, \mathbf{S}'|\mathbf{S}} \left[\nu(n', \mathbf{S}')\omega'\right] \theta' g' \tag{26}$$

s.t.

$$n' = R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') + \frac{(1-\theta') - l'}{\omega'\theta'}$$

$$div + \left[\beta e^Z (1-\theta') + Q(\mathbf{S})\theta'\right] g' + \psi(g') = n + q(\theta', l', \mathbf{S}) l' g'$$

$$div \geq 0, \quad \mathbf{S}' = \Gamma(\mathbf{S})$$

$$\theta' \leq \overline{\theta}$$

The only difference between this problem and the baseline (8) is the presence of the last constraint which impose an upper bound on the share of long-term assets in the bank's portfolio.[28]

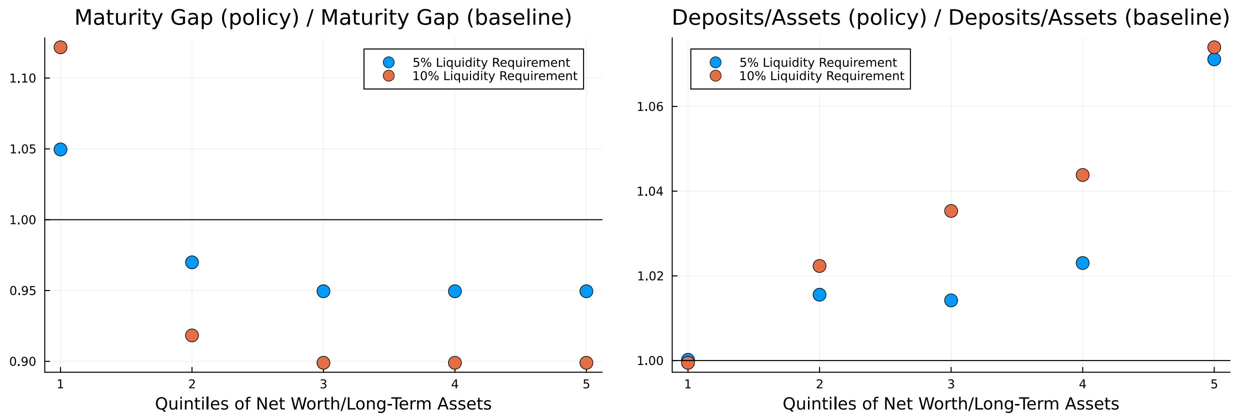
Table 7 presents the effects of two different liquidity requirements—5% and 10%. A stricter liquidity requirement leads to a significant increase in bond holdings and a reduction in the maturity gap, but it also raises the deposit-to-asset ratio. Since banks are constrained in their ability to allocate funds toward long-term investments, they respond by expanding their balance sheets, partly financing this expansion through deposits. Under both counterfactual scenarios, the average default penalty declines, although the failure rate increases slightly when the liquidity requirement is raised to 10%. Finally, tighter liquidity requirements reduce the volatility of asset prices and bank equity values, though this comes at the cost of lower capital and output. Figure 9 presents the impulse response functions to a one-standard-deviation increase in the interest rate for both the baseline model (blue line) and the model with a 5% liquidity requirement (red line).[29] Consistent with the potential stabilization benefits of a liquidity requirement, all responses are more muted under the policy counterfactual, except for the average deposit-to-asset ratio.

Finally, Figure 10 illustrates the heterogeneous effects of the policy across the distribution of networth relative to long-term assets. The left panel shows that the liquidity requirement leads to an increase in maturity gaps at the lower end of the distribution. This result is driven by low–networth banks, which are unlikely to be constrained by the liquidity requirement, and reflects general equilibrium forces. By limiting the accumulation of interest-rate risk by high–networth banks, the policy stabilizes asset prices and makes long-term assets safer investments than in the absence of the policy. As a result, these assets carry lower intermediation premia and become more attractive to low–networth banks, which in turn become more willing to hold them in their portfolios. The right panel shows the effect of the iquidity requirement on

[28] In solving this version of the model, I keep the same parametrization as the baseline economy.

[29] I consider a scenario in which the economy is at its stochastic steady state when the shock occurs.

Figure 10: Heterogeneous Effects of Liquidity Requirement



(a) Maturity Gap **(b)** Deposit-to-Asset Ratio

Notes: This figure shows the effect of the policy for different quintiles of the networth distribution, by maturity gap (left) and leverage (right).

the deposit-to-asset ratio. The policy leads to an increase in leverage across the distribution, particularly at the upper end.

7. Conclusions

This paper develops a quantitative macro-finance framework to study the transmission of interest-rate risk through bank balance sheets. In the model, financial intermediaries optimally choose their leverage and the maturity structure of their portfolios in the presence of limited equity issuance, default risk, and partial deposit insurance. Because long-duration assets expose banks to valuation losses when interest rates rise, optimal maturity choices depend on bank capitalization: well-capitalized banks take on more duration risk, while low-net-worth banks endogenously shorten maturities to preserve their franchise value.

Applying the model to the 2022–2023 tightening episode, I find that the rapid rise in interest rates can generate large losses in asset values and bank equity even though banks have access to short-term assets that provide better self-insurance. Through the lens of the model, a substantial share of the losses experienced in 2022 was predictable ex ante given the information available at the time, whereas the losses in 2023 were largely unexpected. Moreover, endogenous portfolio rebalancing played a stabilizing role: following the initial policy hikes, banks shortened maturities and thereby reduced their exposure to further rate increases.

Finally, I evaluate the potential stabilizing role of liquidity regulation. A policy requiring banks to hold a minimum fraction of short-term safe assets dampens the response of asset prices and bank equity to interest-rate shocks, although the effects vary across the distribution of bank net worth. In this sense, maturity regulation can complement capital regulation as a policy tool to mitigate financial amplification in the presence of significant interest-rate risk.

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Appendices

A. Additional Model Details

A.1. Homogeneity of the Bank Problem

In this section, I show that the problem of the bank is homogeneous in ωA^l. This property allows me to write the value functions of the bank in terms of value per unit of long-term assets, $V(N, \omega A^l, \mathbf{S}) = \nu(n, \mathbf{S})\,\omega A^l$ and $V^c(N, \omega A^l, \mathbf{S}) = \nu^c(n, \mathbf{S})\,\omega A^l$ for some functions ν and ν^c, where $n = \frac{N}{\omega A^l}$ is the ratio of bank networth to long-term assets. The Bellman equation then becomes, using the notation $g' = \frac{A'}{\omega A^l}$, $l' = \frac{B'}{A'}$ and $div = \frac{DIV}{\omega A^l}$.

$$\nu^c(n, \mathbf{S}) = \max_{div, g' \geq 0, \theta' \in [0,1] l' \leq \bar{l}} div + \beta e^Z \mathbb{E}_{\omega, \mathbf{S}'|\mathbf{S}} \left[\nu(n', \mathbf{S}')\omega'\right] \theta' g' \tag{27}$$

s.t.

$$n' = R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') + \frac{(1-\theta') - l'}{\omega'\theta'}$$

$$div + \left[\beta e^Z (1-\theta') + Q(\mathbf{S})\theta'\right] g' + \psi(g') = n + q(\theta', l', \mathbf{S}) l' g'$$

$$div \geq 0, \quad \mathbf{S}' = \Gamma(\mathbf{S})$$

where

$$\nu(n, \mathbf{S}) = (1-\sigma)\left[\iota(n, \mathbf{S})\nu^c(n, \mathbf{S}) - (1 - \iota(n, \mathbf{S}))\zeta\right] + \sigma \nu^{\text{exit}}(n)$$

In this equation, $\iota(n, \mathbf{S})$ is a repayment indicator which is equal to one if the bank repays, and $\nu^{\text{exit}}(n)$ is the value upon exogenously exiting the economy:

$$\nu^{\text{exit}}(n) = \max\{n - \psi(0), 0\} - \zeta \mathbb{1}_{n - \psi(0) < 0}$$

Default threshold. Banks that receive an exogenous exit shock default if and only if $n < \psi(0)$. Banks that do not receive and exogenous exit shock only default when they have no feasible choice which satisfies the no-equity constraint, i.e., there is no $(A' \geq 0, \theta' \in [0,1], B' \leq \bar{l}A')$ choice such that

$$N - \beta e^Z \left[(1-\theta') - Q(\mathbf{S})\theta'\right] A' - \psi(A', \omega A^l) + q(\theta', l', \mathbf{S}) B' \geq 0 \tag{28}$$

Homogeneity of the adjustment cost function implies that (28) is equivalent to

$$n - \left[\beta e^Z (1-\theta') - Q(\mathbf{S})\theta'\right] g' - \psi(g) + q(\theta', l', \mathbf{S}) l' g' \geq 0 \tag{29}$$

Define the default threshold $\underline{n}(\mathbf{S}) = \min_{g'\geq 0, \theta'\in[0,1], l'\leq \bar{l}} \left\{ \left[\beta e^Z (1-\theta') - Q(\mathbf{S})\theta'\right] g' - \psi(g) + q(\theta', l', \mathbf{S}) l' g' \right\}$. This threshold is such that the bank defaults if and only if $n < \underline{n}(\mathbf{S})$.In this case, in fact, there is no feasible choice such that $div \geq 0$.

This allows us to rewrite the bank value function as follows

$$\nu^c(n, \mathbf{S}) = \max_{div, g'\geq 0, \theta'\in[0,1], l'\leq \bar{l}} div + \beta e^Z \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}} \left[\nu(n', \mathbf{S}')\omega'\right] \theta' g' \tag{30}$$

s.t.

$$\nu(n', \mathbf{S}') = (1-\sigma) \left[\mathbf{1}_{n'>\underline{n}(\mathbf{S}')} \nu^c(n', \mathbf{S}') - \left(1 - \mathbf{1}_{n'>\underline{n}(\mathbf{S}')}\right) \zeta\right] + \sigma \left[\mathbf{1}_{n'>\psi(0)} \left(n' - \psi(0)\right) - \left(1 - \mathbf{1}_{n'>\psi(0)}\right) \zeta\right]$$

$$n' = R^K(\mathbf{S}') + (1-\delta) Q(\mathbf{S}') + \frac{(1-\theta') - l'}{\omega'\theta'}$$

$$div + \left[\beta e^Z (1-\theta') + Q(\mathbf{S})\theta'\right] g' + \psi(g') = n + q(\theta', l', \mathbf{S}) l' g'$$

$$div \geq 0, \quad \mathbf{S}' = \Gamma(\mathbf{S})$$

Suppose first that the constraints, $div \geq 0$ and $l' \leq \bar{l}$, are not binding. Then, the first-order condition with respect to g' is

$$\psi'(g') = q(\theta', l', \mathbf{S})\, l' - \left[\beta e^Z (1-\theta') + Q(\mathbf{S})\theta'\right] + \beta e^Z\, \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}}[\nu(n', \mathbf{S}')\, \omega']\, \theta' \tag{31}$$

Combining this with the flow-of-funds constraint yields

$$\psi'(g') g' = div - n + \psi(g') + \beta e^Z\, \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}}[\nu(n', \mathbf{S}')\, \omega']\, \theta' g' \tag{32}$$

This implies

$$\nu^c(n, \mathbf{S}) = n - \psi(g') + \psi'(g') g' \tag{33}$$

which confirms the conjecture.

Consider next the case where the constraints, $div \geq 0$ and $l' \leq \bar{l}$, are binding. Then, the first-order condition with respect to g' is

$$\psi'(g') = q(\theta', l', \mathbf{S})\, l' - \left[\beta e^Z (1-\theta') + Q(\mathbf{S})\theta'\right] + \frac{\beta e^Z\, \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}}[\nu(n', \mathbf{S}')\, \omega']\, \theta'}{1+\lambda}, \quad \lambda \geq 0. \tag{34}$$

which implies

$$n - \psi(g') + \psi'(g') g' = \frac{\beta e^Z\, \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}}[\nu(n', \mathbf{S}')\, \omega']\, \theta' g'}{1+\lambda}, \quad \lambda \geq 0. \tag{35}$$

Using the envelop condition we have that

$$\frac{\partial \nu^c(n,\mathbf{S})}{\partial n} = 1+\lambda \tag{36}$$

This implies

$$\nu^c(n,\mathbf{S}) = \frac{\partial \nu^c(n,\mathbf{S})}{\partial n}(n-\psi(g')+\psi'(g')g') \tag{37}$$

which again confirms the conjecture.

Finally, I verify that the debt price only depends on θ' and l'. Define $\underline{\omega}(\theta,l,\mathbf{S})$ as the realization of the capital quality shock such that

$$n(\underline{\omega}(\theta,b,\mathbf{S})) \equiv R^K(\mathbf{S}) + (1-\delta)Q(\mathbf{S}') + \frac{(1-\theta)-l}{\underline{\omega}(\theta,b,\mathbf{S})\theta} = \underline{n}(\mathbf{S}).$$

A bank that is not hit by an exogenous exit shock defaults if and only if $\omega \le \underline{\omega}(\theta,b,\mathbf{S})$. Similarly, define $\underline{\omega}^e(\theta,l,\mathbf{S})$ as the realization of the capital quality shock such that

$$n(\underline{\omega}^e(\theta,b,\mathbf{S})) \equiv R^K(\mathbf{S}) + (1-\delta)Q(\mathbf{S}') + \frac{(1-\theta)-l}{\underline{\omega}^e(\theta,b,\mathbf{S})\theta} = \psi(0).$$

A bank that is hit by an exogenous exit shock defaults if and only if $\omega \le \underline{\omega}^e(\theta,b,\mathbf{S})$. Therefore, the debt price can be written as

$$q(\theta',l',\mathbf{S}) = \beta e^Z \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}} \Bigg\{ 1 - \Big[1 - \big[(1-\sigma)\mathbf{1}_{\{\omega' \ge \underline{\omega}(\theta',l',\mathbf{S})\}} + \sigma \mathbf{1}_{\{\omega' \ge \underline{\omega}^e(\theta',l',\mathbf{S})\}}\big]\Big]$$
$$(1-\pi_b)\left[1 - \min\left\{\frac{\gamma(1-\delta)Q(\mathbf{S}')\omega'\theta'}{l'}, 1\right\}\right] \Bigg\} \tag{38}$$

A.2. Proof of Proposition 1

I now provide a characterization of the bank's problem for a special case of the model without exogenous exit ($\sigma = 0$), without default penalty ($\zeta = 0$) and without recovery value ($\gamma = 0$).

Default threshold. Banks in the model only default when they have no feasible choice which satisfies the no-equity constraint, i.e., there is no $(g' \ge 0, \theta' \in [0,1], l' \le \bar{l})$ choice such that

$$n - \left[\beta e^Z (1-\theta') - Q(\mathbf{S})\theta'\right] g' - \psi(g) + q(\theta',l',\mathbf{S})l'g' \ge 0 \tag{39}$$

Define the default threshold:

$$\underline{n}(\mathbf{S}) = \min_{g' \geq 0, \theta' \in [0,1], l' \leq \bar{l}} \left\{ \left[\beta e^{Z} (1-\theta') - Q(\mathbf{S})\theta' \right] g' - \psi(g) + q(\theta', l', \mathbf{S}) l' g' \right\} \tag{40}$$

A bank default if and only if $n \leq \underline{n}(\mathbf{S})$, so the repayment decision is $\iota(n, \mathbf{S}) = \mathbf{1}_{\{n \geq \underline{n}(\mathbf{S})\}}$. Define $\underline{\omega}(\theta, l, \mathbf{S})$ as the realization of the capital quality shock such that

$$n(\underline{\omega}(\theta, b, \mathbf{S})) \equiv R^K(\mathbf{S}) + (1-\delta)Q(\mathbf{S}') + \frac{(1-\theta) - l}{\underline{\omega}(\theta, b, \mathbf{S})\theta} = \underline{n}(\mathbf{S}).$$

Using the fact that the capital quality shock is i.i.d., the default probability, given the realization of the aggregate state, can be written as

$$d(\theta, l, \mathbf{S}) = \begin{cases} 0, & \text{if } l \leq (1-\theta) + \omega_1 \left[R^K(\mathbf{S}) + (1-\delta)Q(\mathbf{S}) \right] \theta \\ 1 - \mathbb{E}_{\omega}\left[\mathbf{1}_{\{\omega \geq \underline{\omega}(\theta, l, \mathbf{S})\}} \right], & \text{otherwise.} \end{cases} \tag{41}$$

Unconstrained banks. Let $\{div^*(\mathbf{S}), g^*(\mathbf{S}), \theta^*(\mathbf{S}), l^*(\mathbf{S})\}$ denote the solution to the unconstrained bank problem:

$$\nu^c(n, \mathbf{S}) = \max_{div^*, g^* \geq 0, \theta^* \in [0,1], l^* \leq \bar{l}} div^* + \beta e^{Z} \mathbb{E}_{\omega, \mathbf{S}'|\mathbf{S}} \left[\nu^c(n', \mathbf{S}') \omega' \right] \theta^* g^* \tag{42}$$

s.t.

$$n' = R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') + \frac{(1-\theta^*) - l^*}{\omega' \theta^*}$$

$$div^* + \left[\beta e^{Z} (1-\theta^*) + Q(\mathbf{S})\theta^* \right] g^* + \psi(g^*) = n + \beta e^{Z} l^* g^*$$

$$\mathbf{S}' = \Gamma(\mathbf{S})$$

For $l^* \leq \bar{l}$, the first-order condition with respect to l^* is $\beta e^{Z} = \beta e^{Z}$, which holds for any l^*. This implies that an unconstrained bank is indifferent over the choice of leverage l^* and dividends div^*, as long as the bank remains unconstrained.

Next, I show that if $g^*(\mathbf{S}) > 1$, an unconstrained bank invests entirely in long-term assets, i.e., $\theta^*(\mathbf{S}) = 1$. Suppose, for contradiction, that $\theta^*(\mathbf{S}) \in (0, 1)$. The first-order conditions with respect to g^* and θ^* are

$$\begin{cases} \text{FOC w.r.t } g^*: & \beta e^Z\, \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\Big[\omega'\theta^*\big(R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') - \psi_2'\big) + 1 - \theta^* - l^*\Big] \\ & \quad +\Big(\beta e^Z l^* - (\beta e^Z(1-\theta^*) + Q(\mathbf{S})\theta^*) - \psi'(g^*)\Big) = 0, \\ \text{FOC w.r.t } \theta^*: & \beta e^Z\, \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\Big[\omega'\big(R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') - \psi_2'\big) - 1\Big] + \big(\beta e^Z - Q(\mathbf{S})\big) = 0. \end{cases}$$

Multiplying the second equation by θ^* and subtracting it from the first yields $\psi'(g^*) = 0$, which can only hold if $g^*(\mathbf{S}) = 1$. Similarly, if $\theta^*(\mathbf{S}) = 0$, the FOC with respect to g^* becomes $\psi'(g^*) = -\beta e^Z$, which cannot hold for $g^*(\mathbf{S}) > 1$. Therefore, whenever $g^*(\mathbf{S}) > 1$, an unconstrained bank optimally invests entirely in long-term assets, i.e. $\theta^*(\mathbf{S}) = 1$.

Constrained banks. Banks with $n \in [\underline{n}(\mathbf{S}), \overline{n}(\mathbf{S})]$ are financially constrained and solve the following problem:

$$\nu^c(n,\mathbf{S}) = \max_{div, g'\geq 0, \theta'\in[0,1] l'\leq \bar{l}} div + \beta e^Z \mathbb{E}_{\omega,\mathbf{S}'|\mathbf{S}}\left[\mathbf{1}_{\{\omega'\geq\underline{\omega}(\theta',l',\mathbf{S})\}}\nu^c(n',\mathbf{S}')\omega'\right]\theta' g' \tag{43}$$

s.t.

$$n' = R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') + \frac{(1-\theta') - l'}{\omega'\theta'}$$

$$div + \left[\beta e^Z(1-\theta') + Q(\mathbf{S})\theta'\right]g' + \psi(g') = n + q(\theta', l', \mathbf{S})l'g'$$

$$div \geq 0, \quad \mathbf{S}' = \Gamma(\mathbf{S})$$

Assuming that the choice of θ' is interior to the interval $[0,1]$ and the leverage constraint $l' \leq \bar{l}$ is not binding the first-order conditions of this problem are given by

$$\begin{cases} \text{FOC w.r.t } g': & \beta e^Z \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\Big[\mathbf{1}_{\{\omega'\geq\underline{\omega}(\theta',l',\mathbf{S})\}}\,\tilde{\lambda}(n',\mathbf{S}')\left[\omega'\theta'\big(R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') - \psi_2'\big) + 1 - \theta' - l'\right]\Big] \\ & \quad +\tilde{\lambda}(n,\mathbf{S})\big(q(\theta',l',\mathbf{S})l' - (\beta e^Z(1-\theta') + Q(\mathbf{S})\theta') - \psi'(g')\big) = 0 \\ \text{FOC w.r.t } \theta': & \beta e^Z \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\Big[\mathbf{1}_{\{\omega'\geq\underline{\omega}(\theta',l',\mathbf{S})\}}\,\tilde{\lambda}(n',\mathbf{S}')\left[\omega'\left(R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') - \psi_2'\right) - 1\right]\Big] \\ & \quad +\tilde{\lambda}(n,\mathbf{S})\big(q_\theta(\theta',l',\mathbf{S})l' + \beta e^Z - Q(\mathbf{S})\big) = 0 \\ \text{FOC w.r.t } l': & \beta e^Z \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\Big[\mathbf{1}_{\{\omega'\geq\underline{\omega}(\theta',l',\mathbf{S})\}}\,\tilde{\lambda}(n',\mathbf{S}')\Big] - \tilde{\lambda}(n,\mathbf{S})\big(q(\theta',l',\mathbf{S}) + l'q_l(\theta',l',\mathbf{S})\big) = 0 \end{cases} \tag{44}$$

with $\tilde{\lambda}(n,\mathbf{S}) = 1 + \lambda(n,\mathbf{S})$ and $\lambda(n,\mathbf{S})$ denoting the Lagrange multiplier associated with the non-negativity constraint on dividends. Combining these equations yields (11) in the main text:

$$
\begin{aligned}
\big(Q(\mathbf{S}) - \beta e^Z - q_\theta(\theta', l', \mathbf{S}) b'\big) \frac{\beta e^Z / q(\theta', l', \mathbf{S})}{1 + q_l(\theta', l', \mathbf{S}) l' / q(\theta', l', \mathbf{S})} = \\
\beta e^Z \tilde{\mathbb{E}}_{\omega', \mathbf{S}'|\mathbf{S}} \big(\omega' \left[R^K(\mathbf{S}') + (1-\delta) Q(\mathbf{S}') - \psi_2'\right] - 1\big) \\
+ \beta e^Z \frac{\widetilde{\mathrm{Cov}}_{\omega', \mathbf{S}'|\mathbf{S}} \big(\omega' \left[R^K(\mathbf{S}') + (1-\delta) Q(\mathbf{S}') - \psi_2'\right] - 1,\, 1 + \lambda(n', \mathbf{S}')\big)}{\tilde{\mathbb{E}}_{\omega', \mathbf{S}'|\mathbf{S}} \left[1 + \lambda(n', \mathbf{S}')\right]}
\end{aligned} \tag{45}
$$

with

$$
\tilde{\mathbb{E}}_{\omega', \mathbf{S}'|\mathbf{S}}(X(\mathbf{S}')) = \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}} \big[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S}')\}} X(\mathbf{S}')\big]
$$

$$
\widetilde{\mathrm{Cov}}_{\omega', \mathbf{S}'|\mathbf{S}}(X(\mathbf{S}'), Y(\mathbf{S}')) = \mathrm{Cov}_{\omega', \mathbf{S}'|\mathbf{S}} \left[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S}')\}} X(\mathbf{S}'), \mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S}')\}} Y(\mathbf{S}')\right]
$$

I now show that constrained banks set $div = 0$. Suppose by contradiction that a constrained firm sets $div > 0$, implying that $\lambda(n, \mathbf{S}) = 0$. Consider first a bank that face zero probability of default in the follwing period, i.e. $\underline{\omega}(\theta', l', \mathbf{S}') = \omega_1$ and $\frac{\partial \underline{\omega}(\theta', l', \mathbf{S}')}{\partial \theta'} = \frac{\partial \underline{\omega}(\theta', l', \mathbf{S}')}{\partial l'} = 0$. Then the first-order condition with respect to l' implies $\mathbb{E}\Big[\lambda(n', \mathbf{S}')\Big] = 0$. This is a contradiction given that the bank is constrained and so $\lambda(n', \mathbf{S}') > 0$ for some positive mass of realizations of $\mathbf{S}'$ and ω'.

Consider next a banks that faces some positive probability of default, i.e. $\underline{\omega}(\theta', l', \mathbf{S}') > \omega_1$ and $\frac{\partial \underline{\omega}(\theta', l', \mathbf{S}')}{\partial l'} > 0$ for some state $\mathbf{S}$. Then, the first-order consition with respect to l' becomes

$$
\beta e^Z \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}} \Big[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S})\}} \tilde{\lambda}(n', \mathbf{S}')\Big] - \big(q(\theta', l', \mathbf{S}) + l' q_l(\theta', l', \mathbf{S})\big) = 0 \tag{46}
$$

The debt price is

$$
q(\theta', l', \mathbf{S}) = \beta e^Z \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}} \left\{1 - \left[1 - \mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S}')\}}\right] (1 - \pi_b)\right\} \tag{47}
$$

which implies

$$
q_l(\theta', l', \mathbf{S}) = -\,\beta e^Z (1 - \pi_b)\, \mathbb{E}_{\mathbf{S}'|\mathbf{S}} \left[\sum_{j:\, \omega_j = \underline{\omega}(\theta', l', \mathbf{S}')} \pi_{\omega_j} \frac{\partial \underline{\omega}(\theta', l', \mathbf{S}')}{\partial l'}\right]. \tag{48}
$$

Combining the three equations above we get

$$
\begin{aligned}
\mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}} \left[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S}')\}} \lambda(n', \mathbf{S}') + \big(1 - \mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta', l', \mathbf{S}')\}}\big) \pi_b\right] \\
+ l' (1 - \pi_b)\, \mathbb{E}_{\mathbf{S}'|\mathbf{S}} \left[\sum_{j:\, \omega_j = \underline{\omega}(\theta', l', \mathbf{S}')} \pi_{\omega_j} \frac{\partial \underline{\omega}(\theta', l', \mathbf{S}')}{\partial l'}\right] = 0.
\end{aligned} \tag{49}
$$

Because constrained banks engage in strictly positive borrowing $l' > 0$, the left-hand side is strictly greater than zero, leading to a contradiction.

A.3. Proof of Proposition 2

Define the levered returns on long- and short-term assets as follows:

$$R^l(n,\mathbf{S},\mathbf{S}') = \frac{\omega'\left(R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') - \psi_2'\right) - l'(n,\mathbf{S})}{Q(\mathbf{S}) + \psi'(g'(n,\mathbf{S})) - \left[q(n,\mathbf{S}) + (1-\theta'(n,\mathbf{S}))q_\theta(n,\mathbf{S})\right] l'(n,\mathbf{S})}$$

$$R^s(n,\mathbf{S}) = \frac{1 - l'(n,\mathbf{S})}{\beta e^Z + \psi'(g'(n,\mathbf{S})) - \left[q(n,\mathbf{S}) - \theta'(n,\mathbf{S})q_\theta(n,\mathbf{S})\right] l'(n,\mathbf{S})}$$

where $q(n,\mathbf{S})$ and $q_\theta(n,\mathbf{S})$ are the values implied by the bank's optimal decision, $\theta'(n,\mathbf{S})$ and $l'(n,\mathbf{S})$.

Consider the problem of a constrained bank. Assuming that the choice of θ' is interior to the interval $[0,1]$ and the leverage constraint $l' \leq \bar{l}$ is not binding the first-order conditions with respect to g' and θ' are

$$\begin{cases} \text{FOC w.r.t } g': & \beta e^Z \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\Big[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta',l',\mathbf{S})\}}\,\tilde{\lambda}(n',\mathbf{S}')\left[\omega'\theta'\big(R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') - \psi_2'\big) + 1 - \theta' - l'\right]\Big] \\ & \quad + \tilde{\lambda}(n,\mathbf{S})\big(q(\theta',l',\mathbf{S})l' - (\beta e^Z(1-\theta') + Q(\mathbf{S})\theta') - \psi'(g')\big) = 0 \\ \text{FOC w.r.t } \theta': & \beta e^Z \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\Big[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta',l',\mathbf{S})\}}\,\tilde{\lambda}(n',\mathbf{S}')\left[\omega'\left(R^K(\mathbf{S}') + (1-\delta)Q(\mathbf{S}') - \psi_2'\right) - 1\right]\Big] \\ & \quad + \tilde{\lambda}(n,\mathbf{S})\big(q_\theta(\theta',l',\mathbf{S})l' + \beta e^Z - Q(\mathbf{S})\big) = 0 \end{cases}$$

Multiplying the second equation by $1-\theta'(n,\mathbf{S})$ and taking the difference between the two yields:

$$\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\left[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta',l',\mathbf{S})\}}\,(1+\lambda(n',\mathbf{S}'))\,R^l(n,\mathbf{S},\mathbf{S}')\right] = 1 + \lambda(n,\mathbf{S}) \tag{50}$$

This is equivalent to

$$\begin{aligned} &\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\left[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta',l',\mathbf{S})\}}\,(1+\lambda(n',\mathbf{S}'))\right]\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\left[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta',l',\mathbf{S})\}} R^l(n,\mathbf{S},\mathbf{S}')\right] \\ &\quad + \operatorname{Cov}\left(\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta',l',\mathbf{S})\}}\,(1+\lambda(n',\mathbf{S}')),\, \mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta',l',\mathbf{S})\}} R^l(n,\mathbf{S},\mathbf{S}')\right) = 1 + \lambda(n,\mathbf{S}) \end{aligned} \tag{51}$$

Similarly, multiplying the second equation by $\theta'(n,\mathbf{S})$ and taking the difference between the two yields:

$$\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\left[\mathbf{1}_{\{\omega' \geq \underline{\omega}(\theta',l',\mathbf{S})\}}\,(1+\lambda(n',\mathbf{S}'))\,R^s(n,\mathbf{S})\right] = 1 + \lambda(n,\mathbf{S}) \tag{52}$$

Equations (51) and (52) imply

$$\tilde{\mathbb{E}}_{\omega',\mathbf{S}'|\mathbf{S}}\left[R^l(n,\mathbf{S},\mathbf{S}') - R^s(n,\mathbf{S})\right] = \frac{\widetilde{\mathrm{Cov}}\left(R^l(n,\mathbf{S},\mathbf{S}'), 1+\lambda(n',\mathbf{S}')\right)}{\tilde{\mathbb{E}}_{\omega',\mathbf{S}'|\mathbf{S}}\left[1+\lambda(n',\mathbf{S}')\right]} \tag{53}$$

where I used the following notation:

$$\tilde{\mathbb{E}}_{\omega',\mathbf{S}'|\mathbf{S}}(X(\mathbf{S}')) = \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\big[\mathbf{1}_{\{\omega'\geq\underline{\omega}(\theta',l',\mathbf{S}')\}}X(\mathbf{S}')\big]$$

$$\widetilde{\mathrm{Cov}}_{\omega',\mathbf{S}'|\mathbf{S}}(X(\mathbf{S}'),Y(\mathbf{S}')) = \mathrm{Cov}_{\omega',\mathbf{S}'|\mathbf{S}}\left[\mathbf{1}_{\{\omega'\geq\underline{\omega}(\theta',l',\mathbf{S}')\}}X(\mathbf{S}'), \mathbf{1}_{\{\omega'\geq\underline{\omega}(\theta',l',\mathbf{S}')\}}Y(\mathbf{S}')\right]$$

A.4. Numerical Algorithm

State variables. In this section I provide details on the numerical algorithm employed to solve the quantitative model. It will prove convenient to use as a state variable the ratio of cash-on hands, net of capital sales, to long-term assets defined as

$$x \equiv \frac{R^K(\mathbf{S})\omega A^l + A^s - B}{\omega A^l} = R^K(\mathbf{S}) + \frac{(1-\theta)-l}{\omega\theta} \tag{54}$$

instead of the ratio of networth, including capital sales, to long-term assets $n = R^K(\mathbf{S}) + (1-\delta)Q(\mathbf{S}) + \frac{1-\theta-l}{\omega\theta}$.

At the beginning of each period, the exogenous aggregate and idiosyncratic shocks, (Z,ω_i), are realized. The aggregate state is given by $\mathbf{S} = (Z, \mu(x,\omega A^l))$, where $\mu(x,\omega A^l)$ is the joint distribution of cash-on hands and effective long-term capital of active banks.

Conjectured law of motions. To numerically solve for the equilibrium, I adopt a bounded rationality approach in the spirit of Krusell and Smith (1998). I assume that agents uses as state variables only a set of statistics representing the distribution of banks in the economy. In the model, the marginal product of capital and the equilibrium asset price depend on the perceived policy for the economy's aggregate capital stock, K. Following Morelli *et al.* (2022), in order to avoid inaccuracies, I include as an aggregate state variable an auxiliary variable $\hat{K}$, which denotes the aggregate capital stock that banks carry over to the following period. I assume that agents use the aggregate variables $\hat{\mathbf{S}} = (Z,\hat{K})$ to forecast relevant endogenous objects, namely the marginal product $R^K(\hat{\mathbf{S}})$ and the asset price $Q(\hat{\mathbf{S}})$. Given $\hat{K}$, the marginal product of capital is simply

$$R^K(\hat{\mathbf{S}}) = \alpha\hat{K}^{\alpha-1} \tag{55}$$

For the price of capital, $Q(\mathbf{S})$, I consider the following forecasting rule:

$$\hat{\Gamma}_Q(\hat{\mathbf{S}}) = e^{\lambda_{Q,0}+\lambda_{Q,1}\hat{K}+\lambda_{Q,2}Z} \tag{56}$$

Similarly, for next-period capital stock $\hat{K}'$ I consider the following conjectured low of motion:

$$\hat{\Gamma}_{\hat{K}'}(\hat{\mathbf{S}}) = e^{\lambda_{\hat{K}',0}+\lambda_{\hat{K}',1}\hat{K}+\lambda_{\hat{K}',2}Z} \tag{57}$$

Bank problem. The bank problem can be expressed as follows:

$$\nu^c(x,\hat{\mathbf{S}}) = \max_{div,g'\geq 0,\theta'\in[0,1]l'\leq \bar{l}} div + \beta e^Z \mathbb{E}_{\omega,\hat{\mathbf{S}}'|\hat{\mathbf{S}}}\left[\nu(x',\hat{\mathbf{S}}')\omega'\right]\theta' g' \tag{58}$$

s.t.

$$x' = R^K(\hat{\mathbf{S}}) + \frac{(1-\theta')-l'}{\omega'\theta'}$$

$$div + \left[\beta e^Z(1-\theta') + Q(\hat{\mathbf{S}})\theta'\right] g' + \psi(g') = x + (1-\delta)Q(\hat{\mathbf{S}}) + q(\theta',l',\hat{\mathbf{S}})l'g'$$

$$div \geq 0$$

$$R^K(\hat{\mathbf{S}}) = \alpha \hat{K}^{\alpha-1}$$

$$Q(\hat{\mathbf{S}}) = \hat{\Gamma}_Q(\hat{\mathbf{S}})$$

$$\hat{K}' = \hat{\Gamma}_{\hat{K}'}(\hat{\mathbf{S}})$$

The algorithm is made of two steps.

First step. Given conjectured coefficients for the law of motions $\hat{\Gamma}_Q$ and $\hat{\Gamma}_{\hat{K}'}$, solve the bank problem (58) in the following steps

1. Guess the bank's value functions $\nu^c(x,\hat{\mathbf{S}})$ for every point x in the state space and guess the price of debt $q(\theta',l',\hat{\mathbf{S}})$ for every choice of l'.

2. Compute policy functions $\left\{g'(x,\hat{\mathbf{S}}),\theta'(x,\hat{\mathbf{S}}),l'(x,\hat{\mathbf{S}})\right\}$ by solving problem (58). Update value function accordingly. Store policy functions for the repayment decisions $\left\{\iota^c(x,\hat{\mathbf{S}}),\iota^e(x,\hat{\mathbf{S}})\right\}$, where the latter refers to the case where the bank exits exogenously.

3. Update the debt price function using

$$q(\theta', l', \hat{\mathbf{S}}) = \beta e^{Z} \mathbb{E}_{\omega', \hat{\mathbf{S}}' | \hat{\mathbf{S}}} \Bigg\{ 1 - \Big[1 - \Big[(1-\sigma)\iota^{c}(x', \hat{\mathbf{S}}') + \sigma \iota^{e}(x', \hat{\mathbf{S}}') \Big] \Big] (1-\pi_b) \left[1 - \min\left\{ \frac{\gamma(1-\delta)Q(\hat{\mathbf{S}}')\omega'\theta'}{l'}, 1 \right\} \right] \Bigg\} \tag{59}$$

$$x'(\theta', l', \hat{\mathbf{S}}) = R^{K}(\hat{\mathbf{S}}) + \frac{(1-\theta') - l'}{\omega'\theta'}$$

4. Iterate until convergence of $\nu^{c}(x, \hat{\mathbf{S}})$ and $q(\theta', l', \hat{\mathbf{S}})$.

Second step. I simulate the economy for T periods using the non-stochastic simulation method of Young (2010), which allows me to reduce sampling error from simulating individual firms. At each step I solve for the equilibrium level of aggregate capital next period, $K'(\hat{\mathbf{S}})$, and for the price of capital, $Q(\hat{\mathbf{S}})$. Finally, I use the simulated objects to update the coefficients of the conjectures, $\hat{\Gamma}_Q$ and $\hat{\Gamma}_{\hat{K}'}$. Repeat the first step until convergence of the coefficients.

B. Data Appendix

This section complements the evidence presented in Section 5 and show details on data computations

B.1. Data Sources

Call Reports. Data from Call Reports are obtained from WRDS for years between 1987 and 2021. For 2022 I collect the data directly from the Board of Governors' National Information Center database. Call Reports contain balance-sheet and income information for the entire universe of depository institutions in the US. I follow the approach of Paul (2023) to aggregate bank subsidiaries at the BHC-level. I only include observations such that the sum of subsidiaries' assets is equal to at least 95 percent of the BHC's total assets based on the Y-9C data. I further restrict the sample to only include institutions with a share of loans to total assets greater than 0.25.

Y-9C Filings. Data from Y-9C Filings are collected from WRDS. I use total assets (bhck 2170) to check the quality of the aggregation process from individual commercial banks to Bank Holding Companys.

Interest Rate Shocks. My baseline measure of monetary policy shocks is the series from Gorodnichenko and Weber (2016), used also by Ottonello and Winberry (2020). For robustness, I also use the sequence of shocks from Nakamura and Steinsson (2018).

B.2. Maturity Gap Definition

Starting from the second quarter of 1997, Call Reports includes information on the composition of assets and liabilities by maturity. Analogously to Paul (2023), I define the maturity gap of bank i and time t as:

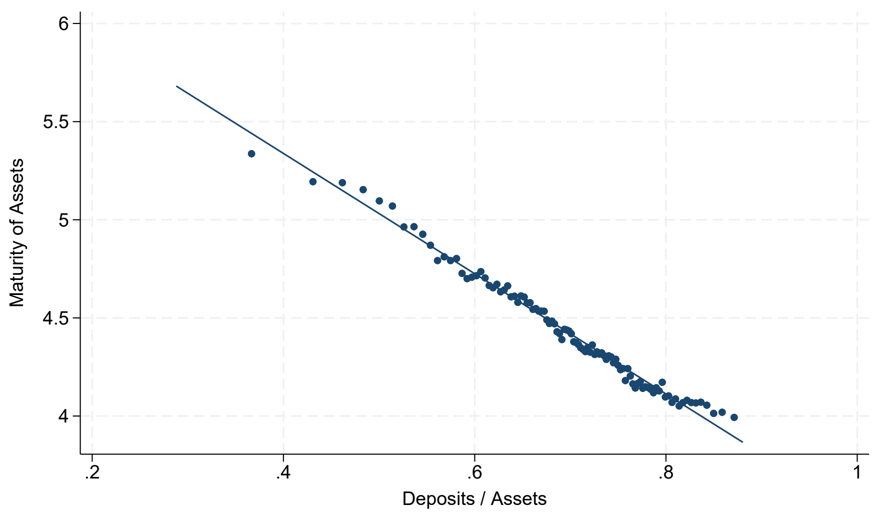
$$\text{Maturity Gap}_{i,t} = \sum_{j \in \mathcal{A}} m_j \frac{\text{Asset}_{j,i,t}}{\sum_{j \in \mathcal{A}} \text{Asset}_{j,i,t}} - \sum_{j \in \mathcal{L}} m_j \frac{\text{Liabilities}_{j,i,t}}{\sum_{j \in \mathcal{L}} \text{Liabilities}_{j,i,t}}$$

where $\mathcal{A}$ and $\mathcal{L}$ are the sets of assets and liabilities for which the breakdown by maturity is available. Asset categories are residential mortgage loans, all other loans, Treasuries and agency debt, mortgage-backed securities (MBS) secured by residential mortgages, and other MBS. Each category, except Other MBS, is broken down into six repricing bins: 0 to 3 months, 3 to 12 months, 1 to 3 years, 3 to 5 years, 5 to 15 years, and over 15 years. The Other MBS category only includes two bins: 1.5 years and 5 years.

Following English *et al.* (2018), I use the midpoint of each range as the maturity, m_j, of the corresponding category. Additionally, following Drechsler *et al.* (2021), I assign a maturity of five years to subordinated debt and zero maturity to cash, Fed funds, transaction and saving deposits.

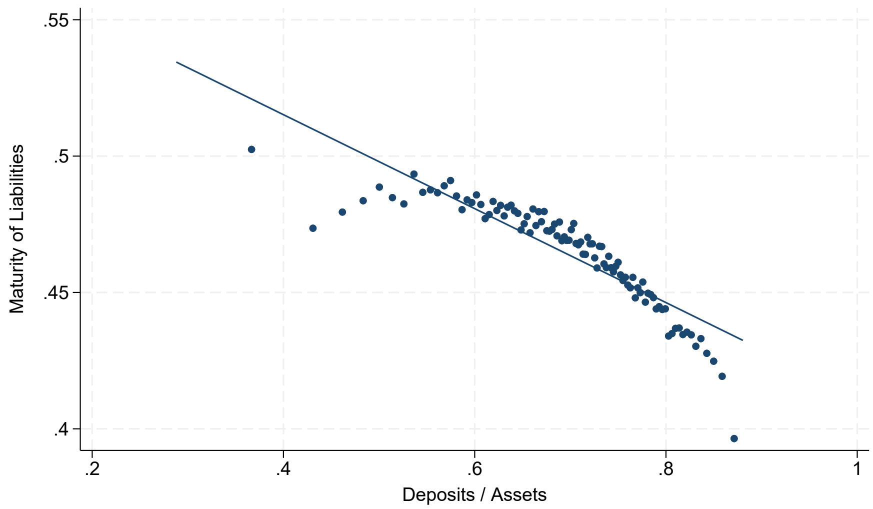
B.3. Additional Empirical Results

Figure B.1: Maturity of Assets and Deposit-to-Asset Ratio



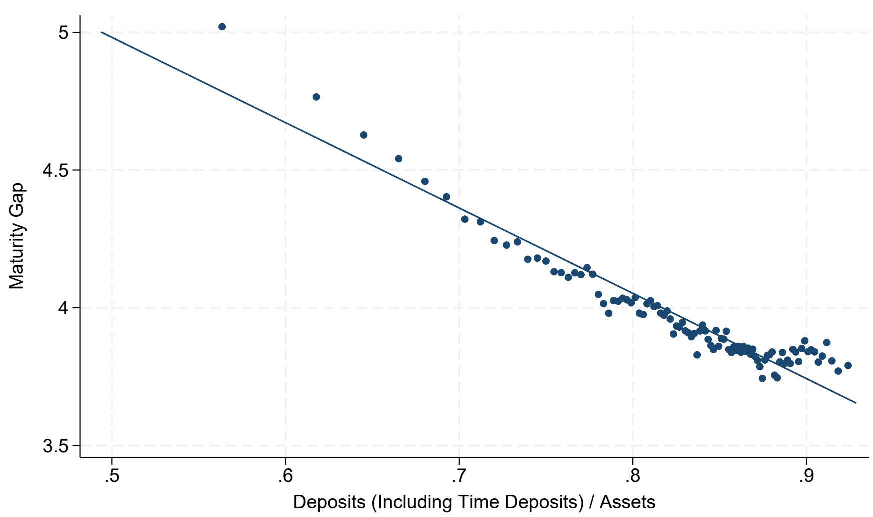
Notes: Cross-sectional binned scatterplot of maturity of assets on deposit-to-asset ratio, where deposits are defined as the sum of checking and saving deposits. The plot residualizes the maturity of assets on bank size, share of wholesale funding in total liabilities, lagged ROA, lagged nonperforming loan ratio, and bank- and time-fixed effects. It then adds back the mean of maturity of assets to maintain centering. Data are from US Call Reports

Figure B.2: Maturity of Liabilites and Deposit-to-Asset Ratio



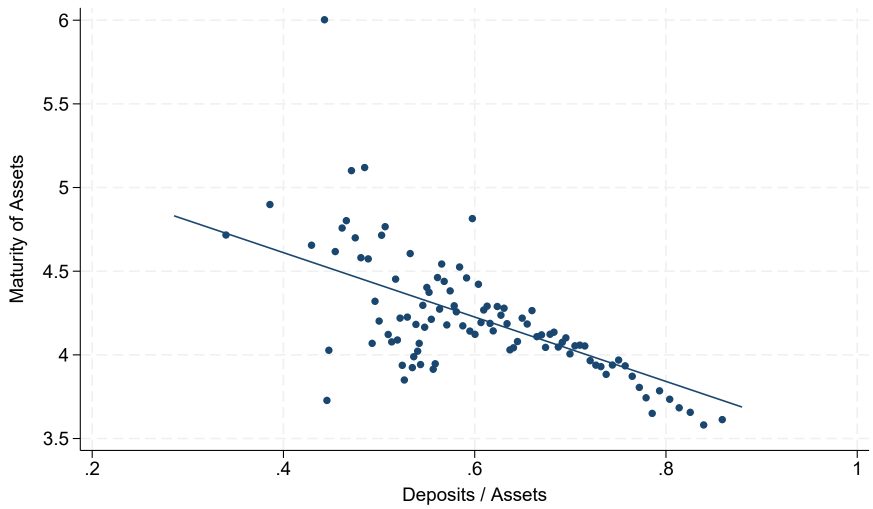
Notes: Cross-sectional binned scatterplot of maturity of liabilities on deposit-to-asset ratio, where deposits are defined as the sum of checking and saving deposits. The plot residualizes the maturity of liabilities on bank size, share of wholesale funding in total liabilities, lagged ROA, lagged nonperforming loan ratio, and bank- and time-fixed effects. It then adds back the mean of maturity of liabilities to maintain centering. Data are from US Call Reports

Figure B.3: Maturity Gap and Deposit-to-Asset Ratio: Including Time Deposits



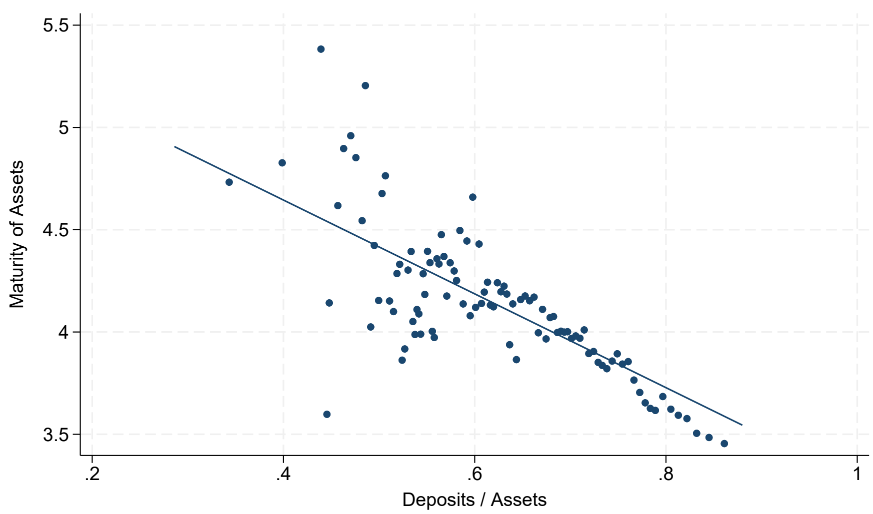
Notes: Cross-sectional binned scatterplot of the maturity gap on the deposit-to-asset ratio, where deposits are now given by total bank deposits, i.e. the sum of checking, savings and time deposits. The plot residualizes the maturity gap on bank size, share of wholesale funding in total liabilities, lagged ROA, lagged nonperforming loan ratio, and bank- and time-fixed effects, and then adds back the mean of the maturity gap to maintain centering. Data are from US Call Reports.

Figure B.4: Maturity Gap and Deposit-to-Asset Ratio: Weighted by Assets



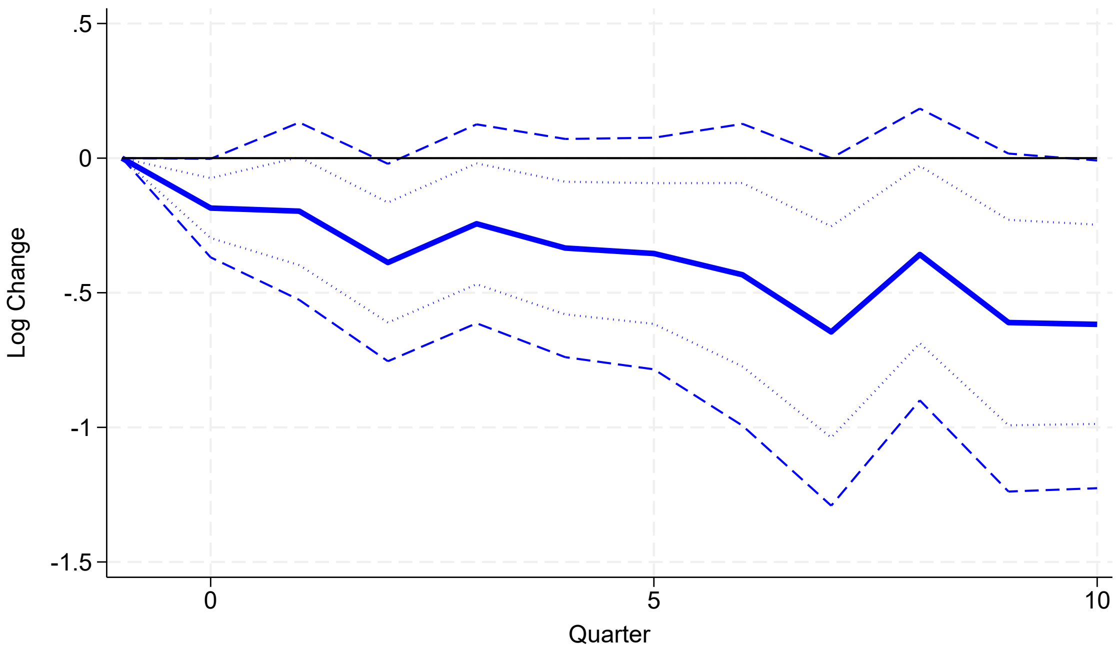
Notes: Cross-sectional binned scatterplot of the maturity gap on the deposit-to-asset ratio, weighted by bank assets. The plot residualizes the maturity gap on bank size, share of wholesale funding in total liabilities, lagged ROA, lagged nonperforming loan ratio, and bank- and time-fixed effects, and then adds back the mean of the maturity gap to maintain centering. Data are from US Call Reports.

Figure B.5: Maturity Gap and Deposit-to-Asset Ratio: Weighted by Deposits



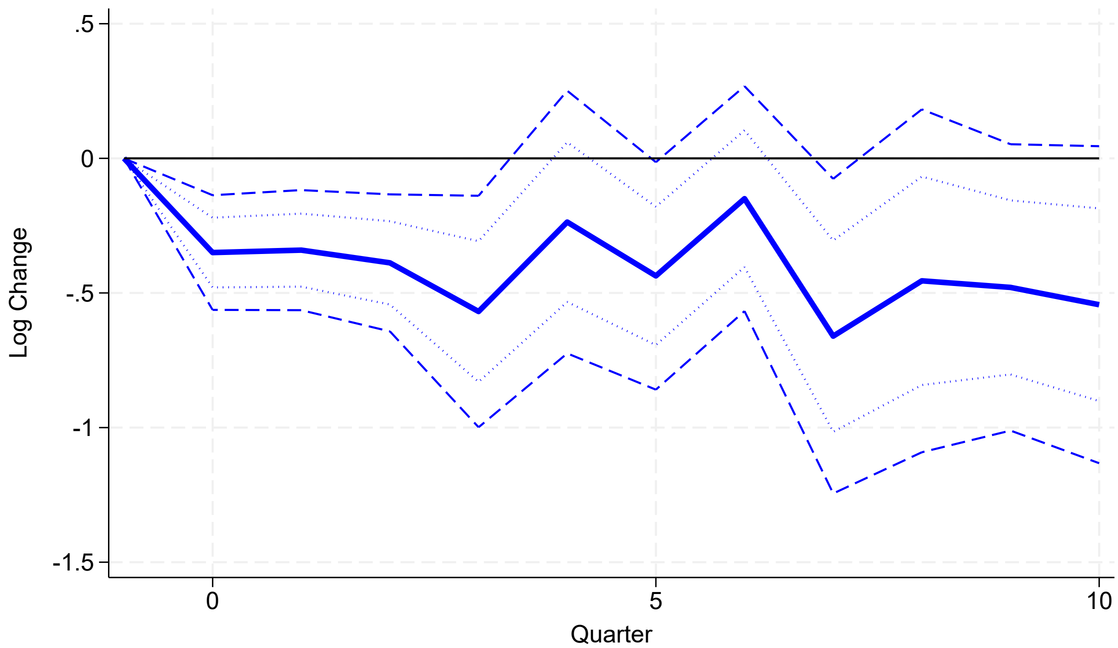
Notes: Cross-sectional binned scatterplot of the maturity gap on the deposit-to-asset ratio, weighted by bank deposits. The plot residualizes the maturity gap on bank size, share of wholesale funding in total liabilities, lagged ROA, lagged nonperforming loan ratio, and bank- and time-fixed effects, and then adds back the mean of the maturity gap to maintain centering. Data are from US Call Reports.

Figure B.6: Heterogeneous Dynamic Response of Maturity Gap to Monetary Shocks: Controlling for Interaction with Total Assets



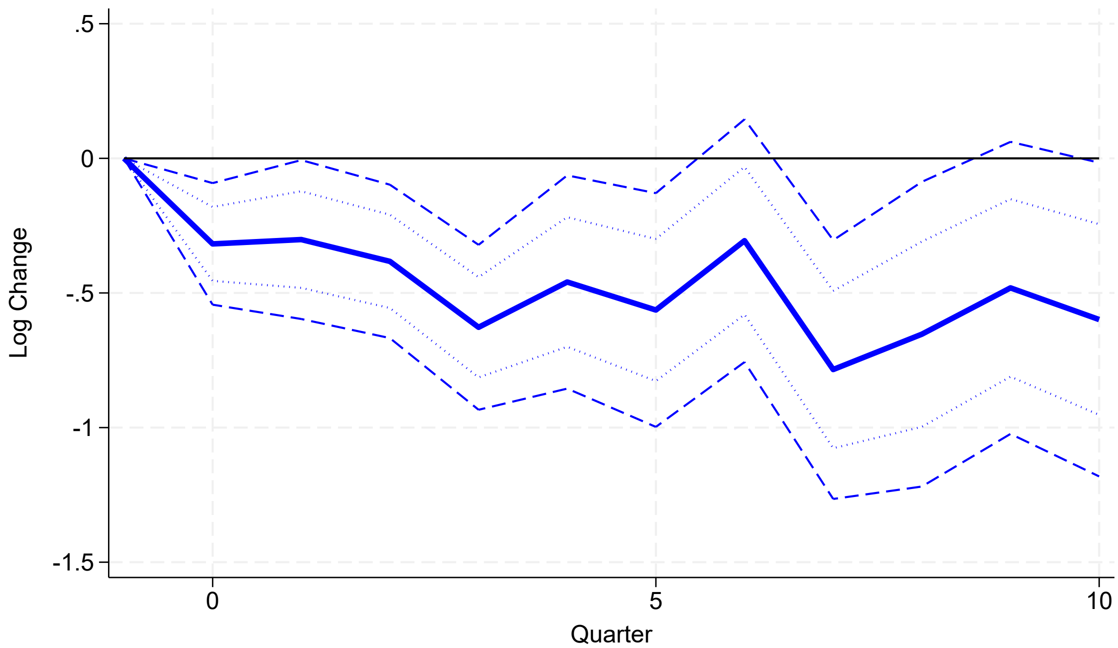
Notes: Dynamics of the coefficient on monetary shocks over time. Reports point estimate, 90% confidence intervals (dashed lines), and one-standard-error bands (dotted lines) for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h(l_{i,t-1} - \mathbb{E}_i[l_{i,t}])\Delta R_t + \delta^h(log(A_{i,t-1}) - \mathbb{E}_i[log(A_{i,t-1})])\Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \alpha_i^h + \alpha_t^h + \epsilon_{i,t}$, where $A_{i,t-1}$ denotes total assets. Covariates included in $\mathbf{X}_{i,t-1}$ are size, market leverage, wholesale funding as a share of total liabilities, the nonperforming ratio, ROE, as well as interaction of the interest-rate changes with size and interest expense beta. Confidence intervals based on two-way clustered standard errors at bank and time levels.

Figure B.7: Heterogeneous Dynamic Response of Maturity Gap to Monetary Shocks: Nakamura-Steinsson Shocks



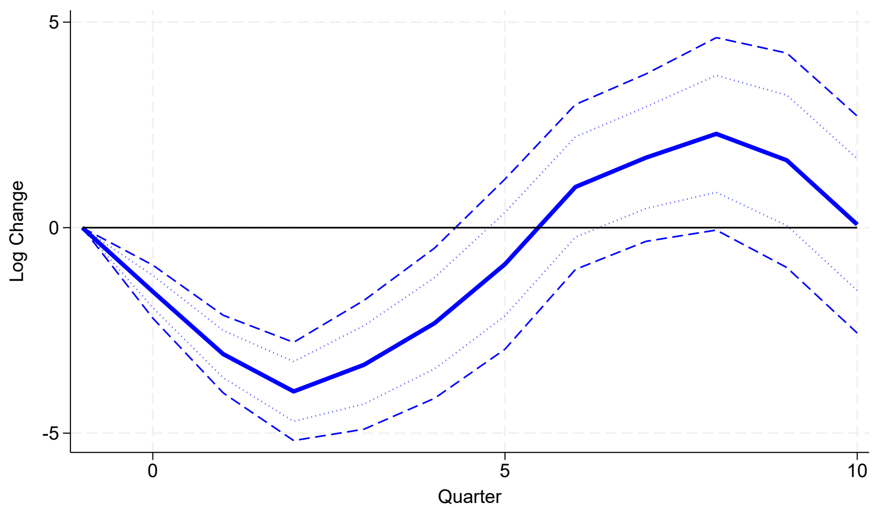
Notes: Dynamics of the coefficient on the interaction term between monetary shocks and deposit-to-asset ratio. The figure reports the point estimates, 90% confidence intervals (dashed lines), and one-standard-error bands (dotted lines) for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h(l_{i,t-1} - \mathbb{E}_i[l_{i,t}])\Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \alpha_i^h + \alpha_t^h + \epsilon_{i,t}$. Interest-rate change, ΔR_t, is instrumented using monetary policy shocks from Nakamura and Steinsson (2018). Covariates included in $\mathbf{X}_{i,t-1}$ are log of total assets, deposit-to-asset ratio, wholesale funding as a share of total liabilities, ROA and the nonperforming ratio. Confidence intervals based on two-way clustered standard errors at bank and time levels.

Figure B.8: Heterogeneous Dynamic Response of Maturity Gap to Monetary Shocks: Nakamura-Steinsson Shocks, 1997q2-2020q4



Notes: Dynamics of the coefficient on the interaction term between monetary shocks and deposit-to-asset ratio. The figure reports the point estimates, 90% confidence intervals (dashed lines), and one-standard-error bands (dotted lines) for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h(l_{i,t-1} - \mathbb{E}_i\left[l_{i,t}\right])\Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \alpha_i^h + \alpha_t^h + \epsilon_{i,t}$, estimated over the full sample (1997q2-2020q4). Interest-rate change, ΔR_t, is instrumented using monetary policy shocks from Nakamura and Steinsson (2018). Covariates included in $\mathbf{X}_{i,t-1}$ are log of total assets, deposit-to-asset ratio, wholesale funding as a share of total liabilities, ROA and the nonperforming ratio. Confidence intervals based on two-way clustered standard errors at bank and time levels.

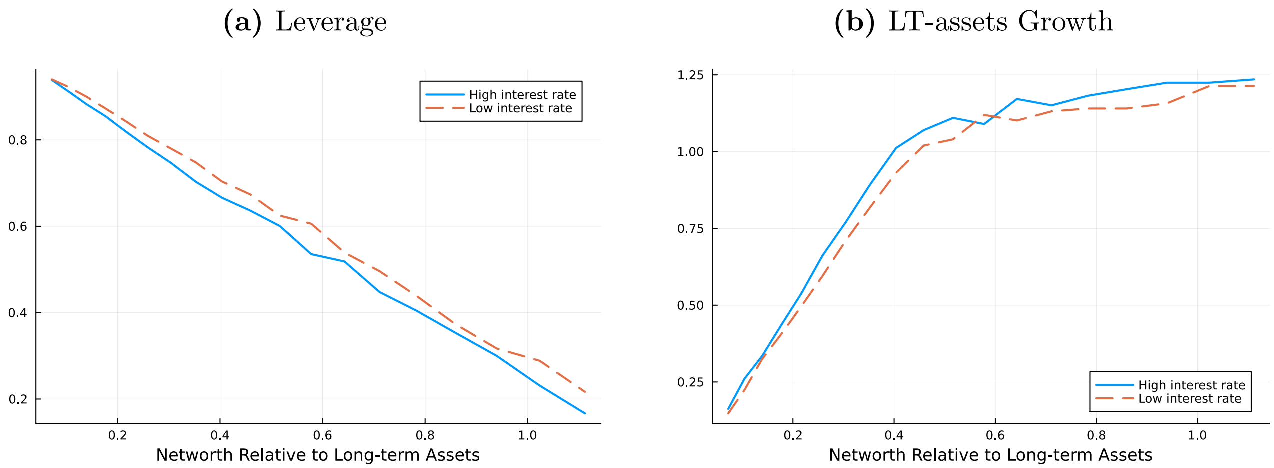
Figure B.9: Dynamics of Average Response of Maturity Gap to Monetary Shocks



Notes: Dynamics of the coefficient on monetary shocks over time. Reports point estimate, 90% confidence intervals (dashed lines), and one-standard-error bands (dotted lines) for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h \Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \sum_{\tau=1}^{4} \mathbf{\Gamma}_{2,\tau}^h \mathbf{Y}_{t-\tau} + \alpha_i^h + \epsilon_{i,t}$. Covariates included in $\mathbf{X}_{i,t-1}$ are size, market leverage, wholesale funding as a share of total liabilities, the nonperforming ratio and ROE. Aggregate controls in $\mathbf{Y}_{t-\tau}$ include GDP growth, the unemployment rate, inflation and the change in the VIX index. Confidence intervals based on two-way clustered standard errors at bank and time levels.

C. Additional Model Results

Figure C.1: Policy Functions for High and Low Interest Rate States



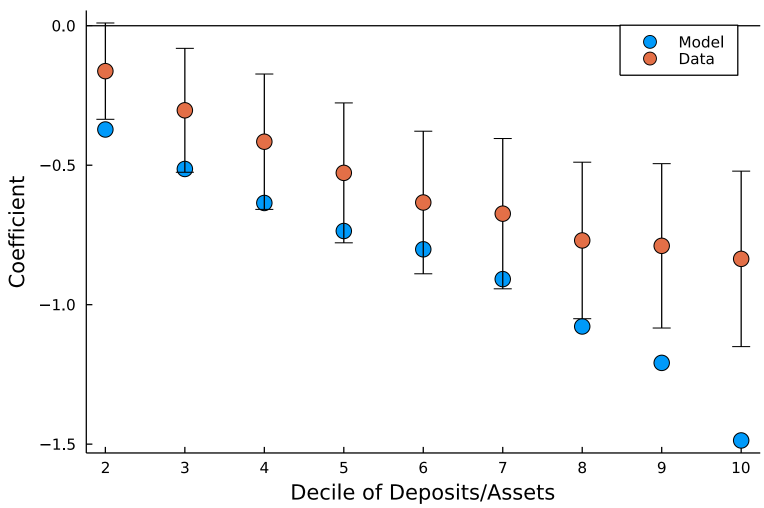
Notes: Panel (a) plots the policy function for for leverage, $l'(n, \mathbf{S})$ (solid line), and for the growth rate of long-term assets, $\theta'(n, \mathbf{S})g'(n, \mathbf{S})$ (dashed line), as a function of the ratio of networth to long-term assets for high (solid line) and low (dashed line) interest rate states.

Table C.1: Untargeted Cross-sectional Moments

Statistic	Data	Model	Source
Balance Sheet			
CS Sd. of Deposits/Assets	0.09	0.12	Call Reports
CS Sd. of log(Assets)	1.44	1.17	Call Reports
Bank Returns			
Avg. ROA	1.01	1.04	Call Reports
Avg. ROE	1.07	1.1	Call Reports

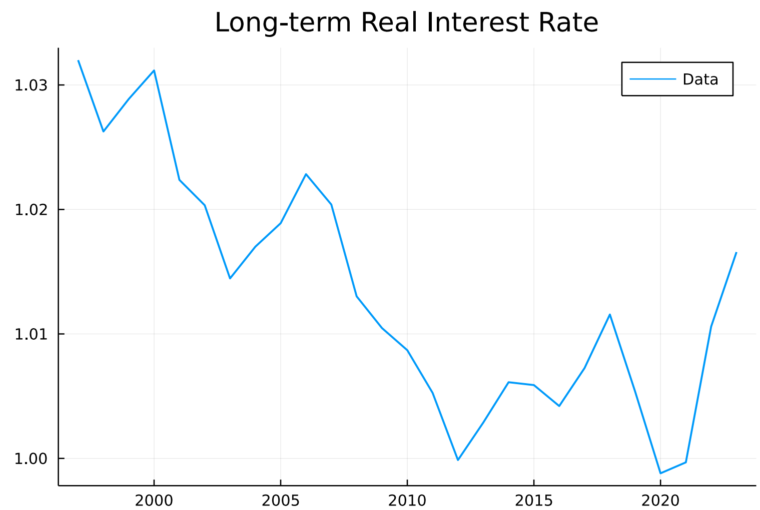
Notes: This table shows a set of cross-sectional data moments that are not targeted in my calibration and their model counterparts computed by simulating a panel of banks from the calibrated model.

Figure C.2: Maturity Gap and Deposit-to-Asset Ratio: Non-linear Relationship



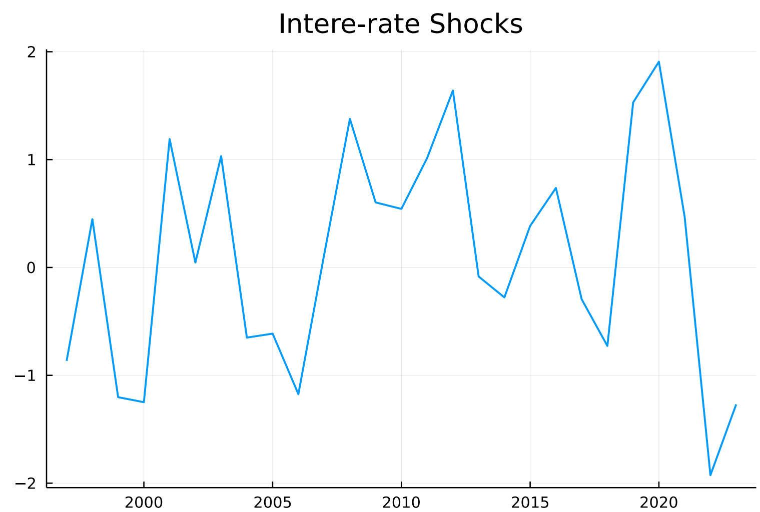
Notes: This table reports the estimated coefficients from regression (22). The data regression includes additional controls, time and year fixed effects. In the model, I include aggregate state variables as controls in the regression. Confidence intervals are at the 95% level. In the data standard errors are clustered at the bank level.

Figure C.3: Empirical Interest-Rate Path



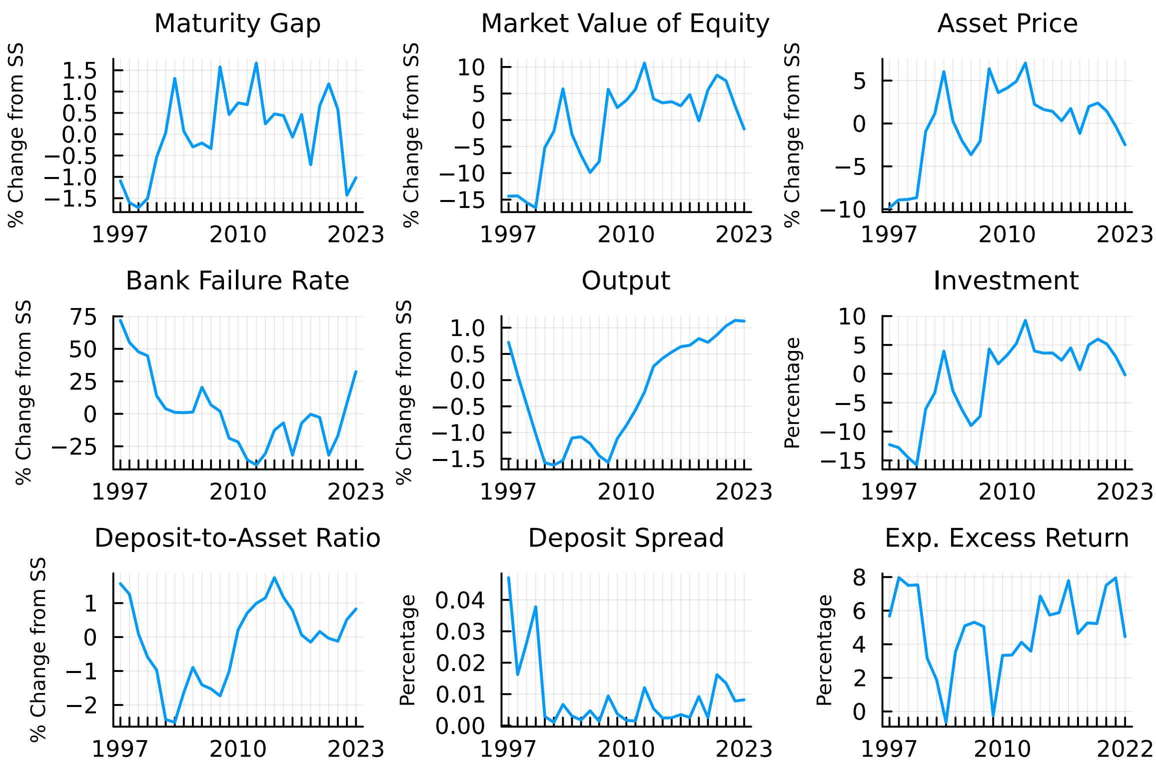
Notes: This figure plots the empirical path for the long-term real interest rate, measured as the inflation-adjusted interest rate on 10-year Treasury securities with a constant maturity.

Figure C.4: Model-implied Sequence of Shocks



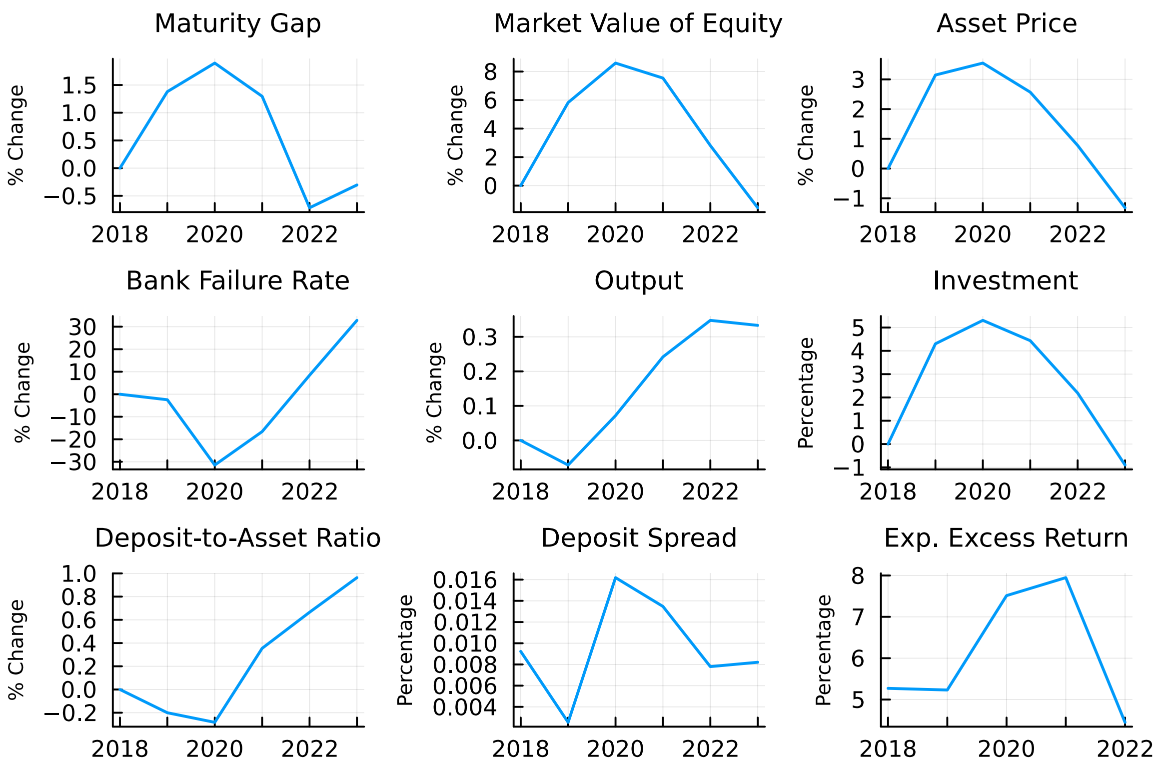
Notes: This figure plots the path of interest-rate shocks, $[\epsilon_{1997}, \epsilon_{1998}, ..., \epsilon_{2023}]$, recovered from the model. These shocks are such that, at each point in time, the model-implied 10-year real interest rate matches its empirical counterpart.

Figure C.5: Model Responses to Interest Rate Path



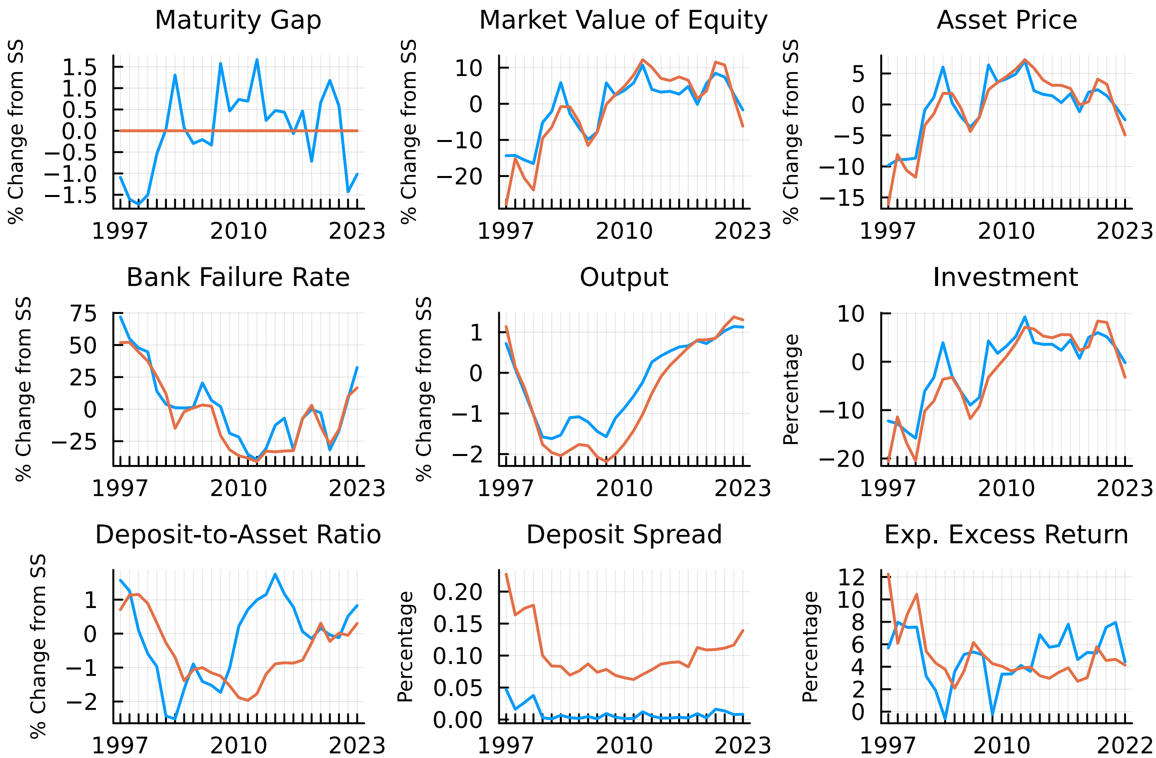
Notes: This figure plots model-implied dynamics of relevant variables obtained by feeding to the model the empirical interest rate path. Deposit spread and expected excess return are in percentage points. All other variables are expressed as percentage deviations from their steady-state averages. Deposit spread is the default premium on bank debt computed as the difference between the debt price and the risk-free rate. The expected excess return for bank i is defined as $\mathbb{E}_t R^l_{i,t+1} - R^s_{i,t+1}$, as in equation (12).

Figure C.6: Model Responses to Interest Rate Path



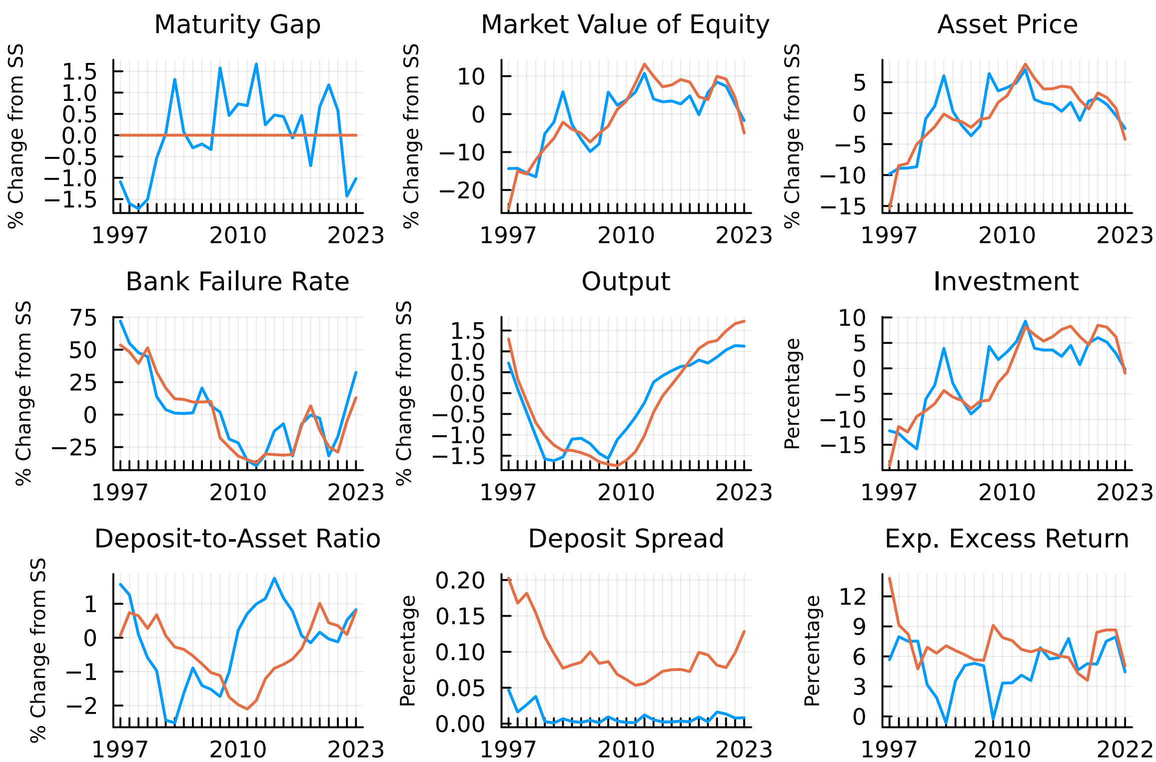
Notes: This figure plots model-implied dynamics of relevant variables obtained by feeding to the model the empirical interest rate path. Deposit spread and expected excess return on bank equity are in percentage points. All other variables are expressed as percentage deviations from their initial vale in 2018. Deposit spread is the default premium on bank debt computed as the difference between the debt price and the risk-free rate. The expected excess return for bank i is defined as $\mathbb{E}_t R^l_{i,t+1} - R^s_{i,t+1}$, as in equation (12).

Figure C.7: Model Responses to Interest Rate Path: Baseline vs No Short-Term Bonds



Notes: This figure plots model-implied dynamics of relevant variables obtained by feeding to the model the empirical interest rate path. The blue lines refer to the baseline model. The red lines to the model without short-term bonds. Deposit spread and the expected excess return are in percentage points. All other variables are expressed as percentage deviations from their steady-state averages. Deposit spread is the default premium on bank debt computed as the difference between the debt price and the risk-free rate. The expected excess return for bank i is defined as $\mathbb{E}_t R^l_{i,t+1} - R^s_{i,t+1}$, as in equation (12).

Figure C.8: Model Responses to Interest Rate Path: Baseline vs Fixed Portfolio Shares



Notes: This figure plots model-implied dynamics of relevant variables obtained by feeding to the model the empirical interest rate path. The blue lines refer to the baseline model. The red lines to the model with fixed portfolio shares. Deposit spread and the expected excess return are in percentage points. All other variables are expressed as percentage deviations from their steady-state averages. Deposit spread is the default premium on bank debt computed as the difference between the debt price and the risk-free rate. The expected excess return for bank i is defined as $\mathbb{E}_t R^l_{i,t+1} - R^s_{i,t+1}$, as in equation (12).