Banks and the Macroeconomic Transmission of Interest-Rate Risk*

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Abstract

I study the role of financial intermediaries in the transmission of interest-rate risk. I develop a quantitative model where banks can invest in assets of different durations and choose optimally their exposure to interest-rate fluctuations. I embed this portfolio problem in a heterogeneous-banks framework with financial frictions and endogenous default. The model predicts that in periods of loose monetary policy banks face weaker financial constraints. As a result, they become more tolerant of interest-rate risk and invest more extensively in long-duration assets. However, when the economy undergoes a sudden monetary tightening, this portfolio shift amplifies contractions in asset prices, credit, and output. I validate the model by showing that it can reproduce aggregate and cross-sectional patterns related to banks' maturity mismatches, the level of the interest rate and leverage. A quantitative application to the 2022 monetary tightening shows that a lengthening of duration in periods of low interest rates gives rise to significant financial amplification. A liquidity requirement that restricts banks' investment in long-term assets makes the economy less vulnerable to sudden interest-rate raises.

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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, is at the heart of banks' exposure 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 significant attention with the monetary tightening of 2022. A rapid series 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 reignited interest in understanding the financial sector's role 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 where banks can invest in assets of different durations, leading to endogenous exposure to interest-rate risk. The model predicts that in periods of low interest rates banks optimally shift investment towards long-term assets. This change in portfolio composition makes the economy more vulnerable to surprise increases in interest rates, which result in sharp asset-price declines and credit contractions. In the second part of the paper, I document empirical patterns related to banks' duration profiles, which I use to validate the predictions of the model. I provide evidence of a negative co-movement between maturity mismatch and interest rates at the aggregate level, and evidence of a negative correlation between maturity mismatch and leverage at the cross-sectional level. Finally, I conduct a quantitative application to the 2022 tightening episode. I show that endogenous fluctuations in banks' duration profiles can be an important source of amplification in the aggregate transmission of interest-rate shocks.

The paper begins by laying out an economy populated by heterogeneous banks that invest in productive assets subject to financial frictions. Agents face aggregate risk stemming from shocks to the household's discount factor, leading to exogenous fluctuations in the interest rate. Banks additionally face idiosyncratic shocks and are ex-post heterogeneous. The model builds on two key blocks. The first, and most novel one, is that banks can invest in two types of assets. One is long-lived and slowly depreciates over time; the other fully depletes at the end of each period. The price of the two assets is endogenous and inversely related to the level of the interest rate. Due to its durability, long-term investment introduces a duration mismatch between assets and liabilities, exposing banks to asset-price fluctuations triggered by interest-rate shocks. In contrast, the short-term asset, while less efficient, is safe because it avoids maturity transformation. Crucially, the option to choose between these two assets makes interest-rate-risk exposure endogenous. The second building block is that banks face balance-sheet constraints and require a risk-premium to hold risky, long-term capital. Financial frictions arise from two sources: (i) banks cannot issue equity and must rely on internal resources and debt to finance investment, and (ii) banks lack commitment and can default on their obligations. Such frictions give rise to a financial accelerator mechanism. 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.

The core feature of the model lies in its ability to generate a negative co-movement between the level of the interest rate and banks' risk exposure. During periods of low interest rates, banks invest more extensively in long-duration assets, taking on additional interest-rate risk. The reason is that interest-rate fluctuations impact the severity of financial frictions. Capital gains experienced by banks in periods of loose monetary policy ease balance-sheet constraints and endogenously lead to a lengthening of maturities through a reduction in risk-premia. Conversely, a sudden monetary tightening depletes net worth and induces banks to shorten maturity through an increase in risk-premia. Via a similar mechanism, the model also delivers testable implications about the cross-sectional relationship between bank leverage and duration. More constrained banks demand a higher risk premium for investing in long-duration assets and endogenously choose portfolios that are less exposed to interest-rate risk.

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 dataset is that it includes information on the composition of assets and liabilities by maturity, allowing me to compute a proxy for a bank's duration or maturity gap. Consistent with Di Tella and Kurlat (2021), I document the presence of a negative correlation between the level of the interest rate and the average maturity gap. Additionally, I provide a causal interpretation using identified monetary policy shocks. Consistent with the model mechanism, I show that an unexpected monetary tightening, i.e., an increase in interest rates, causes banks to lower their maturity gaps. Exploiting cross-sectional variation contained in Call Reports, I also explore heterogeneity in banks' responses to monetary shocks. To do so, I employ local projections in the spirit of Jorda (2005). I find that the effect of a surprise change in interest rates on maturity gap is muted for banks with higher market leverage at the time of the shock. Lastly, examining the banks' cross-section, I provide evidence supporting an inverse relationship between maturity gap and bank leverage, in line with the theoretical analysis.

With the empirical evidence at hand, I use the quantitative model to assess the relevance of banks' duration adjustments for the transmission of interest-rate shocks. I solve for the competitive equilibrium under aggregate uncertainty using global methods, implementing a numerical algorithm in the spirit of Krusell and Smith (1998). To validate the model, I estimate using simulated data the same local-projection specification as the one employed in the empirical analysis. I show that the untargeted response of banks' maturity mismatch to an unexpected rise in interest rate is in line with the data. Following the shock, banks reduce the duration gap, adjusting the composition of their balance sheets in favor of shorter-duration portfolios. The model also reproduces the heterogeneity in banks' responses to the shock. As in the data, the effect of interest-rate changes on duration is muted for more leveraged banks, because these banks invest a relatively larger share in short-term assets and are less exposed to interest-rate shocks. As a last validation exercise, I show that at the cross-sectional level the model is successful in matching the untargeted, negative correlation between leverage and duration gap.

To highlight the value of modeling endogenous duration, I conduct a quantitative application to the 2022 monetary tightening. I focus on this episode due to its significant repercussions on the U.S. financial sector. I feed the model with the empirical path of interest rates up to 2023 and then compare model-simulated dynamics with those observed in the data. The model generates a sharp decline in asset prices in response to the tightening, aligning well with the corresponding empirical pattern. Simulated dynamics also display a significant increase in bank failures and a contraction in credit. Importantly, the model accurately predicts a lengthening of duration in the two years preceding the tightening. Under the lens of the model, this increase in maturity mismatch is a response to the extraordinarily accommodative policy pursued during the COVID-19 pandemic years. The quantitative results support the narrative that a period of unusually low interest rates led financial intermediaries to grow particularly tolerant towards maturity mismatch and interest-rate risk.

To quantify the role of endogenous exposure to interest-rate risk, I compare the dynamics of the baseline model with those of a counterfactual economy where the share of long-term assets in bank portfolios is kept fixed. I find that the increase in duration prior to 2022 amplified the negative effect of the tightening, accounting for roughly one third of the decline in asset prices and one third of the increase in bank failures. Underlying this result is a powerful amplification mechanism driven by the interaction of balance-sheet constraints, portfolio composition, and asset-price dynamics. During periods of loose monetary policy, weakened financial constraints prompt banks to invest more extensively in long-duration assets. However, the increased exposure to interest-rate fluctuations in a low-rate environment makes banks' net worth highly vulnerable to asset devaluations triggered by abrupt rate hikes. Consequently, following an unexpected tightening, banks experience substantial erosion in equity capital. The ensuing balance-sheet losses force banks to cut back on investments, leading to a drop in asset prices and further exacerbating the decline in net worth.

Lastly, I use the model to study whether banking policies can mitigate aggregate fluctuations stemming from interest-rate risk. I consider a liquidity requirement that mandates banks to maintain a minimum share of short-term assets in their portfolios. I show that such a policy is successful in reducing exposure to interest-rate risk in periods of low interest rates when the liquidity requirement is binding. Outside of these periods, the policy can lead to an increase, rather than a decrease, of the overall maturity mismatch in the economy. In the context of the 2022 tightening, my quantitative findings indicate that implementing a liquidity requirement would have bolstered the financial sector's resilience to sudden interest-rate increases, effectively stabilizing both asset prices and output.

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 banks' duration 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 (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) and Wang (2022)). 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

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

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 duration 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 intervention, further departing from the efficient world of Di Tella and Kurlat (2021).

In terms of empirical contributions, I document a negative co-movement between interest rates and banks' maturity mismatch, consistent with Di Tella and Kurlat (2021). Additionally, my empirical analysis makes progress along three dimensions. First, I exploit identified monetary policy shocks to establish a causal effect of interest rates on banks' mismatch. Second, using cross-sectional variation contained in bank-level data I document heterogeneous responses to monetary shock, finding that these responses are muted for more leveraged banks. Third, at the cross-sectional level I provide systematic evidence of a negative relationship between leverage and maturity gap.

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 to this literature by developing a model that generates a distribution of duration gaps, leading to heterogeneous exposures to interest-rate risk. 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.

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 discusses its mechanisms and underlying assumptions. Section 4 illustrates the empirical analysis. Section 5 describes the calibration of the model, its validation against untargeted patterns and aggregate implications. Finally, Section 6 concludes.

3. Model

I consider a discrete-time, infinite-horizon economy populated by a risk-neutral, representative household, a set of heterogeneous banks, a representative final good producer, a representative capital good producer and a government. Banks are the focus of the model. They have access to a short- and a long-duration asset, and finance investment by borrowing from households subject to endogenous default risk.[2] The economy features a single source of aggregate risk: shocks to the household's discount factor, which give rise to exogenous fluctuations in the economy's real risk-free interest rate.

3.1. Technology

There is a continuum of perfectly competitive firms that produce the final good by combining three inputs: short-term capital, long-term capital (both rented from banks) and labor. Long-term capital depreciates geometrically at a rate $\delta \in (0,1)$, while short-term capital fully depreciates after one period. Final good producers use a constant returns to scale Cobb-Douglas production function:

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

[2] I follow a common approach in the literature by consolidating a banks and all the firms it lends to into a single entity. See for example Gertler and Karadi (2011), He and Krishnamurthy (2013), Gertler and Kiyotaki (2015), Begenau (2020) and Begenau and Landvoigt (2022)

This specification assumes that the two types of capital are perfect substitutes in production. Hence, their marginal product is the same and given by

$$MPK_t^s = MPK_t^l \equiv R_t^K = \alpha \left(\frac{K_t^s + K_t^l}{L_t} \right)^{\alpha - 1}$$

3.2. Banks

Assets. There is a constant, unitary measure of heterogeneous banks owned by the household. The objective of bank $i \in [0;1]$ is to maximize its value:

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

where β_t is the discount factor of the household at time t and $d_{i,t}$ are dividends issued by bank i in period t. Each bank can invest in claims to the long-term capital stock, $k_{i,t}^l$, and in claims to the short-term capital stock, $k_{i,t}^s$.[3] Long-term capital depreciates at rate $\delta \in (0,1)$ and is subject to an idiosyncratic quality shock, $\omega_{i,t}$.[4] I assume that this shock is i.i.d across time and banks, and follows a log-normal process, $\log \omega_t = \sigma_\omega \epsilon_{\omega,t}$, $\epsilon_t \sim N(0,1)$.

Holding costs. Investing in capital causes banks to incur each period a holding cost. I assume that this cost is (1) increasing in the share of long-term capital and (2) proportional to total capital:

$$h\left(\frac{k_{i,t}^l}{k_{it,}^s + k_{i,t}^l} \right) \left(k_{it,}^s + k_{i,t}^l \right)$$

One interpretation for the first assumption is that it captures illiquidity costs from holding long-term assets, as in Kozlowski (2021). Another interpretation is that it reflects a distinct value of investing in short-term safe claims, stemming for example from their use in backing demand deposits (Bansal and Coleman (1996)). In Appendix A.1 I provide a micro-foundation based on a collateral advantage of short-term assets in a setting where banks rely on intra-temporal, collateralized loans to finance idiosyncratic investment opportunities.[5] As to the second as-

[3] 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.

[4] 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)).

[5] Making the cost function increasing in the share of long-term capital allows me to obtain a well-defined interior optimum for the portfolio composition.

sumption, I consider a cost function that is proportional to total capital for tractability, to retain homogeneity of the bank's problem.

Bank's Payoff. Given a portfolio, $(k^s_{i,t}, k^l_{i,t})$, the per-period payoff from capital is given by

$$\Pi_t(k^s_{i,t}, k^l_{i,t}) = R^K_t(k^s_{i,t} + k^l_{i,t}) + (1-\delta)\omega_{i,t}k^l_{i,t}Q^l_t - h\left(\frac{k^l_{i,t}}{k^s_{it,} + k^l_{i,t}}\right)\left(k^s_{it,} + k^l_{i,t}\right) \tag{1}$$

where Q^l_t is the price of long-term capital determined by the capital production block and $\omega_{i,t}$ is the idiosyncratic capital quality shock.[6]

The payoff from capital is made of three terms; the first is related to the marginal product of capital, R^K_t, and, crucially, is independent of the realization of the interest-rate shock. This is because the marginal product is predetermined, given the amount of capital carried over from the previous period. The second term is the resale value of long-term capital which depends on the endogenous asset price, Q^l_t. As I explain when I set up the problem of capital good producers, the asset price depends on the realization of the interest-rate shock. The last term is the holding cost.

Equation (1) shows how the option to choose between short- and long-term capital makes interest-rate-risk exposure endogenous. Due to its durability, long-term capital exposes banks to asset-price fluctuations triggered by shocks to interest rates. In contrast, short-term capital does not have a resale value and is effectively a safe asset. Banks' exposure to interest-rate risk is therefore pinned down by the portfolio allocation between these two assets.

Balance Sheet. Bank i enters the period with a portfolio, $(k^s_{i,t}, k^l_{i,t})$, and net worth, $n_{i,t}$, and chooses how much capital of each type to buy for next period, $(k^s_{i,t+1}, k^l_{i,t+1})$. The bank finances investment with own net worth, $n_{i,t}$, and by issuing one-period, defaultable deposits, $b_{i,t+1}$.[7] The bank's net worth is given by

$$n_{i,t} = \Pi_t(k^s_{i,t}, k^l_{i,t}) - b_{i,t} \tag{2}$$

where $b_{i,t}$ is debt from the previous period and $\Pi_t(k^s_{i,t}, k^l_{i,t})$ is defined in equation (1).

As I explain below, I assume that the bank chooses the portfolio composition of its balance

[6] I assume that the capital quality shock hits the banks after production has taken place and so it only affects the undepreciated component of their capital. Note that the payoff includes the resale value of long-term capital. By contrast, short-term capital depreciates fully and hence does not have a resale value.

[7] 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.

sheet only after debt has been issued. This means that creditors cannot offer a price schedule that is conditional on the share of assets allocated to long-term capital.[8] Let $q_{i,t}(k_{i,t+1}, b_{i,t+1})$ denote the endogenous debt price offered by creditors to a firm that chooses new capital, $k_{i,t+1}$, and debt, $b_{i,t+1}$. The bank's flow of fund constraint is given by

$$d_{i,t} + Q^s_t k^s_{i,t+1} + Q^l_t k^l_{i,t+1} + \psi(k_{i,t+1}, \omega_{i,t} k^l_{i,t}) = n_{i,t} + q_{i,t}(k_{i,t+1}, b_{i,t+1}) b_{i,t+1} \tag{3}$$

where Q^s_t is the price of short-term capital and $\psi(k_{i,t+1}, \omega_{i,t} k^l_{i,t})$ is a balance-sheet adjustment cost function which I assume to be homogeneous in its second argument.

Entry and Exit. At the beginning of each period, after all shocks and payoffs are realized, banks can endogenously choose to default on their debt, in which case they immediately exit the economy. In addition, following Gertler and Karadi (2011), banks receive an exogenous exit shock with probability $\sigma \in [0, 1]$, which forces them to exit the economy. This standard assumption prevents banks from fully overcoming financial frictions.

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 capital left by exiting banks. Therefore, the capital endowment of an entrant bank, $k_{0,t}$, is time-varying and given by

$$k_{0,t} = \frac{1}{\bar{\mu}_t} \int_{i \in \mathcal{E}_t} (1 - \delta) \omega_{i,t} k^l_{i,t} di \tag{4}$$

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 a debt $b_{0,t} = l_0 \cdot k_{0.t}$ where l_0 is parameter that governs the leverage of new entrants. Finally, entering banks also face a capital quality shock, $\omega_{i,t}$, that follows the same distribution as that of incumbent banks.

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;

[8] I maintain the assumption that the bank chooses total capital, $k_{i,t+1}$, and next-period debt, $b_{i,t+1}$, taking as given the debt price schedule, which is determined before the $(k_{i,t+1}, b_{i,t+1})$ choice. Even if the price schedule is not conditional on the share allocated to one type of capital or the other, it does depend on total capital, $k_{i,t+1}$, and next-period debt, $b_{i,t+1}$

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 the undepreciated capital stock;

6. Continuing banks issue new debt at the price $q_{i,t}(k_{i,t+1}, b_{i,t+1})$;

7. After debt is issued, banks choose new short- and long-term capital for the next period.

3.3. Debt Price

Households lend resources competitively to banks at the price schedule $q_{i,t}(k_{i,t+1}, b_{i,t+1})$. I assume that if a bank defaults, the government bails-out the bank with probability π_b, in which case it repays depositors in full. If the government does not intervene, then creditors only recover a fraction γ of undepreciated long-term capital, $\gamma(1-\delta)Q^l_t\omega_{i,t}k^l_t$. The remaining of a defaulting bank's value is seized by the government and rebated lump-sum to the household.[9]

Because deposits are held by households, bonds are priced using their discount factor β_t. As mentioned earlier, borrowing cannot be made conditional on banks' portfolio composition. As a result, when forming a price schedule, lenders must form expectations. Let $\hat{k}^l_{i,t+1}(k_{i,t+1}, b_{i,t+1})$ denote creditor's expectations of next-period long-term capital for a bank that chooses $(k_{i,t+1}, b_{i,t+1})$. Similarly, let $\hat{\iota}^c_{i,t+1}(k_{i,t+1}, b_{i,t+1})$ and $\hat{\iota}^e_{i,t+1}(k_{i,t+1}, b_{i,t+1})$ denote expectations for the repayment decision if the bank does not exit exogenously ($\hat{\iota}^c$) and if it does exit exogenously ($\hat{\iota}^e$). More precisely, these are indicators that equal one if creditors expect a bank to repay next period and zero otherwise. The equilibrium price of debt then is given by

$$q_{i,t}(k_{i,t+1}, b_{i,t+1}) = \beta_t\mathbb{E}_t\Bigg\{1 - \big[1 - \big[(1-\sigma)\hat{\iota}^c_{i,t}(k_{i,t+1}, b_{i,t+1}) + \sigma\hat{\iota}^e_{i,t}(k_{i,t+1}, b_{i,t+1})\big]\big] \\ (1-\pi_b)\left[1 - \min\left\{\frac{\gamma(1-\delta)Q^l_{t+1}\omega_{i,t+1}\hat{k}^l_{i,t}(k_{i,t+1}, b_{i,t+1})}{b_{i,t+1}}, 1\right\}\right]\Bigg\} \quad (5)$$

[9] The value of a bank upon default is $\Pi_t(k^s_{i,t}, k^l_{i,t}) - \psi(0, \omega_{i,t}k_{i,t})$. 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. Recursive Bank Problem

A bank's state space is summarized by $(n, \omega k^l, \mathbf{S})$, where n is net worth and ωk^l effective long-term capital. $\mathbf{S}$ denotes the aggregate state, which includes the exogenous aggregate shock, Z, and the endogenous bank distribution, μ. Banks lack commitment and they can default on their debt obligations. Conditional on repaying, the bank's value function solves the following Bellman equation:

$$V^c(\mathbf{s}, \mathbf{S}) = \max_{d, k^{s'} \geq 0, k^{s'} \geq 0, b'} d + \beta e^Z \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}} V(n', \omega' k^{l'}, \mathbf{S}') \tag{6}$$

s.t.

$$n' = R^K(\mathbf{S}')(k^{s'} + k^{l'}) + (1-\delta)\omega' k^{l'} Q^l(\mathbf{S}') - h\left(\frac{k^{l'}}{k^{s'} + k^{l'}}\right)\left(k^{s'} + k^{l'}\right) - b'$$

$$d + Q^s(\mathbf{S})k^{s'} + Q^l(\mathbf{S})k^{l'} + \psi(k^{s'} + k^{l'}, \omega k^l) = n + q(., \mathbf{S})b'$$

$$d \geq 0$$

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

where d is bank's dividend, βe^Z is the discount factor of the household and $\Gamma(\mathbf{S})$ denotes the conjectured law of motion the aggregates state. The first constraint is the low of motion of the bank's net worth, the second is the flow-of funds constraint, the third is the no-equity issuance condition and the last is the law of motion of the aggregate state.

The bank's continuation value function is given by

$$V(n, \omega k^l, \mathbf{S}) = (1-\sigma)\iota(n, \omega k^l, \mathbf{S})V^c(n, \omega k^l, \mathbf{S}) + \sigma V^{\text{exit}}(n, \omega k^l, \mathbf{S})$$

where $\iota(n, \omega k^l, \mathbf{S})$ is a repayment indicator which is equal to one if and only if firm repays, and $V^{\text{exit}}(n, \omega k^l, \mathbf{S})$ is the value upon exogenously exiting the economy. I assume that if 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

$$V^{\text{exit}}(n, \omega k^l, \mathbf{S}) = \max\{n - \psi(0, \omega k^l), 0\}$$

In Appendix A.2 I show that the bank problem is homogeneous in effective long-term capital, ωk^l. This property will prove useful when solving numerically the model.

3.5. Households

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

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

with $\beta_0 = 1$. The household supplies one unit of labor inelastically, owns banks and all other firms in the economy, and prices bank deposits competitively. 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. I assume that Z_t follows an AR(1) process:

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

given Z_0. Shocks to the household's discount factor are the only source of aggregate uncertainty in the model.

3.6. Capital Good Producers

There is a representative capital good producer who produces new investment goods that can be transformed into short- or long-term capital. As a baseline, I assume that the two types of capital can be transformed one-to-one. Capital good producers faces adjustment costs given by, $\Phi(I_t, K_t^s + K_t^l)$ where I_t denotes investment. For tractability, I assume that this function only depends on total capital, $K_t = K_t^s + K_t^l$. The profit maximization problem of the capital good producer is

$$\max_{I_t^s, I_t^l, I}\left\{Q^s I_t^s + Q^l I_t^l - \Phi(I_t, K_t^s + K_t^l)\right\} \tag{7}$$

subject to

$$I_t^s + I_t^l \leq I_t$$

where I_t^s and I_t^l are the amounts of new investment goods used for short- and long-term capital, respectively. I consider a standard functional form for the adjustment cost function

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

where $\hat{\delta}$ is the steady-state investment rate in the absence of aggregate uncertainty. The problem of capital good producers pins down the prices of short- and long-term capital as follows:

$$Q_t^s = Q_t^l \equiv Q_t = 1 + \phi \left(\frac{I_t}{K_t^s + K_t^l} - \hat{\delta} \right) \tag{8}$$

Notably, because the rate of transformation is equal to one, short- and long-term capital have equal price in equilibrium.

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.[10] 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.

3.7. Government

The government levies a lump-sum tax from the household and use it to finance repayment of deposits in case of bank failures. The government budget constraint then is simply

$$T_t = \pi_b \int_{i \in \mathcal{D}_t} b_{i,t} di$$

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

3.8. Equilibrium

Before defining the equilibrium, I need to characterize the law of motion of the distribution of banks. Let $\mu_t(n, \omega k)$ denote the distribution of banks across idiosyncratic states $(n, \omega k)$, 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 $\mu_t^i(n, \omega k)$ denote the distribution of incumbent banks that do not default and let $\mu^e(n, \omega k, \mathbf{S})$ denote the distribution of new entrants.

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

[10] See Kilic and Zhang (2023) for a discussion on the role of inelastic factor demand in the transmission of interest-reate shocks.

$$\mu^i_{t+1}(n', k^{l'}) = \int \iota_t(n, \omega k)\mathbb{1}\{n' = n(b'_t(n, \omega k), k^{s'}_t(n, \omega k), k^{l'}_t(n, \omega k), \omega')\}$$
$$\mathbb{1}\{k^{l'} = \omega' k^{l'}_t(n, \omega k)\}g(\omega')d\omega' d\mu_t(n, \omega k^l) \quad (9)$$

where $n(b'_t(n, \omega k), k^{s'}_t(n, \omega k), k^{l'}_t(n, \omega k), \omega')$ is implicitly defined by (2), and $b'_t(.)$, $k^{s'}_t(.)$ and $k^{l'}_t(.)$ are the policy functions that solve the bank problem.

The distribution of new entrants is

$$\mu^e_{t+1}(n', k^{l'}) = \bar{\mu}_t \int \mathbb{1}\{n' = n(b_{0,t}, 0, k_{0,t}, \omega')\}\mathbb{1}\{k^{l'} = \omega' k_{0,t}\}g(\omega')d\omega' \quad (10)$$

where l_0 is the exogenous leverage of entering banks, $k_{0,t}$ is defined in equation (4) and $\bar{\mu}_t$ is the measure of exiting firms:

$$\bar{\mu}_t = \int \left[(1-\sigma)\left(1 - \iota_t(n, \omega k^l)\right) + \sigma\right] d\mu_t(n, \omega k^l) \quad (11)$$

Finally, the distribution of banks, $\mu(n, \omega k)$, is given by

$$\mu_{t+1}(n', k^{l'}) = (1-\sigma)\mu^i_{t+1}(n', k^{l'}) + \mu^e_{t+1}(n', k^{l'}) \quad (12)$$

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, $\boldsymbol{s} = (n, \omega k^l)$. 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, $\{V(\boldsymbol{s}, \boldsymbol{S}), V^c(\boldsymbol{s}, \boldsymbol{S}), V^{exit}(\boldsymbol{s}, \boldsymbol{S})\}$,*
2. *Policy functions $\{k^{s'}(\boldsymbol{s}, \boldsymbol{S}), k^{l'}(\boldsymbol{s}, \boldsymbol{S}), b'(\boldsymbol{s}, \boldsymbol{S})\}$,*
3. *A debt price $q(., \boldsymbol{S})$,*
4. *Conjectured policies $\{\hat{k}^l(k', b', \boldsymbol{S}'), \hat{\iota}^c(k', b', \boldsymbol{S}'), \hat{\iota}^e(k', b', \boldsymbol{S}')\}$,*
5. *A rate of return $R^K(\boldsymbol{S}) = \alpha K(\boldsymbol{S})^{\alpha-1}$ and a price of capital $Q(\boldsymbol{S})$ given by (8),*
6. *Distributions $\{\mu(\boldsymbol{s}, \boldsymbol{S}), \mu^i(\boldsymbol{s}, \boldsymbol{S}), \mu^e(\boldsymbol{s}, \boldsymbol{S})\}$, and*
7. *A conjectured law of motion for the aggregate state $\Gamma(\boldsymbol{S})$,*

such that

1. *Given the prices* $\{q(., \boldsymbol{S}), R^K(\boldsymbol{S}), Q(\boldsymbol{S})\}$ *and the perceived law of motion* $\Gamma(\boldsymbol{S})$*, the policy functions* $\{k^{s'}(\boldsymbol{s}, \boldsymbol{S}), k^{l'}(\boldsymbol{s}, \boldsymbol{S}), b'(\boldsymbol{s}, \boldsymbol{S})\}$ *solve the bank problem (6) and* $\{V(\boldsymbol{s}, \boldsymbol{S}), V^c(\boldsymbol{s}, \boldsymbol{S}), V^{exit}(\boldsymbol{s}, \boldsymbol{S})\}$ *are the associated value functions.*

2. *Given the conjectured policies* $\{\hat{k}^l(k', b', \boldsymbol{S'}), \hat{\iota}^c(k', b', \boldsymbol{S'}), \hat{\iota}^e(k', b', \boldsymbol{S'})\}$*, the debt price* $q(., \boldsymbol{S})$ *solves (5).*

3. *The conjectured policies* $\{\hat{k}^l(k', b', \boldsymbol{S'}), \hat{\iota}^c(k', b', \boldsymbol{S'}), \hat{\iota}^e(k', b', \boldsymbol{S'})\}$ *and the conjectured law of motion* $\Gamma(\boldsymbol{S})$ *are consistent with agents' policies.*

4. *Distributions* $\{\mu(\boldsymbol{s}, \boldsymbol{S}), \mu^i(\boldsymbol{s}, \boldsymbol{S}), \mu^e(\boldsymbol{s}, \boldsymbol{S})\}$ *satisfy (9), (10) and (12).*

5. *Markets clear*

$$Y(\boldsymbol{S}) = C(\boldsymbol{S}) + I(\boldsymbol{S}) - H(\boldsymbol{S}) - \Phi(I(\boldsymbol{S}), K(\boldsymbol{S})) - \Psi(\boldsymbol{S}) \tag{13}$$

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

3.9. Model Mechanisms

In this section, I provide a characterization of the banks problem. For simplicity, I focus on a special case of the model by assuming that there are no adjustment costs ($\psi(.) = 0$) and there is no exogenous exit ($\sigma = 0$).

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 $(k^{s'}, k^{l'}, b')$ choice such that

$$n - Q^s(\mathbf{S})k^{s'} - Q^l(\mathbf{S})k^{l'} + q(., \mathbf{S})b' \geq 0$$

Define the default threshold $\underline{n}(\mathbf{S}) = \min_{k^{s'}, k^{l'}, b'} \left[Q^s(\mathbf{S})k^{s'} + Q^l(\mathbf{S})k^{l'} - q(., \mathbf{S})b'\right]$. This threshold is such that the bank defaults if and only if $n < \underline{n}(\mathbf{S})$.[11] In this case, there is no feasible choice of $(k^{s'}, k^{l'}, b')$ such that $d \geq 0$. Define $\underline{\omega}(k^s, k^l, b, \mathbf{S})$ as the realization of the capital quality shock such that $n(k^s, k^l, b, \mathbf{S}) = \underline{n}$. Using the fact that the capital quality shock is i.i.d and follows a normal distribution, we get that the ex-ante default probability is given by

$$d(k^s, k^l, b, \mathbf{S}) = \int_{-\infty}^{\underline{\omega}(k^s,k^l,b,\mathbf{S})} d\Phi_{0,\sigma_\omega}(\omega) = \Phi_{0,\sigma_\omega}(\underline{\omega}(k^s, k^l, b, \mathbf{S}))$$

Optimality conditions. I am now ready to derive the optimality conditions of the bank problem. The first-order condition with respect to long-term capital is given by

$$\begin{aligned}(1+\lambda)\left(-Q^l(\mathbf{S}) + b'\frac{\partial q(.,\mathbf{S})}{\partial k^{l'}}\right) \\ + \beta e^Z \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\left[\iota(.,\mathbf{S}')(1+\lambda')\left(R^K(\mathbf{S}') + (1-\delta)\omega' k^{l'} Q^l(\mathbf{S}) - \frac{\partial\left[h(.)\cdot(k^{l'}+k^{s'})\right]}{\partial k^{l'}}\right)\right] \\ + \beta e^Z \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\left[V(k^{s'}, k^{l'}, \underline{n}(\mathbf{S}'), \mathbf{S})\phi_{0,\sigma_\omega}(\underline{\omega}(.,\mathbf{S}))\frac{\partial\underline{\omega}(.,\mathbf{S})}{\partial k^{l'}}\right] = 0 \quad (14)\end{aligned}$$

where λ denotes the Lagrange multiplier on the no-equity issuance constraint.

This first-order condition embeds three components. The first is the marginal cost of long-term capital. This depends on the price of capital, $Q^l(\mathbf{S})$, and on the marginal value of internal resources embedded in the multiplier, λ. In addition, the marginal cost also incorporates the effect of investing in long-term capital on the holding cost, $\frac{\partial\left[h(.)\cdot(k^{l'}+k^{s'})\right]}{\partial k^{l'}}$. The second component is the marginal benefit of long-term capital. This includes the rental return, $R^K(\mathbf{S}')$, and the resale value of long-term capital, $(1-\delta)\omega' k^{l'} Q^l(\mathbf{S})$. In addition, because new capital purchases must be financed through debt, the marginal benefit also incorporates how the bank's capital choice affects the price of debt, $b'\frac{\partial q(.,\mathbf{S})}{\partial k^{l'}}$. Higher capital tends to decrease the price of debt not only because it implies a higher expected payoff but also because it raises the recovery value in case of default. The last component captures the effect of the capital choice on the bank's future default probability. Because, the value of the firm close to the default threshold is approximately zero, this term is quantitatively negligible.[12]

Similarly to equation (14), the first-order condition with respect to short-term capital is

[11] Note that the default threshold only depends on the aggregate state, $\mathbf{S}$. This follows from the assumption that the capital quality shock is i.i.d d. across banks and time.

[12] The fact that the effect operating through the default threshold is approximately zero is a common feature of this class of model (Ottonello and Winberry (2020))

given by

$$(1+\lambda)\left(-Q^s(\mathbf{S})+b'\frac{\partial q(.,\mathbf{S})}{\partial k^{l'}}\right)$$
$$+\beta e^Z\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\left[\iota(.,\mathbf{S}')(1+\lambda')\left(R^K(\mathbf{S}')-\frac{\partial\left[h(.)\cdot(k^{l'}+k^{s'})\right]}{\partial k^{s'}}\right)\right]$$
$$+\beta e^Z\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\left[V(k^{s'},k^{l'},\underline{n}(\mathbf{S}'),\mathbf{S})\phi_{0,\sigma_\omega}(\underline{\omega}(.,\mathbf{S}))\frac{\partial\underline{\omega}(.,\mathbf{S})}{\partial k^{s'}}\right]=0 \quad (15)$$

The key difference between the two equations, (14) and (15), is the presence of the asset resale value in the first-order condition with respect to long-term capital.

Combining the two first-order conditions, allows me to get an expression that directly pins down the portfolio share, $\frac{k^l}{k^s+k^l}$.

$$(1+\lambda)\left[Q^l(\mathbf{S})-Q^s(\mathbf{S})\right]\approx\beta e^Z\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}\left[\iota(.,\mathbf{S}')(1+\lambda')\left((1-\delta)\omega' Q^l(\mathbf{S})-h'\left(\frac{k^l}{k^s+k^l}\right)\right)\right] \quad (16)$$

where I have used the fact that the effect operating through the default threshold is approximately zero. This equation states that the optimal portfolio share depends on two factors: the relative price of the two types of capital (the left-hand side), and the payoff difference between investing in long- versus short- term capital (the right-hand side). This difference is given by the resale value of undepreciated capital net of the marginal holding cost entailed by the long-duration investment.

Because of the assumption that the two assets can be transformed one-to-one, short- and long-term capital have equal price in equilibrium, allowing me to rewrite (16) as

$$\underbrace{\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}[(1-\delta)\omega' Q(\mathbf{S}')]}_{\text{expected resale value}}+\underbrace{\frac{Cov((1-\delta)\omega' Q(\mathbf{S}'),\iota(.,\mathbf{S}')(1+\lambda'))}{\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}[\iota(.,\mathbf{S}')(1+\lambda')]}}_{\text{risk-premium}}\approx\underbrace{h'\left(\frac{k^l}{k^s+k^l}\right)}_{\text{marginal cost}} \quad (17)$$

This equation includes three terms: the expected resale value of long-term capital, the marginal holding cost and a risk-premium component capturing the covariance between the asset price and the bank's shadow value of net worth. This covariance is negative because states where the price of capital is high are also states where the shadow value of net worth is low.

Equation (17) shows that the level of the interest rate affects the optimal portfolio composition via two channels. First, a persistent decrease in interest rates foster optimistic asset value expectations, leading banks in low-rate environments to favor long-term assets. Second, interest-rate fluctuations impact the severity of financial frictions, leading to changes in risk-premia.

Capital gains experienced by banks in periods of loose monetary policy ease balance-sheet constraints and endogenously lead to a lengthening of maturities through a reduction in the risk-premium. Conversely, a sudden monetary tightening depletes net worth and induces banks to shorten maturity. In addition, the covariance term in equation (17) establishes a link between the duration and leverage decisions. Banks operating under tight constraints rely heavily on deposits to finance investment and face higher shadow values of net worth. Consequently, these banks demand a higher risk premium for investing in long-duration assets and endogenously choose portfolios that are less exposed to interest-rate risk.

In summary, the model predicts that the degree of maturity mismatch inversely correlates with the level of the interest rate and with leverage, offering testable hypotheses that can be validated using empirical data.

3.10. Discussion of Assumptions

In this section I discuss the main assumptions of the model.

First, I assume that banks invest directly in physical capital, rather than providing loans.[13] This approach of consolidating into a unique entity the banks and the firms they lend to is common in the financial accelerator literature.[14] In terms of capturing the problem of maturity mismatch, this assumption implies that banks bear the burden of interest-rate risk exposure and not the firms.[15] There is a long-standing literature suggesting that maturity-matching is a key principle of risk management for non-financial firms. Graham and Harvey (2001) conduct a survey of corporate managers and find that aligning the maturity of debt with the maturity of assets is the primary consideration when choosing debt maturity. Stohs and Mauer (1996) and Frank and Goyal (2009) provide evidence that firms issue debt with a maturity that matches the useful life of their assets. Geelen *et al.* (2023) show that debt maturity is negatively related to capital age, suggesting that firms choose the duration of their debt to match the timing of replacement investment. Combining firm-level data from Compustat with loan-level data from Dealscan, De Fraisse (2023) shows that the duration of firm assets correlate very strongly with

[13] The model assumes that banks can invest in short- and long-term assets that have productive uses. This assumption can be justified by the fact that the majority of short-term assets is composed by loans that reprice within the year. Similarly, approximately the same percentage of long-term assets is composed by loans.

[14] This approach is used for example in Gertler and Karadi (2011), He and Krishnamurthy (2013), Gertler and Kiyotaki (2015), Begenau (2020) and Begenau and Landvoigt (2022).

[15] This scenario arises when banks rely on short-term deposits to fund long-term investment to firms. Alternatively, it also applies to situations where banks lend short-term to firms, but these firms become more susceptible to default following an unexpected rise in interest rates.

the maturity of debt issuances.[16]

Second, I assume that holding costs incurred by banks are increasing in the share of long-term capital. One interpretation for this assumption is that it captures illiquidity costs from holding long-term assets. Kozlowski (2021), for example, studies liquidity premia in the U.S. corporate bond market. He finds that these premia are higher for bonds with longer maturity, suggesting a positive slope of liquidity spreads with respect to maturity. Another interpretation for the assumption on the cost function is that it reflects a distinct advantage of investing in short-term safe claims. Bansal and Coleman (1996) outline a theory where short-term safe assets play a special role in backing checkable deposits due to the absolute stability of these assets' cash-flows. Greenwood *et al.* (2015) provide evidence that investor value short-term safety by showing that the yields on short-term treasuries are often too low relative to those of longer-term treasuries. They argue that it may be more costly to evaluate investments in long-term assets because these assets are inherently subject to repricing risk.

Lastly, I assume that there is a technology to transform short-term capital into long-term capital one-to-one, and vice-versa. As previously mentioned, this simplifying assumption means that the price of the two productive assets is the same in equilibrium, leading to two noteworthy implications. First, without the assumption of increasing holdings costs in long-term capital, banks would exclusively favor long-term assets. Second, shifts in interest rates do not trigger relative price changes, which according to equation (16) can affect banks' duration choices. In Section 5.6, I relax the assumption that the short- and long-term capital can be transformed one-to-one. In that version of the model the prices of the two assets are allowed to differ and their responsiveness to changes in interest rates can vary. There I show quantitatively that the two models feature similar dynamics.

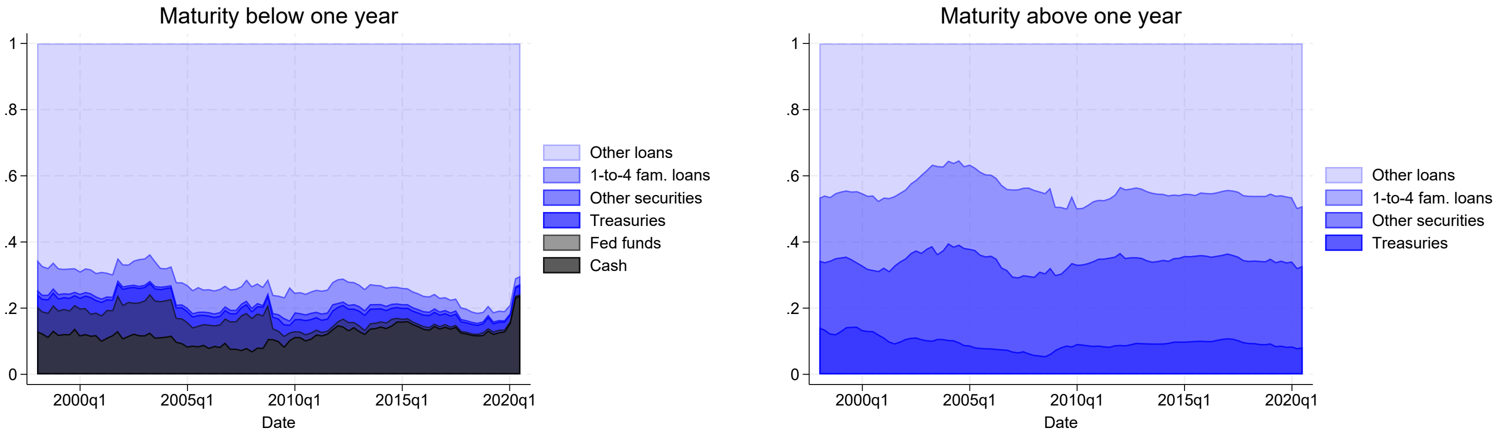
4. Emprical Analysis

Equipped with testable predictions from the model, I present next empirical evidence related to the duration profile of banks. Following a brief overview of the data, I delve into the relationship between maturity mismatch, interest rates and bank leverage.

Data and Measurement. My analysis relies on micro-level data on individual banks obtained

[16] By allowing banks to invest directly in capital, I operate under the assumption that the duration of real assets adjusts to match the duration of the financial assets that funds them. This adjustment can happen within a firm - a firm shift investment towards short-duration projects when banks are more willing to supply short- rather than long-term loans - or across firms - bank channel funds towards firms which naturally undertake short-duration project.

Figure 1: Asset composition by maturity



Notes: Breakdown of bank assets by maturity and asset class. The left panel focuses on assets with repricing maturity below one year. The right panel focuses on assets with repricing maturity above one year. Data come from U.S. Call Reports.

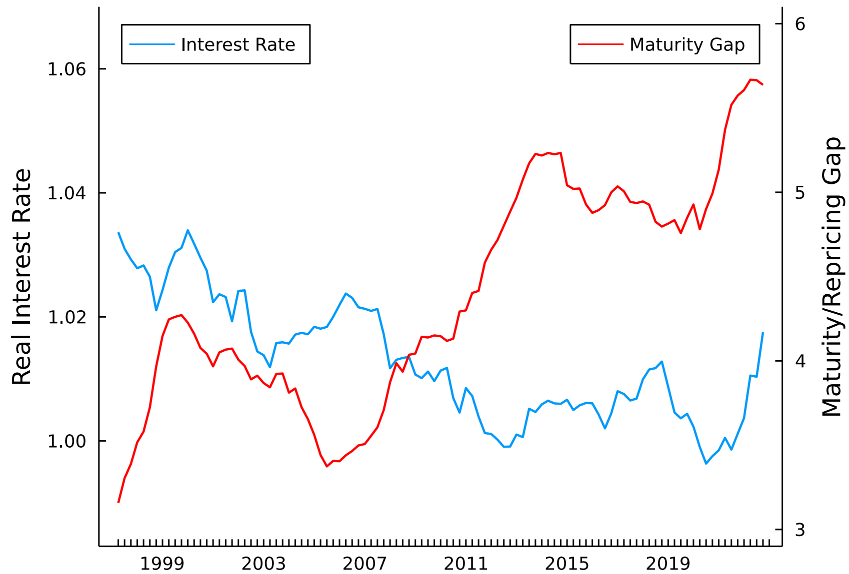
from U.S. Call Reports. I collect balance-sheet and income information for all U.S. commercial banks. To measure banks' duration gaps, I exploit information on repricing maturity provided in Call Reports. Banks are required by regulation to report a breakdown of assets and liabilities by maturity.[17] Consistent with English *et al.* (2018), I use the midpoint of each range as the maturity 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. Repricing maturity is a useful proxy for duration because it distinguishes between long-term fixed-rate assets and short-term floating-rate assets.

Figure 1 provides a breakdown of bank assets by maturity and asset class. I split bank assets into two groups based on whether the repricing maturity is below or above one-year. The left panel, shows the breakdown for assets with maturity less than one-year. Approximately 70% of assets with repricing maturity less than a year is composed of loans. The next most relevant category is cash, followed by Fed funds and treasuries. A similar trend is observed in the right panel which focuses on longer-term assets. Loans continue to be the predominant category, accounting for about 70% of bank assets. Within this category, a larger fraction is represented by 1-to-4 family real estate loans, indicating their substantial presence in the bank's portfolio.

Maturity gap and interest rates. Figure 2 illustrates the dynamics of the average matu-

[17] The set of assets for which the maturity information is available cover approximately 83% of total assets.

Figure 2: Maturity Gap and the Real Interest Rate



Notes: The interest rate is the inflation-adjusted interest rate on 10-year Treasury securities with a constant maturity. The maturity gap is computed as the difference between the average maturity of bank assets and the average maturity of bank liabilities. Maturity data come from U.S. Call Reports.

rity/repricing gap in the data alongside the dynamics of the real interest rate. To measure the real rate, I use the inflation-adjusted interest rate on 10-year Treasury securities with a constant maturity.[18] The figure shows clearly a negative correlation between the two series. This inverse relationship suggests that in periods of loose monetary policy, banks exhibit a higher tolerance for maturity imbalances between their assets and liabilities. Remarkably, the maturity gap has shown a consistent upward trajectory since the aftermath of the Great Financial Crisis, a trend that closely mirrors the secular decline in interest rates observed over the same period.

To provide a causal interpretation of the negative correlation between maturity gap and the real interest rate, I exploit identified monetary policy shocks. I use the series of shocks from Bu *et al.* (2021), which offers two advantages relative to alternative measures: (1) they are largely unpredictable using available macroeconomics information, and (2) contain no significant central bank information effect. To construct a measure of monetary policy shocks at the quarterly frequency, ϵ_t^m, I follow Ottonello and Winberry (2020) and compute an average of the raw shocks weighted by the number of days in the quarter after the shock occurs. Since ϵ_t^m is possibly a noisy measure of the true monetary shocks, I follow Stock and Watson (2018)

[18] Figure B.1 shows a similar pattern using the inflation-adjusted effective fed funds rate as an alternative measure of the real interest rate.

and use ϵ_t^m as an instrument for the policy-rate change, ΔR_t, in an IV regression.[19]

I start by estimating the average effect of a monetary policy shock on banks' maturity gaps. The baseline IV specification is

$$\Delta \log \text{ Maturity Gap}_{i,t+h} = \beta^h \Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \sum_{\tau=1}^{4} \mathbf{\Gamma}_{2,\tau}^h \mathbf{Y}_{t-\tau} + \alpha_i^h + \epsilon_{i,t} \tag{18}$$

where h is the forecast horizon, $\Delta \log$ 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, $\mathbf{X}_{i,t-1}$ is a vector of bank-level controls, such as bank size and market leverage[20], $\sum_{\tau=1}^{4} \mathbf{\Gamma}_{2,\tau}^h \mathbf{Y}_{t-\tau}$ is a vector of aggregate controls which includes lags of GDP growth, the unemployment rate, inflation and the change in VIX index. Importantly, I include bank fixed-effects, α_i^h, to captures permanent heterogeneity in banks' maturity profiles, for example stemming from specialization or different business models.

To focus on conventional monetary policy, I restrict the estimation sample to end in the last quarter of 2007.[21] The coefficients, β^h, depicted in Figure 3, are negative at all horizons, implying that a contractionary monetary policy shock, i.e. an increase in the interest rate, leads to a reduction in maturity gaps. The effect is significant in the first four quarters after the shock and reaches a value of roughly -0.2. The estimated coefficient at the one-year horizon indicates that a one percentage point raise in the interest rate decreases the maturity gap by 20%, which is an economically meaningful effect.

Exploiting cross-sectional variation in Call Reports data, I explore next whether the effect of monetary policy shocks on maturity varies with balance-sheet conditions. To this end, I estimate the following empirical specification

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

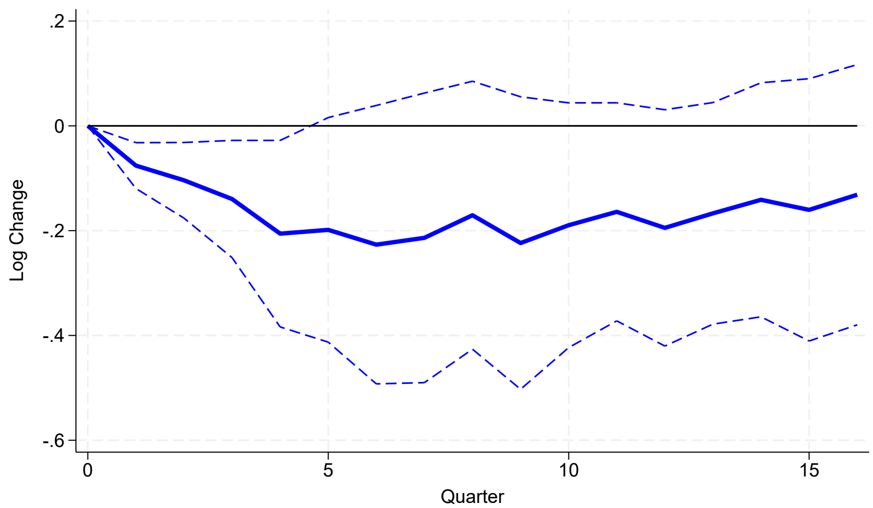
where $l_{i,t-1}$ is the bank's market leverage at time $t-1$, $\mathbb{E}_i [l_{i,t}]$ is the average for market leverage of bank i and $\mathbf{X}_{i,t-1}$ includes additional bank-level controls. To make coefficients easier to interpret, I normalize the banks' demeaned leverage, $l_{i,t-1} - \mathbb{E}_i [l_{i,t}]$, so their units are standard deviations in our sample. The coefficient of interest, β^h, determines how banks with different market leverage respond to the monetary policy shock. Figure 4 illustrates the dynamics of this

[19] As in Stock and Watson (2018), ΔR_t is the change in the interest rate on 1-year U.S. Treasury bonds. Results are very similar if I consider a reduced-form specification that directly uses ϵ_t^m as a regressor (see Figure B.3).

[20] In addition to bank size (log of total assets) and market leverage, I also include as controls wholesale funding as a share of total liabilities and lagged profitability, measured by previous-period ROE and non-performing loans ratio.

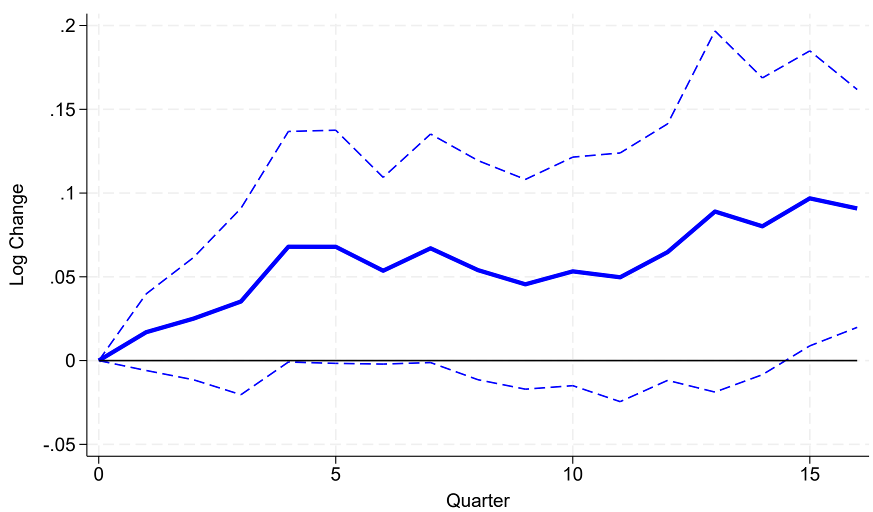
[21] Figure B.2 shows that estimating specification (18) on the full sample (1997-2021) yields similar results.

Figure 3: Dynamics of Average Response of Maturity Gap to Monetary Shocks



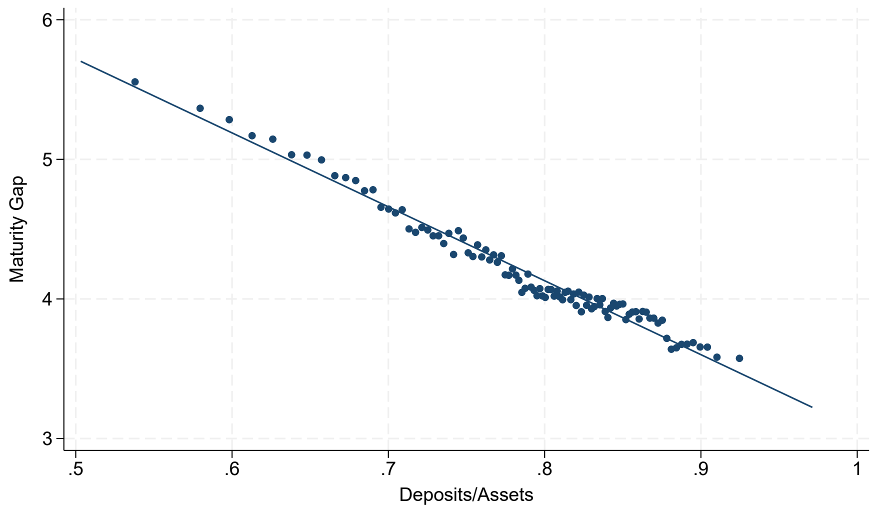
Notes: Dynamics of the coefficient on monetary shocks over time. Reports point estimate and 90% confidence interval for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h \Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \sum_{\tau=1}^{4} \mathbf{\Gamma}_{2,\tau}^h \mathbf{Y}_{t-\tau} + \alpha_i^h + \epsilon_{i,t}$. 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.

Figure 4: Effect of Leverage on Dynamic Response of Maturity Gap to Monetary Shocks



Notes: Dynamics of the coefficient on the interaction term between monetary shocks and market leverage over time. Reports point estimate and 90% confidence interval 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 size, market leverage, wholesale funding as a share of total liabilities, the nonperforming ratio and ROE. Confidence intervals based on two-way clustered standard errors at bank and time levels.

Figure 5: Maturity Gap and Leverage



Notes: Cross-sectional binned scatterplot of maturity gap on deposit-to-asset ratio. The plot residualizes the maturity gap on size, bank and time fixed effects. It then adds back the mean of maturity gap to maintain centering. Data are from U.S. Call Reports

coefficient at different horizons. Estimated values are positive suggesting that more leveraged banks are relatively less responsive to surprise rate changes. The point estimate at the one-year horizon is approximately 0.07, which says that a bank whose leverage is one standard deviation lower than the average (across banks and over time) experiences a 7% stronger reduction in maturity gap in response to a contractionary monetary policy shock. In Figure B.7 I show that results are robust to using the series of Nakamura-Steinsson shocks.

Maturity gap and bank leverage. Next, motivated by the testable implications of the model, I investigate the cross-sectional relationship between bank leverage and maturity mismatch. Figure displays a binned scatterplot depicting the relationship between maturity gap and (deposit) leverage, defined as the ratio of deposits to assets.[22] Figure 5 shows a stark negative correlation between maturity and leverage, suggesting a link between banks' funding structure and their maturity mismatch. 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.8 and B.9 I separately illustrate the maturity gap 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. The maturity of liabilities, instead, is relatively constant across the distribution

[22] The deposit-to-asset ratio is a particularly relevant measure in the context of the model, where all bank debt is short-term and partly insured.

of leverage. To corroborate further the negative association between maturity gap and bank leverage, Figure B.10 plots a binned scatterplot depicting the relationship between maturity gap and market leverage. The figure confirms a negative correlation, albeit weaker, even when employing this alternative measure of leverage.

5. 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 5.1 presents the calibration strategy. Section 5.2 conducts a series of validates exercises against untargeted empirical patters.

5.1. Calibration

I calibrate the model at the annual frequency to match banking moments between 1997 and 2022. The combination of heterogeneity and aggregate uncertainty implies that the distribution of banks, an infinite-dimensional object, is an endogenous state variable. To solve then model in general equilibrium, I follow closely 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.3

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, and follows a process $\log \omega_t = \sigma_\omega \epsilon_{\omega,t},\ \ \epsilon_{\omega,t} \sim N(0,1)$. For the holding cost, $h(.)$, I consider the following functional form:[23]

$$h\left(\frac{k^l}{k^s+k^l}\right) = \frac{1}{\xi_2}\left[e^{\xi_2\left(\frac{\frac{k^l}{k^s+k^l}}{\xi_1}-1\right)} - 1\right],\ \xi_1,\xi_2 > 0$$

[23] A similar functional form is used in the literature to parameterize the cost of capital utilization. See for example Christiano *et al.* (2014).

Finally for bank-level adjustment costs, I assume a standard quadratic function:[24]

$$\psi(k^{s'} + k^{l'}, k^l) = \frac{\psi}{2}\left(\frac{k^{s'} + k^{l'} - (1-\delta)k^l}{k^l} - \delta\right)^2 k^l$$

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 in Gertler and Karadi (2011). For the depreciation rate of long-term capital, I pick a value $\delta = 0.85$, which is consistent with the average duration of assets with maturity greater than one year in the data. Finally, I fix the leverage of new entrants, $l_0 = 0.9$, in line with evidence from Call Reports. 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 real interest rate in the data and set these parameters so that the interest rate process in the model closely approximate the empirical counterpart.[25]

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. A high value, $\pi_b = 0.83$, is needed under the lens of the model to match an average deposit-to-asset ratio of 0.83 in the data. I calibrate the standard deviation of the capital quality shock, $\sigma_\omega = 0.1$, 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, $\gamma = 0.4$, I follow Begenau (2020) 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 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 those related to the holding cost function, ξ_1 and ξ_2, and to the bank-level adjustment costs, ψ. The parameter ξ_1 mostly governs the average share banks allocate to long-term capital. I therefore calibrate $\xi_1 = 0.94$ to match the average duration gap

[24] The assumption that bank-level adjustment costs are homogeneous with respect to k^l instead of $k^s + k^l$ is made for tractability and allows me to reduce the state space of the bank.

[25] I construct time series for the real interest rate as $R_t = (1 + i_t)\mathbb{E}\left[\frac{1}{\pi_{t+1}}\right]$, where i_t denotes the effective fed funds rate, and π_{t+1} denotes core CPI inflation rate in the U.S. I estimate $\mathbb{E}\left[\frac{1}{\pi_{t+1}}\right]$ by regressing the realized inflation rate π_{t+1} on four lags of inflation. Results are similar if I use the (ex-post) real federal funds rate. Results are similar if I use instead a measure of the real interest rate based on longer-term treasury yields.

Table 1: Parameter Values

Panel (a): Fixed and Estimated Parameters			Panel (b): Calibrated Parameters		
Param.	Description	Value	Param.	Description	Value
α	Share of capital	0.3	π_b	Bailout probability	0.85
δ	Depreciation	0.85	γ	Recovery rate	0.4
σ	Exogenous exit rate	0.1	ψ	Bank-level adj. cost	0.15
l_0	Leverage of new entrants	0.9	ξ_1	Holding cost - level	0.94
β	Discount factor, mean	0.987	ξ_2	Holding cost - curvature	0.35
σ_Z	Discount factor, volatility	0.01	ϕ	Aggregate adj. cost	5
ρ_Z	Discount factor, correlation	0.80	σ_ω	Volatility of quality shock	0.1

Notes: Panel (a) shows the parameters that are exogenously fixed $(\alpha, \delta, \sigma, l_0)$ or directly estimated from the data $(\beta, \sigma_Z, \rho_Z)$. Panel (b) shows the parameters that are calibrated to match relevant data moments.

in Call Reports data. Meanwhile, ξ_2 shapes the curvature of the holding cost function. I set $\xi_2 = 0.35$ to target the time-series volatility of cross-sectional average duration gap in the data. To see how this moment identifies the curvature parameter recall the first-order condition for bank's portfolio share.

$$\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}[(1-\delta)\omega' Q(\mathbf{S}')] + \frac{Cov((1-\delta)\omega' Q(\mathbf{S}'), \iota(.,\mathbf{S}')(1+\lambda'))}{\mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}}[\iota(.,\mathbf{S}')(1+\lambda')]} \approx h'\left(\frac{k^l}{k^s + k^l}\right)$$

Changes in interest rates impact the left-hand side of this equation by influencing asset prices and the shadow value of net worth. In contrast, the right-hand side remains unaffected by the aggregate state. When the function $h'(.)$ is steep, corresponding to a high value of ξ_2, movements in the left-hand side lead to minor shifts in banks' portfolio compositions, resulting in a low duration gap volatility. Conversely, when $h'(.)$ is flat, corresponding to a low value of ξ_2 value, movements in the left-hand side cause significant changes in banks' portfolio compositions, leading to a high duration gap volatility.

Finally, the presence of bank-level adjustment costs is crucial for the model to generate a distribution of interest-rate-risk exposure across different banks. Without these costs, banks would opt for identical levels of exposure, regardless of their balance-sheet conditions, due to the homogeneity of the bank problem and the fact that idiosyncratic shocks are i.i.d. both across banks and over time. Given these considerations, I set $\psi = 0.15$ to match the cross-sectional dispersion of interest rate exposures. It is noteworthy that the model doesn't inherently

Table 2: Targeted Bank Moments

Statistic	Data	Model	Source
Duration (Aggregate)			
Avg. Duration Gap	4.41	4.80	Call Reports
Vol. of Duration Gap	0.16	0.09	Call Reports
Duration (Heterogeneity)			
CS Sd. of Duration Gap	0.96	0.73	Call Reports
Balance Sheet and Default			
Avg. Deposit/Assets	83%	78%	Call Reports
Avg. Age at Default	20.5	23.8	Coimbra and Rey (2023)
Avg. Recovery Value	48%	56%	Begenau and Landvoigt (2022)
Vol. Market Leverage	0.02	0.03	Call Reports

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

incorporate ex-ante heterogeneity among banks, which, nevertheless, is a significant determinant of duration gaps in the data. To address this concern, I residualize duration gaps in the data using bank fixed effects and use the standard deviation of the residualized variable as target in my calibration.

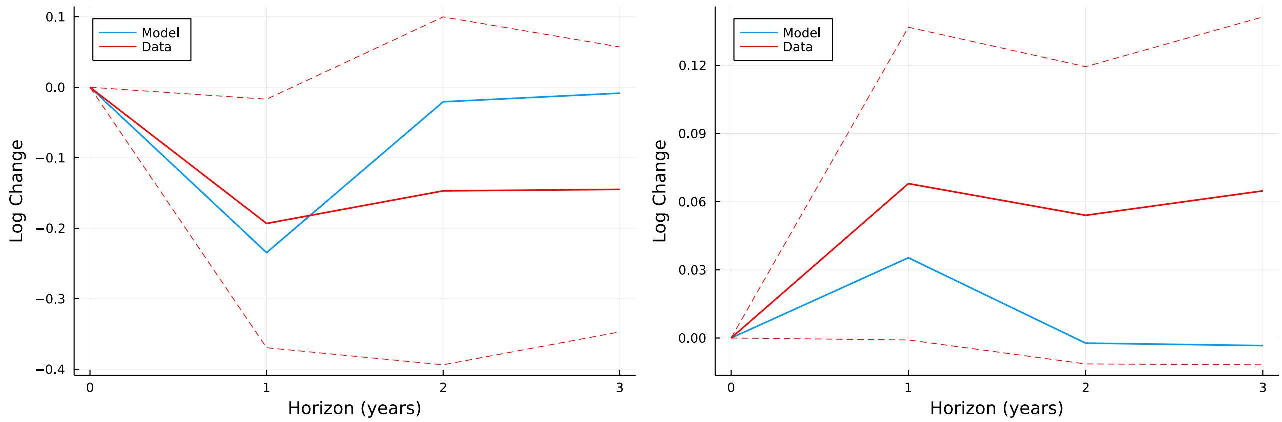
5.2. Model Validation

In this section I show that the model is able to replicate the empirical facts documented in the Section 4, that is (1) the negative response of banks' duration gaps to unexpected increases in interest rates, (2) the smaller magnitude of this response for high-leveraged banks, and (3) the negative cross-sectional correlation between duration gap and leverage.

Maturity gap and interest rates. First, I use simulated data to estimate the model equivalent of equation (18). I regress the change in duration gap at different horizons, h, on the change in the interest rate, including in the regression additional controls and a constant.[26] To align as close as possible with the empirical specification, I include in the regression individual-level variables (size and market leverage) and one aggregate control, namely total capital K_t. The

[26] In order to make the model coefficients comparable with the data, I re-scale the interest-rate shock in the model so that it has the same variance as the interest-rate shock in the data.

Figure 6: Responses of Duration Gap to Interest-Rate Shock: Model vs Data



(a) Average Response **(b)** Heterogeneity

Notes: Panel (a) plots the coefficient, β_1^h, estimated using equation (20) (the blue line). Panel (b) plots the coefficient, β_2^h, on the interaction of interest rate with market leverage estimated using equation (21) (the blue line). For comparison, both panels plot the empirical counterpart (red line), together with the 90% confidence interval.

estimated specification is

$$\Delta \log \text{ Duration Gap}_{i,t+h} = \beta^h \Delta R_t + \gamma_1^h \frac{b_{i,t-1}}{Q_{t-1} k_{i,t-1}} + \gamma_2^h \log(k_{i,t-1}) + K_t + \alpha^h + \epsilon_{i,t}^h \tag{20}$$

where Δlog Duration $\text{Gap}_{i,t+h}$ is the log-change in the duration gap of bank i between t and $t+h$, ΔR_t denotes the interest-rate change, $\frac{b_{i,t-1}}{Q_{t-1}k_{i,t-1}}$ market leverage and $\log(k_{i,t-1})$ total bank assets (logged).[27]

Panel (a) of Figure 6 displays the estimated coefficients, β^h, in the model (blue line) and in the data (red solid line) up to four years after the shock. The estimates are negative at all horizons, showing that the model is successful in replicating the negative response of duration to a rise in the interest rate. The coefficient one year after the shocks closely matches the empirical counterpart. However, for longer horizons, the model's estimate hovers around zero, while the data's coefficient remains negative, albeit statistically insignificant.

Next, I exploit the rich heterogeneity in the model to I explore whether my framework can reproduce the differential responses documented in the data. To compare the model with the

[27] In the model the interest rate is simply $R_t = \frac{1}{\beta e^{Z_t}}$

empirical evidence, I estimate the following specification in the spirit of equation (19)

$$\Delta \log \text{ Duration Gap}_{i,t+h} = \beta_1^h \Delta R_t + \beta_2^h \frac{b_{i,t-1}}{Q_{t-1} k_{i,t-1}} \Delta R_t + \gamma_1^h \frac{b_{i,t-1}}{Q_{t-1} k_{i,t-1}} + \gamma_2^h \log(k_{i,t-1}) + K_t + \alpha^h + \epsilon_{i,t}^h \tag{21}$$

In contrast to (20), this regression includes the interaction between the interest-rate change at time t and bank i's market leverage at $t-1$. The coefficient of interest is β_2^h which captures how the response of duration gap to interest rates varies across banks with different levels of leverage. Panel (b) of Figure 6 plots the results. The model aligns with empirical findings, indicating a muted response to interest-rate shocks for more leveraged banks.

The intuition behind this result is twofold; firstly, the model predicts that more leveraged banks are effectively more risk-averse and optimally choose a lower degree of duration mismatch. Consequently, they endogenously face lower exposures to interest-rate risk. In addition, it is possible that more leveraged banks face a steeper marginal cost for financing investment due to default risk. This feature can also explain why these banks are less responsive to monetary shocks, as highlighted by Ottonello and Winberry (2020) in an application to corporate investment. Finally, notice that, like for the average response, the model falls short in replicating the complete dynamic pattern, as the coefficient diminishes rapidly to zero from the two-year horizon onward.

Maturity gap and leverage. In the rest of this section, I illustrate the ability of the model to capture the relationship between duration gap and leverage in the cross-section of banks. I begin by estimating a simple regression of duration gap on (book) leverage, $\frac{b_{i,t}}{k_{i,t}}$, and total capital (logged), $\log(k'_{i,t})$, including the aggregate state variables, $Y_t = (R_t, K_t)$, as controls. The specification is

$$\text{Duration Gap}_{i,t} = \alpha + \beta_1 \frac{b_{i,t}}{k_{i,t}} + \beta_2 \log(k_{i,t}) + Y_t + \epsilon_{i,t} \tag{22}$$

The results are reported in Table 3, which compares the model estimates for β_1 and β_2 with the empirical counterparts[28] The estimated coefficient on leverage is negative consistent with the data. The coefficient on size is not significant in the date and close to zero in the model consistent again with the empirical finding.

Further exploiting heterogeneity, I examine next the non-linear relationship between duration and leverage both in the data and in the model. To this end, I divide banks into deciles

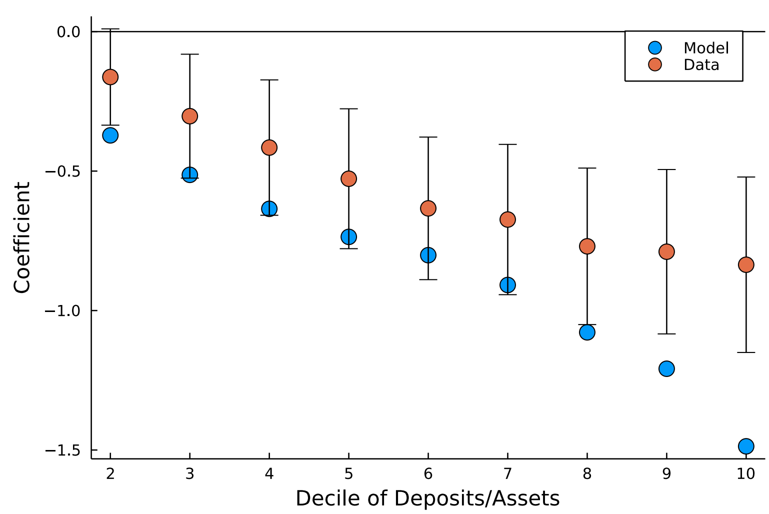
[28] The empirical equivalent of regression (22) is: Duration $\text{Gap}_{i,t} = \alpha + \beta_1 \frac{b_{i,t}}{k_{i,t}} + \beta_2 \log(k_{i,t}) + X_t + \alpha_t + \alpha_i + \epsilon_{i,t}$, where X_t includes additional controls, and α_t and α_i are respectively time and bank fixed effects.

Table 3: Duration Gap and Bank Leverage: Model vs Data

	Duration Gap$_{i,t}$	
	Data	Model
Deposits / Assets ($b_{i,t}/k_{i,t}$)	-0.0521***	-0.1072
	(-7.06)	
Log Assets ($\log k_{i,t-1}$)	-0.0912	0.0280
	(-0.72)	
Time FE	Y	Y
Bank FE	Y	
Controls	Y	
Observations	32606	

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. In the data standard errors are clustered at the bank level.

Figure 7: Duration Gap and Bank Leverage: Non-linear Relationship



Notes: This table reports the estimated coefficients from regression (23). 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.

based on their book leverage and I run the following regression on model-simulated data:

$$\text{Duration Gap}_{i,t} = \alpha + \sum_{d \in \{2:10\}} \beta_{1,d} 1_{d(i)=d} + \beta_2 \log(k'_{i,t}) + Y_t + \epsilon_{i,t} \tag{23}$$

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 book leverage.[29] The results are shown in Figure 7 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.

5.3. Aggregate Implications

In this section, I study quantitatively the implications of endogenous duration for the transmission of interest-rate risk. I focus on the 2022 interest-rate hike, a policy tightening that had sizable negative effects on the financial sector. The goal is to assess the narrative that a period of low interest rates led financial intermediaries to grow overly tolerant towards maturity mismatch and interest-rate risk.[30] To conduct the analysis, I feed the model with the empirical path of interest rates, between 2002 to 2023, depicted in Figure C.1. I then study the dynamic response of the model to this sequence of shocks.

Figure 8 contrasts the dynamics of the average duration gap and of the asset price in the model with those observed in the data between 2018 and 2022.[31] The left panel shows a substantial rise in the average duration gap in the data (indicated by the red, dashed line) during the two years leading up to the tightening. This increase occurred alongside an exceptionally accommodative monetary policy. In line with the data, the model-generated dynamics (illustrated by the blue, solid line) demonstrate a comparable increase in the duration of bank assets. The right panel in Figure 8 plots the model's asset-price dynamics against two empirical measures that the literature has deemed relevant for pricing bank assets.[32] The model predicts a decline in asset prices in response to the tightening, aligning well with the corresponding empirical pattern.

Figure 9 illustrates simulated dynamics for additional variables. The model predicts a con-

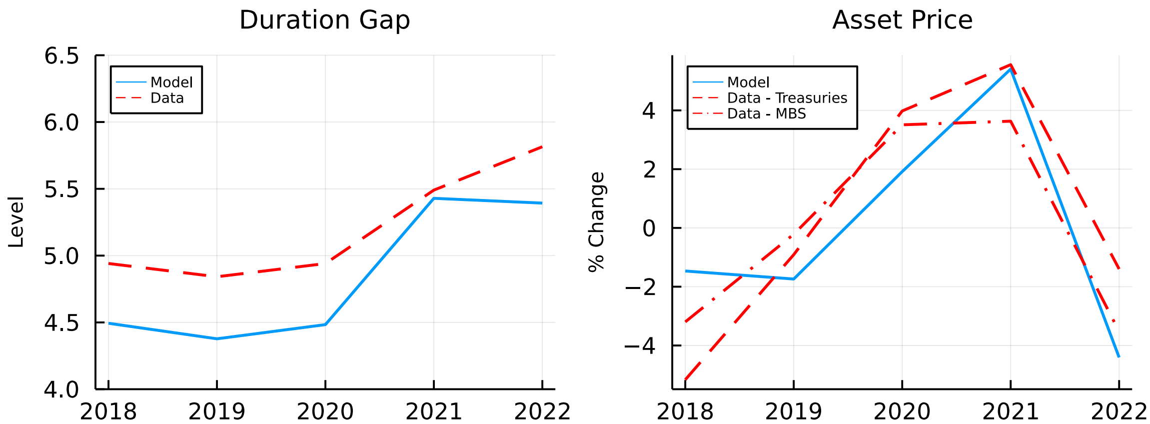
[29] The empirical equivalent of regression (23) is: Duration $\text{Gap}_{i,t} = \sum_{d \in \{2:10\}} \beta_{1,d} 1_{d(i)=d} + \beta_2 \log(k_{i,t}) + X_t + \alpha_t + \alpha_i + \epsilon_{i,t}$, where X_t includes additional controls, and α_t and α_i are respectively time and bank fixed effects.

[30] 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.

[31] Due to bank-level data not being available after 2022, I compare the model with the data only up to 2022.

[32] Jiang *et al.* (2023) rely on exchange-traded funds (ETFs) across various asset classes to evaluate the effect of the monetary tightening on the value of U.S. bank assets.

Figure 8: Response to Interest Rates Path: Model vs Data



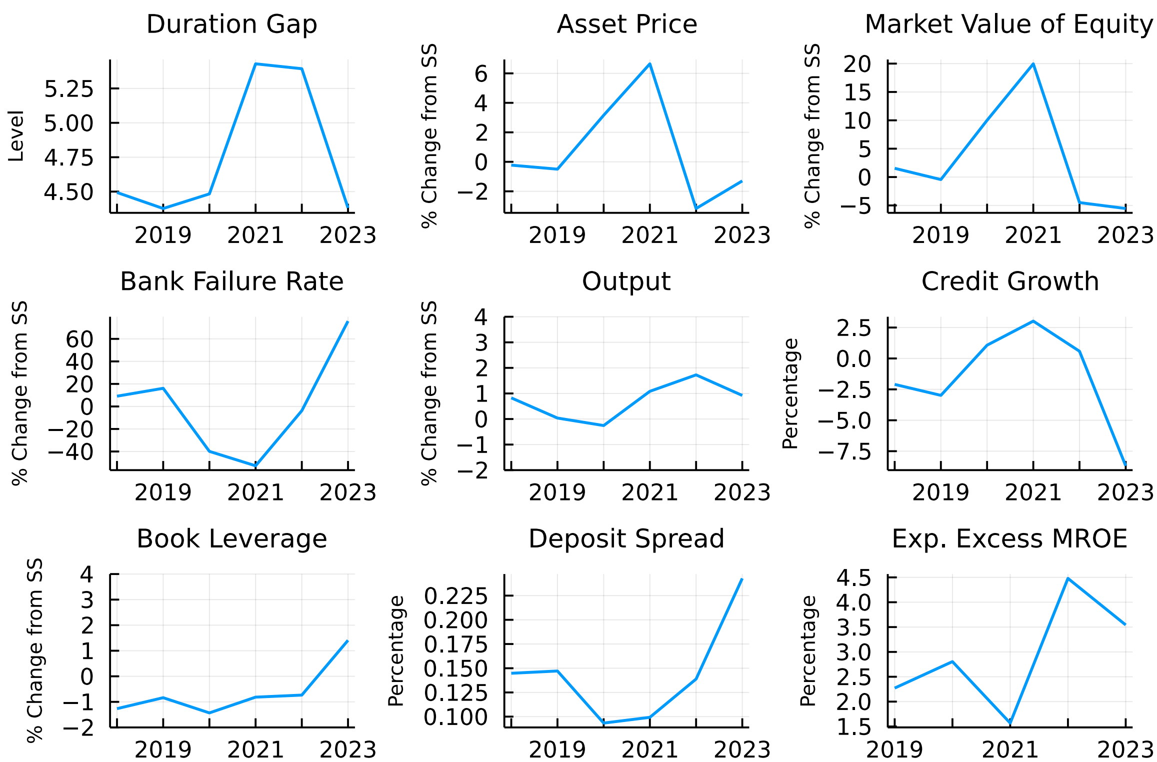
Notes: This figure compares the dynamics of duration gap and asset price in the baseline model (solid, blue line) and in the data. The data counterpart for treasuries is the S&P U.S. Treasury Bond Index (red, dashed line). The data counterpart for Mortgage Backed Securities (MBS) is the SPDR Portfolio Mortgage-Backed Bond ETF (red, dashed and dotted line).

traction in the market value of equity and a notable rise in bank failure rates upon the tightening. The abrupt interest-rate hike leads to capital losses on long-term assets for banks, forcing a significant number of them to default on their debt obligations. Regarding real variables, the model dynamics feature a significant slowdown in credit provision, which is a consequence of the heightened financial stress triggered by the policy hike. Despite this slowdown, the model suggests that, at least in the short term, the monetary tightening might not be severe enough to push the economy into a recession.

Figure 9 also shows the dynamics of book leverage. The interplay between interest rates and leverage reflects two opposite effects. On the one hand, as interest rates decrease, banks experience capital gains, leading to improved balance-sheet conditions. This effect lowers banks' reliance on deposits to finance investment and tends to decrease leverage. On the other hand, a lower risk-free rate reduces the cost of funds, due to lower default probabilities for banks. This effect makes it more costly for banks to take up debt. Figure 9 shows that book leverage remained stable throughout the period, exhibiting a slight increase following the tightening.

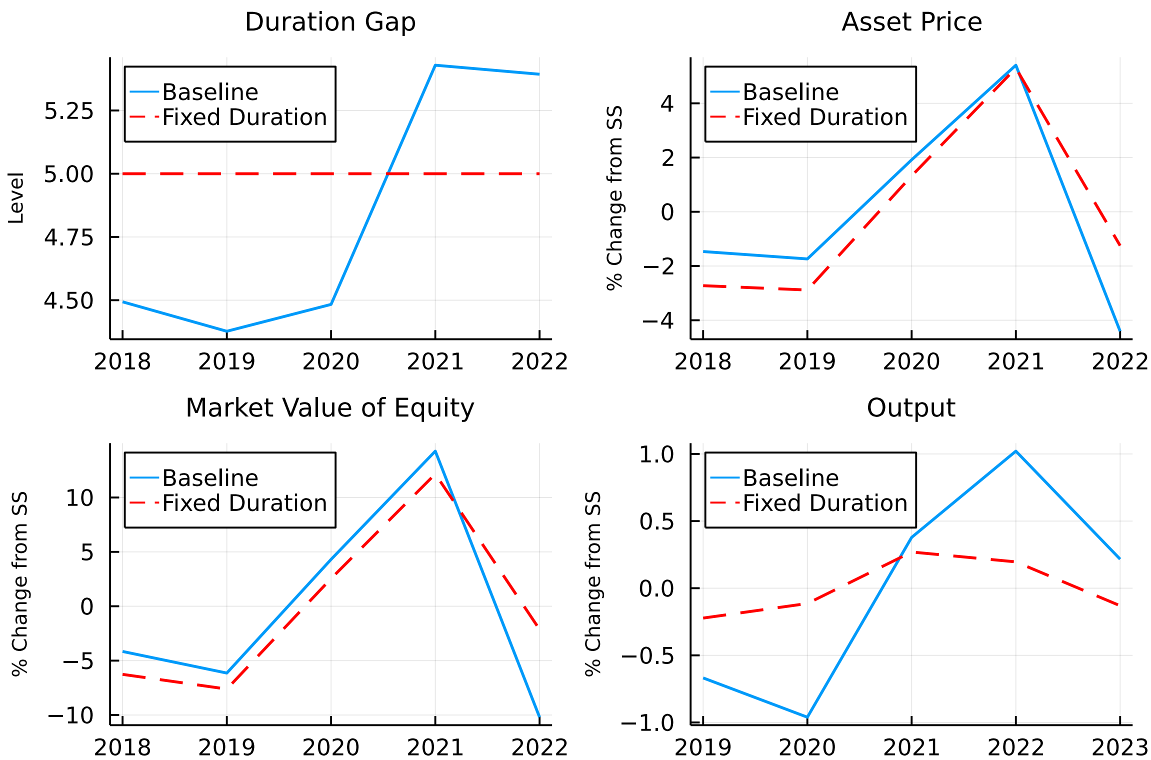
Finally, the figure illustrates how the level of the interest rate influences the expected excess return on bank equity. When the interest rate is low, bank capital is plentiful and the expected excess return is also low. However, when the economy undergoes a sudden tightening, banks incur capital losses and wish to reduce their capital holdings. Therefore, the return on capital must rise, leading in turn to a sharp increase in expected excess returns on bank equity.

Figure 9: 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. Duration gap is reported in level. Deposit spread and expected excess return on bank equity are in percentage points. All other variables are expressed as percentage deviations from their steady-state averages. Credit growth is the rate of change in aggregate capital, i.e. $\frac{K_{t+1}-K_t}{K_t}$. 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 market return on equity for bank i is defined as $\text{MROE}_{i,t} = \frac{\mathbb{E}[V_{i,t+1}]}{V^c_{i,t}-d_{i,t}} - R_t$.

Figure 10: Fixed-duration 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 fixed portfolio share (red dashed line).

5.4. Fixed-duration Counterfactual

So far, the analysis has shown that the recent monetary tightening was preceded by a sharp increase in banks' maturity gaps. I now ask whether this lengthening in maturities can explain the high exposure of the financial sector to the policy hike.

To answer this question, I solve a version of the model where the share of long-term assets in bank portfolios is kept fixed to its ergodic average.[33] This approach allows me to study a setting with a constant degree of duration mismatch in bank balance sheets. I compare the response to the same sequence of interest-rate shocks in the baseline model and in the model with fixed duration. The dynamics of selected variables are displayed in Figure 10.

The counterfactual shows that banks' duration adjustments played an important role in driving the response of both financial and real variables to the sudden interest-rate hike. The

[33] In practice, set I let the curvature parameter in the holding cost function to go to infinity, keeping all other parameters unchanged.

Table 4: Fixed Duration Counterfactual

	$\Delta_{2021,2022}$ Baseline (percentage)	$\Delta_{2021,2022}$ Fixed-duration Counterfactual (relative to baseline)
Asset Price	-9.34%	0.69
Market Value of Equity	-21.7%	0.61
Bank Failure Rate	63.10%	0.65

Notes: This table reports the changes between 2021 and 2022 predicted by the baseline model and by the fixed-duration model for the asset price, the market value of equity and the bank failure rate. Changes in the baseline model are in percentages, while changes in the fixed-duration case are reported relative to the baseline. For example, a value of 0.69 for the asset price means that the effect of the tightening on the asst price is 31% lower in the counterfactual than in the baseline economy.

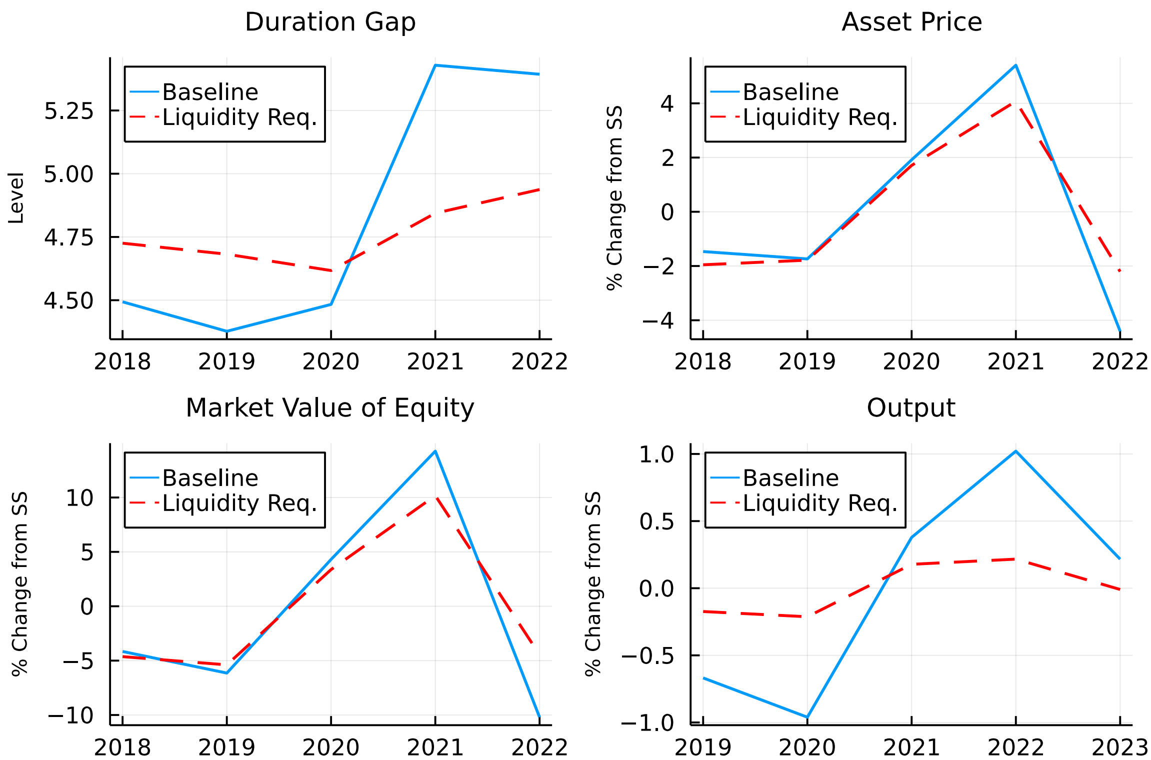
increase in duration leading up to the tightening, exacerbated the subsequent declines in the price of capital and in the market value of bank equity. In terms of real variables, the bottom-right panel of Figure 10 shows that the lengthening of duration also led to higher output volatility. In Table 4 I compare the changes between 2021 and 2021 predicted by the fixed-duration counterfactual with those predicted by the baseline model. The table shows that endogenous movements in banks' interest-rate-risk exposure can account for roughly 30% of the decline in asset prices, 40% of the fall in equity values and 30% of the increase in the number of bank failures.

The counterfactual analysis highlights the value of modelling banks' duration choice to study quantitatively the transmission and amplification of interest-rate shocks. The link between balance-sheet constraints, portfolio composition and asset-price dynamics creates a strong financial accelerator mechanism. The perception of low risk in periods of loose monetary policy induces banks to invest more extensively in long-duration assets. However, the high interest rate exposure in a low-interest-rate environment makes banks' net worth highly susceptible to the declines in asset values triggered by a sudden interest rate rise. Hence, following an unexpected tightening, bank equity capital falls. As balance-sheet losses force banks to reduce investment, asset prices contract further damaging bank capital.

5.5. Liquidity Regulation

The previous analysis has shown that rising interest rates and declining asset values can significantly weaken the financial position of banks. The occurrence of financial turmoil during

Figure 11: 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)

periods of interest-rate hikes underscores the importance of implementing policies designed to mitigate banks' exposure to interest-rate risks. Within my framework there are two motives for such policies. First, the combination of limited liability and deposit insurance gives rise to a standard risk-shifting problem. When investing, banks only value the asset based on its payoff in state where they do not default. Second, there exist pecuniary externalities that lead banks to take excessively risky position, as in the standard financial accelerator literature. In particular, banks do not internalize that asset-price fluctuations would be dampened if they were to reduce the degree of mismatch in their balance sheet. The presence of a risk-shifting motive and of pecuniary externalises leads banks to choose higher leverage and higher duration that it would be optimal from a social planner perspective.

Based on this discussion, I then use the model to assess the impact of policies that limit the ability of intermediaries to take up interest-rate risk. I consider the effect of introducing a liquidity requirement.[34] I assume that banks are required to maintain a share $\hat{\theta}$ of their assets

[34] In Appendix C.1 I study the effect of introducing a capital requirement.

in the form of short-term capital. Under this policy, the recursive problem of the bank becomes

$$V^c(\mathbf{s},\mathbf{S}) = \max_{d,k^{s'}\geq 0,k^{s'}\geq 0,b'} d + \beta e^Z \mathbb{E}_{\omega',\mathbf{S}'|\mathbf{S}} V(n',\omega' k^{l'},\mathbf{S}') \tag{24}$$

s.t.

$$n' = R^K(\mathbf{S}')(k^{s'}+k^{l'}) + (1-\delta)\omega' k^{l'} Q^l(\mathbf{S}') - h\left(\frac{k^{l'}}{k^{s'}+k^{l'}}\right)\left(k^{s'}+k^{l'}\right) - b'$$

$$d + Q^s(\mathbf{S})k^{s'} + Q^l(\mathbf{S})k^{l'} + \psi(k^{s'}+k^{l'},\omega k^l) = n + q(.,\mathbf{S})b'$$

$$d \geq 0$$

$$\frac{k_{k^{l'}}}{k^{s'}+k^{l'}} \leq 1-\hat{\theta}$$

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

The only difference between this problem and the baseline (6) is the presence of a constraint that limits the share of long-term assets in the bank's portfolio. In solving this version of the model, I keep the same parametrization as the baseline economy and fix the regulatory bound $\hat{\theta}$ to some exogenous value. I then feed the empirical sequence of interest-rate shocks and compare the model-implied dynamics with and without the liquidity requirement.

The results of this experiment are depicted in Figure 11. The policy is successful in mitigating exposure to interest-rate risk in periods of low-interest rates.[35] During such times, banks portfolios are more tilted towards the long-term investment technology. This leads to a scenario where the liquidity requirement becomes binding for a significant number of banks. By reducing duration risk, the policy also achieves the goal of stabilizing asset prices and output. Outside of periods of loose monetary policy, the liquidity requirement amplifies interest-rate-risk exposure. By dampening fluctuations in asset prices, the policy effectively makes the long-term assets a safer investment than it would be without the policy. Additionally, since the requirement is less likely to constrain banks when interest rates are not excessively low, the policy leads to an increase, rather than a decrease, of the overall maturity mismatch in the economy.

5.6. Extensions

So far my quantitative analysis has focused on the case where short- and long-term capital can be transformed one-to-one. This assumption means that the two types of capital share the same

[35] Figure C.3 illustrates the heterogeneous effects of the policy across the net worth distribution. Interestingly, the policy is successful in reducing duration gaps at the top of the net worth distribution but not at the bottom. General equilibrium effects are key to explain the behavior of low-net-worth banks that are not constrained by the liquidity requirements.

price in equilibrium. However, in reality, the price of short-maturity assets tends to display less sensitivity to interest-rate fluctuations compared to long-maturity assets. Consequently, shocks to interest rates can lead to changes in their relative price.

To account for this fact, in this section I extend the model by allowing the rate of transformation between short- and long-term capital to be different from one, and potentially time-varying. I assume that capital good producers can transform one unit of long-term capital into $p(Z) \geq 1$ units of short-term capital, where $p(Z)$ is allowed to depend on the exogenous aggregate state.[36] Under these assumptions the problem of capital good producers becomes

$$\max_{I^s, I^l, I} \left\{ Q^s(\mathbf{S}) I^s + Q^l(\mathbf{S}) K^l - \Phi(I, K^s + K^l) \right\} \tag{25}$$

subject to

$$\Phi(I, K^s + K^l) = \frac{\phi}{2} \left(\frac{I}{K^s + K^l} - \hat{\delta} \right)^2 \left(K^s + K^l \right)$$

$$\frac{I^s}{p(Z)} + I^l \leq I$$

The first constraint gives the expression for the adjustment cost function, which is the same as in the baseline model.[37] The second constraint states that each unit of new investment goods can be used to produce either $p(Z)$ units of short-term capital or one unit of long-term capital.

This maximization problem pins down the prices of short- and long-term capital as follows

$$Q^s(\mathbf{S}) = \frac{Q^l(\mathbf{S})}{p(Z)} \tag{26}$$

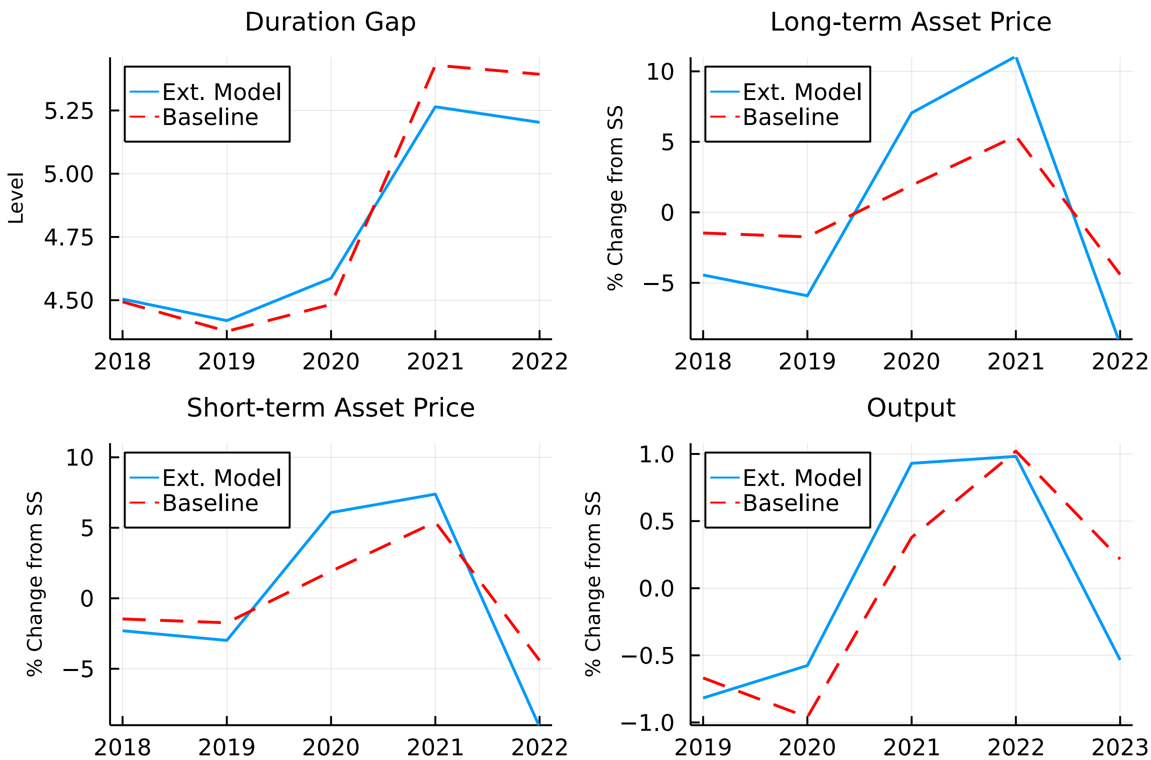
$$Q^l(\mathbf{S}) = 1 + \phi \left(\frac{I}{K^s + K^l} - \hat{\delta} \right) \tag{27}$$

These expressions show that $p(Z)$ effectively pins down the relative price of the two assets. I parameterize $p(Z) = (1+\tau_1)e^{\tau_2 Z}$ with $\tau_1 \geq 0$ and $\tau_2 < 0$. The parameter τ_2 allows me to capture different sensitivities of $Q^l(\mathbf{S})$ and $Q^s(\mathbf{S})$ to interest-rate changes. Setting $\tau_2 < 0$ ensures that the price of short-term capital is less responsive to interest-rate shocks relative to the price of long-term capital. To see this suppose that the interest rate suddenly increases, i.e. the economy experiences a decrease in Z. This shock leads to lower investment and to a contraction in the

[36] The assumption that $p(Z) \geq 1$ means that short-term capital is relatively easier to produce relative to long-term capital. This is a reasonable assumption give the fact that short-term capital is not durable and hence less efficient.

[37] As in the baseline and for tractability, I assume that aggregate adjustment costs only depend on total capital. This allows me to reduce the dimensionality of the problem.

Figure 12: Responses to Interest Rate Path in Model with Different Asset Prices



Notes: This figure compares the dynamics of duration gap, short-term asset price, long-term asset price and market value of equity in the model extended to allow for different prices between the two assets (solid blue line) and in the baseline economy (red dashed line).

price of long-term asset via equation (26). At the same time, given $\tau_2 < 0$, the shock causes $p(Z)$ to increase. From equation (26), we see that the two effects partly offset each-other, resulting in a muted response of the short-term asset price, relative to the long-term one.[38]

I revisit the effect of interest-rate shocks through the lens of this model by feeding the same sequence of shocks as in the previous analysis.[39] Results, shown in Figure 12 , are similar to the baseline, but with two significant distinctions. First, allowing for differential reactions in asset prices dampens adjustments in duration compared to the baseline scenario. The lower sensitivity of short-term asset prices to interest-rate shocks implies that following a rate decrease the price of short-term capital increases by less than the price of long-term capital. As long-term assets become relatively more expensive during periods of low interest rates, banks are less inclined to invest in them compared to the baseline. A second difference is that asset price

[38] Notice that the model reduces to the baseline for $\tau_1 = \tau_2 = 0$.

[39] I do not re-calibrate the extended model. Instead, I keep the same parameterization as in the baseline model and set $\tau_1 = 0$ and $\tau_2 = -2$. The goal is to show robustness of the baseline results to a setting where prices of short- and long-term assets can differ.

volatility is higher in the current version of the model. To understand why consider the impact of the abrupt tightening in 2022. In the baseline, the shock reduces the prices of both long- and short-term assets equally, making it easier for banks to pivot towards short-term investments. In the current framework, by contrast, the price of short-term assets doesn't decline as steeply. This complicates banks' efforts to adjust their duration profiles. Consequently, in the face of the tightening, banks are left with no alternative but to reduce investments.

6. Conclusions

In this paper I study the role of financial intermediaries in the macroeconomic transmission of interest-rate shocks. I build on the traditional view that banks are inherently exposed to interest-rate changes due to the mismatch between the maturity of their assets and liabilities. Departing from existing literature, I develop a framework that endogenizes the degree of maturity mismatch by allowing banks to invest in assets of different duration.

I validate the model against empirical patters and apply it to the 2022 interest-rate hike. My findings are consistent with the narrative that a prolonged low-interest-rate environment made financial intermediaries too complacent towards maturity mismatch and interest-rate risk. The model replicates the increase in the maturity of bank assets observed in the data prior to 2022 and shows that this increase amplified the adverse effects of the monetary tightening.

Finally, I use the model to assess the effect of banking regulation. A liquidity requirement is successful in reducing exposure to interest-rate risk during periods of low interest rates, offering a potential solution to the excessive accumulation of risk in periods of loose monetary policy.

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Appendices

A. Additional Model Details

A.1. Microfoundation

At the beginning of each period, before the payoff from capital is realized, a bank gets a profitable investment opportunity with probability p. This opportunity consists of a technology to transform x units of consumption goods into ax units with $a > 1$. Because the payoff from capital is not yet realized, banks must finance this investment opportunity using intratemporal collateralized loans. I assume that the interest rate on intratemporal loans is zero, but these loans must be collateralized by bank's assets. Short-term capital can be fully pledged, while only a fraction ν of long-term capital can be pledged.

Because $a > 1$, a bank with the investment opportunity will always borrow up to the limit. This implies that the payoff from the investment opportunity is

$$a\left(k^s + \nu k^l\right) = a\left[1 - (1-\nu)\theta\right]k \tag{28}$$

The holding-cost function in the main text can be obtained by setting $p = 1$ and $h(\theta) = -a\left[1 - (1-\nu)\theta\right]$.

A.2. Homogeneity of the Bank Problem

In this section, I show that the problem of the bank is homogeneous in effective long-term capital, $\hat{k}^l = \theta\omega k$. This property allows me to write the value function of the bank in terms of value per unit of long-term capital, $V(n, \mathbf{S}) = \nu(n, \mathbf{S})\hat{k}^l$. We can then rewrite the problem of the firm by noticing that the effective choice variables of the bank are $\tilde{k}' = \frac{k'}{\hat{k}^l}$, capital growth with respect to effective long-term capital, and leverage $l' = \frac{b'}{k'}$. The problem of the firm can be recast as follows

$$\nu^c(n, \mathbf{S})k^l = \max_{\tilde{d}, \tilde{k}' \geq 0, l', \theta'} \tilde{d} + \frac{1}{r(\mathbf{S})}\mathbb{E}_t \nu(\tilde{n}'(\theta', \mathbf{S}'), \mathbf{S})\omega'\theta'\tilde{k}'$$

s.t.

$$\tilde{n}'(\theta', l', \mathbf{S}') = \frac{R^K - h(\theta') + (1-\delta)Q(\mathbf{S}') - l'}{\theta'} \tag{29}$$

$$\tilde{d} + Q(\mathbf{S})\tilde{k}' + \psi(\tilde{k}', 1) = \tilde{n} + q(l', \mathbf{S})l'\tilde{k}' \tag{30}$$

$$\tilde{d} \geq 0 \tag{31}$$

where $\tilde{d}$ and $\tilde{n}$ are respectively dividend and net worth re-scaled by long-term capital. The first equation is the low of motion of scaled net worth. The second is the flow of funds constraint. The last is the no equity issuance constraint.

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 (k', l') choice such that

$$\tilde{n} - Q(\mathbf{S})\tilde{k}' + q(., \mathbf{S})l'\tilde{k}' \geq 0 \tag{32}$$

Define the default threshold $\underline{\tilde{n}}(\mathbf{S}) = \min_{k',l'} \left[Q(\mathbf{S})\tilde{k}' - q(., \mathbf{S})l'\tilde{k}'\right]$. This threshold is such that the bank defaults if and only if $\tilde{n} < \underline{\tilde{n}}(\mathbf{S})$.[40] In this case, in fact, there is no feasible choice of $(\tilde{k}', l')$ such that $d \geq 0$. Define $\underline{\omega}(\theta, l, \mathbf{S})$ as the realization of the capital quality shock such that $\tilde{n}(\theta, l, \mathbf{S}) = \underline{\tilde{n}}$ Using the fact that the capital quality shock is i.i.d we get that the ex-ante default probability is given by

$$d(\theta, l, \mathbf{S}) = \int_{-\infty}^{\underline{\omega}(\theta,l,\mathbf{S})} d\Phi_{0,\sigma_\omega}(\omega) = \Phi_{0,\sigma_\omega}(\underline{\omega}(\theta, l, \mathbf{S})) \tag{33}$$

This allows us to rewrite the bank value function as follows

$$\nu^c(n, \mathbf{S}) = \max_{\tilde{d},\tilde{k}' \geq 0, l', \theta'} \tilde{d} + \frac{1}{r(\mathbf{S})}\mathbb{E}_t(1 - d(\theta', l', \mathbf{S}'))\nu^c(\tilde{n}'(\theta', l', \mathbf{S}'), \mathbf{S})\omega'\theta'\tilde{k}' \tag{34}$$

s.t.

$$\tilde{n}'(\theta', l', \mathbf{S}') = \frac{R^K - h(\theta') + (1 - \delta)Q(\mathbf{S}') - l'}{\theta'} \tag{35}$$

$$\tilde{d} + Q(\mathbf{S}) + \psi(\tilde{k}', 1) = \tilde{n} + q(l', \mathbf{S})l'\tilde{k}' \tag{36}$$

$$\tilde{d} \geq 0 \tag{37}$$

The first-order condition with respect to capital growth $\tilde{k}'$ is given by

$$(1 + \lambda)\left[Q(\mathbf{S}) - q(l', \mathbf{S})l' + \psi_1'(\tilde{k}', 1)\right] = \frac{1}{r(\mathbf{S})}\mathbb{E}_t(1 - d(\theta', l', \mathbf{S}'))\nu^c(\tilde{n}'(\theta', l', \mathbf{S}'), \mathbf{S})\omega'\theta' \tag{38}$$

If the no-equity issuance constraint is not binding, then $\lambda = 0$, so substituting the above

[40] Note that the default threshold only depends on the aggregate state, $\mathbf{S}$. This follows from the assumption that the capital quality shock is i.i.d across banks and time.

equation in (38) we obtain

$$\nu^c(n, \mathbf{S}) = \tilde{n} - \psi(\tilde{k}', 1) + \psi_1'(\tilde{k}', 1)\tilde{k}' \tag{39}$$

which confirms the conjecture. If the constraint is binding then equation (38) yields

$$\lambda = \frac{\beta e^Z \mathbb{E}_t (1 - d(\theta', l', \mathbf{S}'))\nu^c(\tilde{n}'(\theta', l', \mathbf{S}'), \mathbf{S})\omega'\theta' k'}{\tilde{n} + \psi_1'(\tilde{k}', 1) - \psi(\tilde{k}', 1)} - 1 \tag{40}$$

Combining (38) and (40) we obtain

$$\nu^c(n, \mathbf{S}) = \frac{\beta e^Z \mathbb{E}_t (1 - d(\theta', l', \mathbf{S}'))\nu^c(\tilde{n}'(\theta', l', \mathbf{S}'), \mathbf{S})\omega'\theta' k'}{\tilde{n} + \psi_1'(\tilde{k}', 1) - \psi(\tilde{k}', 1)k'} \left[Q(\mathbf{S}) - q(l', \mathbf{S})l' + \psi_1'(\tilde{k}', 1) \right] k' \tag{41}$$

which again confirms the conjecture.

A.3. Numerical Algorithm

State variables. In this section I provide details on the numerical algorithm employed to solve the quantitative model. Let

$$\theta = \frac{k^l}{k^l + k^s} \tag{42}$$

It will prove convenient to use as a state variable (re-scaled) cash-on hands, net of capital sales, defined as

$$x = \frac{R^K - h(\theta) - l'}{\theta'} \tag{43}$$

instead of the re-scaled net worth $\tilde{n} = \frac{R^K - h(\theta') - l'}{\theta'} + (1 - \delta)Q(\mathbf{S})$.

At the beginning of each period, the exogenous aggregate and idiosyncratic shocks, (Z, ω_i) are realized. The aggregate state is given by $\mathbf{S} = (Z, \mu(x, \hat{k}^l))$, where $\mu(x, \hat{k}^l)$ 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, $K = K^s + K^l$. 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 $\hat{S} = (Z, \hat{K})$ to forecast relevant endogenous objects, namely the marginal product $R^K(\mathbf{S})$ and the asset price $Q(\mathbf{S})$. Given $\hat{K}$, the marginal product of capital is simply

$$R^K(\mathbf{S}) = \alpha \hat{K}^{\alpha-1} \tag{44}$$

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

$$\hat{\Gamma}_Q(\hat{\mathbf{S}}) = e^{\lambda_{Q,0}+\lambda_{Q,1}\hat{K}+\lambda_{Q,2}Z} \tag{45}$$

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

$$\hat{\Gamma}_{\hat{K}'}(\hat{\mathbf{S}}) = e^{\lambda_{\hat{K}',0}+\lambda_{\hat{K}',1}\hat{K}+\lambda_{\hat{K}',2}Z} \tag{46}$$

Bank problem. The bank problem can be solved in two steps. First, given any choice of leverage l' compute the optimal portfolio share, $\theta'(l')$, by solving

$$w(l', \mathbf{S}) = \max_{\theta'} \mathbb{E}_{\omega',\mathbf{S'}|\mathbf{S}}(1 - d(\theta', l', \mathbf{S}'))\nu^c(\tilde{x}'(\theta', l', \mathbf{S}'), \mathbf{S})\omega'\theta' \tag{47}$$

s.t.

$$\tilde{x}'(\theta', l', \mathbf{S}') = \frac{R^K(\mathbf{S}) - h(\theta') - l'}{\theta'}$$

Next, given the function $\theta'(l')$ compute optimal investment and leverage, $\left\{\tilde{k}'(x, \mathbf{S}), l'(x, \mathbf{S})\right\}$, by solving

$$\nu^c(x, \hat{\mathbf{S}}) = \max_{\tilde{d}, \tilde{k}' \geq 0, l'} \tilde{d} + \frac{1}{r(\mathbf{S})} w(l', \mathbf{S})\tilde{k}' \tag{48}$$

s.t.

$$\tilde{x}'(\theta', l', \mathbf{S}') = \frac{R^K(\mathbf{S}') - h(\theta') - l'}{\theta'}$$

$$\tilde{d} + Q\tilde{k}' + \psi(\tilde{k}', 1) = x + (1 - \delta)Q(\mathbf{S}') + q(l', \mathbf{S})l'\tilde{k}'$$

$$\tilde{d} \geq 0$$

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

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

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

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 (47)-(48) 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 $q(l', \mathbf{S})$ for every choice of l'.

2. Obtain the optimal portfolio share $\theta'(l')$ for every choice of l' by solving problem (47).

3. Compute policy functions $\left\{\tilde{k}'(x, \mathbf{S}), l'(x, \mathbf{S})\right\}$ by solving problem (48). Update value function accordingly. Store policy functions for the repayment decisions $\{\iota^c(x, \mathbf{S}), \iota^e(x, \mathbf{S})\}$, where the latter refers to the case where the bank exits exogenously.

4. Update the debt price function using

$$q(l', \mathbf{S}) = \beta e^Z \mathbb{E}_t \Bigg\{ 1 - [1 - [(1-\sigma)\iota^c(\tilde{x}', \mathbf{S}') + \sigma\iota^e(\tilde{x}', \mathbf{S}')]] \\ (1-\pi_b)\left[1 - \min\left\{\frac{\gamma(1-\delta)Q(\mathbf{S}')\omega'\theta'(l')}{l'}, 1\right\}\right]\Bigg\} \quad (49)$$

$$\tilde{x}'(\theta', l', \mathbf{S}') = \frac{R^K(\mathbf{S}') - h(\theta') - l'}{\theta'}$$

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

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, $K'(\mathbf{S})$, and for the price of capital, $Q(\mathbf{S})$. 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 4 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 U.S.. 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.

Compustat/CRSP. I use Compustat/CRSP data to compute the market value of equity for the subset of publicly traded BHCs. The market value of equity is obtained by multiplying the number of shares outstanding (cshoq) by the quarterly close price (prccq).

Interest Rate Shocks. My baseline measure of monetary policy shocks is the series from Bu *et al.* (2021). For robustness, I also use the sequence of shocks from Nakamura and Steinsson (2018).

B.2. Variables Definitions

Maturity Gap. 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:

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

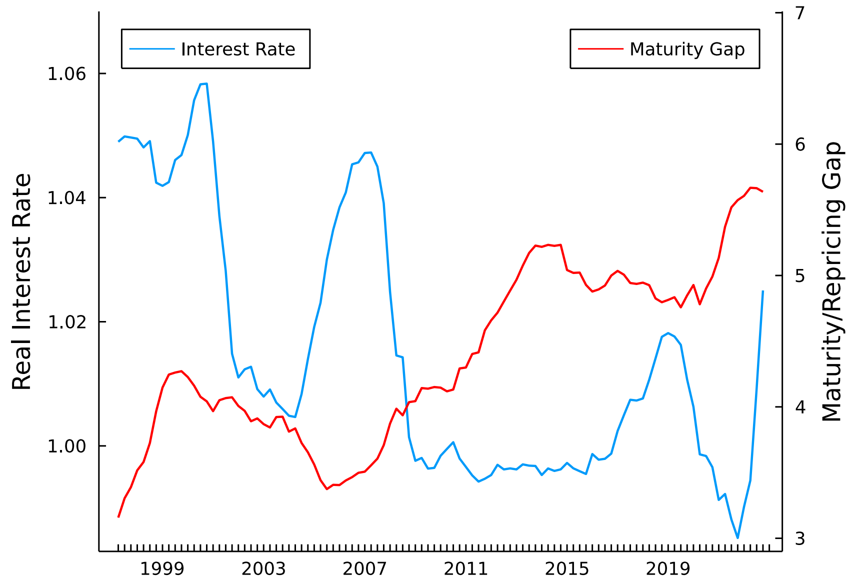
where $\mathcal{A}$ and $\mathcal{L}$ are the sets of assets and liabilities for which the breakdown by maturity is available. Asset categories are residential mortgage loans, all other loans, Treasuries and agency debt, mortgage-backed securities (MBS) secured by residential mortgages, and other MBS. 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.

Bank Leverage. I use two definitions of leverage in the data. First, I consider the ratio of bank deposits to total assets. Second, for the subset of publicly traded BHCs, I also consider market leverage which I define as the ratio of total liabilities to the sum of total liabilities and the market value of equity. To compute the market value of equity I use Compustat/CRSP data in addition to Call Reports.

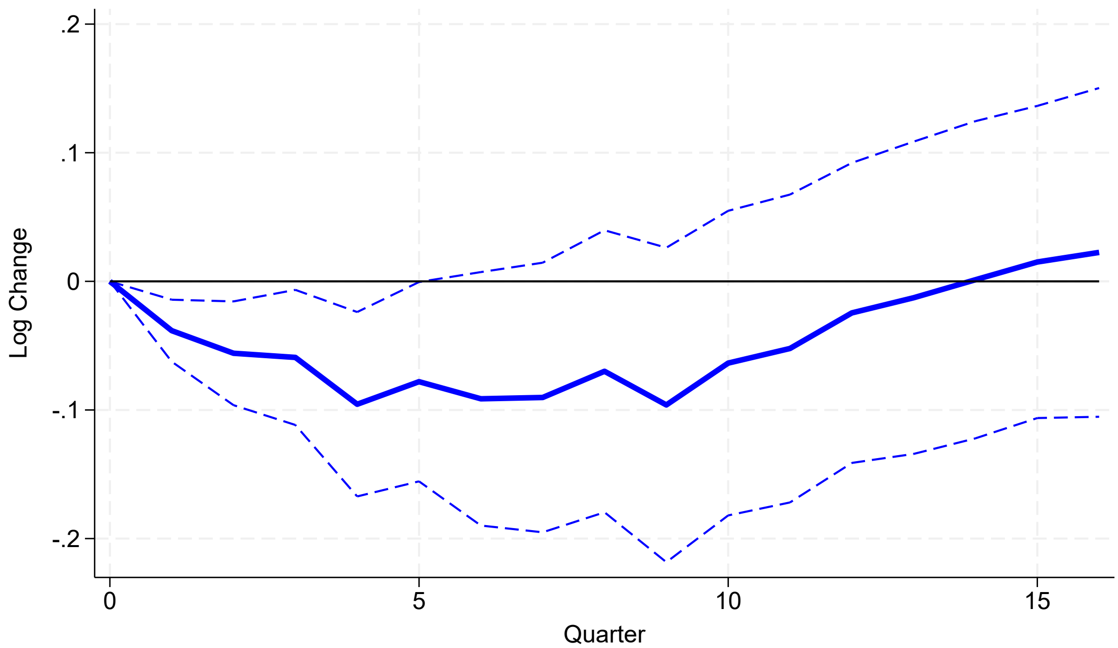
B.3. Additional Empirical Results

Figure B.1: Maturity Gap and the Real Interest Rate: Alternative Measure



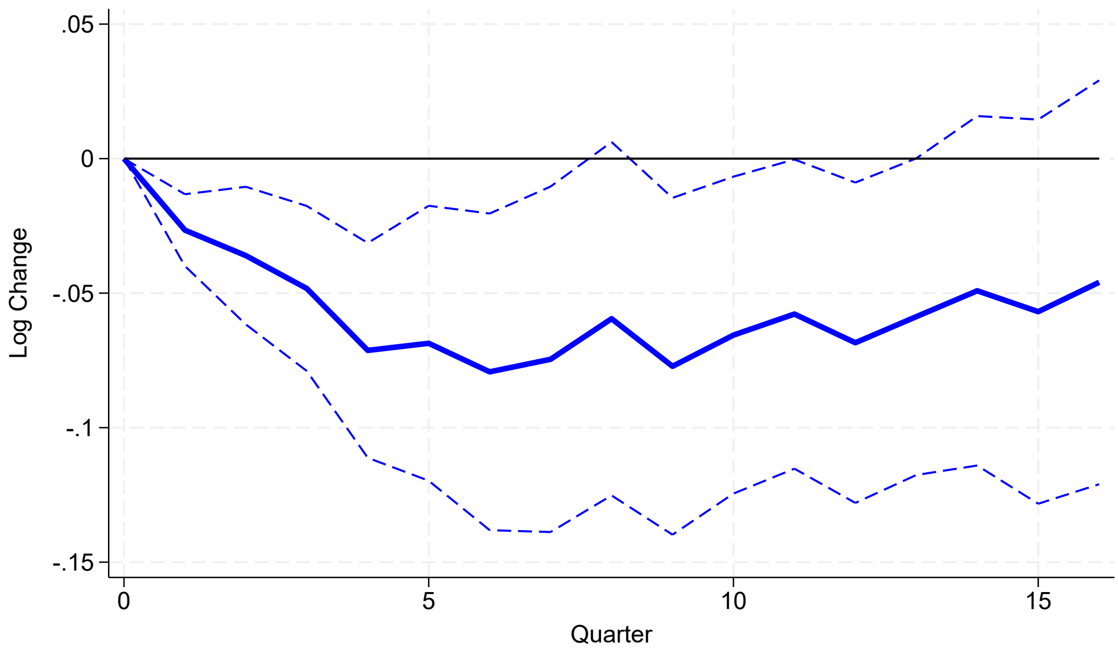
Notes: The interest rate is the inflation-adjusted effective federal funds rate. The maturity gap is computed as the difference between the average maturity of bank assets and the average maturity of bank liabilities. Maturity data come from U.S. Call Reports.

Figure B.2: Average Response of Maturity Gap: Full Sample



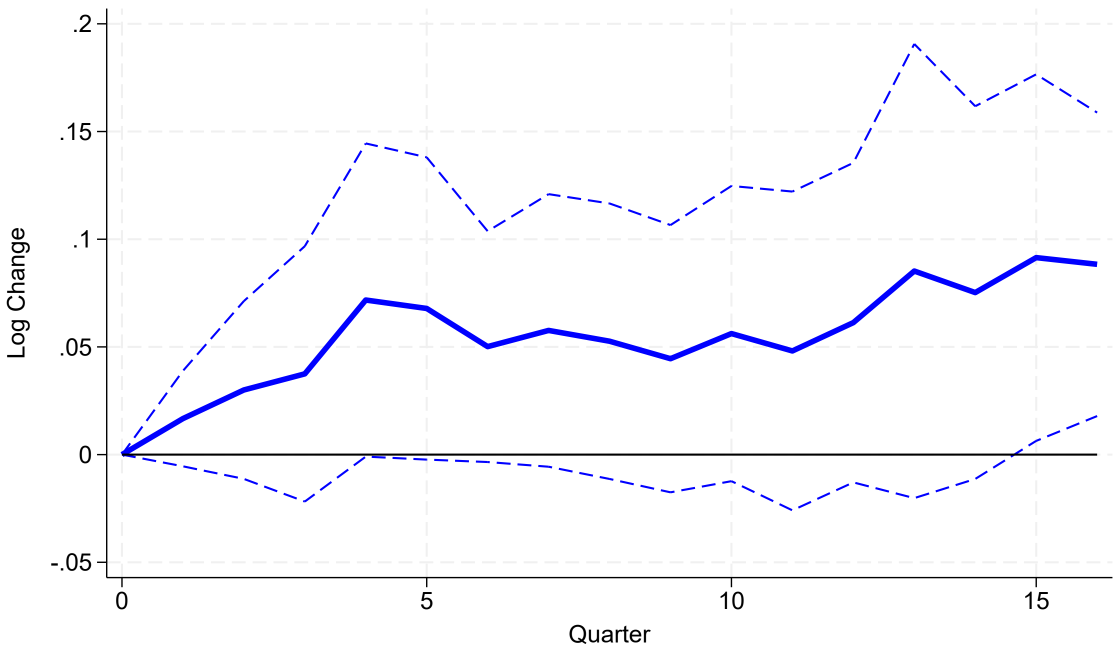
Notes: Dynamics of the coefficient on monetary shocks over time. Reports point estimate and 90% confidence interval for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h \Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \sum_{\tau=1}^{4} \mathbf{\Gamma}_{2,\tau}^h \mathbf{Y}_{t-\tau} + \alpha_i^h + \epsilon_{i,t}$ estimated over the full sample (1997q2-2020q4). 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.

Figure B.3: Average Response of Maturity Gap: Reduced-form Specification



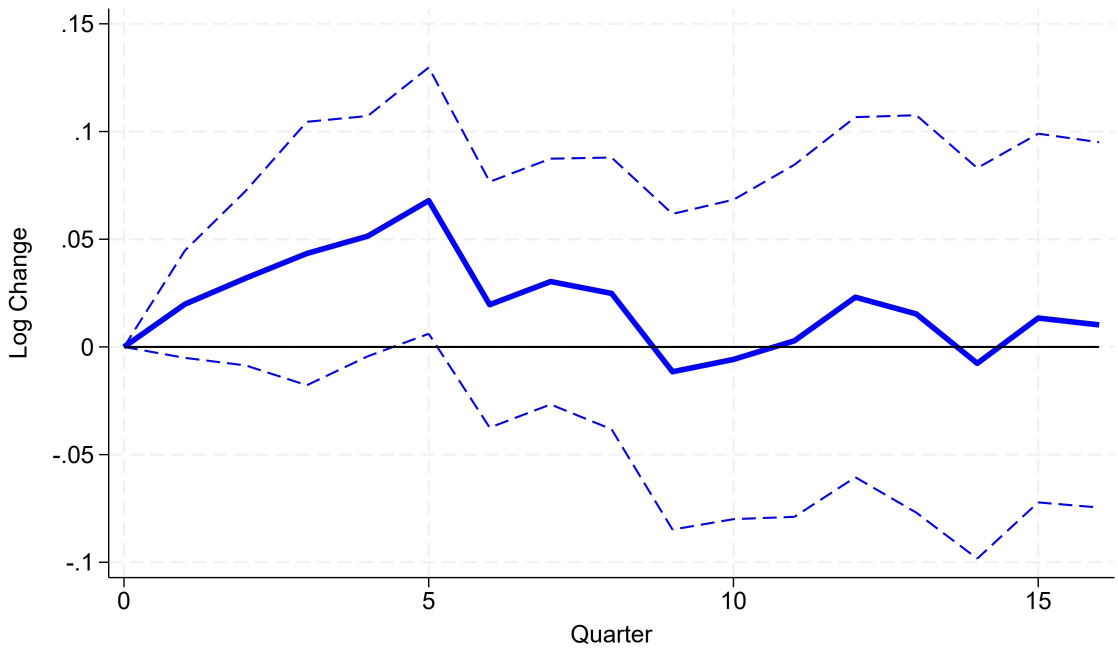
Notes: Dynamics of the coefficient on monetary shocks over time. Reports point estimate and 90% confidence interval for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h \epsilon_t^m + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \sum_{\tau=1}^4 \mathbf{\Gamma}_{2,\tau}^h \mathbf{Y}_{t-\tau} + \alpha_i^h + \epsilon_{i,t}$. 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.

Figure B.4: Effect of Leverage on Dynamic Response of Maturity Gap to Monetary Shocks: Interactions with Other Variables



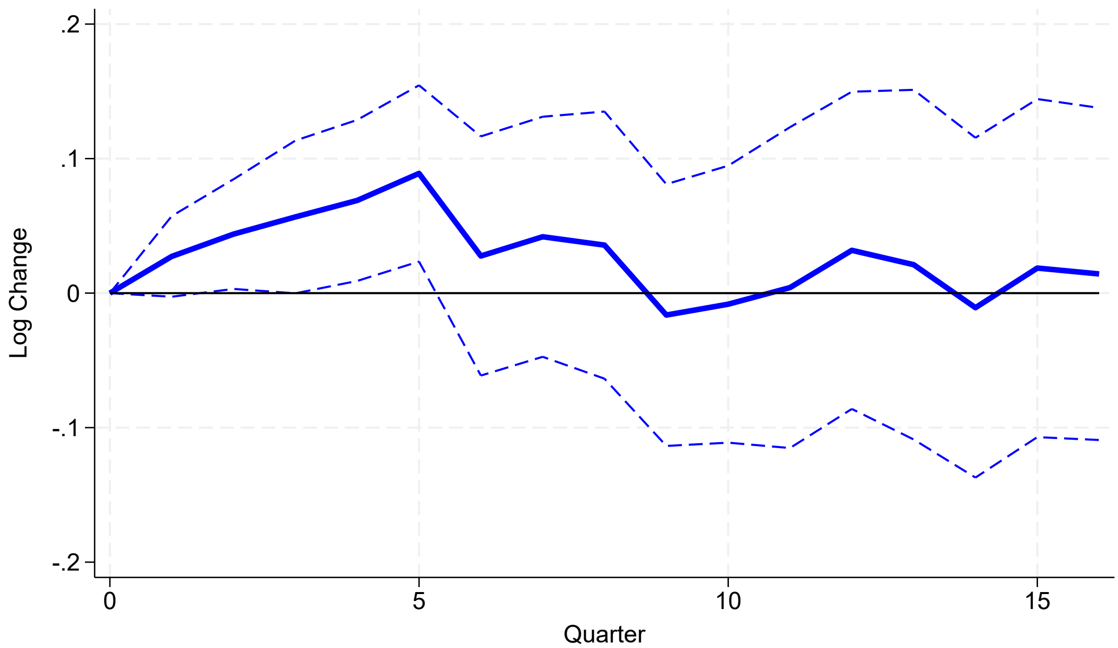
Notes: Dynamics of the coefficient on monetary shocks over time. Reports point estimate and 90% confidence interval for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h(l_{i,t-1} - \mathbb{E}_i\,[l_{i,t}])\Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \alpha_i^h + \alpha_t^h + \epsilon_{i,t}$. Covariates included in $\mathbf{X}_{i,t-1}$ are 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.5: Effect of Leverage on Dynamic Response of Maturity Gap to Monetary Shocks: Full Sample



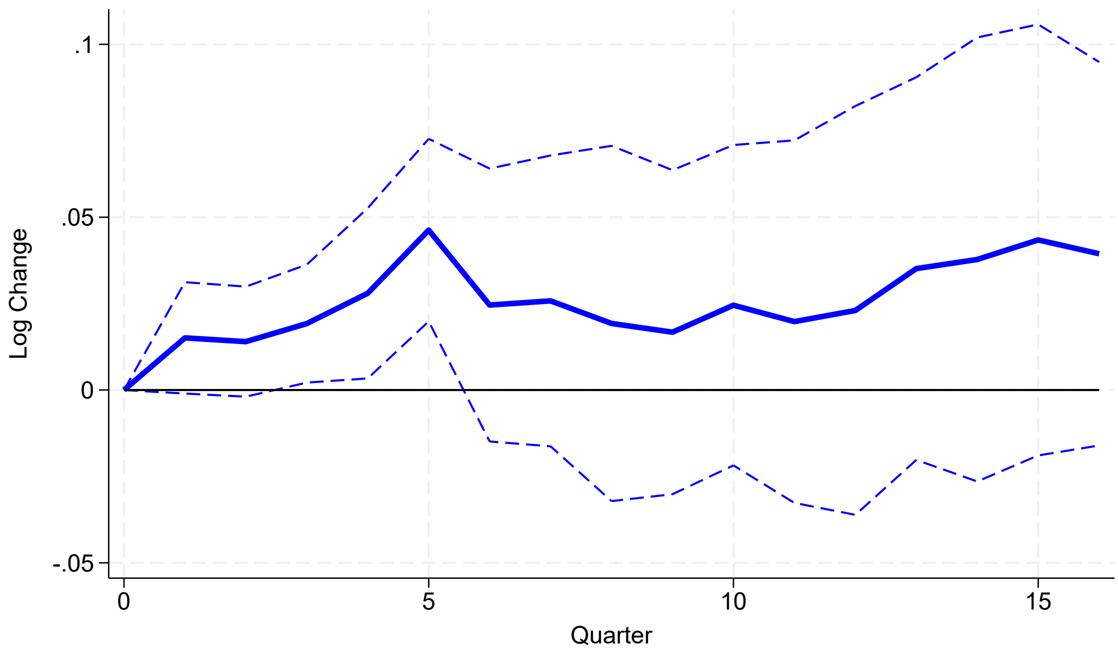
Notes: Dynamics of the coefficient on monetary shocks over time. Reports point estimate and 90% confidence interval for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h(l_{i,t-1} - \mathbb{E}_i\left[l_{i,t}\right])\Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \alpha_i^h + \alpha_t^h + \epsilon_{i,t}$. Covariates included in $\mathbf{X}_{i,t-1}$ are size, market leverage, wholesale funding as a share of total liabilities, the nonperforming ratio, ROE. Regression estimated on full sample (1997q2-2020q4) Confidence intervals based on two-way clustered standard errors at bank and time levels.

Figure B.6: Effect of Leverage on Dynamic Response of Maturity Gap to Monetary Shocks: Reduced-form Specification



Notes: Dynamics of the coefficient on the interaction term between the monetary shock and market leverage over time. Reports point estimate and 90% confidence interval for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h(l_{i,t-1} - \mathbb{E}_i\left[l_{i,t}\right])\epsilon_t^m + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \alpha_i^h + \alpha_t^h + \epsilon_{i,t}$. Covariates included in $\mathbf{X}_{i,t-1}$ are size, market leverage, wholesale funding as a share of total liabilities, the nonperforming ratio, ROE. Confidence intervals based on two-way clustered standard errors at bank and time levels.

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



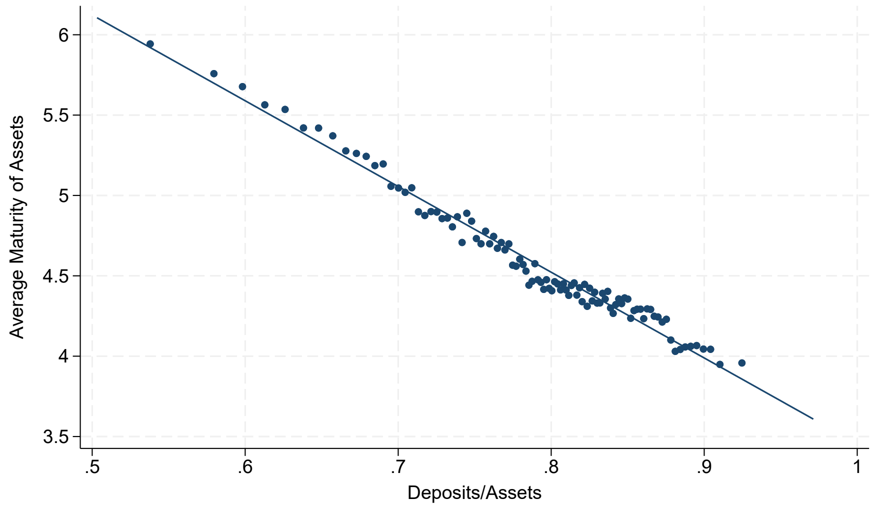
Notes: Dynamics of the coefficient on monetary shocks over time. Reports point estimate and 90% confidence interval for the coefficient β^h from Δlog Maturity $\text{Gap}_{i,t+h} = \beta^h(l_{i,t-1} - \mathbb{E}_i\,[l_{i,t}])\Delta R_t + \mathbf{\Gamma}_1^h \mathbf{X}_{i,t-1} + \alpha_i^h + \alpha_t^h + \epsilon_{i,t}$. 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 size, market leverage, wholesale funding as a share of total liabilities, the nonperforming ratio, ROE. Confidence intervals based on two-way clustered standard errors at bank and time levels.

Table B.1: Cross-sectional Relationship between Maturity Gap and Deposit-to-asset Ratio

	(1) Maturity Gap	(2) Maturity Gap	(3) Maturity Gap
Deposits/Assets	-0.0496***	-0.0527***	-0.0542***
	(-6.99)	(-7.37)	(-7.38)
Log Assets		-0.115	-0.146
		(-0.95)	(-1.54)
Int. Expense Beta			-2.077***
			(-3.53)
Time FE	Y	Y	Y
Bank FE	Y	Y	
Controls		Y	Y
Observations	32606	31590	29309

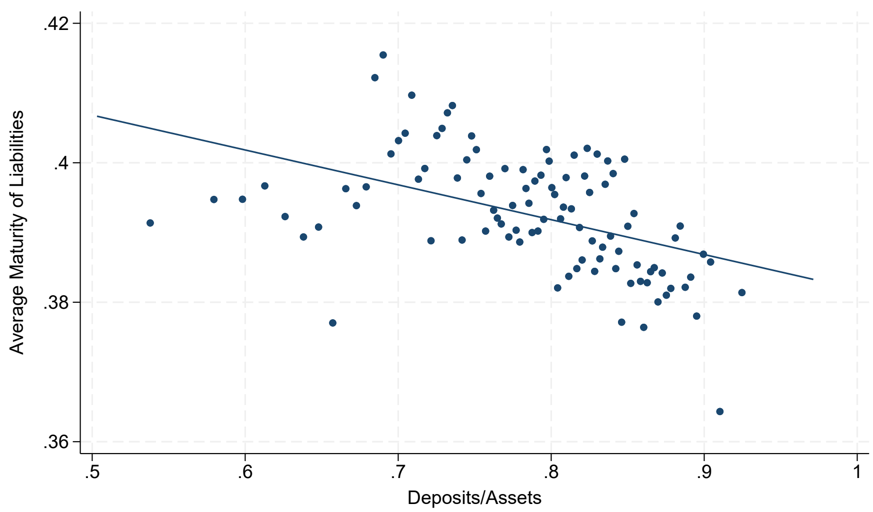
Notes: This table shows the estimated coefficients from a regression of maturity gap on deposit-to-asset ratio. The first column only includes time and individual fixed effects. The second column adds additional controls, which include log-assets, wholesale funding as a share of total liabilities, lagged ROE and lagged loans nonperforming ratio. The last column includes the interest expense beta computes as in Drechsler *et al.* (2021). Standard errors (in parenthesis) are clustered at the bank level.

Figure B.8: Maturity of Assets and Leverage



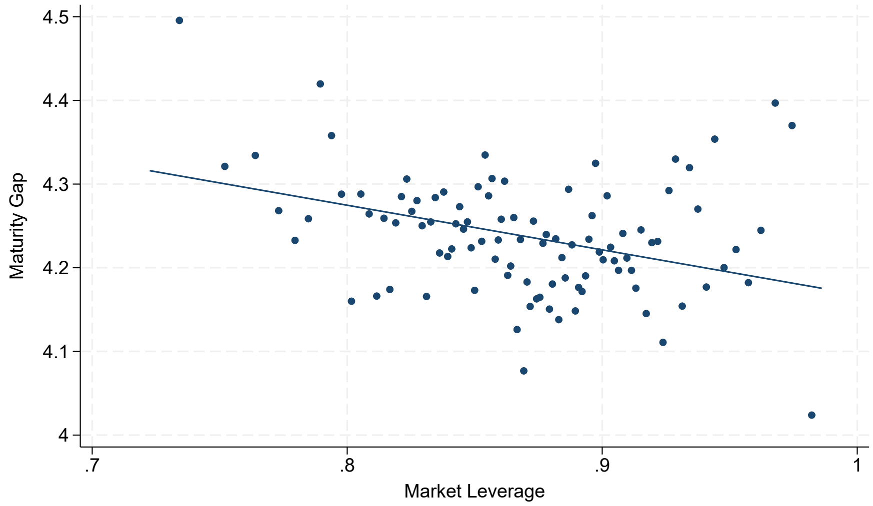
Notes: Cross-sectional binned scatterplot of maturity of assets on deposit-to-asset ratio. The plot residualizes the maturity gap on size, bank and time fixed effects. It then adds back the mean of maturity gap to maintain centering. Data are from U.S. Call Reports

Figure B.9: Maturity of Liabilites and Leverage



Notes: Cross-sectional binned scatterplot of maturity of liabilities on deposit-to-asset ratio. The plot residualizes the maturity gap on size, bank and time fixed effects. It then adds back the mean of maturity gap to maintain centering. Data are from U.S. Call Reports

Figure B.10: Maturity Gap and Market Leverage



Notes: Cross-sectional binned scatterplot of maturity gap on market leverage. The plot residualizes the maturity gap on size, bank and time fixed effects. It then adds back the mean of maturity gap to maintain centering. Data are from U.S. Call Reports

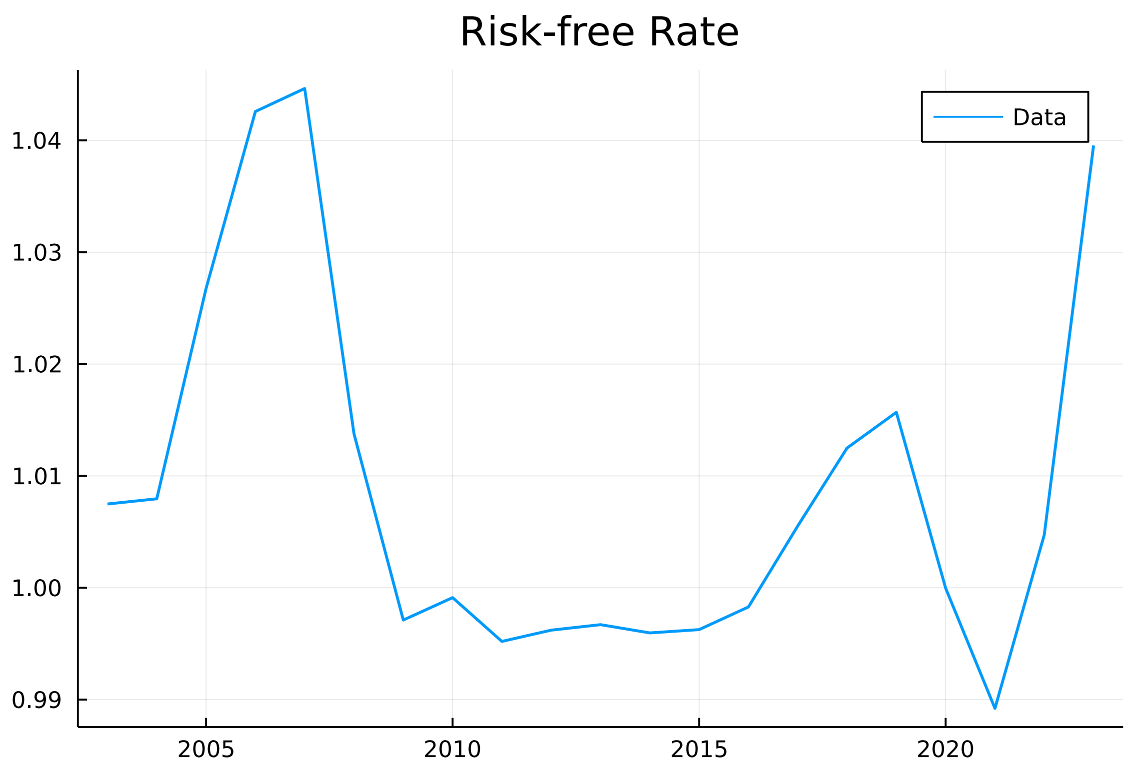
Table B.2: Cross-sectional Relationship between Maturity Gap and Deposit-to-asset Ratio

	(1) Maturity Gap	(2) Maturity Gap	(3) Maturity Gap
Market Leverage	-0.511** (-2.35)	-0.530** (-2.44)	-0.181 (-0.72)
Log Assets		0.149*** (5.02)	-0.00112 (-0.15)
Int. Expense Beta			-2.769*** (-30.42)
Time FE	Y	Y	Y
Bank FE	Y	Y	
Controls		Y	Y
Observations	29307	29307	27213

Notes: This table shows the estimated coefficients from a regression of maturity gap on market leverage ratio. The first column only includes time and individual fixed effects. The second column adds additional controls, which include log-assets, wholesale funding as a share of total liabilities, lagged ROE and lagged loans nonperforming ratio. The last column includes the interest expense beta computes as in Drechsler *et al.* (2021). Standard errors (in parenthesis) are clustered at the bank level.

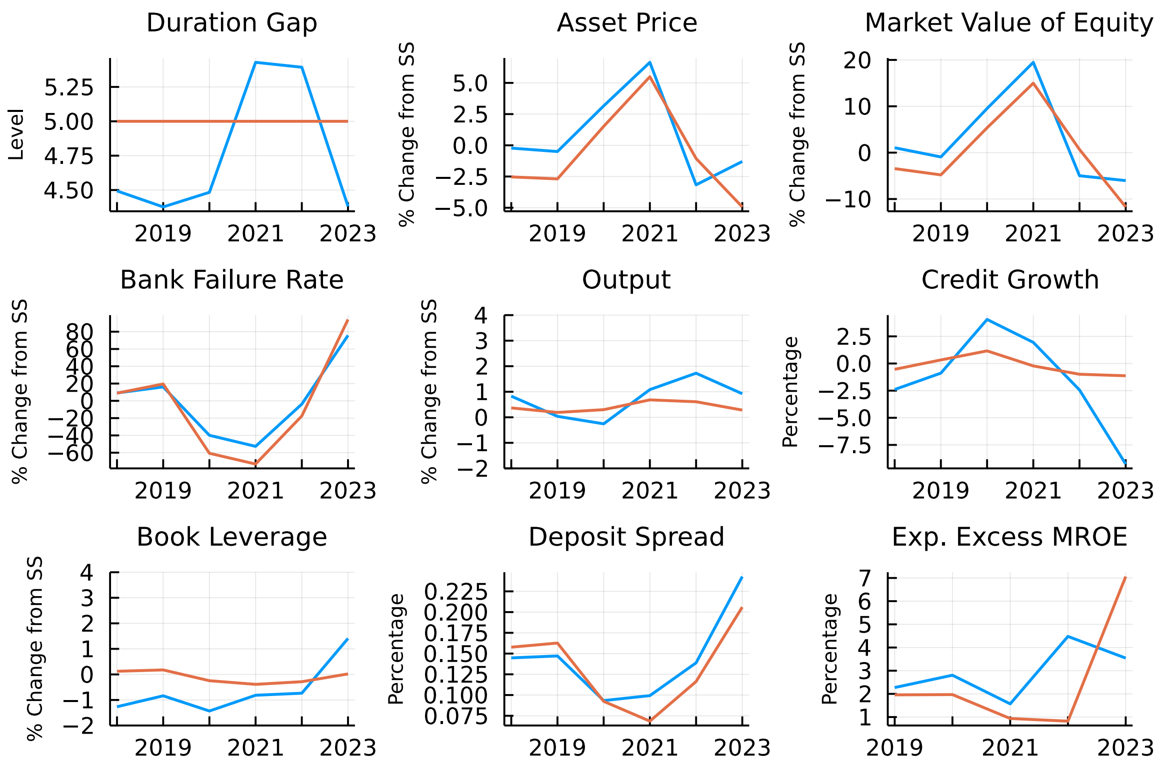
C. Additional Model Results

Figure C.1: Empirical Interest Rate Path



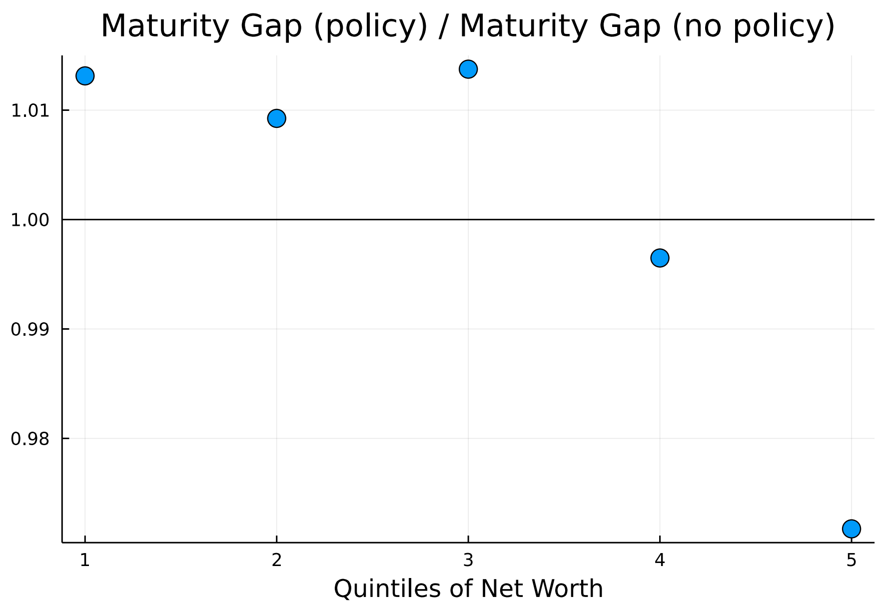
Notes: This figure plots the emprical path of interest rates in the data.

Figure C.2: Model Responses to Interest Rate Path: Baseline vs Fixed-duration Counterfactual



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 duration. Duration gap is reported in level. Deposit spread and expected excess return on bank equity are in percentage points. All other variables are expressed as percentage deviations from their steady-state averages. Credit growth is the rate of change in aggregate capital, i.e. $\frac{K_{t+1}-K_t}{K_t}$. 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 market return on equity is defined as $\text{MROE}_{i,t} = \frac{\mathbb{E}[V_{i,t+1}]}{V^c_{i,t}-d_{i,t}} - R_t$.

Figure C.3: Heterogeneous Effects of Liquidity Requirement



Notes: This figure show the effect of the policy for different quintiles of the net worth distribution.

C.1. Additional Counterfactuals

In this section I study additional model counterfactuals.

Capital Requirement. I study the effect of introducing a capital requirement, by considering an alternative economy where banks face an exogenous limit on leverage $\hat{b}$. Under this policy, the recursive problem of the bank becomes

$$V^c(\mathbf{s}, \mathbf{S}) = \max_{d, k^{s'} \geq 0, k^{s'} \geq 0, b'} d + \beta e^Z \mathbb{E}_{\omega', \mathbf{S}'|\mathbf{S}} V(n', \omega' k^{l'}, \mathbf{S}') \tag{50}$$

s.t.

$$n' = R^K(\mathbf{S}')(k^{s'} + k^{l'}) + (1-\delta)\omega' k^{l'} Q^l(\mathbf{S}') - h\left(\frac{k^{l'}}{k^{s'} + k^{l'}}\right)\left(k^{s'} + k^{l'}\right) - b'$$

$$d + Q^s(\mathbf{S})k^{s'} + Q^l(\mathbf{S})k^{l'} + \psi(k^{s'} + k^{l'}, \omega k^l) = n + q(., \mathbf{S})b'$$

$$d \geq 0$$

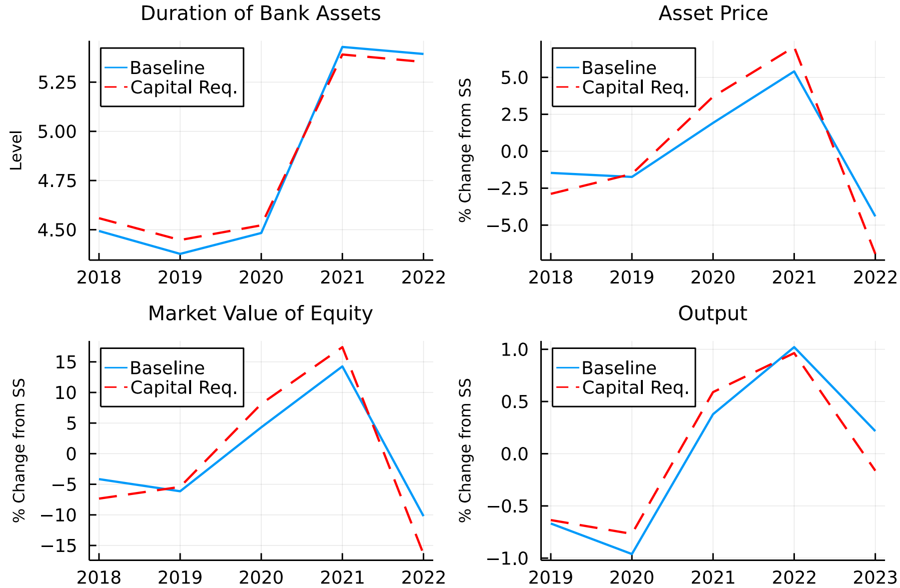
$$b' \leq \hat{b}$$

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

In solving this version of the model, I keep the same parametrization as the baseline economy and exogenously fix the leveage bound $\hat{b}$ to some constant value. I then feed the empirical sequence of interest-rate shocks and compare the model-implied dynamics with and without the capital requirement.

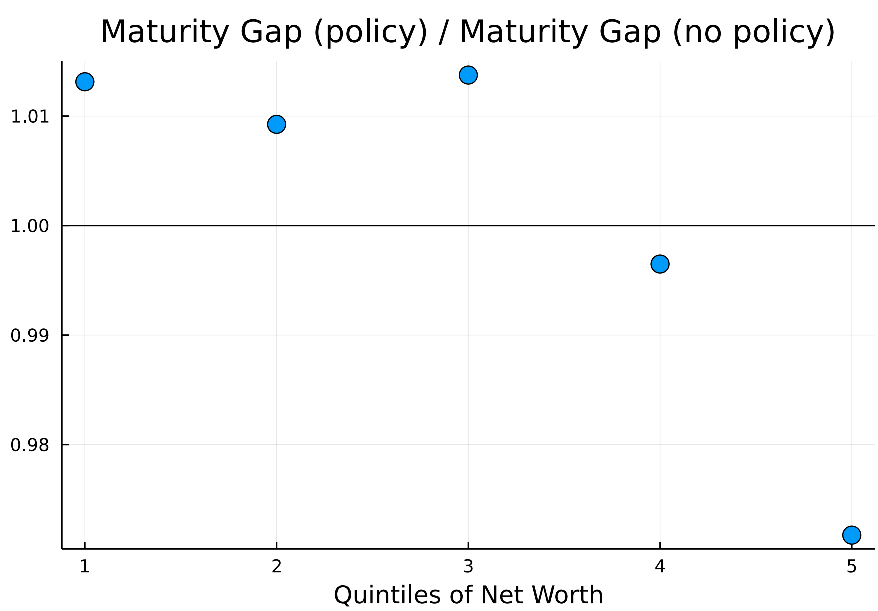
The results of this experiment are depicted in Figure C.4. The capital requirement mitigates slightly fluctuations in bank duration relative to the baseline, as shown in the top-left panel of the figure. However, under the policy the economy exhibits higher asset price volatility and larger fluctuation in bank equity values. To provide the intuition behind this result, Figure C.5 plots the effect of introducing the capital requirement on maturity gap for quintiles of the net worth distribution. The figure shows that the policy reduces bank exposure only at the top of the net worth distribution. At the bottom quintiles, instead, the policy results in an increase in duration. The reason is that by forcing banks to reduce leverage the policy gives them additional incentive to take on interest-rate risk.

Figure C.4: Capital 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 capital requirement. (red dashed line)

Figure C.5: Heterogeneous Effects of Capital Requirement



Notes: This figure show the effect of the policy for different quintiles of the net worth distribution.