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ABSTRACT

We analyze U.S. banks' asset exposure to a recent rise in the interest rates with implications for financial stability. The U.S. banking system's market value of assets is $2.2 trillion lower than suggested by their book value of assets accounting for loan portfolios held to maturity. Marked-to-market bank assets have declined by an average of 10% across all the banks, with the bottom 5th percentile experiencing a decline of 20%. Most of these asset declines were not hedged by banks with use of interest rate derivatives. We illustrate in a simple model that uninsured leverage (i.e., Uninsured Debt/Assets) is the key to understanding whether these losses would lead to some banks in the U.S. becoming insolvent-- unlike insured depositors, uninsured depositors stand to lose a part of their deposits if the bank fails, potentially giving them incentives to run. We show that a bank's survival depends on the market beliefs about the share of uninsured depositors who will withdraw money following a decline in the market value of bank assets. If interest rate increases are small such that the bank's decline in asset values is relatively small, there is no risk of a run equilibrium. However, for sufficiently high increases in interest rates, we have multiple equilibria in which uninsured depositor run making banks insolvent (i.e., a "bad" run equilibrium) becomes a possibility. Banks with smaller initial capitalization and higher uninsured leverage have a smaller range of beliefs supporting a "good" no run equilibrium, increasing their fragility to uninsured depositor runs. A case study of the recently failed Silicon Valley Bank (SVB) is illustrative. 10 percent of banks have larger unrecognized losses than those at SVB. Nor was SVB the worst capitalized bank, with 10 percent of banks having lower capitalization than SVB. On the other hand, SVB had a disproportional share of uninsured funding: only 1 percent of banks had higher uninsured leverage. Combined, losses and uninsured leverage provide incentives for an SVB uninsured depositor run. We compute similar incentives for the sample of all U.S. banks. Even if only half of uninsured depositors decide to withdraw, almost 190 banks with assets of $300 billion are at a potential risk of impairment, meaning that the mark-to-market value of their remaining assets after these withdrawals will be insufficient to repay all insured deposits. If uninsured deposit withdrawals cause even small fire sales, substantially more banks are at risk. Regions with lower household incomes and large shares of minorities are more exposed to the bank risk. We also show that decline in banks' asset values eroded the ability of banks to withstand adverse credit events – focusing on commercial real estate loans. Overall, these calculations suggest that recent declines in bank asset values very significantly increased the fragility of the US banking system to uninsured depositor runs.

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1. Introduction

When central banks tighten monetary policy, it can have significant negative impacts on the value of long-term assets, including government bonds and mortgages. This can create losses for banks, which engage in maturity transformation: they finance long maturity assets with short-term liabilities—deposits. As interest rates rise, the value of a bank's assets can decline, potentially leading to bank failure through two broad, but related channels. First, if a bank's liabilities exceed the value of its assets, it may become insolvent. This is particularly likely for banks which need to increase deposit rates as interest rates rise. Second, uninsured depositors may become concerned about potential losses and withdraw their funds, causing a bank run.[2]

Uninsured depositors represent a significant source of funding for commercial banks, accounting for about half of their deposits and $9 trillion of their liabilities[3], which can make runs a significant risk for these institutions.[4] In fact, during the 1980s and 1990s, nearly one-third of savings and loan institutions failed due to losses incurred from long-term fixed-rate mortgages that declined in value when interest rates surged. This resulted in a substantial reduction in the net worth of the S&L industry. More recently, the largest bank failure since the great recession occurred on March 10, 2023, when Silicon Valley Bank (SVB) was taken into FDIC receivership. 92.5% of its deposits were uninsured, leading to significant withdrawals that ultimately resulted in the bank's collapse within two days. In this paper we provide a simple analysis of all U.S. banks' asset exposure to a recent rise in the interest rates with implications for financial stability.

The Federal Reserve Bank responded to high inflation by increasing interest rates, which resulted in a substantial decline in the market value of long-duration assets. From March 07, 2022, to March 6, 2023, the federal funds rate rose sharply from 0.08% to 4.57% (Figure 1A), and this increase was accompanied by quantitative tightening. As a result, long-dated assets similar to those held on bank balance sheets experienced significant value declines during the same period. For instance, the exchange-traded fund that tracks the market value of residential mortgages (SPDR Portfolio Mortgage-Backed Bond ETF—SPMB) declined by more than 10% (Figure 1B) from 2022:Q1 to 2023:Q1. Similarly, the market value of commercial mortgages indicated by the iShares CMBS ETF declined by more than 10% during this time. Long maturity treasury bonds were particularly affected by monetary policy tightening, with 10-20 year and 20+ year Treasury bonds losing about 25% and 30% of their market value, respectively, as suggested by iShares Treasury ETF (see Figure 1C). Overall, as is evident, the FED's monetary policy tightening caused significant value declines in long duration assets.

To assess the financial stability of U.S. banks, we use bank call report data capturing asset and liability composition of all US banks (over 4,800 institutions) combined with market-level prices of long-duration assets.[5] Our analysis proceeds in multiple stages. Firstly, we examine losses on banks' assets including their loan portfolios held to maturity, which have not been marked-to-market, as well as securities linked to real estate (such as mortgage-backed securities (MBS), commercial mortgage-backed securities (CMBS), US Treasuries, and other asset-backed securities (ABS)). These assets comprise more than two-thirds of bank assets (72% of $24 trillion dollars). Adjusting these assets to their market values, our findings indicate that bank assets decline on average by 10%, with the bottom 5th percentile experiencing a decline of approximately 20%. The market value of U.S. banking system assets is $2.2 trillion lower than suggested

[2] There is a significant body of economic theory, going back to Diamond and Dybvig (1983), that aims to understand banks' role in liquidity transformation and their resulting exposure to depositor runs.
[3] See Table 1 and Figure A1 in the Appendix for composition of bank assets and liabilities in the aggregate.
[4] See Egan et al. (2017) and Chen et al. (2022).
[5] For assessments of U.S. banks' exposure to credit and interest rate risk in periods preceding the 2022-2023 monetary tightening episode see, among others, Begenau et al. (2015), Kelly et al. (2016), Drechsler et al. (2017, 2021), Egan et al. (2017), Atkeson et al. (2018), Begenau and Stafford (2019), and Xiao (2020).

by their book value. Interestingly, SVB does not stand out as much in the distribution of marked-to-market losses, with about 10% of banks experiencing worse marked-to-market losses on their portfolio.

Next, we analyze how this decline in assets impacts the solvency and run incentives of banks. We begin by assessing banks' funding structures before the recent monetary tightening. While SVB was reasonably well-capitalized from a capital perspective, with 10% of banks having less capital than SVB, its use of uninsured deposits stood out. It ranked in the 1st percentile of the distribution in uninsured leverage, suggesting that over 78% of its assets were funded by uninsured deposits.[6] In other words, SVB's bank liabilities were more prone to runs than those of other banks.

We then illustrate in a simple stylized framework how uninsured leverage (i.e., Uninsured Debt/Assets) can be a key to understanding whether a bank will become insolvent. Unlike insured depositors, uninsured depositors stand to lose a part of their deposits if the bank fails, potentially giving them incentives to run. Consequently, a bank's survival depends on the market beliefs about the share of uninsured depositors who will withdraw (or equivalently ask for a higher deposit rate), following a decline in the market value of bank's assets. If interest rate increases are small such that the decline in bank's asset values are relatively small, we are in a "good" equilibrium with no possibility of a run. However, for sufficiently high increases in interest rates, a "bad" equilibrium with uninsured depositor run making banks insolvent becomes a possibility. For banks with smaller initial capitalization and higher uninsured leverage, the range of sustainable beliefs supporting a "good" equilibrium without uninsured depositor run is smaller, increasing the bank fragility. In other words, in such situations a bank remains solvent only if a relatively small share of the uninsured depositors is expected to withdraw, otherwise there will be a run on the bank.

Finally, using the bank balance sheet data, we analyze several scenarios that combine the analysis of declines in marked-to-market asset values, along with banks' capitalization, their uninsured leverage, and the beliefs about the share of uninsured depositors withdrawing. This analysis informs us about the impact of recent rise in interest rates on the solvency and run incentives of banks.

We conclude by discussing several extensions of our framework. First, we illustrate that banks were not likely to have hedged a significant part of the decline of their assets due to raise in interest rates. Second, we compute the extent to which decline in banks' asset values quantified above eroded their ability to withstand adverse credit events – focusing on commercial real estate loans. Finally, we show that the risk in the banking sector due to monetary tightening is not spread uniformly across space, with higher exposure in regions with more minorities and lower income households.

2. Banks' Hidden Losses: "Marking to Market" Bank Assets

To understand the impact of interest rate increases on banks' asset values, we begin by examining bank balance sheets, following Jiang et al. (2020). Since a substantial portion of bank portfolios, specifically loans held to maturity, are not marked to market, we rely on exchange-traded funds (ETFs) across various asset classes to conduct our analysis. For the average bank, real estate loans account for approximately 42% of their assets (Table A1). Moreover, securities linked to real estate (such as mortgage-backed securities (MBS), commercial mortgage-backed securities (CMBS), treasuries, and other asset-backed securities (ABS) constitute approximately 24% of the average bank's assets. As these assets represent more than half of the total assets for a typical bank, we concentrate on marking them to market, which may result in underestimating the effect on the remaining portion of the bank balance sheet, which we leave unchanged.

2.1 Methodology and Data

[6] See Jiang et al. (2020) for a longer analysis of uninsured leverage in the U.S. banking and shadow banking system.

We mark bank assets to market in three steps.

1) We obtain the asset maturity and repricing data for all FDIC-insured banks in their regulatory filings (Call Report Form 031 and 041) in 2022:Q1. Banks are required to report the values of residential MBS and non-residential MBS securities (Schedule RC-B). They are also required to report the values of loans that are secured by first liens on 1- 4 family residential properties and all loans and leases excluding loans that are secured by first liens on 1-4 family residential properties (Schedule RC-C) by maturity and repricing breakdowns.[7]

2) We use traded indexes in real estate and treasuries to impute the market value of real estate loans held on bank balance sheet.[8] Longer duration fixed income assets were affected more by interest rate increases, so we want to adjust the market values of loans based on their maturity. Because of limited maturity information across RMBS maturities, we use one RMBS exchange traded fund, and then adjust across maturities using treasury prices. As a baseline, we use changes in the market price of the U.S. Treasury bonds and RMBS from 2022:Q1 to 2023:Q1. To adjust for maturity, we use the iShares U.S. Treasury Bond ETFs and the S&P Treasury Bond Indices across various maturities that match the maturity and repricing breakdowns in the call reports. For each of these ETFs and indices, we calculate the price declines since 2022:Q1, plotted in Figure 1.

3) We compute the mark-to-market value loss as

$$\begin{aligned} Loss = \sum_t & RMBS\ multiplier \times (RMBS_t + Mortgage_t) \times \Delta TreasuryPrice_t \\ & + Treasury\ and\ Other\ Securities\ and\ Loans_t \times \Delta TreasuryPrice_t, \end{aligned}$$

where t indicates the maturity and repricing breakdowns: less than 1 year, 1-3 years, 3-5 years, 5-10 years, 10-15 years, and 15 years or more. $\Delta TreasuryPrice_t$ is the market price change of Treasury bonds with maturity t from 2022:Q1 to 2023:Q1 that we obtained in the second step. RMBS and residential mortgages have additional risk due to prepayment risk. We account for this by constructing an $RMBS\ multiplier$ that uses average market price changes of RMBS and Treasury bonds across various maturities over this period:

$$RMBS\ multiplier = \frac{\Delta iShare\ MBS\ ETF}{\Delta \text{S\&P}\ Treasury\ Bond\ Index}.$$

We then define the mark-to-market asset value in 2023:Q1 as total assets in 2022:Q1 minus the mark-to-market value loss defined above. In some ways, our estimates are conservative, since we only marked down the value of real estate loans and other assets and securities and loans discussed above, rather than all assets on the bank balance sheets. On the other hand, in our main analysis we do not account for possible interest rate hedges that banks could have entered, potentially offsetting decline in value due to interest rate change. In extension of our main analysis (Section 5.1), we show that use of hedging and other interest rate derivatives was not large enough to offset a vast majority of the loss in the value of U.S. banks' assets that we quantify.

2.2 Declines in the Value of Banks' Assets

Marking the value of real estate loans, government bonds, and other securities results in significant declines in bank assets. Table 1 shows the aggregate losses in the US banking system and their distribution among

[7] The breakdowns are "less than three months," "three months to one year," "one to three years," "three to five years," "five to fifteen years," and "more than fifteen years."
[8] Variable rate notes are recorded as maturity at the repricing date in bank call reports.

small, large, and GSIB banks. In total the U.S. banking system's market value of assets is $2.2 trillion lower than suggested by their book value of assets as of 2023:Q1.

We present the distribution of asset declines due to unrealized losses in Figure 2A. The median value of banks' unrealized losses is around 9% after marking to market. The 5% of banks with worst unrealized losses experience asset declines of about 20%. We note that these losses amount to a stunning 96% of the pre-tightening aggregate bank capitalization.

The unacknowledged losses do differ slightly across the size distribution. They are smallest for GSIBs (Global Systemically Important Banks) at 4.6% and largest for large non-GSIB banks at 10%. Note that there are also differences in the uses of interest rate hedges across the size distribution of banks (esp. GSIBs) as we discuss in Section 5.1. There are substantial differences in the types of loans from which the losses arise. For GSIBs, RMBS is the largest part of the losses, and for small banks, it is other loans.

Perhaps somewhat puzzling at first, the recently failed SVB does not stand out as much in the distribution of marked to market losses. About 11 percent of banks suffered worse marked to market losses on their portfolio (Figure 2). In other words, if SVB failed because of losses alone, more than 500 other banks should also have failed.

3. The Role of Uninsured Leverage

3.1 Banking Sector and the Case of SVB

We next turn to assessing banks' funding structure before the monetary tightening. We show that SVB was not especially thinly capitalized relative to other banks. Instead, we show that it stood out on the dimension of uninsured leverage, making it much more run prone than other banks. Table A1 presents the funding structure of the U.S. banking industry prior to the monetary tightening. The average bank funds 10% of their assets with equity, 63% with insured deposits, and 27% with uninsured debt comprising 23% uninsured deposits and 4% other debt funding.[9] There was very little difference in the capitalization across banks prior to monetary policy tightening. The 10th percentile best capitalized bank had a ratio of equity to assets (E/A) of 14%, while the 10th percentile worst capitalized bank had 8% percent capital. Again, SVB is not an outlier—it is at the 10th percentile of capitalization of U.S. banks.

SVB did stand out from other banks in its distribution of uninsured leverage, the ratio of uninsured debt to assets (see Jiang et al. 2020 for a more comprehensive analysis of uninsured leverage of U.S. banking and shadow banking sector). Banks differ significantly in the share of funding they obtain from uninsured sources. The 5th percentile bank uses 6 percent of uninsured debt. For this bank, 94% of funding is not run prone comprising equity and deposits.

On the other hand, the 95th percentile bank uses 52 percent of uninsured debt. For this bank, even if only half of uninsured depositors panic, this leads to a withdrawal of one quarter of total marked to market value of the bank. If any fire sale discounts result from these withdrawals, this can impose substantial losses on the remaining creditors, increasing their incentives to run. SVB was in the 1st percentile of distribution in insured leverage. Over 78 percent of its assets was funded by uninsured deposits. This fact suggests that uninsured deposits played a critical role in the failure of SVB. We formalize this insight in a simple framework and then illustrate its implications through several numerical scenarios.

3.2 Run Incentives and Uninsured Leverage: Simple Framework

[9] As shown in Table A1 Panel B, only less than 1% of the uninsured deposits are time deposits with time to maturity and repricing in more than a year.

Unlike insured depositors, uninsured depositors stand to lose a part of their deposits if the bank fails, potentially giving them incentives to run. We now illustrate why a bank that faces losses on its investments and is poorly capitalized may not fail if it uses insured deposits for funding, but may fail when it uses uninsured deposits for funding instead. Note that we use a simple and stylized setting to get the intuition across. It does not answer the question of how banks choose the mix of insured and uninsured deposits in their capital structure or their investments. Jiang et al. (2020) deal with these aspects in a richer model, while emphasizing the role of "uninsured deposits leverage" for bank funding.

Basic Setup: Bank Assets and Liabilities

Consider a bank with its initial value of assets and liabilities normalized to 1. The bank holds c share of its assets in cash paying yield of 0. The remaining $(1-c)$ share of its assets are risk free perpetuities (T-bonds with infinite maturity), paying an annual coupon r_f, where r_f is the risk-free rate. We note that the market value of bank assets *A* is given by:

$$A = c + (1-c)\frac{r_f}{r_f} = 1. \tag{1}$$

To make things simple, we assume that the bank earns no rents on the liability side *prior to the monetary tightening*. The bank liability is financed with $(l^i + l^u)$ share of its total liabilities at the deposit cost of r_f,[10] where l^i is the "insured deposits leverage" and where l^u is "uninsured deposits leverage".[11] We further assume that $l^i + l^u = (1-c)$. We note that the market value of bank debt obligations assuming deposits stay forever at the current rate equals to:

$$D = \frac{(l^i + l^u)r_f}{r_f} = (l^i + l^u) = (1-c). \tag{2}$$

The value of equity is then given by:

$$E = A - D = c. \tag{3}$$

We note that the E/A ratio equals to c as well.

Basic Setup: Monetary Policy Tightening

Now suppose that because the unexpected monetary policy tightening, the new risk-free rate equals to

$$r_f^{new} = \frac{r_f}{\gamma} \tag{4}$$

where $0 < \gamma < 1$. Given this increase in the interest rate, the "marked-to-market" value of bank assets is lower and is now given by:

$$A^{new} = c + (1-c)\frac{r_f}{(r_f/\gamma)} = c + \gamma - c\gamma = c + \gamma(1-c). \tag{5}$$

Intuitively, the value of the bank's cash is still the same and equal to *c*. But the bank's long duration assets are now valued at the discount $\gamma < 1$ of their prior market-value. This computation corresponds to the more extensive "marked-to-market" analysis of assets in Table 1 and Figure 2.

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[10] The cost of deposits includes the deposit rate and acquisition costs. The deposits are cheaper than the risk free-rate due to some special value depositors attach to the money lie debt (e.g., see Jiang et al. 2020).

[11] In practice banks also finance their assets with a usually small share of long-term debt. Inclusion of such debt in the bank capital structure would not affect our main insights.

Let's first consider a case under which we compute the solvency of banks by assessing whether the marked to market value of assets is sufficient to cover the face value all non-equity liabilities. In other words, if all depositors withdrew their funding today (or ask for a higher deposit rate matching the increase in interest rates), could banks repay their debts. This is akin to assuming that there is no value to banks' deposit franchise. We assume that when assets are liquidated, there is no additional discount due to liquidation, so assets can be sold at their current market value. In terms of our framework this solvency condition can be expressed as:

$$A^{new} - D \quad = c + \gamma(1-c) - (1-c) = c - (1-c)(1-\gamma) \geq 0. \tag{6}$$

If this condition is satisfied bank could withstand any withdrawal of its insured and uninsured deposits. This condition is extreme, because insured depositors may have no incentives to withdraw funds as a function of default risk and may be content with their legacy deposit rate. On the other hand, it is a useful benchmark to better understand the de facto capitalization of the U.S. banking sector (as done in Column 1 of Table 1). Implicitly, this calculation assumes that increasing interest rates do not decrease the value of bank liabilities, i.e., the fed funds rate instantaneously pass-through to deposit rates.

But let's now assume that the condition (6) does not hold so that

$$c - (1-c)(1-\gamma) < 0, \tag{7}$$

that is the bank assets are below the face value of its non-equity liabilities. Despite a potentially large swing in the value of assets, it is not yet clear whether the bank is insolvent--i.e., whether the value of its assets is less than that of marked-to-market value of its liabilities --and whether depositors should consider running. As we will explain below this may crucially depend on the behavior of its uninsured depositors.

Equilibria with Uninsured Depositors Runs

To simplify the economics of the problem and highlight our main ideas without losing generality, we make two assumptions. First, the insured depositors are sticky. They remain with the bank if they obtain the legacy deposit rate r_f or till the bank's liquidation. This is akin to assuming that the insured deposits generate a considerable franchise value to the bank. Second, let's assume that market participants believe that a share s of uninsured depositors will withdraw their money. The remaining (1- s) of uninsured depositors will stay if the bank remains solvent, that is, if it can pay them their legacy deposit rate equal to r_f. We now characterize the range of beliefs about s that are sustainable in equilibrium.

We first characterize the range of s such that if a share of the uninsured depositors in that range withdraw their money, the bank's remaining assets are insufficient to service the cost of its remaining liabilities. Note that after the s share of the uninsured depositors withdraw, the bank remaining assets are worth:

$$A_s^{new} \ = c + \gamma(1-c) - sl^u. \tag{8}$$

The marked-to market value of bank's debt (deposits) will be equal to:

$$D_s^{new} \ = (l^i + (1-s)l^u)\frac{r_f}{\left(\frac{r_f}{\gamma}\right)} = (1-c-sl^u)\gamma \tag{9}$$

The bank will be insolvent when the value of its marked-to-market assets is insufficient to cover the value of its marked-to-market debt obligations (assuming no default on the debt). In other words, this situation arises when bank is in "negative" equity position:

$$D_s^{new} \ > A_s^{new}\,, \tag{10}$$

which, given (8) and (9), happens if the share of the uninsured depositors running is such that:

$$s > \frac{c}{(1-\gamma)l^u} \tag{11}$$

Let us define

$$s^* = \frac{c}{(1-\gamma)l^u}. \tag{12}$$

We have several possibilities depending on the value of s^*. First, if $s^* \geq 1$, the bank can survive any run by the uninsured depositors. Second, if $s^* < 1$ there will be two possibilities. One, if uninsured depositors believe that share $s \leq s^*$ of uninsured depositors will withdraw, we would be in a "good" equilibrium. The bank can survive in this scenario -- where there is withdrawal by some uninsured depositors -- without triggering a run due to withdrawals by the remaining uninsured depositors. Alternatively, any belief by uninsured depositors that a share $s > s^*$ of the uninsured depositors will withdraw is not an equilibrium, unless $s = 1$. This is because in this scenario all uninsured depositors would run, the bank would be insolvent, and the deposit franchise would collapse (i.e., we would be in a "bad" run equilibrium). To summarize, we have the following proposition:

Proposition 1: Let $s^* = \frac{c}{(1-\gamma)l^u}$. If $s^* \geq 1$, the bank can survive any withdrawal by the uninsured depositors. If $s^* < 1$ there are two types of equilibria:

(i) *Good (No Run) Equilibrium:* If the uninsured depositors believe that a share $s \leq s^*$ of the uninsured depositors will withdraw their money the bank will remain solvent.

(ii) *Bad (Run) Equilibrium:* Uninsured depositors believe that there will be a run on the bank with all uninsured depositors withdrawing money and bank becoming insolvent so $s = 1$.

Note that the range of sustainable beliefs about s in a good equilibrium S ∈ [0, min $(s^*, 1)$] is -- for $s^* < 1$ -- strictly increasing in bank capital *c*, and strictly decreasing with the extent of interest rate increase γ, and the uninsured leverage l^u. According to Proposition 1, as long as the bank has initial positive capitalization *c*>0, for a sufficiently small increase in interest rates (γ close to 1), the only sustainable equilibrium is no run equilibrium as S ∈ [0, 1]. Once interest rates increase sufficiently, we could have multiple equilibria, with bad run equilibrium possible. The range of sustainable beliefs about *s* in a good "no run" equilibrium is smaller for banks that have lower initial capitalization and that have larger uninsured leverage. In such situations a bank remains solvent only if a relatively small share of the uninsured depositors is expected to withdraw, otherwise there will be a run on the bank.

We note that according to Proposition 1, the case below with $s = 0$ is always one of the (good) equilibria.

Equilibrium with Sleepy Uninsured Depositors (s=0): Consider the case where all the uninsured depositors are sleepy so the belief is that none of them will withdraw the money. Specifically, they do not require a change in deposit rates offered to them in spite of the higher rates being offered in the market (say if they invested in Treasury securities). Nor do they consider withdrawing money from a bank if it is potentially impaired.[12] In this case the *market value* of bank liabilities also declines with interest rates and equals to

$$D^{new} = \frac{(l^i + l^u)r_f}{(r_f/\gamma)} = \gamma(l^i + l^u) = \gamma(1-c). \tag{13}$$

Note that this calculation recognizes that, by assumption, the insured depositors are sleepy. The bank is solvent and has the same positive equity value equal to *c*:

[12] See Dreschler et al. (2017) and Egan et al. (2017) who argue that the deposit franchise may allow banks to pay deposit rates that are low and Dreschler et al. (2021) who argue that in addition, this insensitivity in the deposit rates may hedge some of the banks' interest rate risk exposure.

$$E^{new} = A^{new} - D^{new} = c + \gamma(1-c) - \gamma(1-c) = c. \tag{14}$$

Intuitively, if the bank's debt stays in place at the legacy rate (and all insured and uninsured depositors are sleepy), the market value of debt declines at the same rate as value of the assets. Thus, the decline of the value of liabilities perfectly hedges the decline in assets given in (6). Consequently, the market value of equity remains the same as its pre-interest rate increase value.

Instability due to Uninsured Depositors Runs: While s=0 is always one of the equilibria, as interest rate increases, the range of sustainable beliefs about s in a good equilibrium converges to S ∈ [0] since s^* converges to zero. In other words, for sufficiently high increase in interest rates, the bank cannot survive a small withdrawal by uninsured depositors without causing a run. Thus, we can think about (1-s^*) as a measure of bank instability to uninsured depositor run. This index of bank instability will be higher for banks with lower initial capitalization and higher uninsured leverage.

We note that in the above framework we assumed that insured depositors are sticky. In practice, some of them may also consider withdrawing their money following an interest rate increase (see Dreschler et al. 2017). It is easy to incorporate such deposit outflows in our framework and they would further limit the range of sustainable beliefs supporting a good "no-run" equilibrium.

3.3 Numerical Example

We conclude this section by illustrating the properties of our model in a simple numerical example. Consider a bank with initial value of assets equal to \$100BN. The bank's long duration assets are risk free perpetuities (T-bonds with infinite maturity), paying an annual coupon of 3% before monetary tightening, and short duration asset is cash paying 0. Specifically, the bank holds \$10BN in cash and \$90BN in treasuries so that c = 0.1. The bank has \$90BN of deposits at the deposit cost of 3% so that $(l^i + l^u) = 0.9$. The current risk-free rate is 3%. In other words, for simplicity, the market and face value of bank liabilities are the same. Then, the market value of equity is c share of its initial value of assets and equals \$10BN.

Suppose the FED unexpectedly increases the risk-free rate by 100 basis points to 4% due to inflation $(\text{i.e.}, \gamma = 0.75)$. According to (5) the value of the bank's long-term assets is equal to 0.75 of their initial value and the overall mark-to-market value of bank assets equals to \$10BN+0.75×\$90BN = \$77.5BN. Note that in this case the bank would not be able to survive a full withdrawal of its deposits as the market value of its asses is less than the face value of its debt equal to \$90BN and so the solvency condition (6) is violated. Indeed, we have that $c - (1-c)(1-\gamma) < 0$ as 0.1-0.9×0.25 = -0.125.

As we discussed above if the insured depositors are sticky, the bank's solvency will crucially depend on the behavior of uninsured depositors. Suppose that the uninsured leverage equals to l^u =0.8. We can now compute the highest belief about the share of uninsured depositors withdrawing that is sustainable in equilibrium (without causing a run and bank insolvency). According to (12) we have that $s^* = \frac{c}{(1-\gamma)l^u} = \frac{0.1}{0.25 \times 0.8} = 0.5$. Hence any belief that up to a half uninsured depositors withdraw their money can be sustained in equilibrium in this example without causing a bank run and insolvency. The belief that more than half of uninsured depositors withdraw will "lead" to a bank run with all uninsured depositors attempting to withdraw their money.

4. Marked to Market Losses, Solvency, and Run Risk

Motivated by our analysis above, we next more systematically consider whether marking banks' asset to market renders a share of U.S. banks insolvent, or exposes them to run risk. There are several challenges that arise when assessing whether banks in reality are insolvent and run prone, even after marking assets to market. First, it is difficult to evaluate the market value of deposit liabilities. On the one hand deposits are on demand, and thus could be evaluated at their face value at prevailing market rates. On the other hand, there may be a spread between deposit rates to fed funds rates due to banks' market power, allowing banks to earn rents (Egan et al. 2017, Dreschler et al. 2021). Under this scenario one may want to consider on demand liabilities more akin to long duration assets, which also lose value when rates rise (Dreschler et al. 2021). Second, it is unclear how run prone uninsured deposits are. Egan et al. (2017) estimate that uninsured deposits are somewhat elastic to default, but this elasticity can result in multiple equilibria. Such complex counterfactuals are beyond the empirical assessments in this paper. Instead, we follow our framework in Section 3.2 and consider several alternative scenarios with a range of uninsured depositors' withdrawal behavior. We also go beyond our simple framework to consider the role of regulators, which play a central role in bank failures (Granja, et al. 2017).

4.1 Are Assets of U.S. Banks Sufficient to Cover Uninsured Deposits?

The first benchmarking exercise considers the run incentives of uninsured depositors from the perspective of assets after marking assets to market. Specifically, we consider whether the assets in the U.S. banking system are large enough to cover all uninsured deposits. Intuitively, this situation would arise if all uninsured deposits were to run, and the FDIC *did not close the bank prior to the run ending*.

Figure 3A plots the histogram of uninsured deposit to asset ratio and marked-to-market asset ratio. Figure 3B plots uninsured deposit to asset ratio against bank size. As we observe, while the decline in asset values increased the ratio of uninsured deposits to assets, virtually all banks (barring two) have enough assets to cover their uninsured deposit obligations. In other words, if the FDIC does not step in to protect the deposit insurance fund, or if the liquidation of the assets does not cause large enough fire sales, there may be no reason for uninsured depositors to run.[13]

Notably, SVB, is one of the worst banks in this regard. Its marked-to-market assets are barely enough to cover its uninsured deposits. Even a small fire sale discount would result in uninsured depositors in losing money in a run, making a run rational. This fact can help explain why the uninsured depositors run may have occurred for this bank.

4.2 Uninsured Deposits and Scenarios on Running

We next assess the bank solvency across various beliefs regarding the share of uninsured depositors withdrawing (i.e., *s* in the model) using bank balance sheet data and their marked-to-market asset declines. Like in the SVB case, the FDIC steps in to protect insured depositors when a bank is put into receivership (Granja, et al. 2017). Thus, we consider a simple *empirical solvency condition* that reflects the idea that insured depositors being impaired is the lower bar for the FDIC intervention. Specifically, instead of considering whether the marked-to-market value of bank assets after such withdrawal is enough to cover the marked-to-market value of bank liabilities (i.e., solvency condition (10) from Section 3.2), we study whether insured depositors would be impaired under these scenarios. For that purpose, Figure 4 plots the distribution of insured deposit coverage ratio. We defined it as:

$$\text{Insured Deposit Coverage ratio} = \frac{\text{Mark-to-Market Assets} - s \times \text{Uninsured Deposits} - \text{Insured Deposits}}{\text{Insured Deposits}}$$

A negative value of insured deposit coverage ratio means that the remaining mark-to-market asset value – i.e., after paying uninsured depositors who withdraw their deposits -- is not sufficient to repay all insured deposits. We simulate two cases. In case 1 (Figure 4a and 4b), we assume all uninsured depositors run (i.e., s=1). In

[13] We note that the uninsured depositors could start running due to risk of further asset losses even if currently banks have enough assets to cover their uninsured deposit obligations.

case 2 (Figure 4c and 4d), we assume half of all uninsured depositors run (i.e., s=0.5). We compare these cases pre and post FED monetary tightening.

Prior to FED interest rate increases, U.S. banks were solvent under both scenarios, and uninsured depositors had no incentives to run. In other words, even if all uninsured deposits would have been withdrawn, the remaining assets would have been sufficient to cover insured deposits. Of course, this assumes that deposit withdrawals do not result in fire sales, which would further depress assets. But absent fire sales, the U.S. banks would have been able to withstand all deposit withdrawals.

As we discuss above, the recent FED tightening has resulted in substantial losses in the value of banks' long duration assets. Our calculations imply that banks are much more fragile to uninsured depositors runs after the tightening. Suppose that all uninsured depositors were to withdraw funds from U.S. banks. Table 2 shows that 1,619 U.S. banks would have negative insured deposit coverage, suggesting insured deposits would be impaired. While the median bank is small, with assets of $0.3BN, the aggregate losses would be large, and would involve $2.6T of aggregate deposits, and a shortfall for the deposit insurance fund of $300BN. This would provide the FDIC with enormous incentives to intervene during a run, such as in the case of SVB, and thus in fact provide incentives for uninsured depositors to run.

The case under which all uninsured depositors run is likely too extreme, although not impossible once the news of a run spreads as illustrated in our stylized framework in Section 3.2. Therefore, in case 2 we consider whether banks can withstand half of their uninsured depositors withdrawing funds. Again, this scenario assumes that banks can liquidate their assets at market prices, rather than facing a fire sale discount. Even under this scenario, we find that there are 186 banks with assets of about $300 billion that have a negative insured deposit coverage ratio (Table 2). In other words, for these banks comprising about $250 billion of insured deposits, even insured deposits would be impaired absent regulatory intervention (e.g., by the FDIC). The losses to the deposit insurance fund would total approximately $10 billion. If the FDIC shut these banks following a run, there would be no funds left for the remaining uninsured depositors. In other words, the decision to run would have been a rational one. So, our calculations suggest these banks are certainly at a potential risk of a run, absent other government intervention or recapitalization.

Interestingly, while SVB is very close to the boundary of a negative insured deposit coverage ratio, our calculations suggest it should have been able to survive a run without impairing insured depositors. However, even a 0.4% fire sale discount would have resulted in impaired insured deposits if all uninsured depositors ran.

To further assess the vulnerability of the US banking system to uninsured depositors run, we plot the 10 largest banks at the risk of a run, which we define as a negative insured deposit coverage ratio if all uninsured depositors run (see Figure 5). Figure A2 in the Appendix shows the same plot for the universe of all banks that become insolvent if all uninsured depositors run. Because of the caveats in our analysis as well as the potential of exacerbating their situation, we anonymize their names, but we also plot SVB as comparison. We plot their mark-to-market asset losses (Y axis) against their uninsured deposits as a share of marked to market assets. Some of these banks have low uninsured deposits, but large losses, but the majority of these banks have over 50% of their assets funding with uninsured deposits. SVB stands out towards the top right corner, with both large losses, as well as large uninsured deposits funding. As Figure 5 shows, the risk of run does not only apply to smaller banks. Out of the 10 largest insolvent banks, 1 has assets above $1 Trillion, 3 have assets between $200 Billion and $1 Trillion, 3 have assets between $100 Billion and $200 Billion and the remaining 3 have assets between $50 Billion and $100 Billion.

We conclude by plotting the sensitivity of the US banking system to the uninsured depositor runs for a broader range of "run" cases. This exercise assesses the solvency of US banks for a range of beliefs about the share of uninsured depositors that are expected to withdraw their funds, as we did in Section 3.2, given our *empirical solvency condition*. Figure 6 presents the number of insolvent banks (Figure 6A) and their aggregate assets (Figure 6B) associated with a given uninsured deposits withdrawal case. We consider ten cases ranging from 10% to 100% of uninsured deposits being withdrawn at each bank. The bank is considered insolvent if its mark-to-market value of assets – after paying a given share of the uninsured depositors –is insufficient to repay all insured deposits. Figure 6 shows that even if only 10% of uninsured depositors decided to withdraw their money, we would have 66 banks failing with about $210 billion of assets. If 30% of uninsured depositors ran instead, which is close to the share of withdrawals just preceding the shutdown of the SVB, we would have 106 banks failing accounting for $250 billion of assets.

4.3 Extreme Insolvency: No Deposit Franchise

Finally, we also consider an extreme case under which we compute the solvency of banks by assessing whether the marked to market value of assets is sufficient to cover all non-equity liabilities. This is equivalent to empirically assessing the solvency condition (6) from Section 3.2 for the universe of US banks. In other words, if all depositors and debtholders withdrew their funding today, could banks repay their debts. As noted in Section 3.2, this is akin to assuming that there is no value to banks' deposit franchise. We assume that when assets are liquidated, there is no additional discount due to liquidation, so assets can be sold at their current market value. This scenario is extreme, because insured depositors have no incentives to withdraw funds as a function of default risk. On the other hand, it is a useful benchmark to better understand the de facto capitalization of the U.S. banking sector. Implicitly, this calculation assumes that increasing interest rates do not decrease the value of bank liabilities, i.e., the fed funds rate instantaneously pass-through to deposit rates.

We present these results in Appendix A that plots the histograms (density) of the equity to asset ratio as of 2022:Q1 and the mark-to-market equity to asset ratio as of 2023:Q1 (Panel A, Figure A3) and these values by bank size (Panel B, Figure A3). The reference lines in Panel A indicates Silicon Valley Bank's equity to asset ratio as of 2022:Q1 and its mark-to-market equity to asset ratio. As we observe, prior to the recent asset declines all US banks had positive bank capitalization. However, after the recent decrease in value of bank assets, 2,315 banks accounting for $11 trillion of aggregate assets have negative capitalization relative to the face value of all their non-equity liabilities (see Column 1 of Table 2). We further find that regions with lower household incomes and large share of minorities are much more exposed to the bank risk (see Section 5.3).

5. Extensions: Hedging, Credit Risk and Regional Variation

We consider several extensions of our analysis in Section 4. First, we discuss whether banks may have hedged some of the declines of their assets due to raise in interest rates. Second, we consider the extent to which banks can withstand adverse credit events, focusing on the case of commercial real estate. Finally, we consider where the risk in banking sector resides spatially in the US.

5.1 Limited Hedging by U.S. Banks During the 2022 Monetary Tightening

Up to this point, we have not formally considered the possibility that banks may have hedged their interest rate exposure. However, this does not imply that the aggregate $2.2 trillion losses in the banking system are any less relevant for financial stability. Suppose that most banks had hedges covering their interest risk exposure. In that case, an important question arises as to who provided these hedges as a counterparty. If the hedges were provided by other banks, this would not alter the aggregate losses but merely reallocate them across banks. Given that all banks were thinly capitalized prior to the rate increase, with an average Equity to Asset ratio of about 10%, the overall impact and the big picture remain largely unchanged.[14] Alternatively, if the counterparty entities were non-bank institutions that insured the US banking system's

[14] As shown in Table A1, the aggregate equity in the banking system was about $2.3 trillion in 2022:Q1.

aggregate interest rate risk, we would likely witness severe stress in such institutions at this point, as seen with AIG's systemic risk exposure in 2007.

Nevertheless, to address this issue formally, in a companion note (Jiang et al. 2023a) we analyze the extent to which U.S. banks hedged their asset exposure as the monetary policy tightened in 2022. We use call reports data for interest rate swaps covering close to 95% of all bank assets and supplement it with hand-collected data on broader hedging activity from 10K and 10Q filings for all publicly traded banks (68% of all bank assets).

We find that interest rate swap use is concentrated among larger banks who hedge a small amount of their assets. Overall, only 6% of aggregate assets in the U.S. banking system are hedged by interest rate swaps. This analysis implies that the use of hedging and other interest rate derivatives was not large enough to offset a vast majority of the $2.2 trillion loss in the value of U.S. banks' assets. Moreover, we also find that banks with the most fragile funding like the SVB – i.e., those with highest uninsured leverage – if anything sold or reduced their hedges during the monetary tightening.[15] This allowed them to record accounting profits but exposed them to further rate increases. These actions are reminiscent of asset substitution: if interest rates had decreased, equity would have reaped the profits, but if rates increased, then debtors and the FDIC would absorb most of the bank losses.

5.2 Impact of Potential Credit Losses on the Fragility of the US Banking System

We abstracted away from a potential impact of credit losses on bank stability. In a companion note (Jiang et al. 2023b) we analyze the extent to which the losses established in Section 4 eroded banks' ability to withstand adverse credit events. We focus on potential distress on bank's commercial real estate (CRE) loan portfolios.

We focus on commercial real estate for a couple of reasons. First, the commercial real estate loans constitute a substantial share of assets for a typical bank accounting for about quarter of assets for an average bank and $2.7 trillion of bank assets in the aggregate.[16] Second, commercial real estate is also seen as a potential source of adverse credit events in the near term, especially the office sector (e.g., see Gupta et al. 2022).

We find that 10% (20%) default rate on CRE loans – a range close to what one saw in the Great Recession on the lower end – would result in about $80 billion ($160 billion) of additional bank losses. While these losses are an order of magnitude smaller than the decline in bank asset values associated with a recent rise of interest rates, they can have important implications. An additional 285 (578) banks with aggregate assets of $700 billion ($1.2 trillion) would have their marked-to-market value of assets insufficient to cover the face value of all their non-equity liabilities. Even if half of uninsured depositors decide to withdraw, the losses due to CRE distress would result in additional 21 (58) smaller regional banks at a potential risk of impairment to insured depositors (over what we discussed in Section 4). Thus, the unrealized losses due to monetary tightening have made banks less resilient to adverse credit events, further contributing to the fragility of the banking system.

5.3. Regional Exposure to Bank Risk

We conclude our analysis by assessing where the risk in the banking sector – established in Section 4 – resides spatially in the US. We proceed in three steps. We first find banks' deposit impairment ratio by assuming that equity and non-deposit debt are in the first position to absorb mark-to-market losses in the extreme insolvency case discussed above:

[15] SVB hedged about 12% of all securities at the end of 2021. By the end of 2022, they hedged only 0.4%.
[16] We consider all non-residential real estate loans as commercial loans. See Appendix A1 for more detail on banks assets and liabilities.

$$Deposit\ Impairment\ Ratio_j = \frac{Asset_j - Mark\text{-}to\text{-}Market\ Loss_j}{Total\ Deposit_j}.$$

We then obtain information about bank branch networks and the regional distribution of deposit taking from the FDIC Summary of Deposit (SOD) in 2022. We assign bank risk to regions where they have branches. Lastly, we find a county's exposure to bank risk by calculating the percentage of its total deposits at the risk of impairment:

$$Share\ of\ Deposit\ at\ Risk_c = \frac{\sum_{j \in c} \max\{Deposit\ Impairement\ Ratio_j, 0\} \times Deposit_{jc}}{\sum_{j \in c} Deposit_{jc}}.$$

Figure 7 presents the map of local exposure to bank risk. Figure 7A plots the share of deposits at risk. The most exposed counties have up to 13% deposits at the risk of impairment. These counties are clustered in several states, such as New Hampshire, Massachusetts, Wyoming, and New York. Some counties do not have much exposure to the risk, such as Delaware, Nebraska, Arkansas, and Maryland. Figure 7B plots the dollar amount of deposits at risk. The most exposed counties in terms of share of deposit at risk do not necessarily have the largest dollar amount of deposits at risk. As we will discuss below, this is because the most exposed regions are more likely to have lower median income and thus lower total deposit amount.

Figure 8 plots the county-level share of impaired deposits against local demographics. Counties with more minority population, especially those with more than 80% Black and Hispanic population, tend to be more exposed to the bank risk (Figure 8A). For instance, on average, counties with more than 90% Black and Hispanic population have about 4% of total deposits at the risk of impairment. Counties with low median-income are more likely to be exposed to bank risk (Figure 8B). Regions with median annual income below $35,000 are mostly exposed to the risk, with about 4% of deposit at the risk of impairment. Lastly, counties with a larger population without a college degree are more exposed to the risk (Figure 8C). In particular, regions with nearly the entire population with a college degree have no exposure to the risk, while regions with more than 90% population without a college degree have about 2% of deposits at risk of impairment. Thus, the risk in the banking sector due to monetary tightening is not spread uniformly across space, with higher exposure in regions with more minorities and lower income households.

6. Conclusion

We provide a simple analysis of U.S. banks' asset exposure to a recent rise in the interest rates with implications for financial stability. The U.S. banking system's market value of assets is $2.2 trillion lower than suggested by their book value of assets. We show that these losses, combined with a large share of uninsured deposits at some U.S. banks can impair their stability. Even if only half of uninsured depositors decide to withdraw, almost 190 banks are at a potential risk of impairment to even insured depositors, with potentially more than $250 billion of insured deposits at risk absent regulatory intervention. If uninsured deposit withdrawals cause even small fire sales, substantially more banks are at risk. Overall, these calculations suggest that recent declines in bank asset values significantly increased the fragility of the US banking system to uninsured depositors runs (summarized in Table 2 and Figure 6).

There are several medium-run regulatory responses one can consider to an uninsured deposit crisis. One is to expand even more complex banking regulation on how banks account for mark to market losses. However, such rules and regulation, implemented by myriad of regulators with overlapping jurisdictions might not address the core issue at hand consistently (Agarwal et al. 2014).[17] Alternatively, banks could

[17] In addition, such regulations might have implications for non-bank institutions (shadow banks) that provide several services like banks and have gained market share that reflects in part the regulatory actions on banks (see Buchak et al. 2022). These institutions are predominantly financed with short-term uninsured debt, but they are also significantly better capitalized than banks on average (Jiang et al. 2020). See also Greenwood et al. (2017), Corbae and D'Erasmo (2021), and Begenau and Landgvoit (2022) for recent studies of impact of regulatory policies on banks.

face stricter capital requirement, which would bring their capital ratios closer to less regulated lenders, as documented in Jiang et al. (2020). Discussions of this nature remind us of the heated debate that occurred after the 2007 financial crisis, which many might argue did not result in sufficient progress on bank capital requirements (see Admati et al. 2013, 2014 and 2018). They also resonate well with historical studies on the impact of deposit insurance on banks' risk-taking behavior (see Calomiris and Jaremski 2019).

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Table 1: Mark-to-Market Statistics by Bank Size

This table presents the descriptive statistics of our key metrics after marking-to-market the asset values for each FDIC-insured depository institutions in the U.S. Column (1) shows these statistics of all the banks, Column (2) for small banks, Column (3) for large and non-systemically important banks (non GISB), and Column (4) for systemically important banks (GSIB banks). Bank size is based on the reported bank asset value as of 2022:Q1. Small banks have assets less than $1.384 Billion, the Community Reinvestment Act asset size thresholds for large banks. Large (non GISB) banks have asset greater than equal to 1.384 Billion. GSIB banks are classified according to bank regulators' definition as of 2022:Q1. We also assign GSIB status to US chartered banks affiliated with holding companies that are classified as GSIB. The first row shows the aggregate loss which is defined as the sum of the dollar loss at each bank based on marking-to-market their 2022:Q1 balance sheets. Other rows in the table report bank level statistics. Bank level statistics are based on the sample median values. Numbers in parentheses are the standard deviations. Loss for each bank is computed based on marking-to-market all its securities and loans (see text) according to the market price growth from 2022:Q1 to 2023:Q1. We also decompose these dollar losses into those from RMBS, Treasury and other securities, loans secured by residential 1 to 4 family properties (residential mortgage), and other loans. We then report them in terms of the percentage of total losses. Loss/Asset at the bank level is the loss as a percentage of the book value of assets as of 2022:Q1. Uninsured Deposit/MM Asset is the uninsured deposit amount of 2022:Q1 divided by the mark-to-market asset value (MM Asset) as of 2023:Q1. Insured Deposit Coverage ratio is defined as (mark-to-market asset value - uninsured deposit -insured deposit)/insured deposit. Note that our analyses are done at bank charter level instead of bank holding company level. *Sources*: Bank Call Reports in 2022:Q1 and various ETF and indices price data as described in the main text.

	(1) All Banks	(2) Small (0, 1.384B)	(3) Large (non GSIB) [1.384B,)	(4) GSIB
Aggregate Loss	2.2T	144B	1.3T	0.73T
Bank Level Loss	28.6M	22.3M	308.0M	837.0M
	(6.7B)	(38.2M)	(8.9B)	(69.7B)
Share RMBS	13.2	11.4	22.6	17.4
	(19.2)	(18.5)	(20.6)	(32.8)
Share Treasury and Other	15.5	17.0	10.4	8.1
	(35.1)	(37.5)	(14.8)	(33.0)
Share Residential Mortgage	19.9	19.8	20.4	20.5
	(33.4)	(35.4)	(19.5)	(35.9)
Share Other Loan	32.8	32.7	33.8	1.0
	(32.7)	(34.3)	(21.6)	(38.9)
Loss/Asset	9.2	9.1	10.0	4.6
	(4.7)	(4.8)	(4.4)	(6.1)
Uninsured Deposit/MM Asset	24.2	22.7	35.7	19.0
	(14.1)	(12.6)	(15.8)	(26.6)
Insured Deposit Coverage Ratio	4.2	3.9	5.9	15.4
	(32.7)	(30.4)	(36.4)	(115.7)
Number of Banks	4844	4072	743	29

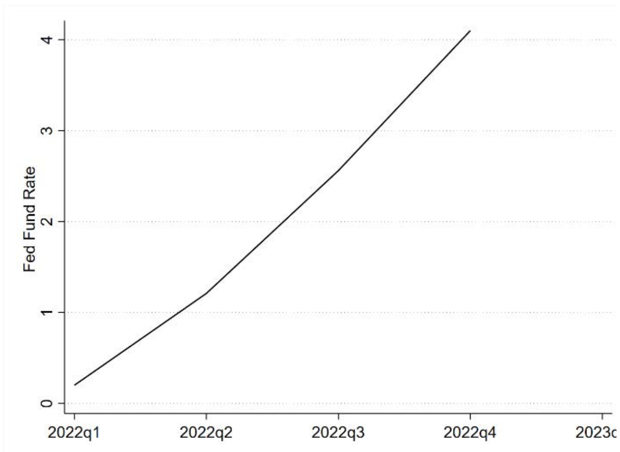
Table 2: Insolvent Banks Under Different Cases

The top panel of the table shows aggregate statistics of insolvent banks as of 2022:Q1. The bottom panel of the table presents the statistics using median values of all the banks in each category as defined below as of 2022:Q1. Numbers in parentheses in the bottom panel are standard deviations. Insolvency is defined based on mark-to-market asset values under four different cases as of 2023:Q1. In column (1), we assume all assets are liquidated at their mark-to-market value. The bank is considered insolvent if the mark-to-market value of assets is insufficient to cover all non-equity liabilities. In column (2) we assume all uninsured depositors run. The bank under this case is considered insolvent if the mark-to-market value of assets – after paying all uninsured depositors -- is insufficient to repay all insured deposits. In column (3) we assume half of the uninsured depositors run. The bank under this case is considered insolvent if the mark-to-market value of assets – after paying half of the uninsured depositors – is insufficient to repay all insured deposits. In column (4) we assume all uninsured depositors run and there is a fire sale discount of 0.4%. The bank under this case is considered insolvent if the mark-to-market value of assets net of fire sales – after paying all uninsured depositors -- is insufficient to repay all insured deposits. The fire sale discount of 0.4% is obtained by considering the case of Silicon Valley Bank (SVB). At this value of fire sale discount, the mark-to-market value of assets net of fire sales – after paying all uninsured depositors -- is just sufficient to repay all insured deposits. Note that SVB is not classified as insolvent in column (2). Aggregate asset shows the sum of total assets of banks in each category as of 2022:Q1. Aggregate equity shows the sum of equity of banks in each category as of 2022:Q1. Aggregate insured deposit is the sum of total insured deposits of banks in each category as of 2022:Q1. Total shortfall is the sum of total uncovered insured deposits as of 2022:Q1. Systemically important banks (GSIB banks) are classified according to bank regulators' definition as of 2022:Q1. We also assign GSIB status to US chartered banks affiliated with holding companies that are classified as GSIB. *Data Sources:* Bank Call Reports in 2022:Q1 and ETF and indices price data.

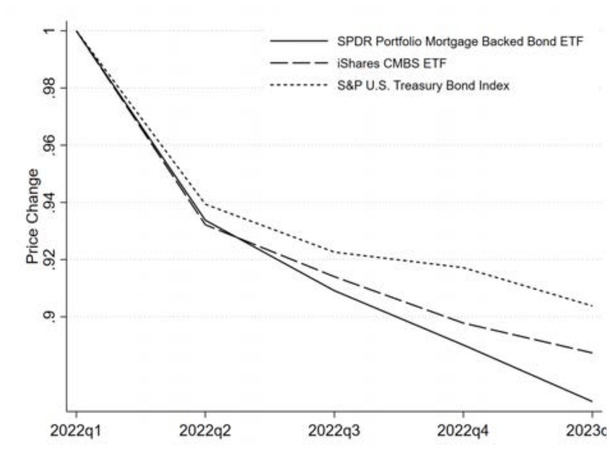
	(1) All Assets Liquidate	(2) 100% Uninsured Depositor Run	(3) 50% Uninsured Depositor Run	(4) 0.4% Fire Sale Discount
Aggregate Asset	11T	4.9T	0.3T	5.3T
Aggregate Equity	1.0T	0.4T	0.02T	0.4T
Aggregate Insured Deposit	5.2T	2.6T	0.25T	2.7T
GSIB Banks	2.2T	1.1T	20B	1.1T
Total Shortfall	1.5T	0.3T	0.01T	0.3T
GSIB Banks	0.6T	0.11T	0.8B	0.1T
Total Asset	0.4B	0.3B	0.2B	0.3B
	(68B)	(46B)	(9B)	(45B)
Liability/Asset	91.7	91.9	92.0	91.9
	(2.3)	(2.3)	(3.0)	(2.3)
Domestic Deposit/Asset	89.6	90.7	90.8	90.7
	(4.9)	(3.1)	(3.7)	(3.0)
Insured Deposit/Asset	66.4	67.8	79.7	67.6
	(11.6)	(11.4)	(5.8)	(11.6)
Uninsured Deposit/Asset	22.1	22.4	10.2	22.5
	(11.7)	(11.8)	(7.2)	(12.0)
Equity/Asset	8.3	8.1	8.0	8.1
	(2.3)	(2.3)	(3.0)	(2.3)
Number of Banks	2315	1619	186	1724

Figure 1: Fed Tightening and Asset Prices

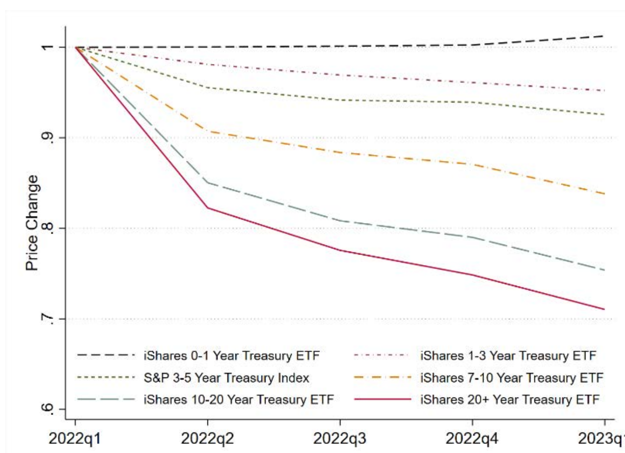
Panel (a) plots the time series of the fed funds rates (in %). Panel (b) plots the market price of the portfolio of residential mortgage-backed securities (RMBS), the commercial mortgage-backed securities (CMBS), and the US Treasuries relative to their values in 2022:Q1 (normalized to one). Panel (c) plots the corresponding market prices of US Treasuries with different maturities, relative to their value in 2022:Q1. The maturity structure is chosen to match the asset maturity breakdowns in the call reports. We plot the prices from 2022:Q1 till 2023:Q1. *Data Sources:* Fed Funds Rate is from the Federal Reserve System data, RMBS market price is from the SPDR Portfolio Mortgage-Backed Bond ETF (SPMB), CMBS market price is from the iShares CMBS ETF (CMBS), and the US Treasury market price indexes are from the S&P U.S. Treasury Bond Index and the iShares Treasury ETF.



(a) Fed Funds Rate (in %)



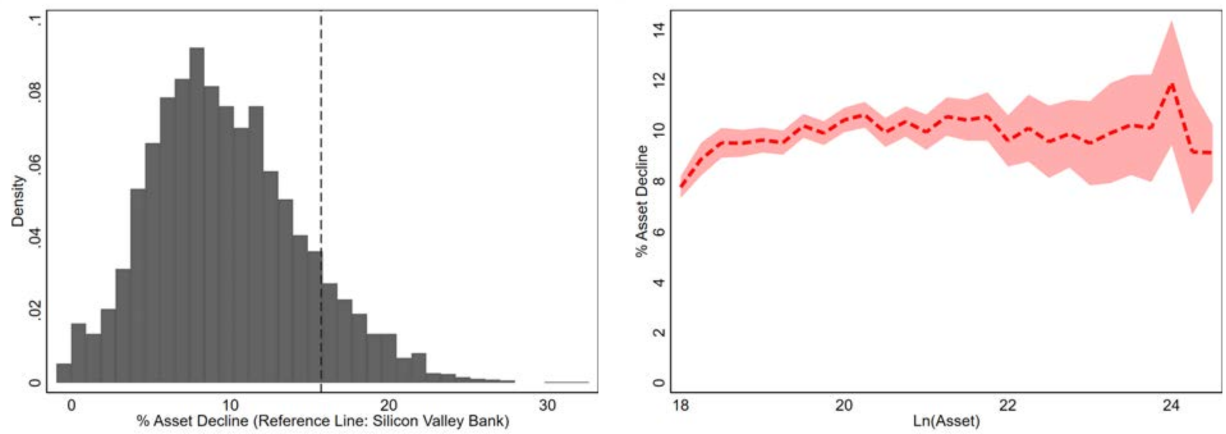
(b) RMBS, CMBS, Treasury



(c) Treasury by Maturity

Figure 2: Distribution of Change in Asset Value ("Marking to Market")

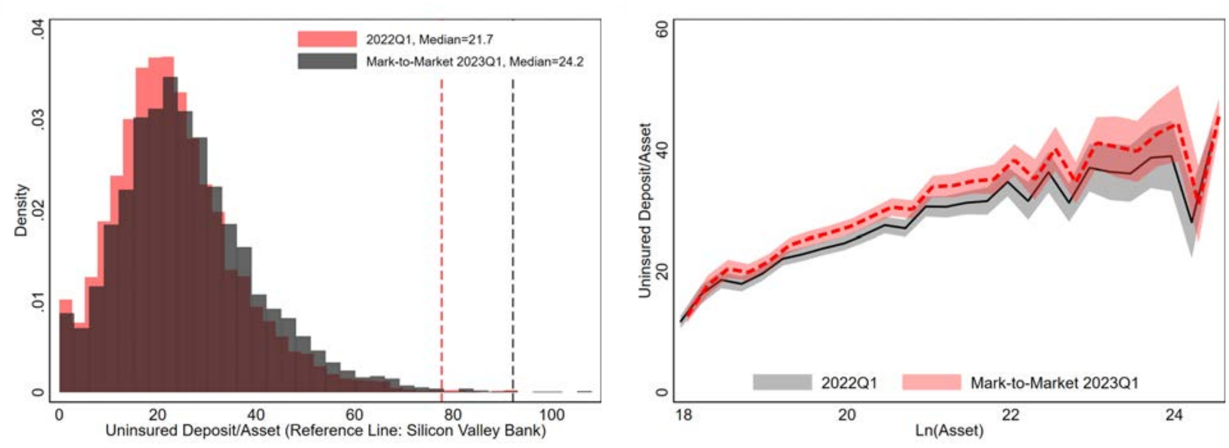
This figure plots the histograms (density) of the percentage of bank's asset value decline when assets are mark-to-market according to market price growth from 2022:Q1 to 2023:Q1 (Panel a) and bank asset value decline by bank size (Panel b). We describe the steps to calculate the mark-to-market asset values in the main text. The reference line in Panel (a) indicates Silicon Valley Bank's asset value decline. Silicon Valley Bank's asset value declines by 15.7%, or $34 billion, after their assets are marked to market. The reference line is at 89th percentile. The 5th, 25th, median, 75th, and 95th percentiles in Panel (a) are 4%, 6%, 9%, 13%, and 19%, respectively. In Panel (b), the x-axis is asset value in log terms. The size distribution of the U.S. banking industry has a fat left-tail, meaning that there are many extremely small banks. The largest 50 banks' asset sizes range from $58.9 billion to $3.5 trillion, while the bottom 10 percentiles have asset values less than $68 million. Log assets of 18, 20, 22, and 24 are about $66 million, $485 million, $3.6 billion, and $26 billion. The decline at the right-end starts around log asset value of 24, which is about $26B. *Data Sources*: Bank Call reports in 2022:Q1 and various ETF and indices price data as described in the main text.



(a) Histogram (b) Asset Decline by Size

Figure 3: Distribution of Uninsured Deposit to Asset Ratio (With & Without "Marking to Market")

This figure plots the histograms (density) of uninsured deposit to asset ratios calculated based on 2022:Q1 balance sheets and mark-to-market values using various ETFs and indices according to the method described in the main text (Panel a) and uninsured deposit ratio against bank size (Panel b). The reference lines in Panel (a) indicate Silicon Valley Bank's (SBV) values. SVB's uninsured deposit ratio is 78% based on its 2022Q1 balance sheet, which is about \$169 billion. Its uninsured deposit to mark-to-market asset ratio is 92%. Both reference lines are at the 100th percentile. The 5th, 25th, median, 75th, and 95th percentiles of the mark-to-market distribution in Panel (a) are 6%, 17%, 24%, 33%, and 52%, respectively. In Panel (b), the decline at the right-end starts around log asset value of 24, which is about \$26B. *Data Sources*: Bank call reports in 2022:Q1 and various ETF and indices price data as described in the main text.



(a) Histogram

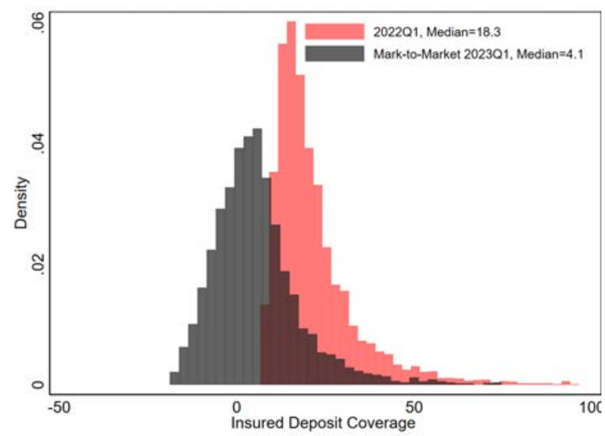
(b) Uninsured Deposit/Asset by Size

Figure 4: Distribution of Insured Deposit Coverage Ratio under Different "Run" Cases

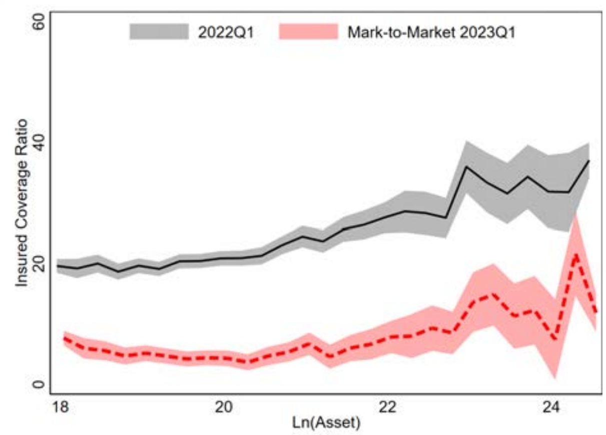
This figure plots the histograms (density) of insured deposit coverage ratio calculated based on 2022:Q1 balance sheets and mark-to-market values as described in the main text (Panel a and c) and insured deposit coverage ratio against bank size (Panel b and d). Insured deposit coverage ratio is defined as

$$\text{Insured Deposit Coverage ratio} = \frac{\text{Mark-to-Market Assets} - s \times \text{Uninsured Deposits} - \text{Insured Deposits}}{\text{Insured Deposits}}.$$

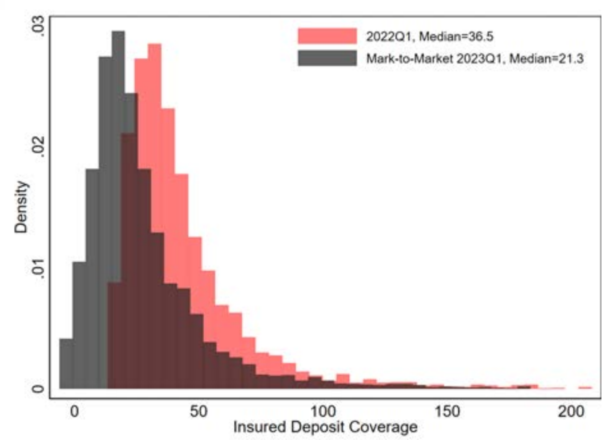
We simulate two cases. In the first case (panel a and b), we assume all uninsured depositors run and withdraw their uninsured deposits from banks (i.e., s=1). In the second case (panel c and d), we assume half of uninsured depositors withdraw their uninsured deposits from banks (i.e., s=0.5). We remove the outliers by truncating the sample at 98th and 1st percentiles. The 5th, 25th, median, 75th, and 95th percentiles of the mark-to-market distribution in Panel (a) are -12%, -2.5%, 4%, 11%, and 34%, respectively and in Panel (b) are 1.3%, 12.5%, 21%, 36%, and 59%, respectively. A negative value of insured deposit coverage ratio means that the remaining mark-to-market asset value after paying uninsured depositors who withdraw their deposits is not enough to repay all insured deposits. For example, -12% means that 12% of total insured deposits will not be repaid without deposit insurance fund. Silicon Valley Bank (SVB) has a positive insured deposit coverage ratio of 5.6%, though notably its liabilities have a very small proportion of insured deposits. Because of this even a tiny additional asset fire sale discount (0.4%) will make the insured coverage ratio of the SVB to fall below zero after the uninsured deposits have withdrawn. *Data Sources*: Bank Call reports and various ETF and indices price data as described in the main text.



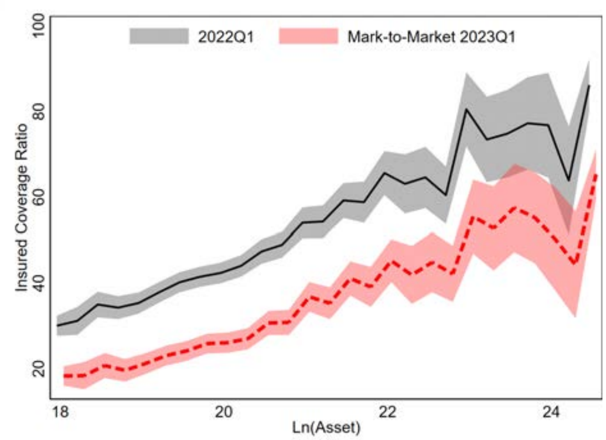
(a) Histogram



(b) Insured Deposit Coverage by Size



(c) Histogram



(d) Insured Deposit Coverage by Size

Figure 5: Largest Insolvent Banks if All Uninsured Depositors Run

This figure plots the 10 largest "insolvent" banks. A bank is considered insolvent if the mark-to-market value of its assets – after paying all uninsured depositors -- is insufficient to repay all insured deposits. On the y-axis we plot mark-to-market losses as a percentage of initial bank asset value. On the x-axis we plot uninsured deposits as a percentage of mark-to-market bank's asset value. Out of the 10 largest insolvent banks, 1 has assets above $1 Trillion, 3 have assets above $200 Billion (but less than $1 Trillion), 3 have assets above $100 Billion (but less than $200 Billion) and the remaining 3 have assets greater than $50 Billion (but less than $100 Billion). We also show Silicon Valley Bank (assets of $218 Billion in the plot). The assets are based on bank call reports as of 2022:Q1. Banks in the top right corner, where Silicon Valley Bank is, have the most severe asset losses and the largest runnable uninsured deposits to mark-to-market assets. The bubble size indicates the size of bank asset in 2022:Q1. *Data Sources*: Bank Call reports and various ETF and indices price data as described in the main text.

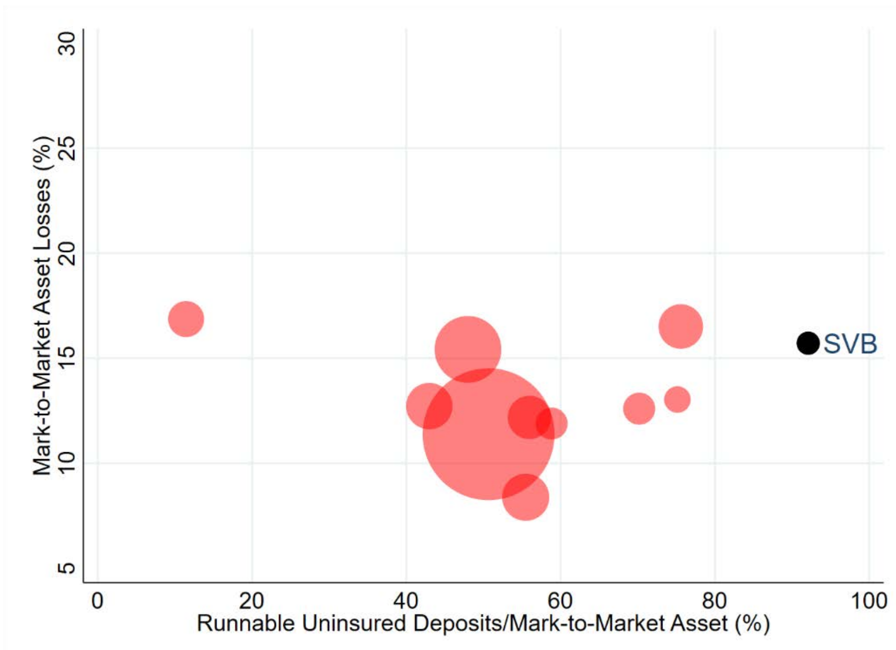
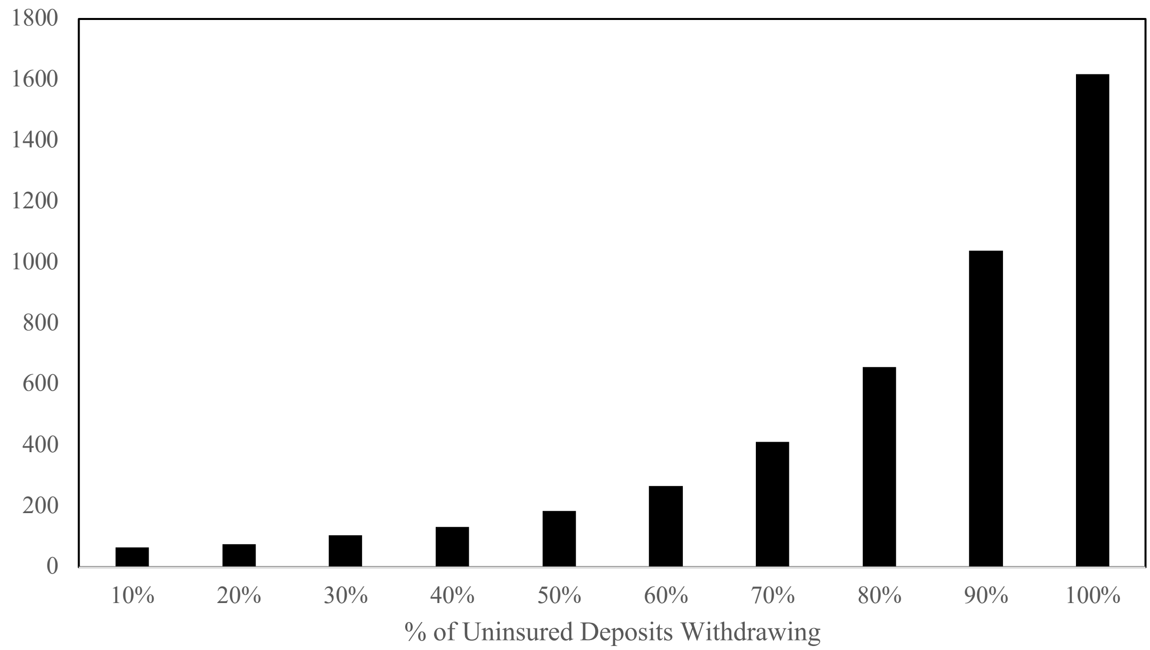
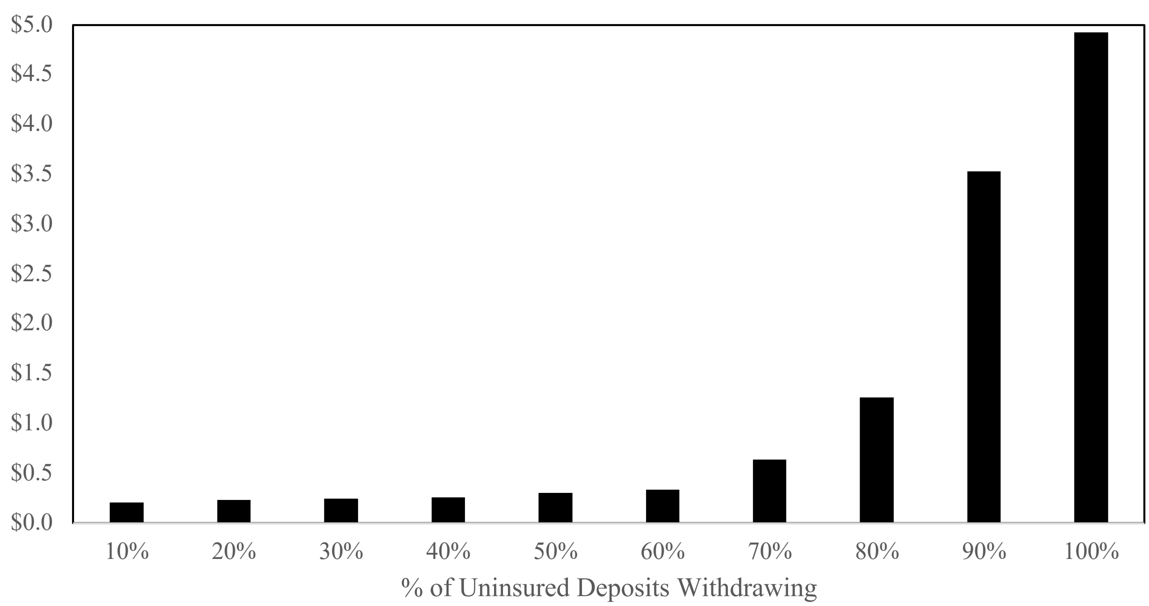


Figure 6: Insolvent Banks under Different Uninsured Deposits Runs Cases

This figure presents the number of insolvent banks (panel a) and their aggregate assets (panel b) associated with a given uninsured deposits withdrawal case. We consider ten cases ranging from 10% to 100% of uninsured deposits being withdrawn at each bank. The bank is considered insolvent if its mark-to-market value of assets – after paying a given share of the uninsured depositors -- is insufficient to repay all insured deposits. *Sources*: Bank Call reports and various ETF and indices price data as described in the main text.



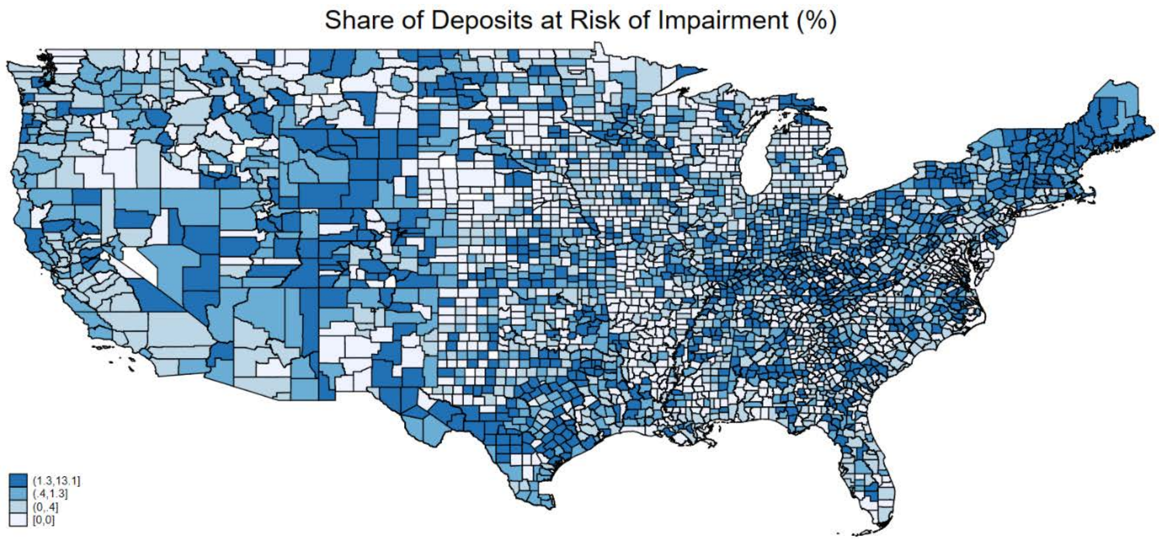
(a) Number of Insolvent Banks



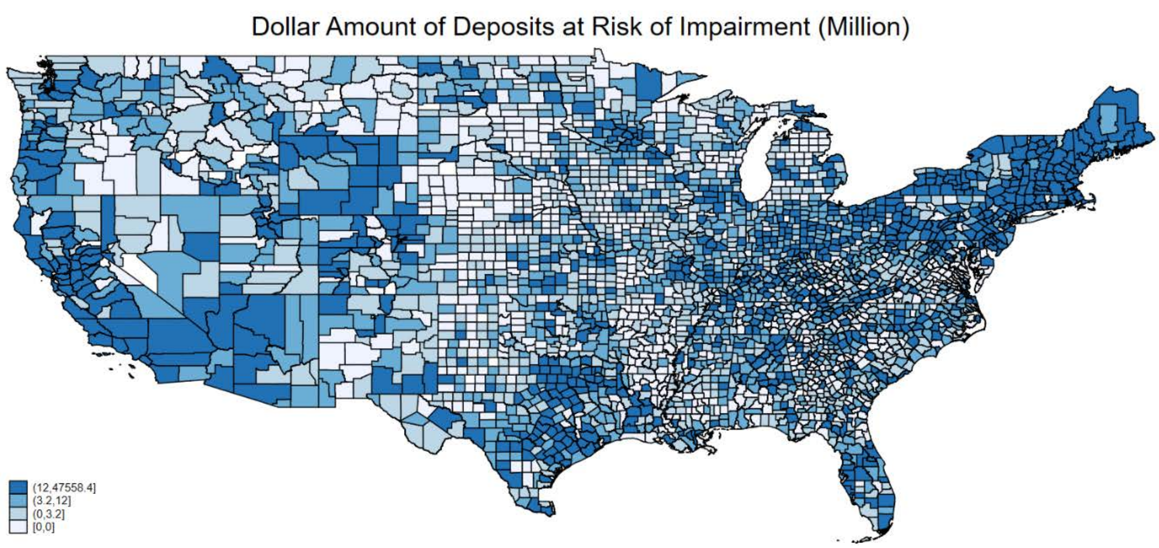
(b) Aggregate Assets of Insolvent Banks (in $ Trillions)

Figure 7: Regional Exposure to Bank Risk

This figure plots the regional exposure to bank risk, measured by the aggregate deposits in 2022 that are at the risk of impairment in each county. To find the deposit at the risk of impairment, we obtain bank branch network information from the FDIC Summary of Deposit in 2022 and assign banks' deposit impairment ratio, defined in the main text, to each county where it has branches. The detailed steps are introduced in the main text. Panel (a) plots the share of deposits at risk of impairment. Panel (b) plots total dollar amount of deposits at risk of impairment. In both panels, counties are divided into four groups based on their at-risk deposits. The darkest blue indicates the top quartile in terms of at-risk deposits. *Data sources*: bank call reports and the FDIC Summary of Deposits.



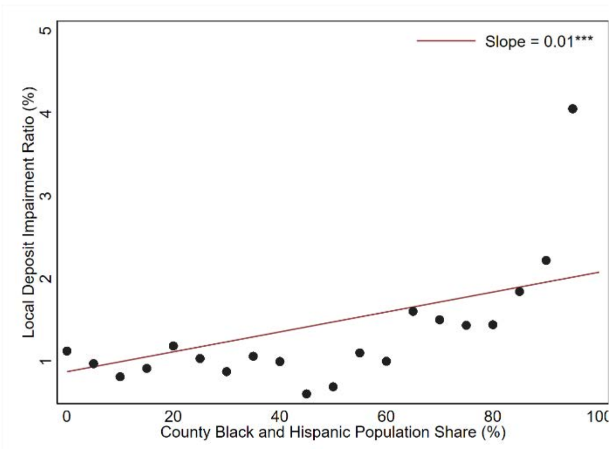
(a) Share



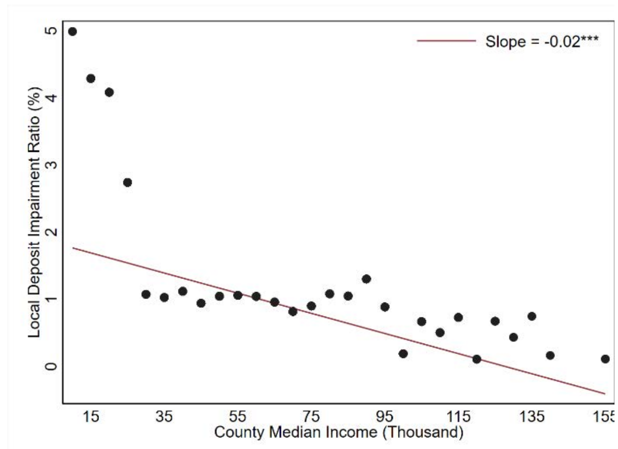
(b) Dollar Amount

Figure 8: Local Bank Exposure Risk Exposure and Local Demographics

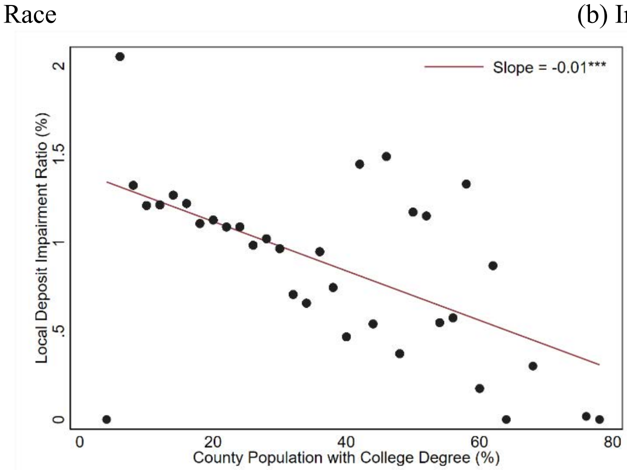
This figure plots the county-level share of impaired deposits against local demographics. In all panels, the y-axis is the share of deposits at the risk of impairment. We divide all counties into various numbers of bins based on its Black and Hispanic population share in Panel (a), median income in Panel (b), and the share of county population that received a college degree in Panel (c). We then plot the average y-value in each bin against the x-value. In Panel (a), each bin covers an incremental value of 2 percentage-points in the Black and Hispanic population share. In other words, the difference between the largest and the smallest Black and Hispanic population share in each bin is 2%. In Panel (b), each bin covers an incremental value of $20,000. In panel (c), each bin covers an incremental value of 2 percentage points. The lines in each panel are the best fit lines based on weighted least squares. The slope and statistical significance is reported in each panel (with ***, ** and * implying significance at 1%, 5% and 10% levels respectively). *Data sources*: bank call reports, the FDIC Summary of Deposit, American Community Survey.



(a) Race



(b) Income



(c) Education

APPENDIX

Table A1: Bank Balance Sheets

This table reports the bank asset composition (Panel A) and liability and equity composition (Panel B) as of 2022:Q1. In all panels, column (1) reports the aggregate statistics. Column (2) reports the average statistics at the bank level in the full sample of banks. Column (3) reports the bank-level statistics in the subsample of small banks, where small banks are defined as having the total asset size below $1.384 billion (the Community Reinvestment Act asset size thresholds for large banks). Column (4) reports the statistics in the subsample of large, non-systematically important banks, where large banks are defined as having the asset size above $1.384 billion. Column (5) reports the statistics of the subsample of systemically important banks (GSIB banks). GSIB banks are classified according to bank regulators' definition as of 2022:Q1. We also assign GSIB status to US chartered banks affiliated with holding companies that are classified as GSIB. All numbers in columns (2)-(5) are based on sample average, after winsorizing at 5th and 95th percentiles. Numbers in parentheses are standard deviations. *Data Sources: Bank Call Reports.*

Panel A: Bank Asset Composition – 2022Q1

	(1) Aggregate	(2) Full Sample	(3) Small (0,1.384B)	(4) Large (non GSIB) [1.384B,)	(5) GSIB
Total Asset $	24T	5.0B	0.3B	19.7B	273.1B
		(74.7B)	(0.3B)	(137.1B)	(618.3B)
Number of Banks	4844	4844	4072	743	29
(Percentage of Asset)					
Cash	14.1	13.1	13.6	10.0	24.3
		(9.8)	(10.0)	(7.9)	(12.4)
Security	25.2	23.9	24.4	21.5	18.1
		(15.7)	(16.1)	(13.0)	(18.1)
Treasury	6.1	2.6	2.7	2.1	4.7
		(4.1)	(4.2)	(3.3)	(5.5)
RMBS	12.1	3.1	2.5	6.6	5.5
		(4.6)	(4.1)	(5.6)	(7.1)
CMBS	2.3	0.9	0.7	1.6	0.8
		(1.6)	(1.5)	(1.9)	(1.5)
ABS	2.7	0.8	0.7	1.3	1.1
		(1.6)	(1.5)	(1.8)	(2.0)
Other Security	2.1	14.9	16.2	7.8	3.0
		(12.7)	(13.0)	(8.3)	(7.8)
Total Loan	46.6	55.7	54.7	61.9	39.5
		(15.6)	(15.6)	(13.9)	(16.3)
Real Estate Loan	21.9	41.9	41.4	45.2	19.4
		(16.7)	(16.6)	(16.5)	(14.8)
Residential Mortgage	10.6	15.5	15.9	13.9	10.3
		(11.7)	(11.8)	(10.7)	(14.0)
Commercial Mortgage	2.2	2.1	1.8	3.6	0.9
		(2.5)	(2.4)	(2.9)	(1.8)
Other Real Estate Loan	9.1	23.0	22.6	25.7	4.4
		(11.9)	(11.8)	(11.9)	(4.9)
Agricultural Loan	0.3	2.6	2.9	0.7	0.1
		(4.1)	(4.4)	(1.8)	(0.4)
Commercial & Industrial Loan	9	6.9	6.6	9.1	4.2
		(5.2)	(5.0)	(6.0)	(5.6)
Consumer Loan	7.7	2.2	2.2	2.3	2.8
		(2.5)	(2.3)	(3.1)	(3.8)
Loan to Non-Depository	2.8	0.1	0.0	0.2	0.3
		(0.2)	(0.1)	(0.3)	(0.4)
Fed Funds Sold	0.1	1.4	1.6	0.2	0.0
		(3.1)	(3.3)	(1.0)	(0.1)
Reverse Repo	1.2	0.0	0.0	0.0	0.0
		(0.0)	(0.0)	(0.0)	(0.0)

Panel B: Bank Liability Composition – 2022Q1

	(1) Aggregate	(2) Full Sample	(2) Small (0, 1.384B)	(3) Large (non GSIB) [1.384B,)	(4) GSIB
Total Liability	90.5	89.8	89.8	89.9	86.9
		(3.2)	(3.3)	(2.7)	(4.9)
Domestic Deposit	76.6	86.8	87.1	85.7	79.9
		(5.3)	(5.2)	(5.1)	(7.7)
Insured Deposit	41.1	62.7	64.6	53.0	44.9
		(12.3)	(11.4)	(11.9)	(16.8)
Uninsured Deposit	37.4	23.3	21.7	32.0	24.4
		(11.3)	(10.4)	(11.4)	(18.5)
Uninsured Time Deposits	1.8	3.6	3.8	3.0	0.8
		(3.0)	(3.0)	(2.7)	(1.6)
Uninsured Long-Term Time Deposits	0.4	0.8	0.9	0.6	0.1
		(1.0)	(1.0)	(0.7)	(0.3)
Uninsured Short-Term Time Deposits	1.3	2.6	2.7	2.3	0.7
		(2.4)	(2.4)	(2.1)	(1.5)
Foreign Deposit	6.5	0.0	0.0	0.0	0.0
		(0.0)	(0.0)	(0.0)	(0.0)
Fed Fund Purchase	0.1	0.0	0.0	0.0	0.0
		(0.0)	(0.0)	(0.0)	(0.0)
Repo	0.6	0.3	0.2	0.5	0.3
		(0.7)	(0.7)	(0.9)	(0.6)
Other Liability	2.3	2.3	2.1	3.0	4.3
		(2.8)	(2.7)	(2.8)	(3.4)
Total Equity	9.5	10.2	10.2	10.1	13.1
		(3.2)	(3.3)	(2.7)	(4.9)
Common Stock	0.2	0.4	0.4	0.2	0.9
		(0.6)	(0.6)	(0.5)	(1.1)
Preferred Stock	0.1	0.0	0.0	0.0	0.0
		(0.0)	(0.0)	(0.0)	(0.0)
Retained Earning	4	6.8	7.0	5.7	7.6
		(4.0)	(4.1)	(3.2)	(5.4)

Figure A1: Aggregate Asset and Liabilities of US Banks

This figure plots the composition of aggregate total assets and liabilities of US banks as of 2022:Q1 in trillions of dollars (see also Table A1). On the asset side bank had about $24 trillion of assets as of 2022:Q1. Of these *Cash* constitutes about 14% of the aggregate bank assets. *Security* that includes bank investments in US Treasuries, RMBS, CMBS, ABS, and other securities accounts for about 25% of the aggregate bank assets. *Real Estate Loan* are the residential and commercial loans and other real estate loans that account for about 22% of the aggregate bank assets. *Other Loan* are commercial and industrial loans, consumer loans, loans to non-depository institutions, and agricultural loans that account for about 20% of aggregate bank assets. *Other Assets* account for the reminder of bank assets. On the liability side, *Insured Deposits* account for about 41% of total bank funding. *Uninsured Deposits* account for about 37% of total bunk funding and amount to about $9 trillion. *Other* includes other loans and liabilities. *Equity* accounts for about 9.5% of total bank liabilities. *Data Sources*: Bank Call reports.

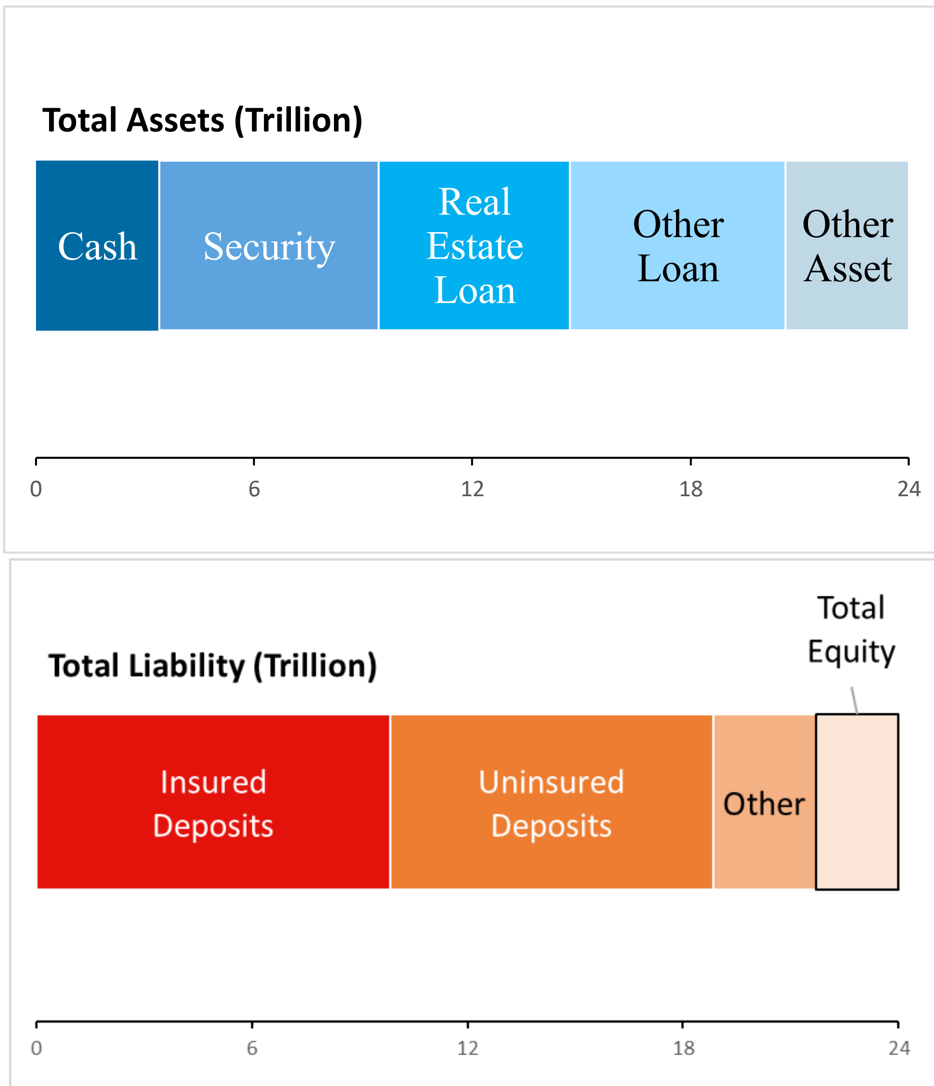


Figure A2: Full Set of Insolvent Banks if All Uninsured Depositors Run

This figure plots the full set of "insolvent" banks. A bank is considered insolvent if the mark-to-market value of its assets – after paying all uninsured depositors -- is insufficient to repay all insured deposits. On the y-axis we plot mark-to-market losses as a percentage of initial bank asset value. On the x-axis we plot uninsured deposits as a percentage of mark-to-market bank's asset value. The assets are based on bank call reports as of 2022:Q1, and banks with larger asset size are marked with bigger dots. Banks in the top right corner, where Silicon Valley Bank is, have the most severe asset losses and the largest runnable uninsured deposits to mark-to-market assets. The red dots correspond to the 10 largest insolvent banks plotted in Figure 5. *Data Sources*: Bank Call reports and various ETF and indices price data as described in the main text.

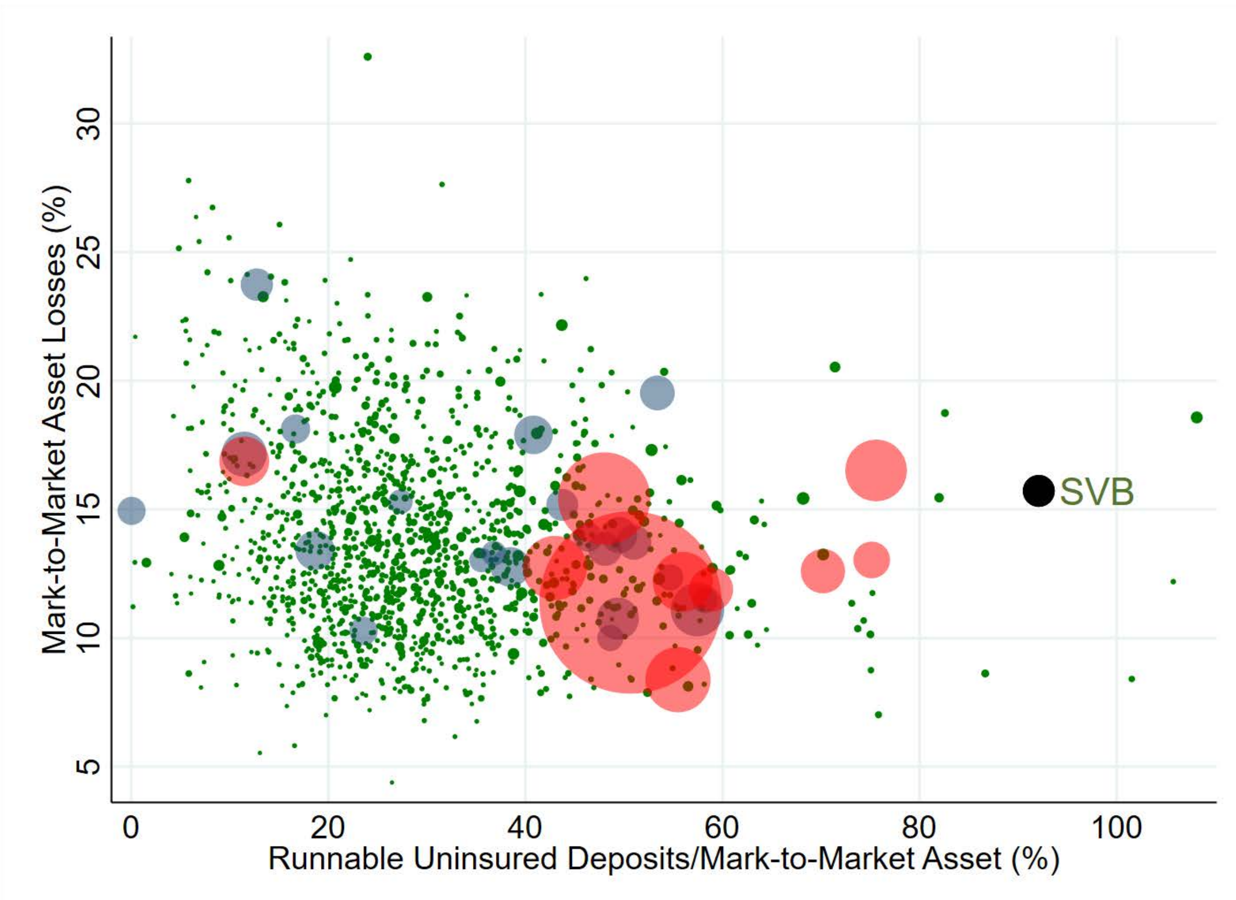
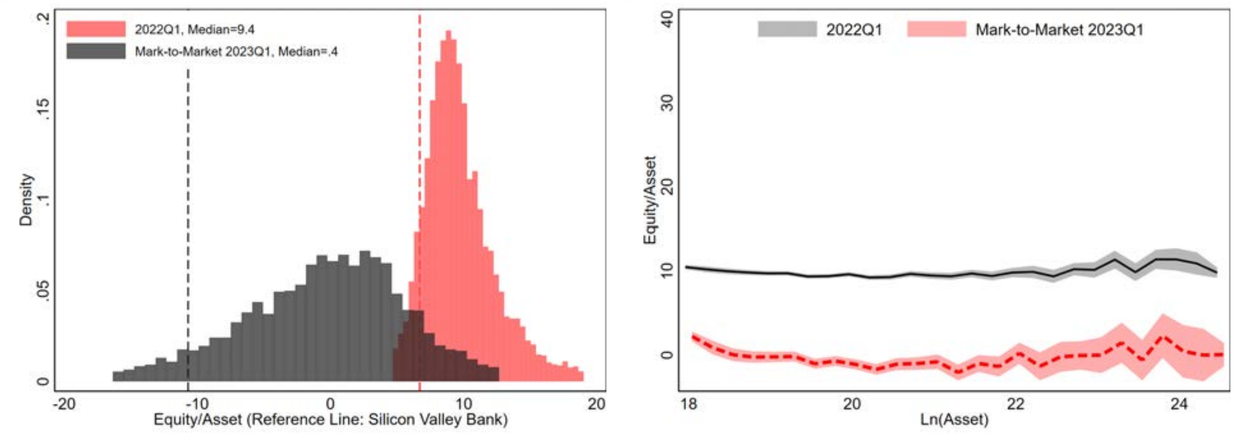


Figure A3: Distribution of Bank Equity to Asset Ratio (With & Without "Marking to Market")

This figure plots the histograms (density) of equity to asset ratios calculated based on 2022:Q1 balance sheets and mark-to-market values using various ETFs and indices according to the method described in the main text (Panel a) and equity to asset ratio against bank size (Panel b). The reference lines in Panel (a) indicate Silicon Valley Bank's (SBV) values. Silicon Valley Bank's equity to asset ratio 6.7% based on its 2022Q1 balance sheet. Its equity to mark-to-market asset ratio is -10.7%. The red and the gray lines are at the 10th and 7th percentiles, respectively. In Panel (b), the decline at the right-end starts around log asset value of 24, which is about $26B. *Data Sources*: Bank Call reports and various ETF and indices price data as described in the main text.



(a) Histogram

(b) Equity to Asset by Size