Interest Rate Risk in the U.S. Banking Sector ☆

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Abstract

We study interest rate risk at U.S. banks by measuring the impact of interest rate changes on banks' earnings and net worth. Changes in interest rates affect (i) future earnings by altering income and expenses from rate-sensitive assets and liabilities and (ii) current net worth by altering the present value of cash flows from current assets and liabilities. We find that a 100 bps increase in interest rates, on average, increases banks' net interest margin (NIM) by 13 bps and reduces the net worth of the aggregate banking sector in the range of 8% to 18%, depending on the composition of banks' balance sheets. We find that small banks have higher interest rate risk than large banks. During the pandemic period of 2020-2021, U.S. banks became more exposed to interest rate risk due to an increase in the share of long-term securities with low interest rates. Overall, although banks manage the maturity mismatch between assets and liabilities, we provide evidence of substantial remaining interest rate risk at U.S. banks.

(JEL classification: E47, G21, G28)

Keywords: Banks, Interest Rate Risk

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1. Introduction

In 2022, the Federal Reserve began increasing the policy rate after a prolonged period of low interest rates. The increase in interest rates has brought renewed attention to the question of the banking sector's vulnerability to interest rate risk. As noted in the Financial Stability Oversight Council's *2022 Annual Report*,[1] a rapid increase in rates may decrease profitability for banks with larger shares of longer-term fixed-income securities or mortgage loans. In addition, higher rates cause mark-to-market losses on fixed-income securities, reducing banks' equity capital.

First, we theoretically motivate the two effects of interest rate changes on banks: the interest income effect and the balance sheet effect. The interest income effect refers to changes in interest rates causing changes in net interest income. If banks engage in maturity transformation by borrowing short term and lending long term, then an interest rate increase should result in higher interest expenses relative to interest income, reducing net interest margins (NIM). Alternatively, if banks adjust deposit interest rates slower than market interest rates and originate a considerable share of assets under higher interest rates, then net interest margins increase. Thus, in principle the interest income effect can reduce or increase net interest margins. The balance sheet effect refers to a higher interest rate lowering a discount factor and thus reducing the present value of assets and liabilities locked under lower interest rates. Our theoretical model shows two opposing effects of rate changes on banks: an increase in net interest income and a decrease in current equity. These opposing effects, however, provide complementary information. The income effect measures the interest rate sensitivity of future net interest income, and the balance sheet effect measures the interest rate sensitivity of the bank's current value.

Second, we empirically quantify the above two effects on U.S. banks. To quantify the interest income effect, we use regression analysis of the relationship between NIM and the interest rate. To quantify the balance sheet effect, we estimate the sensitivity of the economic value of equity (EVE) to interest rate changes. EVE is a measure of banks'

[1] *2022 Annual Report* Financial Stability Oversight Council , pp. 38-39

net worth and is quantified as the present value of discounted cash flows from current assets and liabilities. Interest rate changes affect the present value of future cash flows, and, consequently, the values of underlying assets and liabilities change as do banks' economic values.

Our main empirical results are as follows. First, we find that a 100 bps increase in the short-term interest rate increases NIM by 13 bps, and a 100 bps increase in the spread between long-term and short-term interest rates increases NIM by 11 bps for a U.S. bank on average. While these magnitudes of NIM's sensitivity are small relative to interest rate changes, we demonstrate that they imply material impacts on interest rate profitability. A 13 bps decline in NIM translates to a \$26 billion decline in net interest income for U.S. banks in aggregate in 2021. Moreover, from 1997 through 2021, NIM declined by 31.5% or 148 bps, and our model attributes 68 bps of this decline to interest rate changes. In addition, we demonstrate that banks hold assets with longer maturities during low interest rate periods to mitigate the decline in interest rate earnings.

Second, we find that a 100 bps parallel upward shift in the yield curve reduces the EVE of the aggregate U.S. banking sector in the range between 8% and 18% during the post-2008 financial crisis. Thus, consistent with the prediction of our theoretical model, increases in interest rates have a positive impact on earnings but come with the cost of substantially reducing the current economic value of equity.

Third, we examine differences in the interest rate sensitivities of small and large U.S. banks using \$10B of total assets as a size threshold. We find that small banks' NIM and EVE exhibit higher interest rate sensitivities. Although small banks receive higher gains in NIM from an interest rate increase than large banks, it comes with the cost of a larger decline in EVE. We show that large banks compensate for lower NIM profitability with higher non-interest income profitability relative to small banks. We explain it by large banks having diverse business structures that generate higher shares of non-interest revenues.

Fourth, we show that U.S. banks' exposure to interest rate risk increased during the pandemic period of 2020-2021. We attribute these results primarily to the increase in the share of long-term securities on banks' balance sheets. During this period, banks increased their holdings of long-term securities with low interest rates, and their increased share in banks' total assets caused NIM to decline by more than the decline associated with the interest rate decrease. In addition, the increase in the share of long-term securities extended the repricing maturities of assets, and it increased the interest rate sensitivity of EVE. We note that most assets are valued at the amortized cost rather than mark-to-market on the balance sheet. Therefore, financial statements mostly do not reflect the impact of interest rate changes on EVE. However, the interest rate sensitivity of EVE reflects lost economic value as fixed cash flows are discounted at higher rates. Moreover, the interest rate sensitivity of EVE creates short-term risk in stressful economic scenarios when banks experience liquidity constraints and need to sell long-term assets at a discount, realizing losses.

Overall, our results show material interest rate risk at U.S. banks. We find that (1) interest rate changes materially impact banks' earnings and net worth, (2) interest rate risk increased substantially during the pandemic, (3) small banks have higher interest rate risk than large banks.

The rest of this paper is organized as follows. Section 2 discusses the relevant literature and our contribution. Section 3 presents our theoretical model. Section 4 describes our empirical models and key assumptions to quantify interest rate sensitivities. Section 5 describes our data sets. Section 6 analyzes our results. Section 7 concludes.

2. Related Literature and Contribution

Our study provides two main contributions to the literature. First, we contribute to the literature on structural modeling of banks, and second, we contribute to the empirical literature on interest rate risk in banking.

In our paper, we extend the original Merton (1974) structural model by explicitly incorporating a fixed-income portfolio in the balance sheet. This extension allows the structural model to decompose the impact of interest rates on bank value for our two effects and provides a theoretical foundation for our empirical analysis. The previous literature on structural modeling mainly focuses on default risk. For example, Nagel and Purnanandam (2019) develop a structural bank model by explicitly incorporating the loan portfolio on the bank balance sheet. They find that a standard structural credit risk model could underestimate the default risk of banks. Hugonnier and Morellec (2017) develop a structural credit risk model of banks that incorporates taxation cost, issuance cost of securities, and default cost. Our extension is targeted to analyze banks' interest rate risk and shows that if the weighted-average duration for assets is longer than the weighted-average duration of liabilities then an increase in interest rates results in a decrease in bank's current equity. In addition, our model shows that when a bank's deposits are less sensitive to the market short-term interest rate than the interest rate applied to newly originated assets, an increase in interest rates results in an increase in net interest income.

We also contribute to the literature characterized by opposing views on the sensitivity of bank value to interest rate changes. The first view focuses on the fact that banks are involved in maturity transformation by funding long-term assets with short-term liabilities. For example, English et al. (2018) find that banks' values decline significantly following an increase in the level or slope of the yield curve. The decline is larger for banks with a large maturity mismatch. Similarly, Paul (2020) finds that banks' values are materially sensitive to interest rate changes. In an alternative view, banks match asset and liability maturities and therefore they are insensitive to the interest rate. For example, Drechsler et al. (2021) argue that banks perfectly match asset maturities with term deposits, exercising significant market power in deposit markets. Hoffmann et al. (2019) find that, in aggregate, banks in Europe are insensitive to interest rate risk, although the sensitivity is heterogeneous across banks. Similarly, Williams (2020) finds that the median U.S. bank matches interest income and interest expenses, however, the sensitivity of interest rate income to the interest rate is heterogeneous across banks. In contrast to this alternative view in the literature, we find that banks, in aggregate and on average, are exposed to material interest rate risk.

Commonly used methods in the literature measure stock price reactions to surprise changes in policy interest rates to proxy the impact of interest rate changes on bank value (e,g., English et al. (2018), Flannery and James (1984a), Ampudia and Van den Heuvel (2018), and Paul (2020)). Arguably, it is challenging to separate stock price reactions to interest rate shocks from other confounding factors imbedded in interest rate shock announcements (e.g., the central bank's assessments of future macroeconomic growth or inflation). Unlike this approach in the literature, the EVE approach directly estimates the impact of interest rate changes on the current value of equity. In our model, we capture the main components of interest rate risk, including: (i) re-pricing risk by accounting for maturities of assets and liabilities and (ii) pre-payment risk by modeling embedded optionality. Fixed-rate mortgage loans and mortgage-backed securities (MBS), which are subject to pre-payment risk, comprise a considerable share of U.S. banks' assets. Our method is conceptually similar to Hoffmann et al. (2019) who also study the sensitivity of net worth and net interest income to interest rate shocks. Meanwhile, our simulation-based EVE model allows us to incorporate an interest-rate-dependent prepayment model for mortgage loans and MBS, resulting in a more accurate measurement of interest rate sensitivity. Our EVE pricing methods account for differences in types of assets and liabilities. In addition, we study interest rate risk at U.S. banks while Hoffmann et al. (2019) study the European banking sector, and we present contrasting results.

The estimates of the interest rate sensitivity of banks' net worth vary in the literature. English et al. (2018) estimate the reaction of bank stock prices to the surprise movements in interest rates prompted by FOMC announcements. Their findings imply that a 100 bps parallel upward shift in the yield curve lowers the average bank's stock price between 8% and 10%. Paul (2020) estimates that the average bank's stock price will fall by around 17% in response to a 100 bps increase in expected short-term rates. Di Tella and Kurlat (2021) calibrate their theoretical model to match with data on interest rates, deposit spreads, bank leverage, and other macroeconomic variables. They find that a 100 bps increase in the interest rate reduces banks' mark-to-market net worth by about 30%. We estimate that a 100 bps increase in interest rates reduces banks' net worth between 8% and 18% in aggregate for U.S. banks during period 2010-2021, depending on the composition of banks' balance sheets.

Unlike the methods used in the literature, our method allows us to estimate time-varying sensitivity and shows the dependence on repricing maturity and asset and deposit compositions. Begenau et al. (2020) propose time varying measures of interest rate risk exposure and report significant exposures of U.S. banks to interest rates. Similar to our finding, Begenau et al. (2020) document time variation in interest rate risk exposure. As discussed in Drechsler et al. (2021), the sensitivity of deposit rates to market rates is the key in the assessment of the impact of interest rates on banks' value. The deposit literature (e.g., Driscoll and Judson (2013), Drechsler et al. (2017), and Gerlach et al. (2018)) suggests that deposit rates have relatively low sensitivity to market interest rates. We use average deposit betas by deposit types reported by the largest banks to the Federal Reserve and published in Gerlach et al. (2018). By applying industry-reported deposit betas, we avoid making our own assumptions in our EVE model.

The empirical banking literature varies in estimates of the interest rate sensitivity of NIM. For example, Genay et al. (2014) and Drechsler et al. (2021) report that NIM is insensitive to interest rate changes. Drechsler et al. (2021) report that with a 100 bps increase in the short-term rate, both interest income and interest expense increase by about the same amount, around 35 bps, and as a result NIM is not sensitive to interest rate changes on average. Genay et al. (2014) estimate that a 100 bps increase in the short-term interest rate results in only a 1.5 bps increase in NIM of the smallest banks and a 0.3 bps increase in the average NIM of large banks. Among papers which report larger sensitivities are English et al. (2018) and Claessens et al. (2018). English et al. (2018) report that a 100 bps increase in interest rates results in a roughly 20 bps increase in NIM after one quarter, although the impact declines over time. Claessens et al. (2018) use a sample of banks from 47 countries from 2005 to 2013 and estimate that a 100 bps interest rate drop causes an 8 bps decline in NIM, and the effect increases to 20 bps at low rates. Our estimates imply that a 100 bps interest rate increase results in a 13 bps increase in NIM. We demonstrate that our estimates explain reasonably well changes in NIM over various sub-periods of interest rate changes in our sample from 1997 through 2021. We explain the difference between estimates of NIM sensitivities in Drechsler et al. (2021) and in our paper by differences in research questions and empirical approaches. Drechsler et al. (2021) employ individual time-series regressions to study the heterogeneity in interest income sensitivity across banks. We use a panel analysis to study how banks, on average, respond to changes in interest rates, and therefore, our approach is better suited to explain the dynamics of the bank-average NIM.

Hanson and Stein (2015) use the aggregate fraction of securities with a re-pricing maturity of one year or longer and find that in response to an interest rate decrease banks increase bond holdings toward longer maturities to reduce the degree of interest income decline. We use more granular data on repricing maturities of assets and find similar results to Hanson and Stein (2015).

3. Theoretical Model

To motivate our empirical analysis of the impact of interest rate changes banks, we extend the Merton (1974) model and incorporate a fixed-income portfolio into the balance sheet. The original Merton (1974) model describes a firm's asset value in total. We represent the total assets of a bank's balance sheet as a portfolio of fixed-income bonds with different maturities. This allows us to analyze how the short-term interest rate impacts the bank's value through the balance sheet channel and the interest income channel. Our modeling approach is close to Nagel and Purnanandam (2019) who describe a bank's asset value as a collection of defaultable loans. Unlike Nagel and Purnanandam (2019), who study credit risk, we focus on interest rate risk.

We compute the mark-to-market value of the portfolio of fixed income bonds, assuming short-term interest rates follow a stochastic process. We assume that banks cannot re-balance their portfolios during a certain time period under stress. The balance sheet effect is captured through the impact of interest rate changes on the mark-to-market value of the fixed-income portfolio and hence affects the equity value. The interest income effect is captured by assuming that the drift term of total assets depends on the interest rate.

The short-term interest rate follows a stochastic process:

$$dr_t = \mu_r(r_t)dt + \sigma_r dW_t \tag{3.1}$$

where μ_r is the drift of the interest rate under the risk-neural measure; σ_r is the volatility of the interest rate; and W_t is a Brownian motion process.

We assume that the bank has a portfolio of zero-coupons bonds $B_t(\tau, r_t)$ with different maturities τ. With the interest rate increase, the bond price declines (i.e., $d(B_t(\tau, r_t))/d(r_t) < 0$). The bank's total asset value, denoted A_t^{NR}, is the sum of all bond values

$$A_t^{NR} = \sum_{k=1}^{K_A} N_{A,k} B(\tau_{A,k}, r_t) \quad t_0 \leq t \leq t_0 + \delta, \tag{3.2}$$

where $N_{A,k}$ is the amount of bonds with maturity $\tau_{A,k} = T_{A,k} - t$ $(k = 1, \cdots, K)$ on the asset side; $T_{A,k}$ is the expiry of the k-th bond; and K_A is the number of different bond maturities on the asset side.

When the fixed-income markets are stressed and liquidity dries up, we assume that the bank cannot rebalance its portfolio from t_0 to $t_0 + \delta$. We call δ a non-rebalancing time period. While the bank cannot re-balance its fixed-income portfolio during the non-rebalancing time period, it can change its portfolio after $t + \delta$. Therefore, we obtain the total asset value during the non-rebalancing period and the post non-rebalancing period

$$A_t = \begin{cases} \sum_{k=1}^{K_A} N_{A,k} B_t(\tau_{A,k}, r_t) & for \quad t_0 \leq t \leq t_0 + \delta, \\ A_{t_0+\delta} e^{\int_{t_0+\delta}^{t} \mu_A ds - \frac{1}{2}\sigma_A^2 (t - t_0 - \delta) + \sigma_A W_{A,t}} & for \quad t > t_0 + \delta, \end{cases} \tag{3.3}$$

where μ_A is the drift term of total assets under the physical measure, and σ_A is its volatility.

Similar to the asset side, we assume that the total liability D_t consists of zero-coupon bonds with different maturities

$$D_t = \begin{cases} \sum_{k=1}^{K_D} N_{D,k} B_t(\tau_{D,k}, r_t) & for \quad t_0 \leq t \leq t_0 + \delta, \\ D_{t_0+\delta} e^{\int_{t_0+\delta}^{t} \mu_D ds - \frac{1}{2}\sigma_D^2 (t - t_0 - \delta) + \sigma_D W_{D,t}} & for \quad t > t_0 + \delta, \end{cases} \tag{3.4}$$

where μ_D is the drift term of the total liability; $N_{D,k}$ is the amount of bonds with maturity $\tau_{D,k}$; and K_D is the number of different bond maturities on the liability side.

We assume that the drift term of total assets and liabilities linearly depends on the short-term interest rate

$$\mu_{A,t} \quad = \quad a_0 + a_r r_t, \tag{3.5}$$

$$\mu_{D,t} = d_0 + d_r r_t, \tag{3.6}$$

where a_0,a_r,d_0, and d_r are constant parameters.

Finally, the economic value of equity $E_t(= A_t - D_t)$ is given by

$$E_t = \begin{cases} \sum_{k=1}^{K_A} N_{A,k} B_t(\tau_{A,k}, r_t) - \sum_{k=1}^{K_D} N_{D,k} B_t(\tau_{D,k}, r_t) \\ for\ t_0 \leq t \leq t_0 + \delta, \\ \\ A_{t_0+\delta} e^{\int_{t_0+\delta}^{t} \mu_A ds - \frac{1}{2}\sigma_A^2 (t-\delta) + \sigma_A W_{A,t}} - D_{t_0+\delta} e^{\int_{t_0+\delta}^{t} \mu_D ds - \frac{1}{2}\sigma_D^2 (t-\delta) + \sigma_D W_{D,t}} \\ for\ t > t_0 + \delta, \end{cases} \tag{3.7}$$

Suppose that the short-term interest rate increases from r_t to $r_t + \Delta r$. We analyze the impact of an interest rate increase on economic value during the non-rebalancing and rebalancing periods.

The impact of an interest rate increase on economic value during the non-rebalancing period should be interpreted as an instantaneous impact on the balance sheet. The impact is approximately equal to

$$\Delta EVE_t = \Delta E_t \approx - \left(\sum_{k=1}^{K_A} N_{A,k} B_t(\tau_{A,k}, r_t) \tau_{A,k} - \sum_{k=1}^{K_D} N_{D,k} B_t(\tau_{D,k}, r_t) \tau_{D,k} \right) \Delta r. \tag{3.8}$$

This equation suggests that an interest rate increase results in a decline in EVE impact if the weighted-average duration for assets is longer than the weighted-average duration of liabilities.

The effect of an interest rate increase on economic value during the rebalancing period reflects its impact on the bank's future profitability. It arises from the growth rate of the bank's assets and liabilities which are captured in the drift term.

Distance-to-default is widely used as a measure of financial soundness and its decline implies a decline in equity value. In our model, the distance-to-default $DD_{t_0+\delta,T}$ is given by

$$DD_{t_0+\delta,T} = \frac{\log\left(A_{t_0+\delta}^{NR} / D_{t_0+\delta}^{NR}\right) + \left(\bar{\mu}_{A,T} - \bar{\mu}_{D,T} - \frac{1}{2}\sigma_A^2 + \frac{1}{2}\sigma_D^2\right)(T - t_0 - \delta)}{\sigma_{AD}\sqrt{T - t_0 - \delta}}. \tag{3.9}$$

where $\bar{\mu}_{A,T}$ and $\bar{\mu}_{D,T}$ are the time average of the drift terms ($\bar{\mu}_{i,T} = \int_{t_0+\delta}^{T} \mu_{i,t} dt/(T-t_0-\delta)$) for $i = A, D$) and σ_{AD} is defined as

$$\sigma_{AD}^2 = \sigma_A^2 - 2\rho_{AD}\sigma_A\sigma_D + \sigma_D^2. \tag{3.10}$$

where ρ_{AL} is the correlation between two Brownian motions for the total assets and liabilities ($\rho_{AD} = dW_A dW_D$).

The first term in the numerator captures how the current values of assets and liabilities on the balance sheet are affected by the interest rate during the non-rebalancing period. The values of total assets and liabilities, A_t^{NR} and D_t^{NR}, are decreasing functions of the interest rate during the non-rebalancing period (i.e., $\partial A_t^{NR}/\partial r_t < 0$ and $\partial D_t^{NR}/\partial r_t < 0$). If assets have longer maturities relative to liabilities, then the first term, and hence the current value of equity, deceases with an increase in the interest rate. This component corresponds to the balance sheet effect of the interest rate change.

In the second term in the numerator, we observe the following drift terms $\bar{\mu}_{A,T} - \bar{\mu}_{D,T} = a_0 - d_0 + (a_r - d_r)\bar{r}_T$ where $\bar{r}_T$ is the time average of the short-term interest rate ($\bar{r}_{i,T} = \int_{t_0+\delta}^{T} r_t dt/(T - t_0 - \delta)$). The drift term captures how a bank's future value changes due to shifts in future net income resulting from movements in the interest rate. If $a_r > d_r$, then the future value of assets increases more than the future value of liabilities, and the bank's future value increases with an increase in the short-term interest rate. This occurs when a bank's liabilities, which mostly comprise deposits, are less sensitive to the market short-term interest rate than the lending rate applied to newly originated assets (i.e., $\partial(\bar{\mu}_{A,T} - \bar{\mu}_{D,T})/\partial\bar{r}_T > 0$). This component corresponds to the interest income effect of the interest rate change.

Thus, the model demonstrates that an interest rate increase impacts a bank's value by affecting: (1) the bank's current value by changing the present value of current assets and liabilities and (2) the bank's future value by changing net interest income from future assets and liabilities. In this paper, we focus on interest rate risk. A valuable extension, though, would be to incorporate credit risk into the model for an integrated framework to design stress scenarios for both interest rate risk and credit risk.

4. Measures of Interest Rate Risk

In this section, we describe two empirical measures of interest rate risk: the sensitivity of future interest earnings and the sensitivity of the current equity value to interest rate changes. These two sensitivities correspond to the interest income and balance sheet effects that we theoretically motivated using Equation 3.9. The Basel Committee on Banking Supervision's (2016) standards require banks to manage interest rate risk to both future earnings and economic equity. If a bank minimizes earnings risk by altering the maturities of assets and liabilities in response to interest rate changes, it may create risk to its economic capital. Alternatively, minimizing economic value risk by matching maturities of assets and liabilities may cause earnings volatility risk. In the next two subsections, we describe our methods for measuring these two interest rate effects.

4.1. Model for the Interest Rate Sensitivity of NIM

To quantify the impact of interest rate changes on net interest income, we use panel regression analysis. Specifically, we estimate the sensitivity of NIM, the interest income ratio, and the interest expense ratio to interest rate changes using the following specification:

$$\Delta y_{i,t} = \alpha_i + \beta \Delta r_{t-1} + \gamma \Delta s_{t-1} + \epsilon_{i,t}, \tag{4.1}$$

where Δ denotes quarterly change; $y_{i,t}$ is one of three variables – NIM, the income ratio, or the expense ratio of bank i in quarter t; r_{t-1} is the quarterly average of the daily 3-month Treasury rate in quarter $t-1$; and s_{t-1} is the term spread defined as difference between the quarterly average 10-year Treasury rate and the quarterly average 3-month Treasury rate.

The interest income (expense) ratio is computed as the ratio of quarterly interest income (expense) to quarterly average earning assets. To annualize and express these ratios in percentage units, we multiply the quarterly ratios by 400. NIM is the ratio of net interest income to average earning assets and is mathematically equivalent to the difference between the income ratio and expense ratio. The regressions include bank fixed effects.

We use one-quarter-lagged independent variables to account for a time lag between the market rate change and the bank's internal interest rate reaction. Specifying our regression in differences as opposed to levels helps us avoid the need to control for risk-taking characteristics which change slowly over time. We use panel regressions instead of the time-series regressions for individual banks used by Drechsler et al. (2021), Hoffmann et al. (2019), and Williams (2020) because of the differences in our research questions. The above papers study the sources of heterogeneity in interest income sensitivity across banks. In our paper, we use cross-sectional information to study how banks, on average, respond to changes in interest rates. In this approach, we are similar to English et al. (2018) who also use panel regressions to quantify the average sensitivity of NIM to policy-induced interest rate changes.

4.2. Model for the Interest Rate Sensitivity of EVE

We define the interest rate sensitivity of EVE as the relative change in EVE after applying a shock to the current yield curve:

$$\%\Delta EVE = \frac{EVE_1 - EVE_0}{EVE_0} \times 100\%, \tag{4.2}$$

where EVE_0 and EVE_1 denote economic values of equity under current and shocked yield curve scenarios.

EVE is computed as the difference between the sums of the present values of assets and the present values of liabilities

$$EVE_y = \sum_a PV_y^a - \sum_b PV_y^l, \tag{4.3}$$

where EVE_y denotes economic value of equity and PV_y^a and PV_y^l denote the present values of assets and liabilities under yield curve scenario y.

The present values of assets and liabilities are computed as the sum of discounted cash flows for each maturity bucket:

$$PV_y^x = \sum_{m=1}^{M} CF_{y,m}^x \times DF_{y,m}, \tag{4.4}$$

where $CF_{y,m}^x$ is a cash flow from asset or liability x under yield curve scenario y at maturity bucket m; $DF_{y,m}$ is a discount factor under yield curve scenario y for maturity bucket m; and M is the total number of maturity buckets.

We apply a continuously compounded discount factor defined by

$$DF_{s,m} = exp(-r_s(t_m) \times t_m), \tag{4.5}$$

where t_m is time in years to the mid-point of maturity bucket m and $r_s(t_m)$ is a discount rate at time t_m, implied by yield curve scenario s. We use discount rates extracted from the yield curve scenario and discount cash flows to compute the present values of assets and liabilities. The difference between the present values of assets and liabilities results in the EVE for a given yield curve scenario.

We follow the Basel Committee on Banking Supervision's (2016) guidance and compute the EVE with a run-off balance sheet where current positions mature over their lifetime and no new businesses replace maturing positions. Thus, one should interpret $\%\Delta EVE$ as the impact of a shock to interest rates on current assets and liabilities. In general, we conceptually follow the method for computing the EVE described in Abdymomunov and Gerlach (2014) with modifications to account for actual balance sheet data and more specific pricing of each asset class.

4.2.1. Pricing Debt Securities

The present value of a debt security, such as a government bond, is the sum of discounted monthly cash flows. The present value of one unit of the debt security is computed as

$$\mathrm{PV}_t^{Debt} = \sum_{k=0}^{K} \mathsf{exp}(-y_t(\tau_k)\tau_k)c_D + \mathsf{exp}(-y_t(\tau_K)\tau_K), \tag{4.6}$$

where c_D is coupon rate for the debt security with coupons paid at periods $\tau_k(k = 1, ..., K)$; K is the number of periods until maturity; τ_K is the maturity, and $y_t(\tau_k)$ is the yield to maturity τ_k at time t.

The above formula requires zero-coupon yields $y_t(\tau_k)$ for each monthly maturity τ_k. We obtain monthly yields by interpolating yield curve data at reported maturities using the Nelson-Siegel functional form proposed by Diebold and Li (2006):

$$y_t(\tau) = L_t + \frac{1 - e^{-\lambda\tau}}{\lambda\tau} S_t + \left(\frac{1 - e^{-\lambda\tau}}{\kappa\tau} - e^{-\lambda\tau}\right) C_t, \tag{4.7}$$

where $y_t(\tau)$ is the zero-coupon yield at time t and with maturity τ; L_t,S_t,and C_t are the level, slope, and curvature factors, respectively.

We extract the time series of three Nelson-Siegel factors by fitting the Nelson-Siegel functional form to the yield curve data every quarter. κ is obtained by minimizing the yield fitting errors over the sample period. This procedure results in $\kappa = 0.7183$ in our sample of yield data.

4.2.2. Pricing Mortgage Loans and Mortgage-Backed Securities

Our pricing formula for mortgage loans and MBS follows Chernov et al. (2018) where the mortgage balance I_t is represented as:

$$I_t = I_0 \frac{1 - e^{-r^m(T-t)}}{1 - e^{-r^m T}}, \tag{4.8}$$

where I_0 is the initial notional amount of a mortgage loan, r^m is the contractual mortgage rate, and T is the maturity.[2]

Without loss of generality, we set the initial notional amount of a mortgage loan I_0 =\$1 and the initial value of the notional balance of the mortgage loan pool is normalized to N_0=1.

The mortgage pool decreases over time through the maturity due to prepayments. The remaining notional balance of the mortgage loan pool N_t is a function of the prepayment intensity h_t:

$$N_t = \exp(-\int_0^t h_s ds) \tag{4.9}$$

The remaining principal balance of the mortgage loan pool is $N_t I_t$. In this intensity-based prepayment approach, we follow the previous literature on pricing mortgage loans

[2]This representation of the principal of the mortgage balance I_t is obtained by solving the ordinary differential equation $dI/dt = r^m I(t) - c$ with the boundary condition at $I_T = 0$, where c is the monthly mortgage payment.

and MBS with embedded optionality (e.g., Goncharov (2006) and Rom-Poulsen (2007)).

The present value of MBS is given by[3]

$$\mathrm{PV}^{MBS} = \mathrm{E}\left[\int_0^T \exp\left(-\int_0^t r_s ds\right) N_t(c + h_t I_t)dt\right] \tag{4.10}$$

While some prepayment factors are idiosyncratic, such as selling a house and prepaying a mortgage loan due to relocation, the interest rate is a systemic factor. Intuitively, if the market interest rate decreases below the contractual loan interest rate, then the borrower has an incentive to refinance the loan under new interest rate terms. To account for prepayment optionality, we use the prepayment model described in Gorovoy and Linetsky (2007):

$$h_t = h_0(t) + \gamma \max(\phi - r_t, 0), \tag{4.11}$$

where γ and ϕ are parameters. In our empirical analysis, we follow Gorovoy and Linetsky (2007) and set $\gamma = 5$ and $\phi = r_0$. As discussed in Gorovoy and Linetsky (2007), this specification implies that a decline in the market interest rate leads to a proportional increase in prepayment intensity. We note that the short-term rate at time $t = 0$, and therefore parameter ϕ, are updated in our EVE calculations for each period in our sample.

The time-dependent deterministic component $h_0(t)$ is defined as

$$h_0(t) = b(at\mathbf{1}_{t<T^*} + aT^*\mathbf{1}_{t>T^*}) \tag{4.12}$$

where parameters a, b, and T^* are constant. This time-dependent component captures the dependence of the prepayment intensity on the mortgage loan age. Following the recommendation from the Public Securities Association (PSA), we assume that the parameters are $a = 0.024$, $b = 1$, and $T^* = 2.5$. As discussed in Gorovoy and Linetsky (2007), these assumptions are accepted by practitioners as an industry benchmark for prepayment intensity. We note that $h_0(t)$ increases from 0% at time $t = 0$ to 6% at

[3]In Chernov et al. (2018), the discount rate is formulated as $r_t + w_t$ where w_t is credit or liquidity spread. As our main focus is interest rate risk, we set $w_t = 0$.

$t = T^* = 2.5$ and capped at 6% thereafter ($t > T^*$).

The final building block is to specify the time dynamics of short-term interest rates. For simplicity, we follow Rom-Poulsen (2007) and employ the Vasicek process (Vasicek (1977)):

$$dr_t = \kappa(\theta - r_t)dt + \sigma dW_t, \tag{4.13}$$

where θ is the mean-reverting level, κ is the mean-reverting speed, and σ is the interest rate volatility. We use the Federal Funds Rate historical data and calibrate $\kappa = 0.21$, and $\sigma = 0.006$ and $\theta = L_0$ which is the Nelson-Siegel level factor. Note that L_0 is updated given the yield curve in each year and thus not constant. We simulate the short-term interest rate for creating both the discount factor and the interest-rate-dependent component in the prepayment intensity.

Given our parameter values, the prepayment hazard rate, h_t, ranges between 0% at time $t = 0$ and 10% at time $t = T^*$.[4] When we use the inputs as of 2021Q4, the effective duration of 30-year mortgage is 3.4 years, which is computed as $\frac{dPV}{PV}/dr$. Our estimate of the effective duration is consistent with estimates in Hanson (2014).[5]

We conduct Monte Carlo simulation-based pricing as follows:

- The time frequency of the simulation is monthly. The number of simulation paths is $N = 10,000$.
- Simulate a path of the short-term interest rate r_t from time $t = 0$ to $t = T$ (the maturity of MBS), using Equation 4.13.
- For each simulated path i, obtain the present value PV_i^{MBS} as a sum of discounted cash flows by applying interest rates to the MBS pricing formula 4.10. The prepayment hazard rate $h_t(r_t)$ is determined by applying a generated interest rate at each time t.

[4] We obtain 10% by computing $h_0(T^*) + \gamma \max(r^m - r_t, 0) = 0.06 + 5 \cdot 0.007 \approx 0.1$ where 0.007 is obtained as the maximum of the Nelson Siegel slope factor $S_0 = r_0 - L_0$.

[5] Hanson (2014) reports that the average effective duration is 3.35 years during the time sample period from January 1989 to April 2011.

- Compute the present value of MBS as the average of the PV across simulated paths: $\text{PV}^{MBS} = \sum_{i=1}^{i=N} \text{PV}_i^{MBS}/N$.

4.3. Pricing loans

To price non-mortgage loans, we apply the above pricing method with the assumption of constant prepayment intensity h_t for simplicity. We follow Hoffmann et al. (2019) and assume that loans have a constant prepayment intensity of 5%.[6]

4.3.1. Pricing Deposits

We compute the present value of time deposits, which are deposits with defined maturity periods, following Equation 4.5 for debt securities. We derive an analytical solution for the interest rate sensitivity of the present value of non-maturity deposits (NMDs). In contrast to time-consuming simulation-based pricing of NMDs, this solution instantaneously provides the interest rate sensitivity and is another contribution of our paper.

Computing the present value of NMDs requires making assumptions about their expected maturity. As discussed in Drechsler et al. (2021), banks have power over deposit rates, and deposits are sticky. The literature proposes different ways of modeling NMDs (e.g., Ellis and Jordan (2001), Kalkbrener and Willing (2004), and Avsar and Ruimy (2021)). To compute the present value of NMDs, we use Equation 11 in Ellis and Jordan (2001):

$$\text{PV}^{NMD} = \sum_{t=1}^{T} \frac{(i+c)D_{t-1} + (D_{t-1} - D_t)}{(1+r_t)^t} \tag{4.14}$$

$$D_t = D_{t-1}(1-d), \tag{4.15}$$

where D_t is the deposit balance at time t; i is the deposit rate; c is the cost of ac-

[6] We assume one prepayment rate for all types of non-mortgage loans (wholesale and retail loans) because our data report repricing maturities for non-mortgage loans as one category. Wholesale loans tend to have zero prepayment rate because they commonly have contractual prepayment penalties. We assume that retail loans have prepayment rates around 12%. The shares of wholesale loans and consumer loans are around 55% and 45%, respectively, for the banking industry in aggregate in our data for the period between 2015 through 2021. Using this information we justify our assumption of $5\% = 0.55 * 0\% + 0.45 * 12\%$ for non-mortgage loans in aggregate.

quiring and servicing deposits expressed as a rate; r_t is the short-term interest rate for discounting; d is the decay rate; and T is the time horizon for deposits to decay.

If we assume that at time $t = 0$ the future values of r, i, and c are not expected to change over time ($r_t = r$), we can obtain an analytical solution:

$$\mathrm{PV}^{NMD} = \frac{i + c + d}{r + d} \cdot D_0 \tag{4.16}$$

Now let us introduce the instantaneous interest rate shock at $t = 0$

$$r = r_0 + \Delta r \tag{4.17}$$

$$i = i_0 + \Delta i \tag{4.18}$$

$$= i_0 + \beta \Delta r \tag{4.19}$$

where β is the sensitivity of the deposit rate to the change in market interest rate. Substituting these equations into Equation 4.16, we obtain:

$$\mathrm{PV}^{NMD} = \frac{i_0 + \beta \Delta r + c + d}{r_0 + \Delta r + d} \cdot D_0 \tag{4.20}$$

For simplicity, we assume that the deposit servicing cost $c = 0$. This assumption does not impact our sensitivity estimates because the servicing cost is not a direct function of the interest rate. The interest rate sensitivity is given by

$$\frac{d\mathrm{PV}^{NMD}}{dr} = \frac{\beta r_0 - i_0 + (\beta - 1)d}{(r_0 + \Delta r + d)^2} \cdot D_0 \tag{4.21}$$

Therefore, $\frac{d\mathrm{PV}^{NMD}}{dr}$ is negative if

$$\beta < \frac{i_0 + d}{r_0 + d} \tag{4.22}$$

If banks pay a deposit interest rate that is lower than the market interest rate at time $t = 0$, then the ratio in the inequality is less than 1. Thus, if *beta* is less than 1 then $\frac{d\mathrm{PV}}{dr}$ is negative, meaning that banks benefit from the present value decrease in deposits when the market interest rate increases.

Computation of the present value of NMDs using the above equation requires assumptions for beta and the decay rate. For both assumptions we use industry estimates that are based on banks' internal data. We use the beta estimates reported in Gerlach et al. (2018). These betas are averages of banks' estimates collected by the Federal Reserve as part of the supervisory confidential information from U.S. bank holding companies which are subject to the Dodd-Frank Wall Street Reform and Consumer Protection Act. As part of the FR Y-14Q - Schedule G reporting requirement, these financial firms report the balance-weighted average deposit repricing betas by deposit types. We use the following betas reported in Gerlach et al. (2018): 0.816 for time deposits, 0.498 for savings and other NMDs, and 0.822 for deposits in foreign offices. We use the average life of savings deposits and other NMDs, which is 1/decay rate, reported in Office of the Comptroller of the Currency (2022). The OCC compiles interest rate risk data collected from banks and produces distributional statistics. We use the median of the distribution of the average life of deposits for savings deposits, which is 4.29 years for small banks (we use the median for banks with less than $100 million in assets) and 5.10 years for large banks (we use the median for banks with over $10 billion in assets).[7]

In aggregate for U.S. banks, the share of savings and other NMDs in total deposits increased from 66% in 1997 to 94% in 2021. The average beta of 0.498, which is substantially smaller than 1, represents a relatively long average life of NMDs and indicates that banks manage maturity mismatch and have power over deposit interest rates.

5. Data

5.1. Interest income & expense and balance sheet data

We obtain quarterly bank income statement and balance sheet data from FFIEC 031 Call Reports for the period from 1997Q2 though 2021Q4. The most granular re-pricing maturity structure reporting, which is critical for the EVE calculations, is available from 1997Q2. On the asset side, the data are grouped into seven buckets of the following upper bound maturities: 0 months, 3 months, 1 year, 3 years, 5 years, 15 years, and longer than 15 years. On the liability side, the data are grouped into 5 maturity buckets: 0

[7] The OCC does not have a separate category for banks with less than $10 billion in assets, which is our threshold for separating small and large banks, so we use the OCC data for banks with less than $100 million in assets to represent small banks.

months, 3 months, 1 year, 3 years, and longer than 3 years. In each maturity bucket, we take the midpoint as the representative maturity. For example, we use 2 years as the representative maturity for the bucket with maturities between 1 and 3 years. We assume that the upper bounds of the last asset and liability maturity buckets are 30 years and 5 years, respectively. Table 1 reports statistics of the shares of asset and liability items and their value-weighted re-pricing maturities in our sample of banks and time period.

[Insert Table 1 about here]

We use the above data to compute the quarterly NIM and interest income and expense ratios. In these calculations, we closely follow NIM methodology described by FRED.[8] Average earning assets, which are used as the denominator of these ratios, are computed as the sum of interest-bearing balances, total loans and leases net of unearned income, total trading assets, total held-to-maturity securities, total amortized cost of available-for-sale securities, Federal funds sold, and securities purchased under agreement to resell. Table 2 reports statistics of these ratios in our sample of banks and time period. We winsorize the ratios reported in Tables 1 and 2 at the 2.5 and 97.5 percentiles of the quarterly distributions of the ratios.

[Insert Table 2 about here]

5.2. Interest Rate Data

The interest rate data are constant maturity Treasury rates for maturities of 3, 12, 24, 36, 60, 84, and 120 months. The data are obtained from the website of the U.S. Department of Treasury for the sample period from 1997-01-01 through 2021-12-31 at the daily frequency. For EVE calculations, we convert daily interest rate data into quarterly frequency by selecting the quarter-end data. For our regression analyses of

[8] See the FRED's methodology for NIM in $https://fred.stlouisfed.org/series/USNIM$

NIM, we use quarterly average interest rates to avoid potential daily end-period spikes in interest rates which would not materially impact quarterly income or expense flows. In our EVE computations, we also use the rate for 30-year fixed-rate mortgages and the bank prime loan rate data from FRED.

5.3. Deposit Rate Data

To compute the present value of deposits, we use deposit rates data from Ratewatch. Ratewatch reports weekly deposit rates by instrument types. We match the Ratewatch instrument types with deposit types in our study, such as savings deposits, transaction accounts, and time deposits by maturity buckets. We use the mean weekly rate data for each quarter by deposit types.

6. Results

6.1. Interest Rate Sensitivity of NIM

In this section, we analyze the sensitivity of NIM to interest rate changes. Panel A of Figure 1 shows that the variation in NIM is small relative to the variation in the interest rate. The bank-average NIM declined from 4.7% in 1997Q2 to 3.2% in 2021Q4, while the short-term interest rate changed by 5.1 percentage points. However, this level change in NIM translates into a 31.5% change in relative terms which is a substantial decline in interest income profitability. As Panel B of Figure 1 shows, NIM is correlated with the short and long-term interest rates with sample correlation coefficients of 84.2% and 70.2%.

[Insert Figure 1 about here]

More formally, Table 3 reports estimation results from the panel regressions based on Equation 4.1. The estimated NIM betas for the short interest rate and the term spread changes are 0.1304 and 0.1074, respectively. These coefficients mean that for a 100 bps increase in the short-term interest rate, NIM increases by 13 bps, and with a 100 bps increase in the term spread, NIM increases by 11 bps. In addition, NIM betas can be derived by taking the differences between income ratio betas and expense ratio betas.

NIM betas from NIM regression are very close to those computed using betas from the income and expense ratio regressions. Specifically, the income ratio beta and expense ratio beta for the short term rate are 0.4162 and 0.2891 and for the term spread are 0.1251 and 0.0181. We note that the term spread impacts primarily the interest income ratio and has a relatively small effect on the interest expense. This result is consistent with longer maturities of assets which should be more sensitive to the long-term interest rate relative to liabilities.

[Insert Table 3 about here]

The estimated NIM betas indicate that the interest rate sensitivity of NIM is relatively small. This result is consistent with Drechsler et al. (2021) who find that banks manage net earnings well and closely match interest income and expenses. However, as we note above, NIM changes substantially over longer periods of time, and we demonstrate that the interest rate is the key factor driving these changes. Specifically, we analyze NIM changes over different interest rate environments to determine how much rate changes explain changes in NIM. We split our sample into subperiods of interest rate changes: peak-to-trough and trough-to-peak of the short-term interest rate. Table 4 reports identified sub-periods, actual NIM changes, values of the model variables, and the fitted NIM using interest rate changes in those sub-periods. In calculations of the fitted NIM, we omit the intercept term to demonstrate the impact of the interest rate changes only. In all sub-periods, our model correctly predicts NIM directions, and magnitudes of fitted values are comparable to actual NIM changes. The correlation between actual and predicted changes in the reported subperiods is 85%. We demonstrate that the model explains substantial portions of the long-term variation in NIM. Similar to Drechsler et al. (2021), we conduct sensitivity analysis of our estimates by analyzing NIM at the bank holding company level. Our results are robust to the panel of BHCs: the short-term and term spread betas are 0.0853 and 0.0815 and they are statistically significant at the 0.001 level.

[Insert Table 4 about here]

In decreasing interest rate environments banks may mitigate the interest income decline by investing in longer-term assets which typically have higher interest rates than short-term assets. Consistent with this hypothesis, Figure 2 shows that the interest rate and asset maturity are negatively correlated with a coefficient of -74%. To test this hypothesis, we regress the change in asset maturity on the change in the short-term interest rate. We consider two measures of asset maturity: value-weighted asset maturity in years and the share of assets subject to re-pricing within one year. We follow Flannery and James (1984b) and Angbazo (1997) in constructing our measure of the share of short-term assets. As Table 5 reports, the regression results confirm that banks pursue assets with longer maturities in response to an increase in the interest rate, and the results are robust to the measure of asset maturity.

[Insert Figure 2 about here]

As Table 4 reports, NIM declined by 65 bps during the period 2019Q1 through 2021Q4, and most of this decline occurred during the pandemic period. Our model explains 20 bps of that decline by the interest rate decrease. We explain the remaining decline as resulting from the increase in the share of government securities, which pay the lowest interest rates among all assets, during the pandemic period. From 2020Q1 to 2021Q4, the share of government debt securities increased from 10.7% to 14.7% as a percentage of total assets.

6.1.1. NIM Sensitivity: Small and Large Banks

To study the interest rate sensitivity of NIM for small and large banks separately, we split our sample into two sub-samples of banks with the size threshold of $10B of total assets. The $10B size threshold is used in the previous banking literature (e.g., Cortes et al. (2020) and Choi et al. (2022)) and reflects significant changes in regulatory requirements for banks above that threshold. As described in Congressional Research Service (2021), banks above $10B in total assets are subject to a series of additional regulations such as mandatory stress testing, heightened consumer compliance supervision and enforcement, and additional reporting requirements.

As Table 6 reports, the interest rate sensitivity of NIM is higher for small banks relative to large banks. Specifically, the NIM betas for the short term rate and term spread are 0.1309 and 0.1080 for small banks vs. 0.0887 and 0.0615 for large banks. The lower interest rate sensitivity of NIM for large banks originates from both a lower interest rate sensitivity of interest income and a higher interest rate sensitivity of interest expense. In addition, Table 7 shows that the interest rate sensitivity of asset maturities is lower for large banks. In other words, large banks less actively increase asset maturities in response to interest rate decreases than small banks. Thus, large banks are less NIM responsive to interest rate changes than small banks.

[Insert Table 6 about here]

[Insert Table 7 about here]

Panel A of Figure 3 shows that the average NIM of large banks is systematically lower than the one for small banks. Table 2 reports sample average NIM of 4.0% and 3.7% for small and large banks, respectively. Panel B of Figure 3 shows that both the interest income and expense contribute to the difference in NIM dynamics between large and small banks, raising the question of how large banks afford to have lower interest income profitability. To answer this question, we analyze return on total assets (ROA) and net non-interest income (NNII).

[Insert Figure 3 about here]

Panel C of Figure 3 shows that the ROA for large banks is higher than that of small banks during most of the sample, except for the period of the 2008 financial crisis and the COVID period of 2020-2021. In addition, Panel D of Figure 3 demonstrates that large banks have a higher ratio of NNII than small banks. Thus, large banks compensate for lower interest rate profitability with higher non-interest income profitability. To formally quantify the role of NIM and NNII in ROA, we regress the change in ROA on three main components – the change in NIM, the change in the NNII ratio, and the change in the provisions-to-total-assets ratio – separately for small and large banks. As Table 8 reports, the NIM beta is smaller for large banks, while the NNII beta is larger for large banks, relative to small banks. This result confirms that large banks compensate for a lower NIM with higher NNII, relative to small banks. In this regression analysis, we include net non-interest income instead of non-interest income, as well as provisions, for the completeness of key control variables. NNII is negative because non-interest expenses are associated with all bank activities, rather than only with non-interest income lines of businesses.

[Insert Table 8 about here]

6.2. Interest Rate Sensitivity of EVE

In this section, we analyze the sensitivity of the EVE to interest rate changes. We estimate the EVE for the aggregate banking sector rather than for each individual bank because the simulation-based estimations are time-consuming. We estimate the interest rate sensitivity of the EVE annually for our sample from 2010 through 2021. We use a shorter period than one used for NIM analysis because regulatory changes affected banks and increased their capital substantially during the post 2008 financial crisis period. Therefore, estimates of the EVE sensitivity during the post 2008 period are more relevant for the current banking structure. We quantify the interest rate sensitivity of the EVE as a relative change between the EVE estimated using the actual yield curve for each year and the EVE estimated using the actual yield curve shifted 100 bps upward in parallel. As Panel A of Figure 4 displays, $\%\Delta EVE$ ranges between -8% and -18% in our sample. The decline in the EVE is significant and has wide variation. To identify sources of such a significant decline and time variation, first we analyze changes in the present value of asset types ($\%\Delta PV$) with long re-pricing maturities. These asset types comprise non-mortgage loans, mortgage loans, debt securities, and MBS. In addition, we analyze $\%\Delta PV$ of non-maturity deposits.

[Insert Figure 4 about here]

As Panel B of Figure 4 displays, $\%\Delta PV$ of debt securities, MBS, and mortgage loans are relatively large. The time variation in $\%\Delta EVE$ is primarily explained by variations in $\%\Delta PV$ of debt securities and MBS, which vary in the ranges between -4.2% and -5.6%, and -3.7% and -4.5%, respectively. $\%\Delta PV$ for non-mortgage loans ranges between -1.3% and -1.6%. While changes in the present value of non-mortgage loans are small relative to the total present value of loans, these changes are significant relative to the equity value due to leveraging. As Panel A of Figure 5 displays, the share of non-mortgage loans in total assets ranges between 38% and 45%. The declines in the PV of assets are compensated by the decline in the PV of NMDs. Similar to non-mortgage loans, while $\%\Delta PV$ for NMDs is relatively small, around -2%, the change substantially contributes to the decrease in the EVE sensitivity due to NMD's large share in liabilities (see Panel C of Figure 5). Thus, the market power over NMDs helps banks to reduce the impact of interest rate increases on $\%\Delta EVE$. In contrast to NMDs, $\%\Delta PV$ for time deposits is only around -0.2%, and they have very small impact on the EVE.

[Insert Figure 5 about here]

As Panel B of Figure 5 displays, MBS have relatively long contractual repricing maturities. However, MBS prepayments substantially reduce the impact of interest rate changes on the present value of MBS. The prepayment optionality of MBS explains why variations in $\%\Delta PV$ of MBS and debt securities are comparable in magnitudes despite the longer maturities of MBS.

During the pandemic period of 2020-2021, the interest rate sensitivity of the EVE increased substantially. $\%\Delta EVE$ decreases from -11% at the end of 2019 to -15% at the end of 2021. This change is a result of the increase in the share and maturities of debt securities and MBS. The aggregate share of debt securities increased from 9.2% to 12.3%, and value-weighted re-pricing maturity increased from 5.7 to 6.4 years during this period. These changes led to a decrease in $\%\Delta PV$ of debt securities from -4.7% to -5.6%. Similarly, $\%\Delta PV$ of MBS decreased from -4.1% to -4.5% in this period. Thus, the economic value of the U.S. banking sector became more sensitive to interest rate changes during the pandemic period of 2020-2021.

6.2.1. Interest rate sensitivity of EVE: small and large banks

In this subsection, we analyze differences in the interest rate sensitivity of the EVE for small and large banks. Panel A of Figure 6 shows that the EVE sensitivity for small banks is higher than for large banks. $\%\Delta EVE$ ranges between -10.5% and -21.1% for small banks and between -7.8% and -17.3% for large banks in our sample.

[Insert Figure 6 about here]

As Panels B.1 and B.2 of Figure 6 show, $\%\Delta PV$ of debt securities and non-mortgage loans have the largest differences between small and large banks among asset types. $\%\Delta PV$ of debt securities ranges between -5.4% and -7.7% for small banks and between -3.7% and -5.3% for large banks. $\%\Delta PV$ of non-mortgage loans ranges between -1.6% and -2.3% for small banks and between -1.1% and -1.4% for large banks. Panel A of Figure 7 shows that the share of non-mortgage loans for small banks is substantially larger than that of large banks. In addition, Panel B of Figure 7 shows that small banks hold debt securities and non-mortgage loans with substantially longer re-pricing maturities relative to large banks. The longer re-pricing maturities of non-mortgage loans and debt securities at small banks explain the higher interest rate sensitivity of their PVs, and the larger shares of these assets in small banks' portfolios amplify their contributions to $\%\Delta EVE$ relative to large banks. As Panel D of Figure 7 shows, large banks have a higher share of NMDs in total liabilities relative to smaller banks, and this helps mitigate the EVE sensitivity to interest rate changes.

[Insert Figure 7 about here]

As Panels B.1 and B.2 of Figure 6 show, unlike debt securities and non-mortgage loans, MBS and mortgage loans have higher interest rate sensitivities at large banks. This is a result of the longer re-pricing maturities of mortgage loans and MBS at large banks relative to small banks, displayed on Panels A and B of Figure 7.

Panels B and C of Figure 7 suggest that small banks more actively increase repricing maturities of debt securities and non-mortgage loans in response to interest rate changes relative to large banks. Indeed, sample pairwise correlation coefficients between repricing maturities of debt securities and non-mortgage loans and the 3-month interest rate are (-0.82, -0.66) for small banks and (0.27, 0.21) for large banks. Thus, small banks are more focused on generating interest earnings and less on managing the interest rate risk of the EVE. During the pandemic period of 2020-2021, while both small and large banks experienced substantially increased interest rate sensitivities of the EVE due to increases in shares of debt securities and their repricing maturities, the magnitudes of increases are considerably larger for small banks.

We note that most assets are valued at amortized cost rather than mark-to-market on the balance sheet. Therefore, financial statements generally do not reflect the impact of interest rate changes on EVE. For example, the interest rate sensitivity of the present value of most loans does not impact the income statement or balance sheet. However, the interest rate sensitivity of the EVE reflects lost or gained economic opportunity due to locking assets under fixed interest rates. Unlike most loans, banks hold securities for liquidity or investment purposes. Banks classify securities held for liquidity purposes as available for sale (AFS) and securities held for investment as held to maturity (HTM). AFS securities, unlike HTM securities, are marked-to-market on the balance sheet. Thus, the interest rate sensitivity of AFS securities has an impact on the income statement and balance sheet. As Figure 8 shows, the share of AFS securities is more volatile for large banks than small banks. During the low interest rate environment, large banks aggressively reduced the share of AFS securities to avoid potential negative impacts of interest rate increases on their financial statements and regulatory capital. In contrast, small banks' securities holdings are mostly AFS, and their share has not changed dramatically. At the beginning of pandemic, large banks sharply increased their AFS securities holdings, but this increase quickly waned as the economy showed improvement. Although regulation does not constrain banks from reclassifying securities holdings from AFS to HTM, reclassification in the opposite direction is highly constrained.

[Insert Figure 8 about here]

7. Conclusion

In this paper, we study interest rate risk at banks. First, we extend the structural Merton (1974) model by explicitly incorporating a fixed-income portfolio in the bank balance sheet. This theoretical model shows that an interest rate increase has two opposing effects on banks: an increase in net interest earnings and a decrease in the bank's current equity due to a decrease in the present value of current assets. Second, we empirically quantify two measures of interest rate risk for U.S. banks: the interest rate sensitivity of NIM and the interest rate sensitivity of the EVE.

We report four main empirical findings: First, we find that a 100 bps increase in the short-term interest rate increases NIM by 13 bps, and a 100 bps increase in the spread between long-term and short-term interest rates increases NIM by 11 bps for U.S. banks on average. We show that this sensitivity translates into a material change in interest income profitability, and that banks pursue assets with longer maturities when interest rates are low to mitigate the decline in interest earnings.

Second, we find that a 100 bps parallel upward shift in the yield curve reduces EVE for the aggregate U.S. banking sector between 8% and 18% during the period 2010-2021. Thus, an increase in interest rates has a positive impact on earnings, but it comes with the cost of substantially reducing the current economic value of equity, creating short-term risk in stressful environments when a bank may need to sell assets at a discount, realizing losses. Thus, our empirical findings are consistent with the prediction of our theoretical model.

Third, we examine differences in the interest rate sensitivities of small and large banks. We find that small banks have higher interest rate sensitivities of NIM and EVE. Although small banks have higher gains in NIM from interest rate increases than large banks, it comes at the cost of a larger decline in EVE.

Fourth, we show that U.S. banks' exposure to interest rate risk increased during the pandemic period of 2020-2021, and it is related to the increase in the share of long-term securities in assets. Overall, we provide evidence of substantial interest rate risk for future earnings and net worth at U.S. banks.

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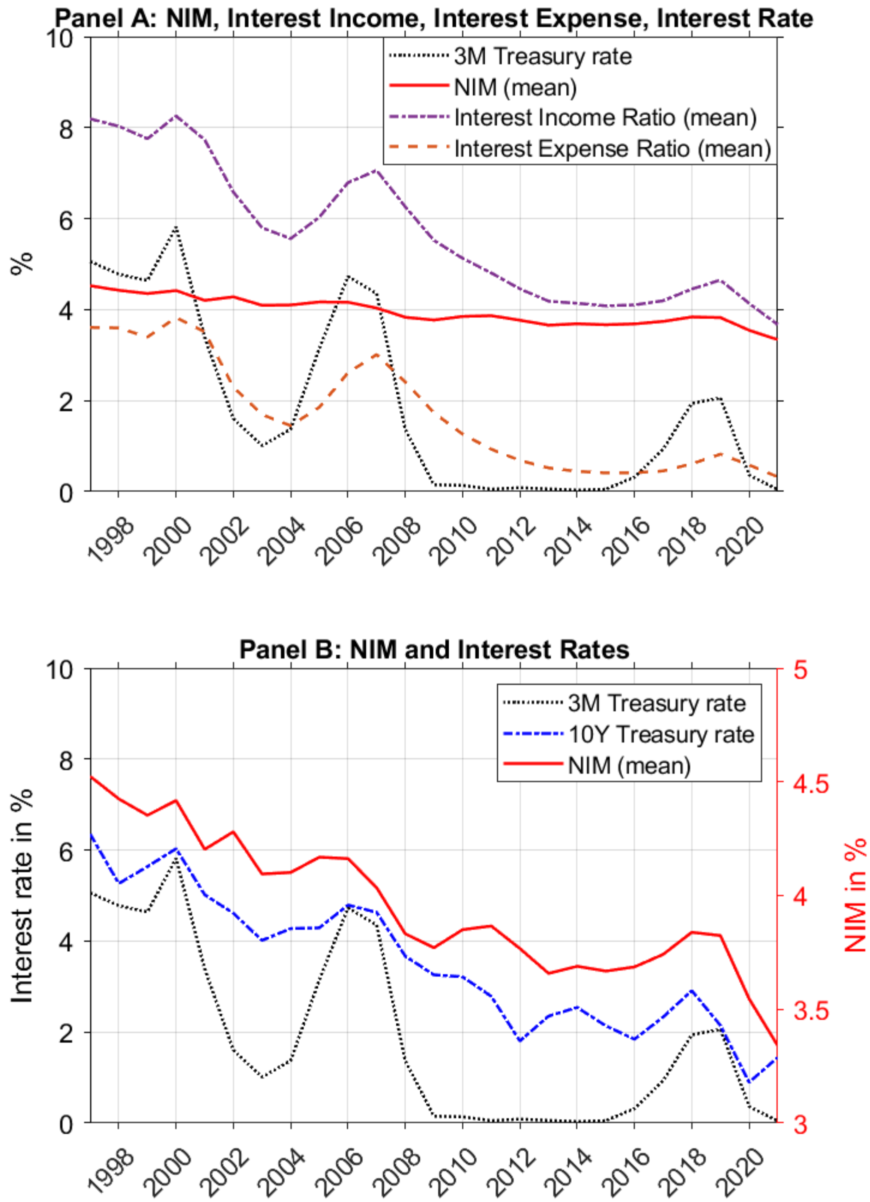

Figure 1: Panel A displays bank-average Net Interest Margin (NIM), Interest Income Ratio, Interest Expense Ratio, and the 3-month Treasury rate. The interest income and expense ratios equal to interest income and expense divided by average earning assets. NIM equals the net interest income divided by average earning assets. **Panel B** displays bank-average NIM and the 3-month and 10-year Treasury rates on two separate y-axes to highlight the variation in NIM. In this figure, the 3-month and 10-year Treasury rates are annual averages of daily rates.

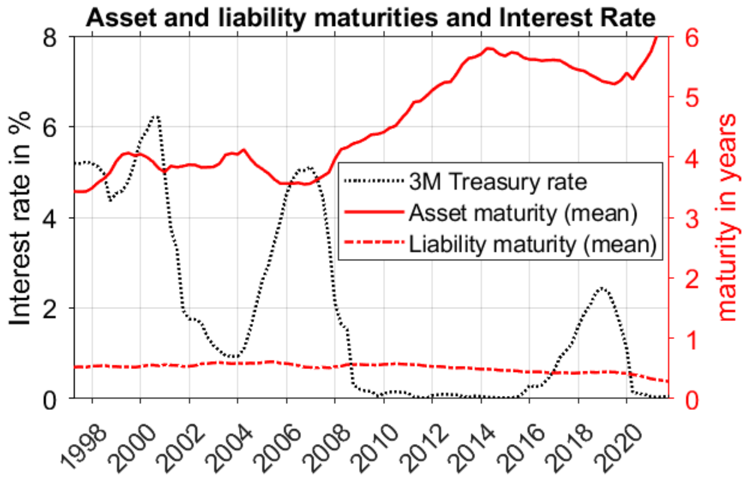

Figure 2: The figure shows the bank-average repricing maturities of assets and liabilities, and the 3-month Treasury rate.

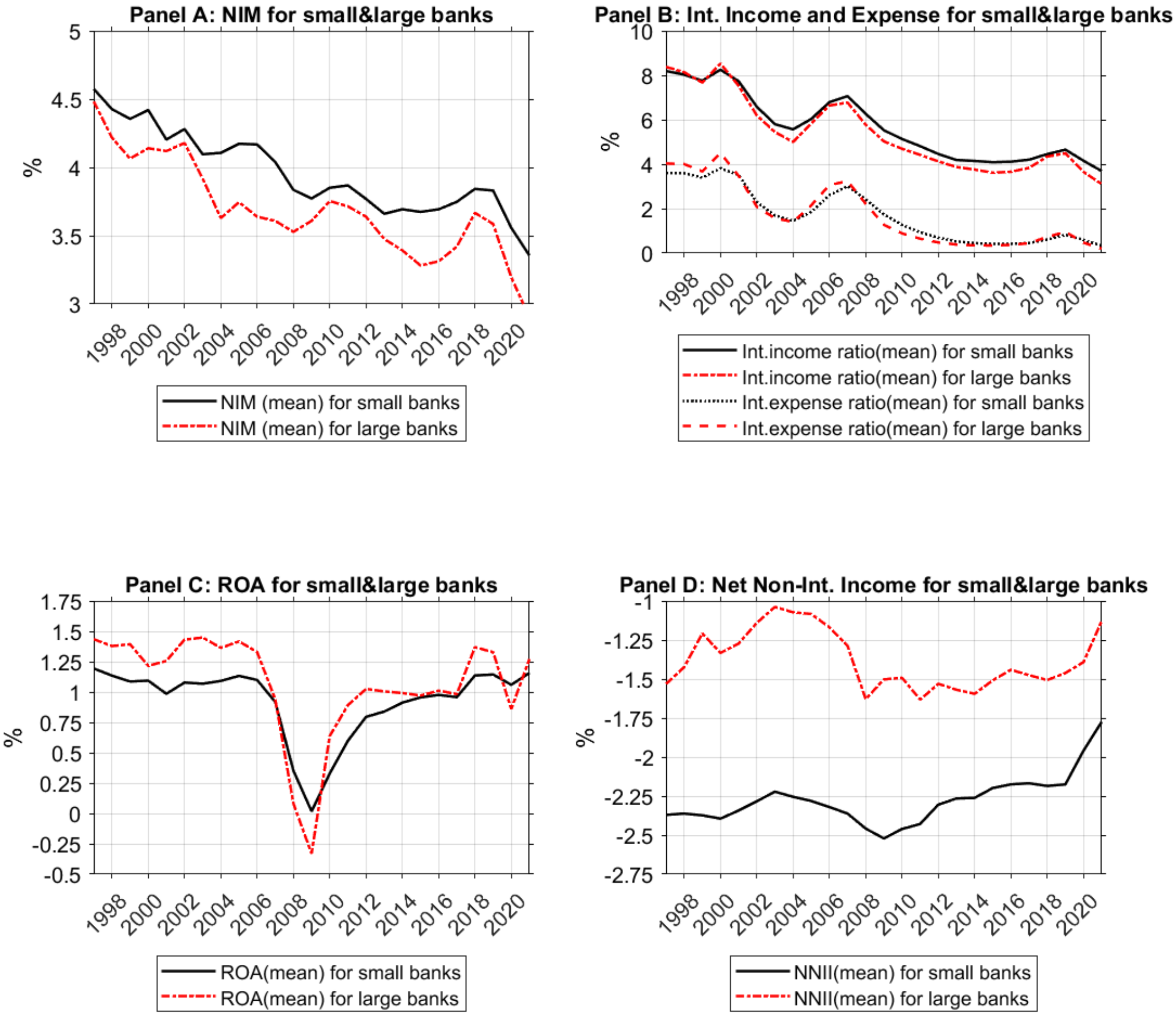

Figure 3: The figure displays bank-average Net Interest Margin, Interest Income and Expense Ratios, Return-on-Assets Ratio, and Net Non-Interest Income Ratio for small and large banks. The group of small (large) banks comprises banks with total assets less than (greater than or equal to) than $10B.

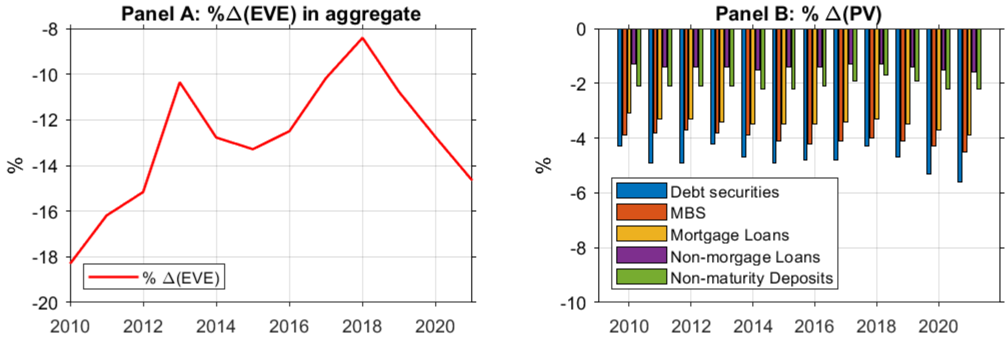

Figure 4: Panel A shows the impact of an interest rate scenario shock on the economic value of equity (EVE) of U.S. commercial banks in aggregate. The interest rate shock is defined as a 100 bps parallel upward shift in the yield curve. **Panel B** displays the percentage change in the present value (PV) of assets and non-maturity deposits (NMD) after the interest rate scenario shock.

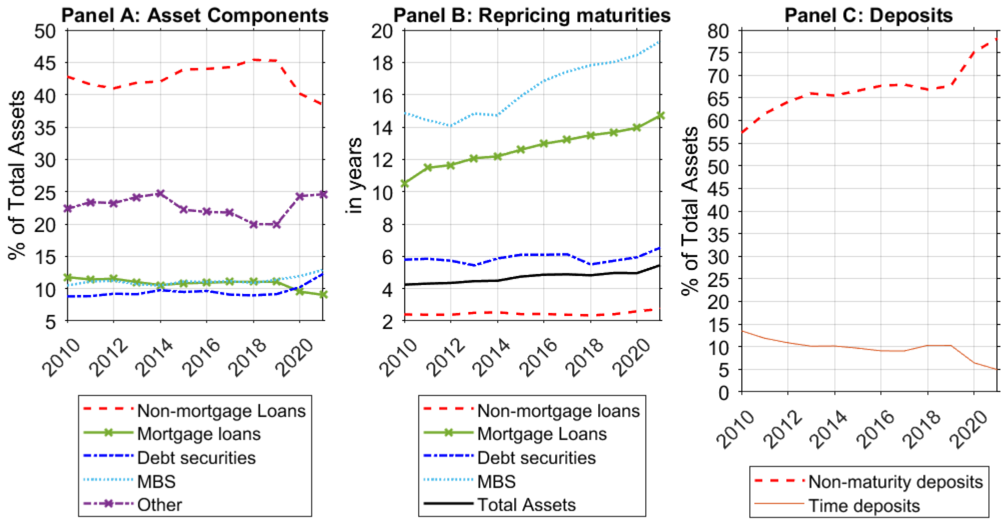

Figure 5: Panel A displays the shares of asset components for all banks in aggregate. **Panel B** shows the repricing maturities of total assets and its components for all banks in aggregate. **Panel C** displays non-maturity deposits and time deposits as a percentage of total assets for all banks in aggregate.

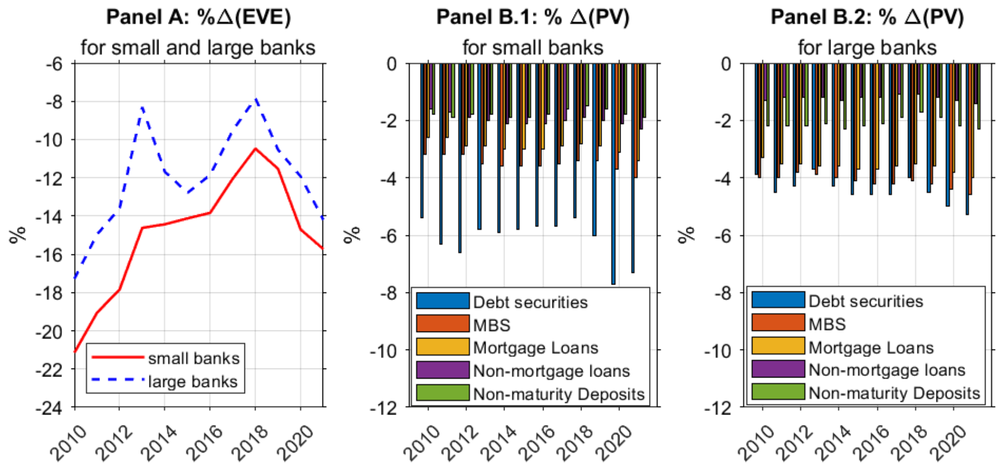

Figure 6: Panel A shows the impact of the interest rate scenario shock on the economic value of equity (EVE) of small and large banks in aggregate. The interest rate shock is defined as a 100 bps parallel upward shift in the yield curve. **Panels B.1 and B.2** display percentage changes in the present value (PV) of assets and non-maturity deposits (NMD) after the interest rate shock for small and large banks in aggregate.

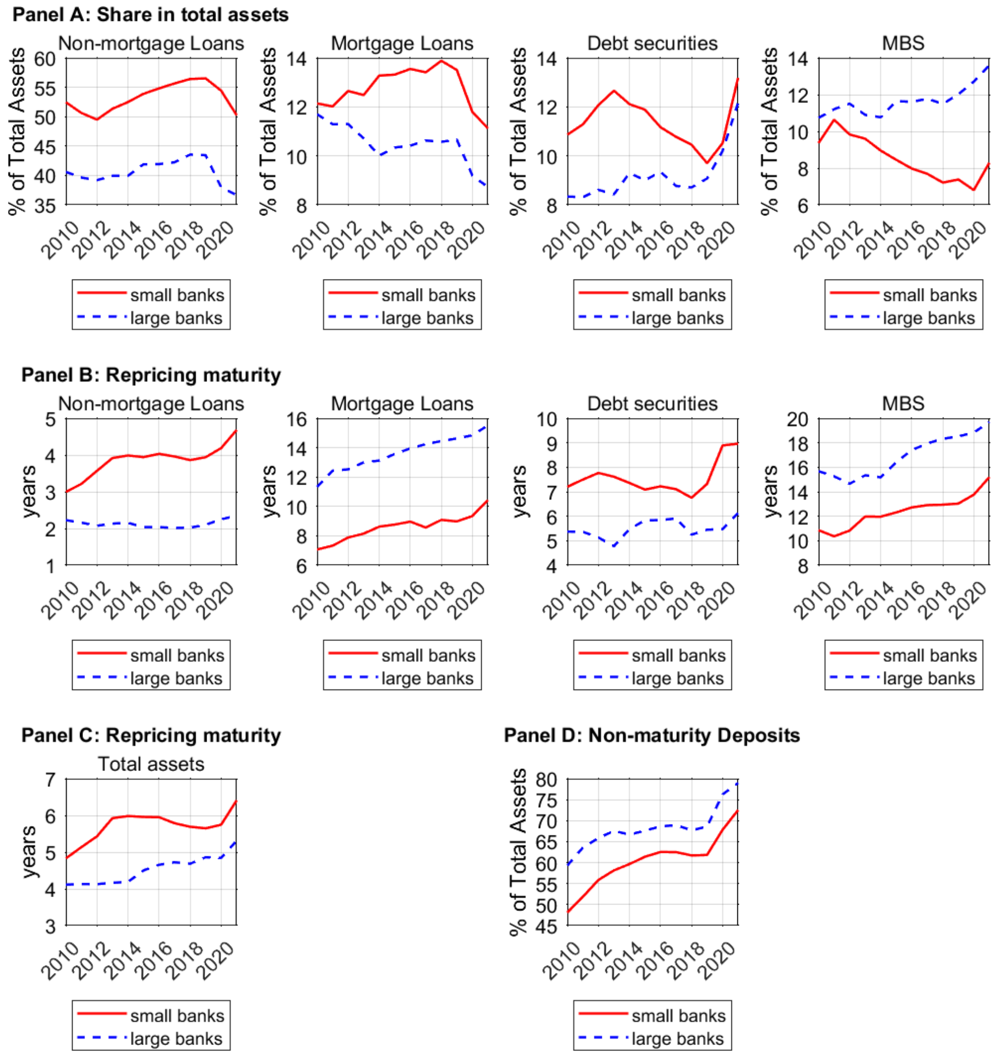

Figure 7: **Panel A** shows the shares of asset components for small and large banks in aggregate. **Panel B** displays the repricing maturities of asset components for small and large banks in aggregate. **Panel C** shows the repricing maturities of total assets for small and large banks in aggregate. **Panel D** displays non-maturity deposits as a percentage of total assets for small and large banks in aggregate.

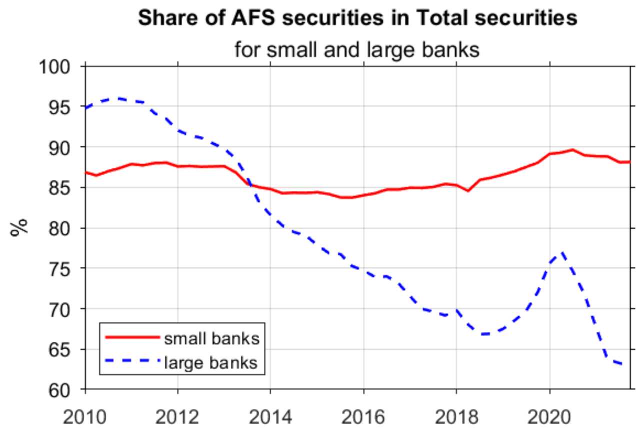

Figure 8: The figure shows the share of available-for-sale (AFS) securities in total securities (debt securities and MBS) for small and large banks in aggregate.

Table 1: Descriptive Statistics

The table reports summary statistics on the composition of bank balance sheets and the repricing maturities of assets and liabilities. The samples in **Panels A and B** comprise all U.S. commercial banks and the subset of banks with total assets greater than or equal to \$10B, respectively. The sample period is from 1972Q2 through 2021Q4.

	Share of Assets (%)		Repricing Maturity (in years)		Share of Assets (%)		Repricing Maturity (in years)	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
	Panel A: All banks				Panel B: Large banks			
Assets	100.0		4.5	2.3	100.0		4.7	2.3
Cash	7.1	7.8	0.0	0.0	7.2	8.3	0.0	0.0
Loans	62.4	16.4	3.6	2.4	63.0	17.1	4.2	2.7
Securities	26.1	16.0	6.0	4.3	20.8	13.0	8.9	5.3
Debt securities	16.3	13.2	5.6	3.9	7.4	9.0	6.1	4.4
MBS	6.2	8.7	7.3	6.6	11.0	8.9	12.2	6.3
Repo securities	3.6	6.9	0.2	0.0	2.3	5.5	0.2	0.0
Other assets	4.3	4.2	0.0	0.0	9.0	6.8	0.0	0.0
Liabilities	89.2	8.0	0.5	0.3	89.0	4.3	0.4	0.3
Deposits	83.7	10.4	0.4	0.2	71.5	15.6	0.3	0.4
Saving deposits	24.1	14.1	0.0	0.0	41.2	21.1	0.0	0.0
Time deposits	35.4	14.9	1.0	0.4	15.6	12.0	1.0	0.5
Other deposits	24.3	12.3	0.0	0.0	14.6	13.7	0.0	0.0
Other int. liab.	4.7	7.3	1.0	1.3	14.5	14.6	0.9	0.7
Other non-int. liab.	0.8	1.9	0.0	0.0	3.1	2.5	0.0	0.0
Equity	11.4	6.9	0.0	0.0	11.2	3.9	0.0	0.0
N of bank-quarter obs.	657,327				8,812			
N of banks	11,387				267			

Table 2: Descriptive Statistics: Income and Expense Ratios

The table reports summary statistics on income and expense ratios. The samples in **Panels A and B** comprise all U.S. commercial banks and the subset of banks with total assets greater than or equal to $10B, respectively. The sample period is from 1972Q2 through 2021Q4.

	Mean	St. Dev.	Mean	St. Dev.
	(%)		(%)	
	1	2	3	4
	Mean	St. Dev.	Mean	St. Dev.
	Panel A: All banks		Panel B: Large banks	
NIM	4.0	0.8	3.7	1.0
Interest income ratio	6.0	1.7	5.2	1.9
Interest expense ratio	1.9	1.3	1.5	1.4
ROA	1.0	0.8	1.1	0.8
NNII ratio	-2.3	0.8	-1.3	0.6
N of bank-quarters	657,327		8,812	
N of banks	11,387		267	

Table 3: Panel Regression Results: Interest Rate Sensitivity of NIM, the Interest Income Ratio, and the Interest Expense Ratio

The table reports estimates of the sensitivity of NIM, interest income, and interest expense to changes in the short rate and term spread. The results are from the panel regressions specified in Equation (4.1). The columns report results for changes in NIM, the Interest Income Ratio, and the Interest Expense Ratio. All three ratios are expressed in annualized percentage terms. Δr_{t-1} denotes a one-period change in the quarterly average 3-month Treasury rate and s_{t-1} is the change in the term spread defined as a difference between the quarterly average 10-year Treasury rate and the quarterly average 3-month Treasury rate. The row denoted *N obs.* reports the number of bank-quarter observations in each regression. The regressions account for bank fixed effects.

	ΔNIM	$\Delta IncomeRatio$	$\Delta ExpenseRatio$
	(1)	(2)	(3)
Δr_{t-1}	0.1304***	0.4162***	0.2891***
	(0.0016)	(0.0016)	(0.0009)
Δs_{t-1}	0.1074***	0.1251***	0.0181***
	(0.0014)	(0.0015)	(0.0007)
Constant	-0.0068***	-0.0241***	-0.0169***
	(0.0004)	(0.0005)	(0.0002)
Bank FE	Yes	Yes	Yes
N Obs.	653,261	653,261	653,261
R^2	0.0188	0.1282	0.2574

*p < 0.10, **p < 0.05, ***p <0.01

Parentheses report heteroscedasticity-consistent standard errors.

Table 4: Actual and Fitted NIM Over Different Rate Periods

The table reports the model fit of NIM changes in different interest rate environments in our data sample. Columns 1 and 2 report the start and end of subperiods identified as peak-to-trough or trough-to-peak of the short-term interest rate. Column 3 describes directions of short interest rate changes in subperiods. Columns 4 and 5 reports values of model variables in subperiods. Column 6 reports the fitted NIM using the values of model variables reported in Columns 4 and 5. Column 7 and 8 report actual absolute and relative NIM changes.

$t-2$	$t-1$	Short rate direction	Δr_{t-1}	Δs_{t-1}	ΔNIM_t fit	ΔNIM_t actual	$\%\Delta NIM_t$ actual
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1997Q1	2021Q3	entire sample	-5.15	-0.09	-0.68	-1.48	-31.5
1997Q1	1998Q4	decrease	-0.83	-1.07	-0.22	-0.41	-8.7
1998Q4	2000Q3	increase	1.84	-0.61	0.17	0.14	3.2
2000Q3	2004Q1	decrease	-5.27	3.39	-0.32	-0.31	-7.1
2004Q1	2006Q3	increase	4.10	-3.22	0.19	0.10	2.4
2006Q3	2009Q2	decrease	-4.86	3.29	-0.28	-0.40	-9.5
2009Q2	2015Q3	low rate	-0.13	-0.97	-0.12	-0.10	-2.6
2015Q3	2019Q1	increase	2.40	-1.97	0.10	0.16	4.3
2019Q1	2021Q3	decrease	-2.39	1.06	-0.20	-0.65	-16.9

Table 5: Panel Regression Results: Interest Rate Sensitivity of Asset Maturity
The table reports estimates of the interest rate sensitivity of asset maturity. The results are from the panel regressions specified in Equation (4.1). Columns 1 and 2 report results for two measures of asset maturity: value-weighted maturity of assets in years and the share of assets with maturities less than one year.

	Δ Asset maturity	Δ Share of ST assets
	1	2
Δr_{t-1}	-0.0787***	0.0070***
	(0.0016)	(0.0002)
Constant	0.0256***	-0.0008***
	(0.0006)	(0.0001)
Bank FE	Yes	Yes
N Obs.	654,972	657,045
R^2	0.0139	0.0102

*p < 0.10, **p < 0.05, ***p <0.01

Parentheses report heteroscedasticity-consistent standard errors.

Table 6: Panel Regression Results for Small and Large Banks: Interest Rate Sensitivity of NIM, the Interest Income Ratio, and the Interest Expense Ratio
The table reports estimates of the sensitivity of NIM, interest income, and interest expense to changes in the short rate and term spread for small and large banks. The group of small (large) banks comprises banks with total assets less than (greater than or equal to) $10B. The results are from the panel regressions specified in Equation (4.1). The columns report results for changes in NIM, the Interest Income Ratio, and the Interest Expense Ratio. All three ratios are expressed in annualized percentage terms. Δr_{t-1} denotes a one-period change in the quarterly average 3-month Treasury rate and s_{t-1} is the change in the term spread defined as a difference between the quarterly average 10-year Treasury rate and the quarterly average 3-month Treasury rate. The row denoted *N obs.* reports the number of bank-quarter observations in each regression. The regressions account for bank fixed effects.

	ΔNIM	$\Delta IncomeRatio$	$\Delta ExpenseRatio$
	(1)	(2)	(3)
	Panel A: Small banks		
Δr_{t-1}	0.1309***	0.4153***	0.2873***
	(0.0016)	(0.0016)	(0.0009)
Δs_{t-1}	0.1080***	0.1253***	0.0177***
	(0.0014)	(0.0015)	(0.0007)
Constant	-0.0066***	-0.0240***	-0.0170***
	(0.0004)	(0.0005)	(0.0002)
Bank FE	Yes	Yes	Yes
N Obs.	644,477	644,477	644,477
R^2	0.0192	0.1287	0.2579
	Panel B: Large banks		
Δr_{t-1}	0.0887***	0.4844***	0.4264***
	(0.0179)	(0.0193)	(0.0111)
Δs_{t-1}	0.0615***	0.1019***	0.0487***
	(0.0150)	(0.0166)	(0.0088)
Constant	-0.0180***	-0.0321***	-0.0141***
	(0.0046)	(0.0050)	(0.0026)
Bank FE	Yes	Yes	Yes
N Obs.	8,772	8,772	8,772
R^2	0.0125	0.1149	0.2689

*p $<$ 0.10, **p $<$ 0.05, ***p $<$0.01

Parentheses report heteroscedasticity-consistent standard errors.

Table 7: Panel Regression Results: Interest Rate Sensitivity of Asset Maturity for Small and Large Banks

The table reports estimates of the interest rate sensitivity of asset maturity for small and large banks. The group of small (large) banks comprises banks with total assets less than (greater than or equal to) \$10B. The results are from the panel regressions specified in Equation (4.1). Columns 1 and 2 report results for two measures of asset maturity: the value-weighted maturity of assets in years and the share of assets with maturities less than one year.

	Δ Asset maturity	Δ Share of ST assets
	1	2
	Panel A: Small banks	
Δr_{t-1}	-0.0792***	0.0070***
	(0.0016)	(0.0002)
Constant	0.0258***	-0.0008***
	(0.0006)	(0.0001)
Bank FE	Yes	Yes
N Obs.	646,175	648,234
R^2	0.0141	0.0104
	Panel B: Large banks	
Δr_{t-1}	-0.0308**	0.0026**
	(0.0144)	(0.0013)
Constant	0.0105**	0.0006
	(0.0050)	(0.0005)
Bank FE	Yes	Yes
N Obs.	8,784	8,799
R^2	0.0209	0.0102

*p < 0.10, **p < 0.05, ***p <0.01

Parentheses report heteroscedasticity-consistent standard errors.

Table 8: Panel Regression Results for Small and Large Banks: Sensitivity of ROA
The table reports estimates of the impact of changes in the components of the Return on Assets (ROA) for small and large banks. The group of small (large) banks comprises banks with total assets less than (greater than or equal to) $10B. The results are from the panel regressions specified in Equation (4.1). NIM denotes the net interest income margin, NNII denotes the ratio of net non-interest income to total assets, Provision denotes the ratio of provisions for loan and lease losses to total assets. The regressions are at the annual frequency due to the strong quarterly seasonality of ROA.

	ΔROA	ΔROA	ΔROA
	1	2	3
	Panel A: Small banks		
ΔNIM	0.4320***	0.6939***	0.6548***
	(0.0061)	(0.0059)	(0.0046)
$\Delta NNII$		0.8012***	0.7161***
		(0.0075)	(0.0057)
$\Delta Provision$			-0.8514***
			(0.0049)
Constant	0.0153***	0.0046***	0.0073***
	(0.0015)	(0.0013)	(0.0009)
Bank FE	Yes	Yes	Yes
N Obs.	157,278	157,278	157,277
R^2	0.1327	0.3988	0.7197
	Panel B: Large banks		
ΔNIM	0.3473***	0.5695***	0.5706***
	(0.0401)	(0.0320)	(0.0237)
$\Delta NNII$		0.8742***	0.7765***
		(0.0651)	(0.0422)
$\Delta Provision$			-0.7359***
			(0.0405)
Constant	0.0056	0.0030	0.0062
	(0.0161)	(0.0123)	(0.0091)
Bank FE	Yes	Yes	Yes
N Obs.	2,172	2,172	2,172
R^2	0.1282	0.5025	0.7229

*p $<$ 0.10, **p $<$ 0.05, ***p $<$0.01

Parentheses report heteroscedasticity-consistent standard errors.