

Interest-rate risks of banks: lessons from recent crises

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For a long time, during the era of low interest rates that began well before the global financial crisis and continued after, interest-rate risk seemed to be a secondary concern for investors and financial intermediaries. Rate of return objectives, credit and funding risk, and regulatory compliance took precedence. With the dramatic rise in rates since 2021, any complacency about interest-rate risk is a thing of the past.

This chapter provides a brief overview of interest-rate risk and its management, and describes recent financial market events highlighting its importance. Episodes such as the March 2023 banking turmoil go well beyond a case study, and reveal how markets have changed in the aftermath of the crisis.¹

1 Interest-rate risk

1.1 Basics of interest-rate risk

The values of loans and debt securities vary as interest rates change. The broad sources of yield curve uncertainty are:

Expected future rates: the current risk-free curve fluctuates with expected future rates;

Liquidity risk: the cost and risk of exiting, adjusting, or maintaining an investment position;

Inflation risk: the risk of loss from a rise in the general price level; and

Credit spreads: the risk of default and credit migration losses, or of changes in the market-clearing compensation for credit risk.

¹More on the topics of this chapter can be found in Malz (2025).

Each source of volatility is compensated through a component of the risk premium of the loan or security. Risk premiums are generally positive, making bonds cheaper and increasing prospective future returns, but may be negative for the most sought-after "safe assets."

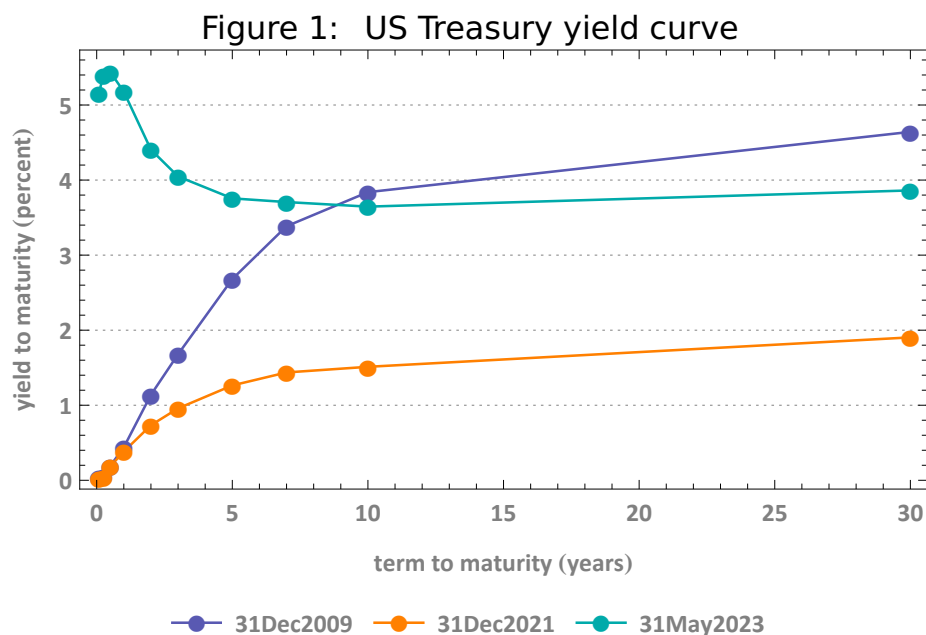
Longer-term rates along a risk-free curve can be decomposed into the short-term rates expected to prevail up to maturity, or the expected return from rolling over short-term debt, and a term premium, the additional yield compensating lenders for bearing the interest-rate risk of a longer-term security. The term premium is sometimes defined simply as the observable spread between longer- and shorter-term government bond yields, but more generally is the unobservable spread between the long-term nominal rate and the rate implied by the expected path of short-term risk-free nominal rates.

The term premium as well as expected short-term rates fluctuate; aversion to term risk may change without a material change in expected future interest rates. The term premium can be negative if investors are eager to lock in the current level of longer-term rates and avoid the possibility that short-term rates decline more than expected. Estimates of US Treasury term premiums have ranged between 5 percent at the height of the early 1980s disinflation effort, when investors were still wary of holding long-term nominal securities, and low negative levels during the global financial crisis, when investors craved safe assets.

The term structure is generally, but by no means invariably, upward sloping, with longer-term risk-free interest rates and credit spreads higher than short-term. The yield curve may be downward sloping—display yield curve inversion—overall or in some segments. Inversion at the short end of the curve, while unusual, can occur if short-term rates spike, and are not expected to persist at the higher levels. This may happen, for example, for interest rates on debt denominated in emerging-market currencies that come under devaluation pressure, or for individual obligors whose creditworthiness is suddenly called into question, or if monetary policy has tightened sharply and markets expect some reversal. In-

version can also occur at the long end of the yield curve, brought about by the expectation that shorter-term rates will eventually decline, or by high demand for safe long-term bonds, equivalent to negative risk premiums.

Examples in US Treasury markets include the 2005 "Greenspan conundrum," and the 2023 monetary tightening. During the 2005 conundrum episode, low long-term interest rates indicated that policy might not yet be tight enough, although short-term rates had already been increased substantially. In the rapid 2022–23 tightening, as seen in Figure 1, long-term rates eventually rose enough to indicate that markets expected higher short-term rates to endure, but not remain quite as high as current short-term rates. In both episodes, uncertainty about term and risk premium behavior clouded interpretation.



US on-the-run Treasury benchmark yield curve (1-month T-bill to 30-year bond), percent. *Source:* Bloomberg.

A positive liquidity premium expresses an aversion to the risk of holding less liquid, generally longer-term securities. Liquidity premiums vary across maturities for a given issuer and across issuers. Many long-term

credit-risky bonds are infrequently traded or have small issuance volume, exposing them to market liquidity risk. High liquidity premiums are therefore more likely for corporate and sovereign bonds issued outside advanced market economies. A relatively easy to observe, but narrow, set of liquidity premiums arises from the US Treasury's auction calendar for its debt securities, measured by the on-the-run/off-the-run spread.

Liquidity risk can have a disparate effect on yields: Financial stress is likely to impair general liquidity conditions and induce a flight to quality, increasing yields and widening many spreads to risk-free rates. Sovereign issues of advanced market economies may have negative liquidity risk premiums, as they are considered safe assets to which investors may flee in stressed markets. Yields on the most liquid sovereign bonds tend to decline sharply during these episodes.

Shorter-term safe assets enjoy a negative money premium, raising their prices and lowering their yields because they provide money services. Interest rates on very short-term US Treasuries, for example, are close substitutes for cash balances and bear lower yields in compensation for the money services they provide. The very short end of the Treasury yield curve is likely therefore steeper than it otherwise would be. In Figure 1, even on the sharply inverted yield curve of May 31, 2023, the 1-month bill has a slightly lower yield than the 3- and 6-month.

Nominal interest rates have declined as sharply as they have from the 1980s because both the inflation compensation component and real interest rates, adjusted for actual or expected inflation, have declined. The Fisher equation or identity relates expected inflation to nominal interest rates. It defines the real rate $\tilde{r}_t$ as the difference between the (observable) nominal interest rate (defined for convenience as the discount yield of a t -year bond) and (unobservable) expected future inflation:

$$\tilde{r}_t \equiv r_t - \mathbf{E}[\pi_t],$$

with π_t denoting inflation over the life of the bond. Although an iden-

tity, it is also taken as a statement about the long-term relationship of real and nominal rates. We can combine the Fisher and term premium decompositions to see the yield on a longer-term bond as the sum of the expected future path of inflation, the expected path of real short-term interest rates, and a set of risk premiums. The yields on inflation-protected bonds are a market-adjusted measure of real rates that may be lower than the unobservable expected real rate by a positive inflation risk premium.

Investors in bonds also take spread risk into account. It is closely related to credit risk, but is itself the market risk of credit exposures. An example of a pure credit risk event would be a deterioration of a firm's credit quality without credit spreads generally widening. If reflected in a change in rating, for example, a AA-rated company might be downgraded to A with no change in AA or A spreads generally, or in risk-free rates. The formerly AA-rated firm's spread would widen consistently with its new A rating. A pure market risk event would be a spread widening—a decline in risky bond prices—due to a shift in investor sentiment. One might, for example, see a widening spread between AA yields and risk-free rates without widespread downgrades, other credit events, or changes in credit quality.

There are also deterministic sources of fixed-income return that are realized even with no change in market interest rates. These include the cash flows of the security, and the roll-down or theta. As time passes, and the time to maturity of the investment shortens, each future cash flow has drawn closer. It is priced differently even with an unchanged yield curve. Typically, yield curves are upward sloping, so the now more-proximate cash flows will be discounted at lower spot rates, and the value of the security will rise. For example, a 3-year bond held for one year becomes a 2-year bond, with a typically lower yield and higher market value.

1.2 Interest-rate risk measurement

There are several ways to measure interest rate risk. Scenario analysis measures the impact of a specified change in the yield curve on the price P_t of a bond. The scenario result is a price change $\tilde{P}_t - P_t$. Some commonly encountered scenario analyses include:

Parallel shifts: the price change if all spot interest rates or yields to maturity rise, say, 25 basis points.

Curve steepening: longer-term risk-free rates rise, while short-term rates or credit spreads remain unchanged.

Roll-down return: the bond ages by, say, one year, while rates along the yield curve remain unchanged.

Credit spread widening: credit spreads increase, while risk-free rates remain unchanged. The change in price is the same for an equal change in the risk-free rate.

Rate sensitivity can be measured using duration and convexity, approximate measures of the impact of small changes in yield or small parallel shifts in the yield curve on the bond price P_t . They are related to the first and second derivatives of the bond value with respect to yield or the level of the spot curve and provide parameters by which scenarios on yield can be evaluated. The first derivative is the DV01, the change in price. The modified duration of the bond is the proportional or percent change in bond price as the yield or level of the yield curve rises 1 percent, and converts the DV01 to a relative change. Because of the negative relation between price and yield, the convention is to express it as a positive number.

Convexity is the change in duration as the yield changes. Most plain-vanilla coupon and discount bonds, including most nominal advanced-economy central government issues, have modest positive convexity.

Duration declines slightly as the yield rises, attenuating the price decline. A back-of-the-envelope approximation might omit the convexity term if it is known to be small. Convexity is similar to the gamma of options in that even small moves in interest rates can have a large impact on bond prices, while increases in interest rates may have a much greater or smaller effect than decreases. Negative convexity behaves like the gamma of short option positions, increasing the market risk of long fixed income exposures.

The effect on price of a Δy increase in yield can then be estimated using the linear-quadratic approximation:

$$\frac{\Delta P_t}{P_t} \approx -\text{modified duration} \times \Delta y + \frac{1}{2} \text{convexity} \times \Delta y^2,$$

with $\frac{\Delta P_t}{P_t}$ and Δy representing changes in price and yield.

Convexity has a potentially large impact on securities with cash flows that themselves depend on interest rates. Examples include mortgage-backed securities (MBS), for which interest rate changes may induce sharp variations in prepayments, and bonds with embedded options. All bonds exhibit some convexity, but MBS are unusual in their high negative convexity.²

Agency MBS constitute a large part of the US bond market. They are secured by pools of mortgage loans that are in turn secured by residential properties. Payment of the bonds' principal and interest is guaranteed by the government sponsored enterprises (GSEs), the Federal National Mortgage Association, (Fannie Mae) and the Federal Home Loan Mortgage Corporation (Freddie Mac), which are understood to enjoy an implicit US federal government solvency guarantee.

Constituent Federal Home Loan Banks (FHLBs) of another GSE, the Federal Home Loan Bank System, are owned by their member banks and in-

²See Vickery and Wright (2013) and Kish (2022) on the structure of MBS markets, and Hanson (2014) on the market impact of mortgage convexity.

insurance companies, to which the FHLBs make loans, called "advances," collateralized by residential mortgage loans, Treasuries, or agency MBS. The FHLB System was used extensively by SVB and by Silvergate and Signature Banks before their collapse, as well as by others during the March 2023 episode.³

If the underlying mortgages meet certain credit quality and maximum size criteria, they are deemed conformable by the GSEs and the federal regulatory authorities, and can be sold by the banks and other intermediaries originating them into the pools securing agency MBS. Prepayment penalties are limited or prohibited for most conventional US residential mortgages under regulations at the state and federal level that were tightened as part of the Dodd-Frank Act. The resulting prepayment option allows homeowners to refinance their mortgages at a lower rate and with minimal transactions costs if mortgage interest rates fall. Essentially an interest-rate option written by the lender, it induces high negative convexity in agency MBS.

Most mortgages originated in the United States, and most of those securing agency MBS, are fixed-rate 30-year mortgages, a preponderance attributable primarily to the implicit federal government guarantee of agency MBS and the mandatory prepayment option. Most agency MBS trading and hedging transactions are in to-be-announced (TBA) 30-year agency MBS, a type of forward contract for delivery of an agency MBS. The class of securities—issuing agency, coupon and principal amount—supporting a TBA will have been announced, but not the exact list of its constituent pools.

The interest rate risk of MBS differs greatly from that of Treasury securities. Embedded in the underlying mortgages is the prepayment risk that pool loans will be repaid earlier than anticipated, ahead of the contractually stipulated amortization schedule. When mortgages prepay, a

³Bob Fernandez, "Banks turn to Federal Home Loan Bank funding as system faces review," *Wall Street Journal*, March 31, 2023, <https://www.wsj.com/articles/pro-take-banks-turn-to-federal-home-loan-bank-funding-as-system-faces-review-2da1ea70>.

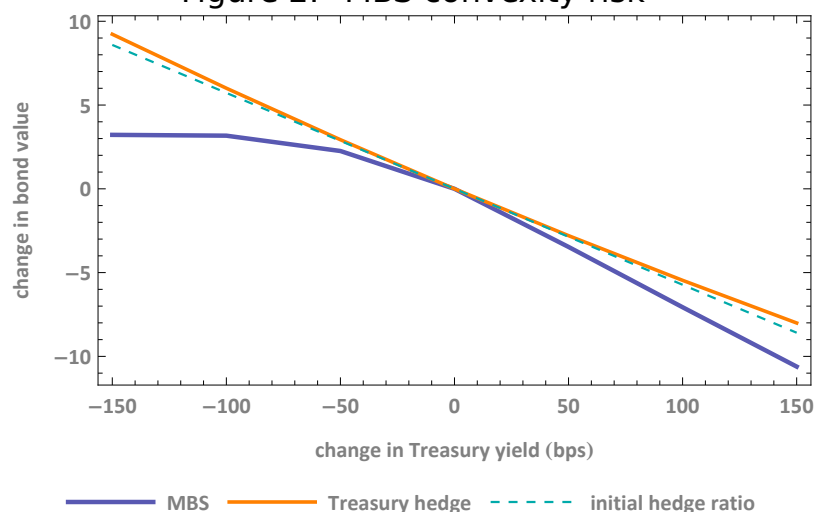
portion of the long-term agency MBS they support will also be prepaid from mortgage pools. When interest rates fall, more homeowners refinance their existing loans into new lower-rate mortgages. Cash flows to securitization investors occur earlier and can only be reinvested in bonds with lower yields, reducing the bond's value and shortening its duration. However, when rates rise, refinancing activity tends to decline and prepayments fall. Mortgage borrowers are not apt to repay their existing mortgage and borrow at a higher rate unless motivated by life circumstances such as a new job in a different region. Mortgage bond durations lengthen, extending the period of time investors receive below-market rate returns on their investment. This is known as extension risk in MBS markets.

MBS have extension-risk induced negative convexity, becoming longer-duration bonds just as interest rates are rising and bond prices are falling. A rise in yields lengthens duration. When rates fall, MBS prices rise much less than Treasury securities because of their shortening duration. When rates rise, MBS prices fall much faster than Treasury securities because of their lengthening duration.

Many market participants, particularly dealers in MBS, hedge negative convexity using short positions in US Treasuries. The appropriate hedge ratios and estimates of risk are based on duration estimates calculated using prepayment models of homeowner behavior that attempt to measure the labor market and demographic determinants of prepayment behavior and distinguish their impact from that of interest rates and the prepayment option.

If interest rates were to drop sharply, prepayments would be expected to increase and the duration of the MBS to fall. The sensitivity of the TBA MBS to further declines in rates would rapidly fall away, calling for a reduction in the short Treasury position to near zero. But if rates were to rise sharply, the MBS duration would extend, calling for an increase in the Treasury short position to stay hedged. Figure 2 illustrates these analytics and the sharp negative convexity of the MBS.

Figure 2: MBS convexity risk



For credit risky bonds, the credit spread01, or CS01, is a common metric of spread risk, analogous to the DV01. It measures the change in the price or value of a credit-risky bond for a 1 basis point change in its credit spread, as represented, say, by the z-spread—the spread to an estimated zero-coupon riskless yield curve—and stated as the change in value per \$100 or \$1,000,000 notional underlying amount or bond par value. We can compute the CS01 the same way we do the DV01: increase and decrease the z-spread by 0.5 basis points, reprice the bond for each of these shocks, and compute the difference. Analogous to the duration measure of the proportional impact of a change in yield on bond value, spread duration, defined as the ratio of the CS01 to the bond price, is the proportional impact of a spread change on the price of a credit-risky bond.

1.3 Hedging interest-rate risk

Forwards and futures are claims on the future value of a stated amount of an asset. One party agrees to pay the other an agreed price, either for the asset itself or its future monetary value, delivered in the future.

Forward and futures prices are related by arbitrage relations to spot or cash prices, money market rates, the underlying asset cash flows, and unobservable factors such as storage cost and convenience yield. If an asset had no cash flows, the cash price would be lower by the interest earned by going long in the forward market and holding a money market account. Positive cash flows reduce that difference. Stock index futures prices, for example, will be higher than the current value of the underlying index if the dividend yield is lower than the money market rate.

Interest rate swaps are contracts in which counterparties exchange fixed-rate for floating-rate interest payments at agreed rates, on an agreed notional principal amount, at set times (quarterly, semi-annually, or annually), until the maturity date. The notional principal is stipulated at initiation but is not necessarily exchanged at the start and end of a swap contract. The payments each counterparty is bound to deliver in the future has a present value, and the difference is the swap's net present value (NPV).

Multi-period swaps are structured so that one counterparty will pay fixed (the "fixed leg"), making fixed payments based on market pricing at initiation. The other will receive fixed (the "floating leg"), making floating payments based on realizations of an index, reference rate, or uncertain future event, such as default.

Like other financial benchmarks, many reference rates had been calculated by private-sector organizations, based on recent yields on different types of money-market instruments, and found wide acceptance. For the most widely used currency, the US dollar, by far the most important reference rates, before it was phased out entirely at the end of September 2024, had been the London Interbank Offered Rate (LIBOR) curve. These were based on the interbank rates at which large banks lend to one another at short term, and are generally higher than those on US Treasury bills, reflecting the presence of credit risk in the transaction. Similar curves were set for other major currencies. As discussed below (Section 4), these privately calculated reference rates are being replaced by

rates published by central banks.

The value of an interest rate swap is the NPV of its future payments, or the difference between the values of a fixed rate bond with a coupon equal to the swap fixed rate and of a floating rate bond:

$$\text{NPV of swap} = \text{PV of fixed payments} - \text{PV of floating payments.}$$

The most common is the plain-vanilla interest rate swap, initiated with an NPV of zero. It is generally done initially through a large bank or broker-dealer and governed by a standardized contract, an ISDA Master Agreement. The swap's floating rate index in the past had typically been LIBOR, but more recently, a central bank reference rate. The NPV of a swap fluctuates over its life as market interest rates fluctuate, so a swap that has been in effect for some time generally has a nonzero NPV.

The par swap rate is the market-clearing fixed rate on a newly initiated at-market plain-vanilla swap that sets its NPV to zero. The swap is at-market, with no additional credit risk or basis risk spread, at initiation, and arbitrage enforces equality of the present values of the swap's fixed and floating payments. The par swap rate is equal to the coupon rate at which a congruent fixed-rate bond, with the same credit and other risks, would price at par. Some counterparties may pay a positive or negative credit spread vis-à-vis the index or reference rate due to their lower or higher credit quality than that of the typical counterparty. Most swaps are initiated at-market, with regular payments equal to the index and no positive or negative spread.

An overnight index swap (OIS) is similar to an interest rate swap in that it is an exchange at regular intervals of interest payments on a notional principal amount, with a term to maturity between a few weeks and several years. The payments are based on a market-clearing fixed rate determined at initiation, reflecting market expectations for the average overnight reference rate over the term, and a floating overnight reference rate. One party pays to the other the difference between the pro-

ceeds of an overnight investment rolled over daily at the fixed rate, and the proceeds of investing the notional amount at the reference rate and rolling it over continuously. The floating leg is thus equal to the notional amount multiplied by a geometric average of the reference rate. The overnight money market indexes on which OIS are based are calculated in different ways in different currencies, generally averaged from overnight unsecured interbank loans, and published by central banks. For US dollar-denominated OIS, that rate is the effective federal funds rate (EFFR), and for the euro, the euro short-term rate (€STR).

OIS are less exposed to the credit and counterparty risk of commercial banks than interbank loans, because, like most other swaps, they don't involve the exchange of notional payments at initiation and are typically collateralized. The fixed rates on OIS are therefore generally lower than interbank rates with the same time to maturity. The gap tends to widen, sometimes dramatically, during periods of financial stress. Prior to the LIBOR cessation, the LIBOR-OIS, or LOIS, spread had been a useful indicator of concern about the stability of the banking system (see Section 4 below.).

Swaps have an allocative role. Most businesses have regular cash flows related to financing, such as receivables from customers and payables to suppliers, cash flows related to debt financing, capital expenditures, and returns on investments. These cash flows may be predictably and enduringly mismatched in some dimension that creates risk. For import and export businesses, the currency of inflows may not match that of outflows. Multinational firms may have a funding advantage in their home country but a large volume of business or investments abroad. Swaps are a mechanism for mitigating the problem.

A swap can be used to “transform” fixed into floating cash flows or vice versa. An interest rate swap potentially provides risk mitigation for both counterparties. The receiver of floating/payer of fixed is protected against a rise in short-term interest rates. Gains on the swap offset at least some losses due to a rise in rates. The receiver of fixed/payer of

floating is protected against a fall in long-term interest rates.

A market participant with a comparative advantage in longer-term funding markets, for example, a well-established firm that can issue bonds, can transform its cash flows via an interest rate swap so that it instead pays a floating rate based on short-term rates. It faces the risk then of collateral calls should long-term interest rates rise. Since it's harder for some borrowers to issue long-term fixed-rate bonds, they face rollover risk on short-term credit.

Financial intermediaries borrow from providers of capital and lend to employers of capital. For banks, funding costs are usually closely tied to short-term interest rates, while interest income is more closely related to the longer-term rates on commercial and real estate loans, a motivation to pay fixed in a swap. Institutional investors, such as pension funds and life insurance companies, must meet long-term fixed-rate commitments and are motivated to receive fixed.

It may not always be possible to exactly match an exposure to a derivatives contract employed to mitigate it. There can also be differences in the exact definitions of the payoffs, introducing basis risk. For example, a floating-rate bond may stipulate a particular short-term interest rate. The bond issuer uses an interest rate swap to take on a fixed-rate obligation instead, but the floating-rate index of the swap is not identical to that of the bond.

2 Bank leverage and liquidity

2.1 Leverage and liquidity risk

Both sides of the balance sheet are important in assessing risk. Market risk measures focus on asset risk, but don't reveal funding risk. High leverage induces greater vulnerability to a surprise asset price decline.

Rates and spread risk measures must be compared to equity to fully capture the effect of asset risk on firm viability.

Financial leverage is used extensively in banking, trading and investment, as well as by nonfinancial firms and takes many institutional forms. For a firm, leverage measures the funding of assets by issuance of debt relative to shareholders' equity, the firm owners' own resources. A thinner equity share increases default risk, the likelihood that the asset value falls sharply enough to deplete equity entirely.

Most nonfinancial firms fund themselves at least partly through debt. Even small firms routinely have some short-term debt to suppliers and other business outstanding. Financial firms typically employ more leverage than nonfinancial firms as an essential aspect of how they carry out intermediation, and as part of a larger system for distributing leverage and liquidity risks through the financial system. Banks and many other financial intermediaries are very exposed to interest-rate and credit risk because they couple the asset risks of loans and securities with extensive leverage.

Certain types of trades, with relatively low risk over long periods of time, but also relatively low returns, are reliant on leverage. They are profitable enough to attract investors only if they employ extensive leverage, raising the return on the trade to the hurdle rate investors seek. Basis trades and similar near-arbitrage trades, which identify small pricing discrepancies between similar assets and are positioned to profit as prices converge, are among those reliant on high leverage for profitability. Carry trades rely on cash flows from an asset that exceed the cost of funding and on no significant change in prices occurring. They are a staple of many hedge fund portfolios.

The term "liquidity" has several closely related meanings. Funding, or balance-sheet, liquidity describes the ability to maintain debt-financed asset positions and meet immediate cash obligations. A market participant is liquid in this sense. Market, or transactions, or liquidity describes

a market participant's ability to buy or sell an asset without influencing prices adversely, pushing them up if buying or down if selling. A market or a financial instrument is liquid in this sense.

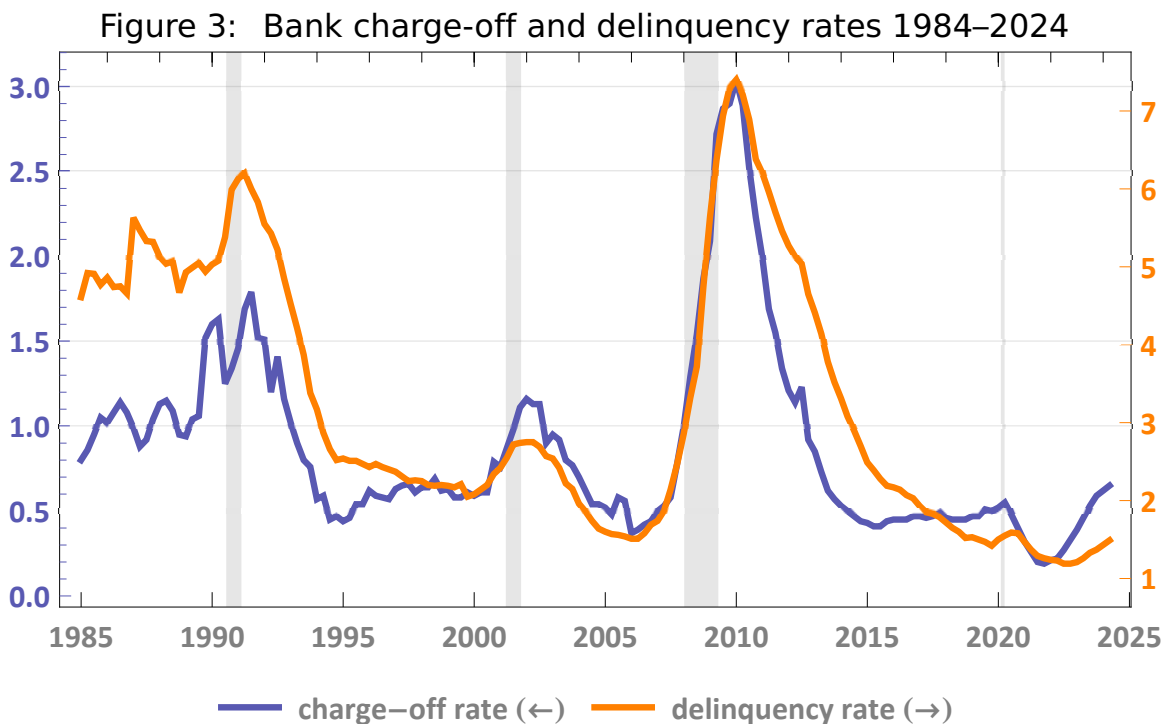
Liquidity is also used to describe a stock of assets available to carry out exchanges. The different meanings of liquidity are linked by different ways to use an asset to raise funds. An asset can function as money directly, as a means of payment, or indirectly, because it can be readily sold to obtain money or used as collateral to borrow money. Funding liquidity reflects the ability to borrow against an asset, while market liquidity is defined by the ease with which an asset can be exchanged for money.

Funding and market liquidity are rooted in two transformations that lead to the creation of assets that resemble or can be used as money, primarily by banks. Banks issue loans by creating a deposit liability and crediting it to the borrower. To make use of the funds, the borrower can withdraw cash, write checks, or transfer the deposit. Banks effect a maturity, or duration transformation of a longer- into a shorter-term asset by borrowing short-term deposits and lending long-term. Banks also carry out a liquidity transformation by creating deposits that are transferable and for the most part redeemable on demand. Both transformations are effected by banks "using balance sheet" as if it were a manufacturing process.

Short-term borrowers and lenders both gain. Depositors have a short-term asset, earning reduced or no interest, that can be more readily used as or converted to cash. Banks pay a lower interest rate than earned on their longer-term interest earning assets. In this way, maturity transformation is linked to liquidity transformation, making an asset more readily exchangeable for goods or other assets. Banks also effect the settlement and clearing of payments by offsetting debts, repaying one debt with others. Banks thereby transfer liquidity among market participants and enhance liquidity overall.

2.2 Bank risk management

Banks are primarily exposed to credit, liquidity, and interest rate risk. Nonperforming loans (NPLs) are bank loans on which borrowers are delinquent, failing to pay interest or principal due. When banks recognize losses on the loans, they are charged off, or recognized in banks' accounting statements. Figure 3 plots US banks charge-off and delinquency rates over the past few decades.



All commercial banks, all loans. Percent of aggregate loan balances, seasonally adjusted at annual rate, Q4 1984 to Q1 2024. Charge-offs are the value of loans removed from the books and charged against loss reserves, net of recoveries. Delinquent loans are those past due 30 days or more and still accruing interest as well as those in nonaccrual status. Vertical shading represents NBER recession dates. *Source:* Federal Reserve Board.

Universal banks that combine commercial banking with investment activities, and commercial banks increasingly in recent decades, are exposed to interest rate and other market risks. A commercial bank's primary source of earnings is net interest margin (NIM), the difference

between interest earned and interest paid:

$$\text{NIM} = \frac{\text{net interest income}}{\text{interest earning assets}} = \frac{\text{interest income} - \text{interest expense}}{\text{interest earning assets}}.$$

Net interest margin is generally substantially positive, since banks fund a large part of their assets with deposits. The yield curve tends to be particularly steeply upward sloping at the very short end because the shortest-term deposits provide money services and thus bear a negative risk premium; the interest rate on sight deposits is often zero.

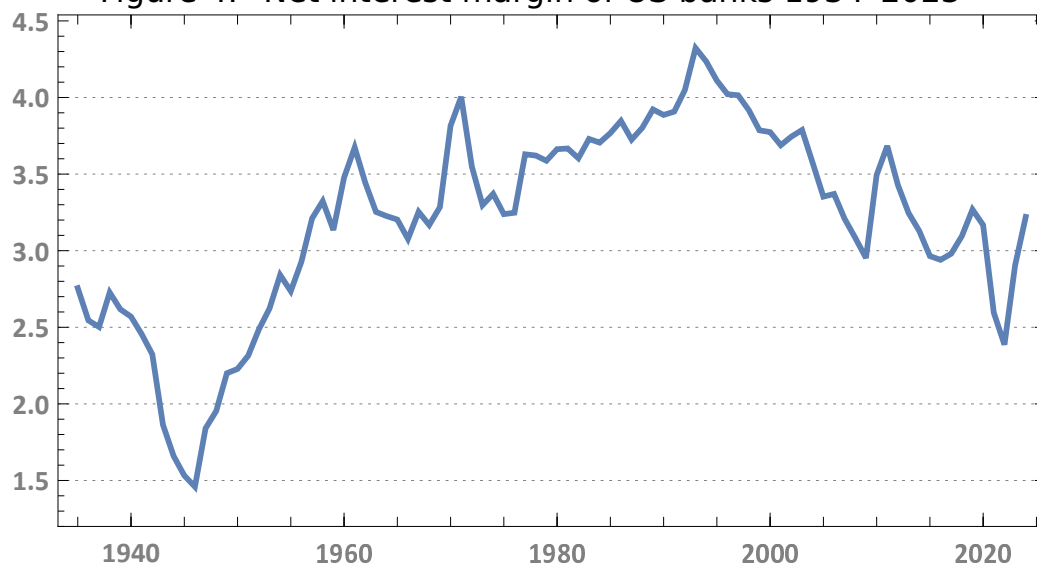
But Figure 4 shows how widely this source of banks' net income has fluctuated over the past century for US banks as interest rates change. NIM was at its lowest when Treasury and Federal Reserve policy deliberately aimed at keeping rates low and the yield curve flat, during the Second World War and its aftermath to facilitate war financing and during the global financial crisis in an effort to lower the hurdle rates to investment and keep asset prices buoyant.

High market interest rates generally lead to higher NIM and benefit banks, but the transition, periods of rising rates, can be difficult. For example, during the "conundrum" period of rising short-term rates from 2004 to 2007, long-term rates were unusually sluggish in moving higher, resulting in a very flat yield curve and lower NIM. A more complex set of difficulties for banks marked the rising rate environment from mid-2022.

Larger banks enjoy implicit and explicit government guarantees, and can offer lower deposit rates in exchange for the additional safety, a competitive advantage over smaller ones. But since they also fund through higher-cost means such as bond issuance, their overall cost of funding may be higher. Large depositors may be concentrated geographically or by sector, increasing a bank's funding liquidity risk. NIM is generally higher for smaller banks with a stable deposit base that can rely on a lower-cost funding source compared to larger banks.

Liquidity risk sharing has historically been a primary function of banks.

Figure 4: Net interest margin of US banks 1934–2023



Ratio of net interest income (NIM) to total interest earning assets (INTBAST), all FDIC-insured commercial banks, annual, percent. *Source:* Federal Deposit Insurance Corporation (FDIC), Historical Statistics on Banking (<https://banks.data.fdic.gov/bankfind-suite/historical>).

Banks are a vehicle for depositors to coinsure against liquidity risk by pooling with others. Banks mostly lend to finance projects or assets requiring a long time to pay off. Early liquidation is often possible only at a loss. Apart from the usefulness of deposits as a means of payments, a primary motivation for household depositors to hold liquid but lower-yielding assets is to insure the value of stored wealth if consumption is desired earlier than planned. Similarly, corporate treasuries keep liquid assets to insure against contingencies. All accept lower interest rates because deposits also provide money services. Interbank money markets provide similar coinsurance to banks themselves.

The bank can offer a better return to short-term depositors than the early liquidation value of projects, and provide money services to depositors in exchange for low-interest financing of their assets. Pooling of deposits smooths out random fluctuations in withdrawals and makes them more predictable for banks. Banks estimate the size and likelihood of a low-probability, but plausible, cluster of simultaneous withdrawals. Banks

hold reserves, a buffer stock of liquid assets, to meet unexpected cash withdrawals by depositors.

To smooth out fluctuations in their own cash balances, commercial banks can borrow and lend reserve balances held at central banks in the short-term interbank lending market. These reserve balances are a liability of the central bank, and banks may regard them as part of their liquidity reserves, as a yield-bearing asset, or as satisfying a regulatory requirement. The role of reserve balances on banks' balance sheets depends on the level and shape of the yield curve, central banks' approach to monetary policy, and the overall configuration of bank regulation.

In a fractional-reserve banking system, banks cannot meet simultaneous withdrawals by all or even a large number of depositors. Liquidity transformation is viable if the bank can accurately predict the distribution of the timing of withdrawals and holds sufficient reserves, but can nonetheless offer a better return to short-term depositors than the projects' early liquidation value. The trade-off of the risk of an underestimate against the opportunity cost of holding low-yield reserves instead of higher-yielding but less liquid loans or securities is at the heart of the phenomenon of bank runs.

Like other intermediaries, banks are agents of their principals: Shareholders, depositors, and other lenders seek reliable mechanisms to monitor bank management. Several characteristics of banks make this more complicated. Banks are generally more leveraged than nonfinancial firms, with much of its senior funding provided by small, dispersed deposits. Banks are opaque and their corporate structure often complex. It can be difficult for outsiders, or even insiders, to understand their risks. Higher leverage shifts risk to the banks' lenders, strengthening the need for monitoring, while the dispersion of deposits and their senior position in the banks' capital structure weakens individual depositors' incentive to monitor.

It has in contrast been argued that banks are more disciplined in their

underwriting and liquidity risk management because they are carefully watched by jittery depositors, making banks more stable rather than less. Large depositors are especially motivated to carefully monitor their banks' asset and funding risks. Banks have been important money market creditors of other banks and in monitoring other banks' soundness.

The argument that banks' leverage enhances their stability by providing incentives to closer scrutiny is controversial. It is at odds with the argument that bank opacity facilitates the use of deposits as money by limiting the flow of potentially adverse information. The prevalence of deposit insurance, a government guarantee of deposits against losses, and expectations that all depositors will be made whole in the event of bank failures weaken protected depositors' incentives to monitor banks.⁴

Insolvency and illiquidity are conjoined causes of bank failure, but difficult to distinguish in practice. The risk of insolvency arises if firms fund assets primarily through debt liabilities relative to equity. The risk of funding illiquidity arises if firms maintain inadequate reserves of liquid assets given the maturities of their debt liabilities and other cash obligations. If problems such as unanticipated loan credit problems or a decline in the value of banks' securities holdings arise, depositors may flee highly leveraged banks, fearing insolvency. It may not then be possible to sell assets quickly except at a loss. But banks with high capital funding don't typically experience liquidity problems apart from extreme market stress episodes.

Loan-to-deposit ratios are a measure of liquidity risk for banks. A low ratio indicates a bank is reliant on a stable funding source or has liquid assets it could sell to meet withdrawals. Loan-to-deposit ratios should be interpreted cautiously as a risk metric, as they tend to be different for different types of banks. They are generally higher for smaller banks more reliant on deposits and with limited access to public debt markets

⁴Calomiris and Kahn (1991) and Admati and Hellwig (2024) provide contrasting views on whether deposit funding enhances bank monitoring. Bank opacity is discussed in Gorton (2014).

for funding.

2.3 Interest rates, runs, and crises

Financial crises often either lead to or are triggered by concerns about intermediaries' liquidity as well as solvency. A run or panic is a sudden withdrawal by lenders of short-term credit to intermediaries, coupled with a sudden increase in liquidity preference, the demand for liquidity related to risk aversion and uncertainty. Originally coined to refer to banks, the term is applied also to demands for the immediate return of other forms of short-term lending, such as repo and money market funds.

Deposits have contractual characteristics that motivate bank runs, simultaneous attempts at withdrawals by many depositors out of fear a bank's liquidity reserves will be depleted. Par redemption is the right to redeem deposits on demand in cash, in full, at par and without delay when the demand is presented. The sequential service constraint, or "first-come first-served," obliges banks to satisfy depositors seeking withdrawals in the order in which they present their demands until and unless reserves are depleted. A failure to pay triggers insolvency, so depositors not redeeming ahead of others are either compensated out of deposit insurance funds or become unsecured claimants on a bankrupt firm, though senior to other unsecured creditors.

Runs occur when there is extensive maturity and liquidity transformation and a lack of asset and funding diversification on the balance sheet of the intermediary, vulnerabilities to which the commercial banking model is highly susceptible. In simplified models, there are multiple equilibria: all can run or all can stay. Fractional-reserve banks are fragile: demand deposits only work in the "good," no-run equilibrium.

Fire sales and margin spirals lie at the intersection of market and funding liquidity. In a fire sale, a seller is obliged to sell assets at a "wrong"

low price, measured by how quickly and how far the price has dropped below estimates of fair value. Fire sales are typically triggered by the inability of market participants to roll over the short-term debt funding their portfolios, or by collateral calls that cannot be met immediately using liquid assets, forcing an unwinding of positions. Some market participants may sell higher credit-quality securities and at least initially avoid selling those more susceptible to suspicion of adverse selection. If some intermediaries still need to raise cash as stocks of more liquid securities are exhausted, less liquid securities are offered, accelerating the effect on prices.

The need by dealers, many of them subsidiaries of banks, to hedge agency MBS portfolio has a large impact on fixed-income markets. Dealers and other market participants with hedged positions are obliged to increase their hedge ratios by increasing their short positions in Treasuries. With the large volume of agency MBS outstanding, the convexity in these and other widely held securities and derivatives positions can greatly amplify shocks originating elsewhere, and have episodically affected US rates markets. In these convexity events, a type of fire sale, an increase in interest rates forces some market participants out of rate-sensitive positions because they encounter loss or other trading limits, or because they are unable to continue financing positions. While the impact of rising rates on dealer behavior can't be observed directly, convexity events can be identified through the behavior of the repo rates at which dealers finance their inventories, futures market activity, and market participants' anecdotes.

The liquidation of these positions drives interest rates higher and accelerates the selling pressure, just as option dealers exposed to gamma risk might be forced to sell into a falling market. The rapid rise in interest rates can have a large impact on the economy as a whole. The volatility in rates is ultimately driven by the indirect subsidies of the US residential mortgage market. The regulatory requirement to incorporate a prepayment option increases the demand for 30-year mortgages, while

the implied guarantee of the agencies' solvency permits them in turn to guarantee the mortgages and securitize them on a large scale, expanding the market for their risks beyond banks and other mortgage lenders. In this originate-to-distribute model, banks can originate 30-year mortgages without having to bear the interest and prepayment risk.

In early 1994, the Federal Reserve aggressively increased short-term interest rates. While the tightening was not a surprise—the yield curve had been steepening for some time—the rapid pace was. Long-term rates rose sharply, inducing large losses and considerable turmoil in markets, though falling short of a full-fledged crisis. The first money market fund ever to "break the buck," the Community Bankers US Government Fund, had a quarter of its NAV invested in adjustable-rate derivative securities, which had severe losses. Another large casualty of the convexity event was Orange County's investment fund.

The increase in US rates affected long-term rates in other countries, with sharp selloffs in the large government bond markets of the United Kingdom and Germany. The increase in rates also triggered a currency crisis in Mexico (the so-called "tequila crisis").

3 Bank regulation and interest rate risk

Banks are regulated at the local and national levels, and in the case of the European Union, at the supranational level. Large banks are subject to more complex regulation than smaller ones. Bank regulation in advanced economies, particularly of large banks, adheres substantially to international standards. The largest banks, 29 of them worldwide as of 2023, are thought to pose systemic risk either through their activities while solvent or their potential failure and are identified as Global Systemically Important Banks (GSIBs).

US banks are classified into four categories, broadly distinguished by their size as measured by total assets. Banks particularly reliant on

short-term wholesale funding may be assigned to a higher category than based on size alone. Eight G-SIBs domiciled in the United States are Category I firms. They and the Category II firms are obliged to apply advanced approaches in calculating their risk-based capital requirements. Categories III and IV encompass mid-size and smaller firms.

3.1 Bank accounting standards and treatment of losses

The international and US capital standards rely to a large extent on bank accounting, loss and valuation concepts, different in many respects from those of nonfinancial firms. Accounting, regulatory and tax rules influence the timing of loss recognition and impact lenders' reported income statements and balance sheets. Regulators treat similar positions differently because of their different accounting treatment and motivation. The differences for banks are determined in the United States in part by decisions on Generally Accepted Accounting Principles (GAAP) by FASB and similar semi-private organizations in other jurisdictions and internationally.

Accounting standards and US regulation require banks to estimate a loss reserve, the amount of loans not expected to be collected due to borrower defaults and insolvencies, and report it in an allowance for credit losses (ACL) account, a contra asset account on its balance sheet. As loan losses are recognized, they are absorbed by the loss reserve rather than hitting net income; loan assets and the loss reserve are reduced by a charge-off or write down. The income statement is unaffected unless losses differ from the initial estimate. If losses are expected to be greater than initially estimated, loss provisioning by a bank increases the loss reserve. If loans mature without loss, net income will be higher as the reserve is released.

Regulators in 2016 introduced the current expected credit losses (CECL) methodology, based on the bank's forward-looking estimate of loan losses

over the entire life of a debt as determined at the time a loan is extended. It is intended to ensure timely recognition of losses, deter manipulation to smooth earnings and gain tax advantages, and avoid the procyclicality caused by banks increasing provisioning during bad times.

The accounting treatment of banks' securities holdings has also been a focus of regulation. Securities held by banks fall into one of three accounting categories:

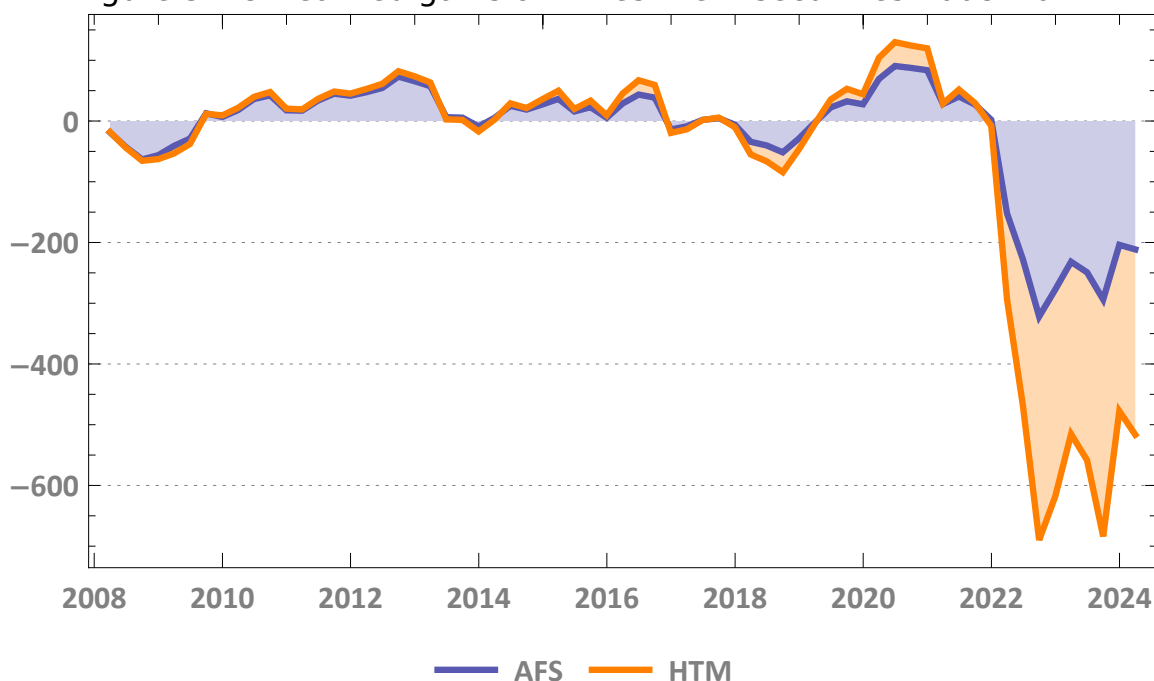
Trading securities are held principally for the purpose of selling in the near term, including market-making inventories, and reported at fair value.

Available for sale (AFS) debt securities are held with the intent of selling if the need arises, for example, for liquidity, or opportunistically, and also reported at fair value.

Held to maturity (HTM) debt securities are held as investments, and reported at amortized cost.

Banks account for unrealized or mark-to-market (MTM) gains and losses stemming from changes in the market or fair values of securities portfolios. For trading securities, MTM fluctuations flow through to reported earnings and net income. For AFS securities, they affect the capital account of the balance sheet through the accumulated other comprehensive income (AOCI) account, a component of shareholders' equity. A mark-to-market loss decreases AOCI and equity, but doesn't flow to earnings or net income until realized. Gains and losses on HTM securities are not recorded on the balance sheet, but banks make them public in report footnotes. Changes in securities' creditworthiness also affect trading, AFS and HTM securities, and are recorded as other than temporary impairment (OTTI). It is closely analogous to loss provisioning for bank loans, and reflected in earnings. For a sense of how important these fluctuations can be, Figure 5 shows the drastic increase in losses following the rapid interest-rate hikes of 2022 and 2023.

Figure 5: Unrealized gains on investment securities 2008–2024



Quarterly, Q1 2008 to Q1 2024 Source: FDIC Quarterly Banking Profile.

3.2 Regulation of banks' capital funding and liquidity

The Basel III standards set regulatory minimum capital ratios and define in detail the numerator (capital) and denominator (assets). The numerator is the quantity of capital, the aggregate volume of specific types of liabilities issued by the bank. The denominator may be either:

Risk-weighted assets (RWA), calculated using detailed weighting systems for broad sources of risk. This denominator is used to compute the risk-based capital ratio, intended to provide a risk-sensitive measure that ideally varies accurately with the riskiness of banks' assets and activities. It addresses the disjunction between the size of a bank's balance sheet and the amount of asset risk it faces. A trading book, for example, may include a large volume of low-risk assets. Basel III set more stringent minimum capital ratios to RWA,

regarding both quality and quantity.

Total or balance-sheet assets, adjusted using regulatory definitions. This denominator is used to compute the leverage-based capital ratio introduced under Basel III, and intended primarily as a backstop or control on risk-based capital, and limit manipulation of risk measures by banks.

Banks must compute both the risk- and leverage-based minimum ratios and meet the higher one. If binding, risk-based minimum capital makes lower-risk assets more attractive; if binding, the leverage ratio makes higher-risk assets relatively attractive and disincentivizes lower-risk activities such as repo and bond market intermediation. The risk-based minimum is typically binding on a bank, but banks are acutely aware of both as they manage their assets and funding.

The capital standards distinguish between a bank's banking and trading books. Largely aligned with accounting designations, it arises because the capital standards seek to identify the market risk in the banking book and the credit risk in the trading book, and fully capture both.

Banking book assets, the original focus of the Basel framework, are primarily commercial industrial and residential loans and mortgages, and the bulk of assets in most commercial banks. They are valued at par, but with provisions for default loss through the ACL account. The exposures present mostly credit risk, but also some market, especially interest-rate risk. The banking book also includes illiquid assets such as unlisted equities and real estate. Securities in the banking book are considered HTM and not marked-to-market.

The trading book consists of positions held for liquidity, market making, and proprietary trading purposes and hedges of those positions, and includes trading and available for sale (AFS) securities. They are mostly exposed to market risk, but also to credit risk.

Shareholders, debt investors and managers of financial as well as non-financial firms are averse to fluctuation in earnings, and only somewhat less averse to fluctuations in AOCI and the book value of equity. There is therefore a bias toward classifying securities as HTM rather than AFS, and a temptation to opportunistically reclassify securities as market conditions change. A reclassification might avoid reporting a loss, or accelerate the reporting of gains. An example from the aftermath of the global financial crisis is Citibank's completion in the first quarter of 2011 of a round-trip transfer of securities from trading to HTM, then back to the trading portfolio. In doing so, they avoided reporting an initial MTM loss as a reduction of net income followed by a gain when the market value of the securities recovered, smoothing reported earnings.⁵

The distinction between the banking and trading book thus creates an opportunity for regulatory arbitrage. The same asset may have different required capital funding depending on how it is assigned. The Basel Committee's Fundamental review of the trading book (FRTB), concluded 2013, tightened the so-called "boundary," to limit regulatory arbitrage of trading versus banking book assignments. Following these regulatory changes, selling any HTM securities causes the bank's entire HTM portfolio to be irrevocably reclassified as AFS and reported at fair value. Reclassification of AFS securities as HTM still permits banks to avoid marking them to market on their balance sheet and incurring AOCI losses. In 2021, as interest rates began rising sharply, Silicon Valley Bank (SVB) transferred \$9.0 billion of securities from AFS to HTM. Banks assiduously shifted bonds into their HTM portfolios in 2022 and 2023.⁶

Regulators and central banks have long been attentive to liquidity. In the United States, liquidity risk is a long-standing element of bank supervision, for example, of the FDIC's CAMELS ratings. Indirectly, central bank

⁵Tracy Alloway, "Citi's Basel-dodging, capital-avoiding, accounting switch," *Financial Times*, April 19, 2011, <https://www.ft.com/content/0440dc92-b065-39b5-b405-ba6a47867c6d>.

⁶Jonathan Weil, "As interest rates rose, banks did a balance-sheet switcheroo," *Wall Street Journal*, March 29, 2023, <https://www.wsj.com/articles/as-interest-rates-rose-banks-did-a-balance-sheet-switcheroo-8e71336f>.

reserve requirements, intended primarily to control the money supply, also serve to protect banks against losses due to sudden deposit withdrawals.

The motivation of new rules on funding liquidity is to constrain maturity mismatches, and prevent runs on wholesale funding sources, such as the 2008 “run on repo.” In 2013 and 2014, the Basel Committee put forward a set of standards for minimum liquidity ratios for banks that are being implemented in advanced market economies. The liquidity standards apply to large banks, and more stringent rules apply to the largest banks. US implementation of Basel liquidity standards took place with issuance of a final rule in 2014. The US rules will ultimately apply to any bank with assets exceeding \$50 billion, with the exception of US offices and branches of foreign banks.

The Basel liquidity standards rely on two measures, conceptualized as the results of liquidity stress tests with different time horizons. The liquidity coverage ratio (LCR) requires banks to hold high-quality liquid assets (HQLA) sufficient to cover cash outflows over a 30-day stress scenario. Its focus is on the tenuousness of short-term funding. Banks in compliance will hold liquid assets in excess of “runable” liabilities. The net stable funding ratio (NSFR) requires banks to have a volume of stable funding liabilities—equity and long-term debt—sufficient to cover an entire year of extended stress. Banks in compliance have stable funding in excess of illiquid assets.

4 Crises and the banking industry

The sequence of crises since 2007 has changed the finance industry in fundamental ways. Central bank balance sheet have grown enormously. Even the largest and most liquid financial markets, which routinely functioned smoothly in the past, have regularly become impaired. Interbank markets in central bank reserve balances have shriveled. The cost of

financing Treasury positions and their prices have in recent years occasionally fluctuated wildly. Spreads between different money market rates and basis spreads are wider and more persistent than in the past and prone to sudden widening. The end of a very long period of extremely low interest rates and subdued inflation was succeeded by a dramatic, rapid and unexpected rise in both.

These developments coincide with major changes in financial regulation. Central bank efforts to expunge privately-set reference rates have transformed interest-rate derivatives markets. Banks have had to make interacting adaptations in their interest-rate risk management.

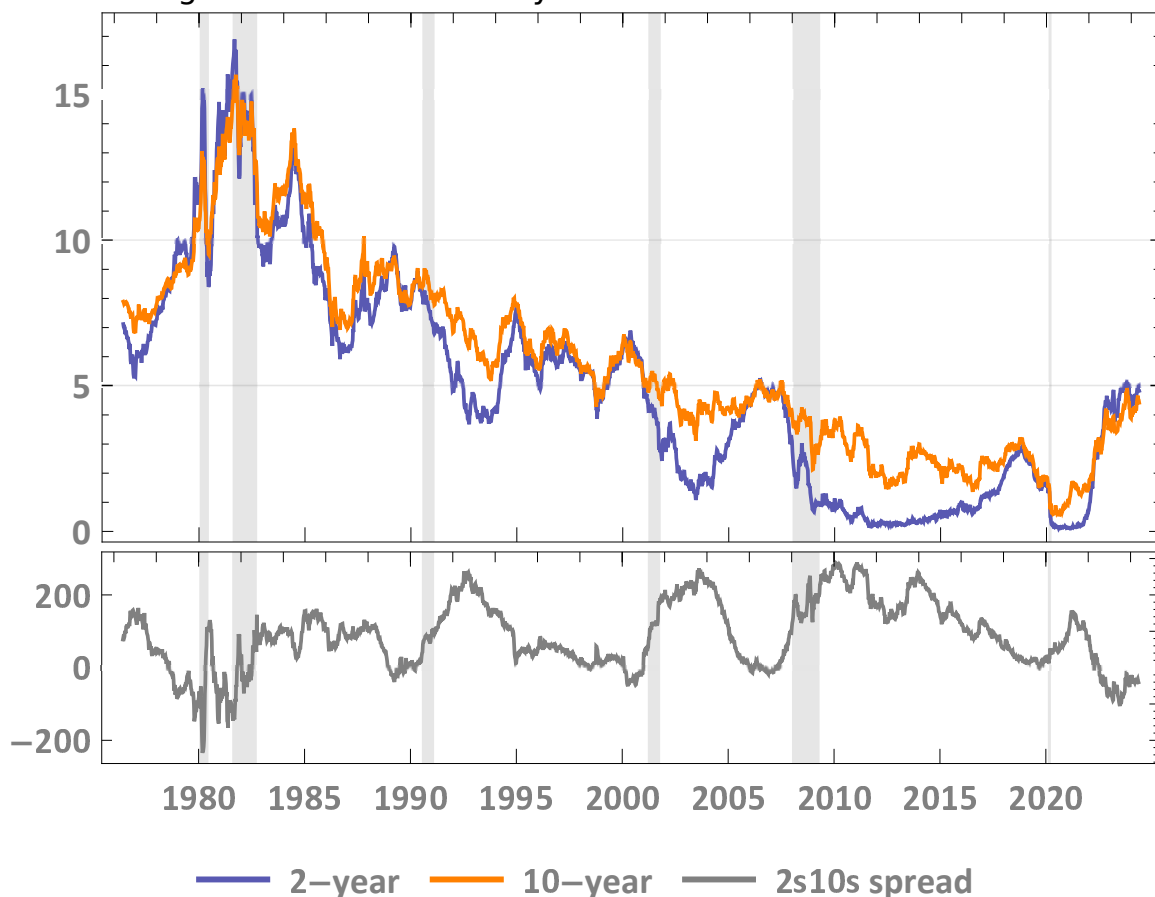
4.1 How we got here

It's impossible to understand today's financial world except against the backdrop of the low level of interest rates of recent decades. Assets have multi-period lives by definition, whether a physical investment, a loan, or a business, and their valuation depends in part on interest rates. Interest rates are in some respects the most important prices in the economy, with a role in the valuation of anything involving the passing of time and determining the attractiveness of borrowing to fund investment or consumption.

Until the rapid worldwide post-Covid rise in interest rates, nominal and real interest rates had been unusually low for several decades. Figure 6 displays the behavior of shorter- and longer-term US nominal rates over the past 50 years. Figure 7 displays estimates of real US interest rates over the past 50 years, applying macroeconomic modeling and inferring them from market prices.

Low risk-free rates result in a lower absolute level of yields, regardless of expected returns and risk premiums, though these may be lower as well. The decline in rates set in following the inflation episode that ended in the 1980s. It occurred in several phases, an initial large drop due to

Figure 6: US 2- and 10-year nominal rates 1976–2024

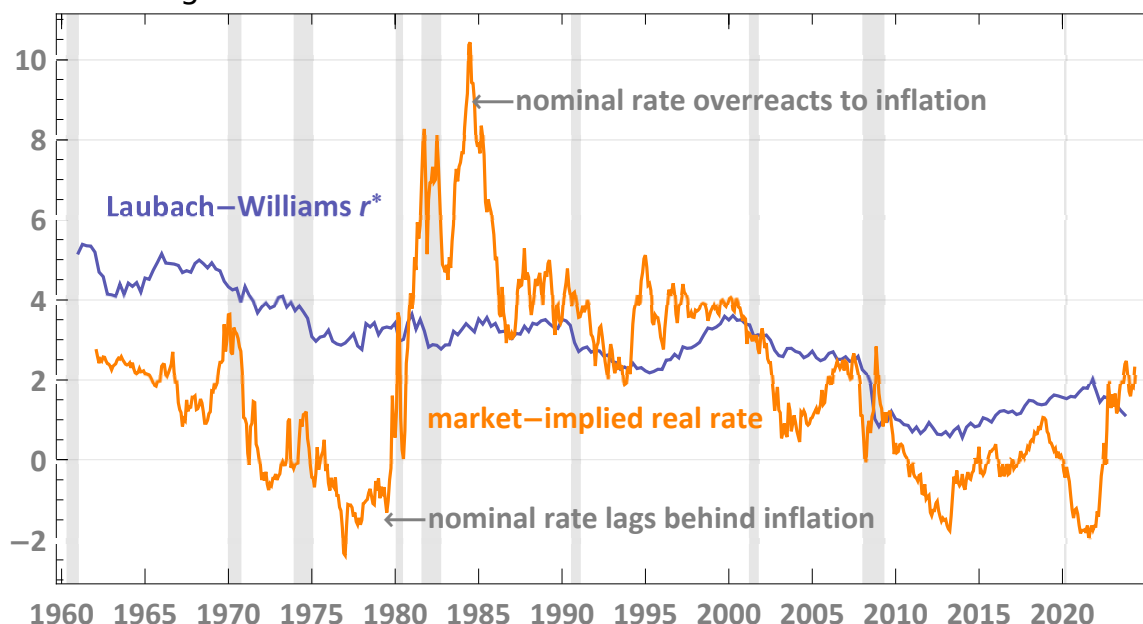


Upper panel: US Treasury note yields, percent. Lower panel: 2s-10s spread (10- minus 2-year rate), basis points. Vertical shading represents NBER recession dates. Weekly, 04 June 1976 to 05 January 2024. *Data source*: Bloomberg.

disinflation, and a subsequent steady decline. The fall in interest rates went even further, to zero and even negative values in some countries, after the 2007 onset of the global financial crisis and the introduction of highly accommodative monetary policies. Data from the 14th to the 21st century suggest a long-term trend of declining real interest rates, but their levels the past quarter century have been below that trend, even after their recent rise.

Zero or negative real interest rates had an early manifestation in Japan from the mid-1980s and have occurred across regions and currencies. Japanese bond yields have been exceptionally low and economic growth

Figure 7: Estimated US real interest rates 1961–2023



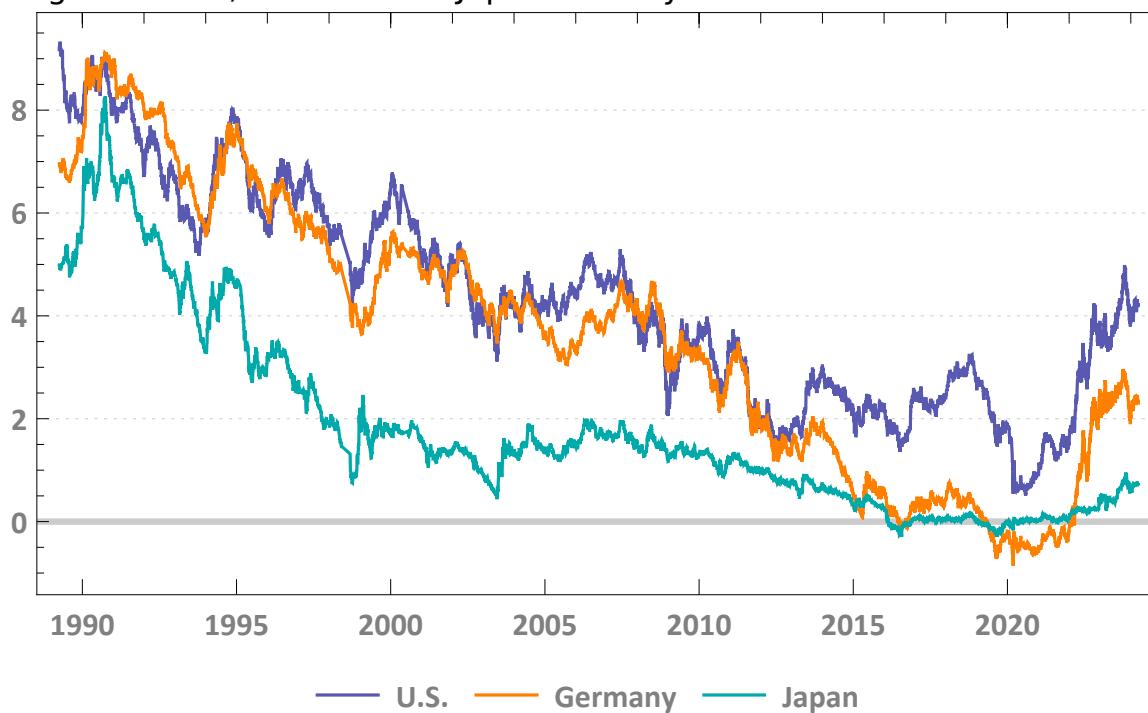
Estimates of the short-term natural rate r^* : based on Laubach and Williams (2003) March 1961–October 2023, quarterly. Market-implied real rate: 5-year US TIPS yield July 1997–Dec. 2023 (Bloomberg ticker USGGT05Y) and 5-year nominal yield (Bloomberg ticker USGG10YR) minus a 10-year moving average of annual CPI-U All Items inflation rates centered on the current month January 1967–June 1997, monthly. Vertical shading represents NBER recession dates. *Source:* <https://www.newyorkfed.org/research/policy/rstar>, Bloomberg.

stagnated following a sharp stock market decline in 1990. Figure 8 shows nominal yields of Germany's and Japan's 10-year government bonds, which fell to negative levels after 2007, alongside those of the United States.

For a long time, the unusually low level of rates seemed to be a benign phenomenon, as it coincided with a sharp and then sustained decline in inflation. As seen in Figure 9, US inflation as measured by the two predominant indexes fell from a peak near 10 or 12 percent in 1980 to an average below 2 percent annually between 1996 and 2020. It appeared far less benign with the onset of the global financial crisis in 2008.

Assets and liabilities of central and commercial banks and central government debt have grown rapidly in response to the sequence of financial crises and smaller stress events that began in 2008. The Federal Re-

Figure 8: US, German and Japanese 10-year nominal rates 1976–2024

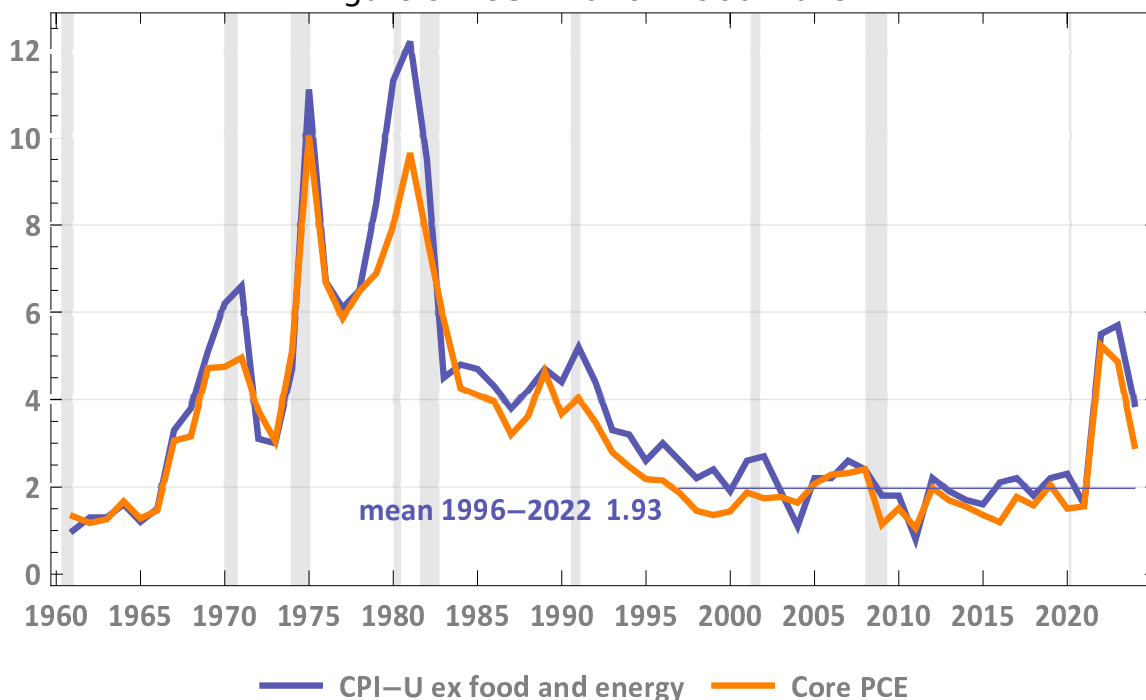


10-year benchmark yields of US Treasury notes, German bunds, and Japanese government bonds (JGBs), percent, daily 03 April 1989 to 29 March 2024. *Data: Bloomberg.*

serve responded to the global financial crisis with both well-established and new measures: lowering short-term interest rates, massive repo operations, outright purchases of US Treasury securities and agency MBS, more narrowly targeted emergency lending programs, and forward guidance, the practice of signaling that extremely accommodative monetary policy would be continued for a long time. The Fed's balance sheet grew from under \$1 trillion in September 2008, to a peak of about \$4.5 trillion by late 2014.

Term interbank rates reflect banks' wariness about lending to other banks for longer periods and contain term, credit and liquidity risk premiums as well as embedding expectations of the path of overnight rates. OIS rates in contrast are influenced primarily by rate expectations rather than risk premiums, as the instrument does not involve payment of principal at initiation and has lower credit risk. The spread between LIBOR and OIS

Figure 9: US inflation 1960–2023

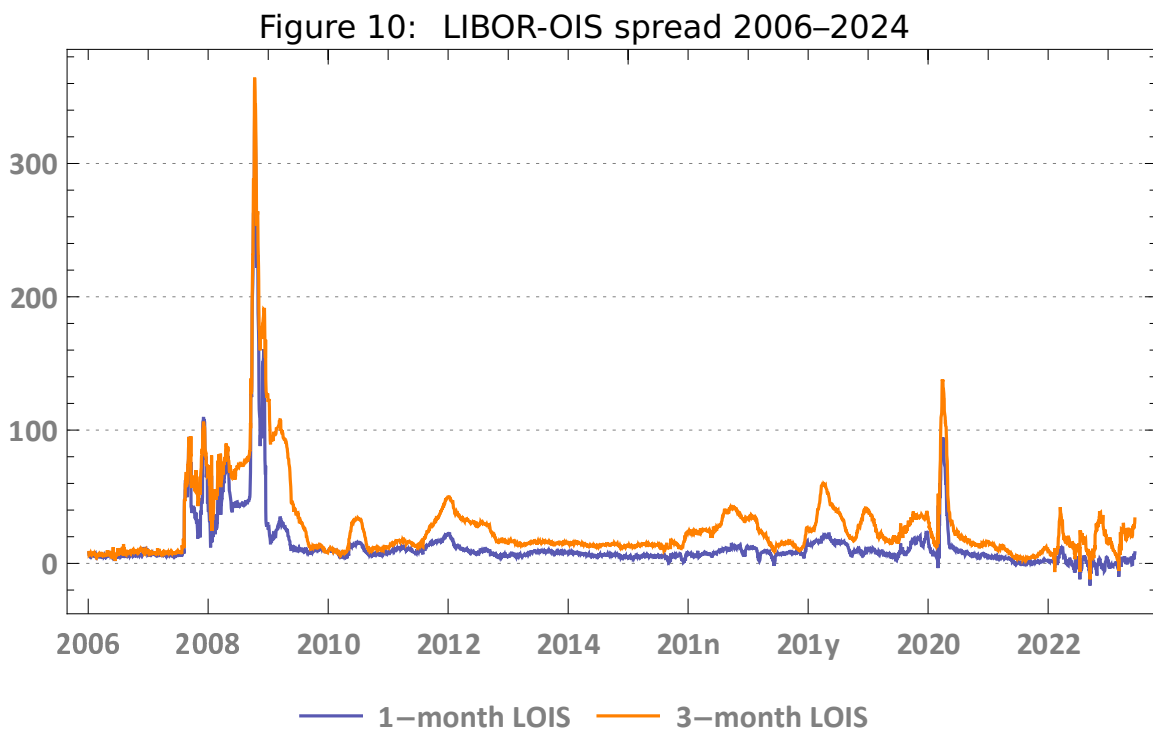


Annual percent change in the consumer price index–all urban consumers (CPI-U), all items less food and energy (*Source*: US Bureau of Labor Statistics, series CUUR0000SA0L1E), and core Personal Consumption Expenditures price index (PCE) (*Source*: US Bureau of Economic Analysis). The core PCE is a broader index and has different weights from the CPI-U. Vertical shading represents NBER recession dates.

rates—the LOIS spread—was one way to measure market perceptions of the liquidity and credit risks of interbank lending. It represented the difference between term interbank money market rates, as represented by LIBOR, and prices of OIS derivatives serving the same function of locking in a lending rate for one or three months.

The LOIS spread rose sharply during the global financial crisis because banks are eager to term out their funding, but other banks are reluctant to extend credit. Until the recent decline in the volume of interbank lending and the phasing out of LIBOR, it had been an important indicator of concerns about solvency of banks during periods of financial stress. It was narrow and apt to widen only sporadically before the global financial crisis. After 2007, it was persistently wide and understood to compensate for banks' default risk, of which markets had become far

more conscious. The sudden widening of the LOIS spread also indicated that banks had limited confidence in their ability to monitor one other. Figure 10 illustrates the extraordinarily rapid widening of LOIS spreads during the global financial crisis. Less dramatic but still pronounced widening can be seen at other times of significant stress, such as the 2011 US debt-ceiling crisis, Covid, and the 2023 banking turmoil. The suddenness of the widening is also evidence that depositors, including other banks, don't see themselves as effective monitors of bank solvency.



1-month and 3-month USD BBA LIBOR minus OIS of like maturity, basis points, daily, 05 January 2006 to 28 March 2024. *Source:* Bloomberg.

4.2 The LIBOR transition

Most swap reference rates had been based on representative rates submitted by a panel of large banks and published by their trade associa-

tion. The 2012 LIBOR manipulation scandal revealed that some submitted rates were off-market, manipulated by the traders submitting them to affect the banks' mark-to-market valuations, or to avoid the potential stigma of a high submitted rate, which might be interpreted as indicating that the bank faces reluctance to lend to it.

Following the LIBOR manipulation scandal, the Federal Reserve, along with other major central banks, initiated an effort to replace LIBOR with reference rates drawn from market data and published by central banks. The effort took longer than expected, since LIBOR is embedded in a large volume of long-term private debt and derivatives contracts. It also expanded beyond the initial objective of taking the business of publishing reference rates out of the hands of private-sector panels, to also include replacing benchmarks and reference rates based on interbank loans with "nearly risk-free" rates drawn from liquid and observable secured overnight money markets. The main US reference rate, Secured Overnight Financing Rate (SOFR), is based on Treasury repo, and is considered as free of credit risk as a nongovernment claim can be.⁷

These goals were initially advanced through suasion, in the United States particularly the influence the Federal Reserve can bring to bear on primary dealers. The United Kingdom's Financial Conduct Authority stopped LIBOR from being published after mid-2023. Under rules the Fed has issued implementing the Adjustable Interest Rate (LIBOR) Act of 2022, legacy contracts will replace LIBOR with newly-developed reference rates. Outside the United States, similar interbank curves for other currencies are also being gradually phased out, and intermediaries are in the process of revising existing contracts that extend beyond the cessation dates. Nearly risk-free rates have been developed as benchmarks for non-dollar bonds, derivatives, and other contracts.

While the transition is complex and costly for market participants, resistance to it has been muted, in part because the significant presence

⁷On reference rates, see Tuckman (2023), Schrimpf and Sushko (2019) and Huang and Todorov (2022) for analysis and a survey covering several countries.

of credit risk in longer-term interbank rates impaired its use as a benchmark, as seen in the wide LOIS spread during periods of stress. There has also been a sharp decline in the volume of interbank lending on which LIBOR curves are based since the global financial crisis, so reference rates based on transactions in these markets became less representative of short-term funding costs.

However, interest-rate swaps using SOFR or other nearly risk-free rates as a floating index are mismatched with the bank funding cost risk they may be used to hedge against. Interbank lending rates may rise sharply, while SOFR or T-bill rates driving swap payoffs do not, or even fall. Spread widening coupled with a nearly risk-free hedge can cause severe losses. Banks need a hedging instrument reflecting their funding costs that is more suitable for hedging than repo. The problem has no easy solution, as attenuated price discovery in the interbank market makes accurate observation of bank funding costs in roiled financial conditions more difficult.

Similar difficulties arise in the provision of credit lines indexed to SOFR rather than to a benchmark more closely related to banks' funding costs. Corporate clients will be more eager to draw down credit lines linked to a benchmark that is likely to remain stable or even fall during a period of stress. Banks will be more reluctant to issue credit lines apt to be drawn upon just when the reliability of their own equity and debt funding is more uncertain and their cost more likely to have risen sharply. The result is to reduce the volume and increase the cost of credit lines in normal times.⁸

Regulators have been unwelcoming of the introduction of new credit-risk sensitive money-market benchmarks based on unsecured rates that have been developed by some data providers and exchange operators, citing their low turnover volume and the propensity for these markets to shrivel during crises. SOFR and other nearly risk-free rates are the

⁸See Cooperman et al. (2023).

only benchmarks that can be relied on not to attract negative regulatory scrutiny, limiting banks' and other market participants' ability to contract privately to hedge unsecured funding rate risk.

Swap markets have been transformed by the transition. The permanent discontinuation of LIBOR reference rates related to interbank loans requires not only a new type of contract but also revisions to a large volume of existing contracts. Newly originated swaps using SOFR or other nearly risk-free rates are priced, as in the past, so the NPV of the swap is zero. The new reference rates are often used as the floating rates stipulated in OIS swaps (SOFR OIS).

For existing swaps to be converted to a new reference rate, two adjustments are required, for the difference in credit risk and for the term to maturity of the legacy and new reference rates:

- A credit adjustment spread must be estimated to equalize the old and new rates. The level of this adjustment has been a source of controversy between banks and customers.
- The new reference rates are overnight rates, leaving the problem of how to obtain nearly risk-free rates for use in swaps and floating-rate bonds, with payment dates a calendar quarter or more apart. This can be done in a backward- or forward-looking fashion. One approach is to determine floating payments in arrears, by compounding the past quarter's or 180 days' daily SOFR rates.

For US dollar instruments, the CME Group and Intercontinental Exchange (ICE), operators of futures and options exchanges, have developed longer-term SOFR futures that can be used as forward-looking reference rates. SOFR futures are similar to OIS: they pay the difference between a fixed rate determined at the contract's initiation and the compounded return on SOFR over the term of the contract. Term SOFR and to a lesser extent SOFR in arrears are gradually replacing LIBOR in US dollar swaps and other fixed-income instruments.

The role of the interbank lending market in determining money market rates has become attenuated since 2008. Reserve balances have vastly increased along with the Federal Reserve assets they fund, and now pay interest. The main driver of an active fed funds market in which banks trade reserve balances with one another, banks' desire to minimize holdings of a zero-yield asset while still meeting end-of-day payment obligations and minimum reserve requirements, has vanished. The share of fed funds, as assets or liabilities, on US banks' balance sheets has fallen to near zero.

LOIS has lost relevance with the transition from LIBOR to secured rates as benchmarks. Other unsecured market rates that can be compared to term OIS to discern bank credit risk fears include banks' commercial paper and term certificate of deposit (CD) rates.

4.3 The Covid response and the 2023 crisis

The Federal Reserve response to the Covid pandemic was similar to its operations of 2008 and after, but introduced new emergency liquidity programs and, most importantly, was far more immediate and drastic. The Fed's assets and liabilities, which had been gradually running off as the economy recovered and financial conditions eased, more than doubled from about \$4.2 trillion at the end of February 2020 to \$9 trillion in early 2022. Nearly \$3 trillion of that increase occurred in the three months from March through May of 2020.

Much of the liabilities on the Fed's balance sheet consists of reserve balances, a liquid asset for commercial banks. Before the crisis, reserve balances were desired primarily for liquidity, but have since also become an earning asset, especially for larger banks. They are valued as means of settlement of interbank liabilities and as earning assets, but also viewed as costly to hold. As with any other asset, they must be financed, likely by deposits or other liquid short-term liabilities, absorbing and offsetting

their liquidity. This increases liquidity risk for banks in aggregate, particularly large banks holding the bulk of reserves, which have become warier of providing liquidity to the market in any stress period.

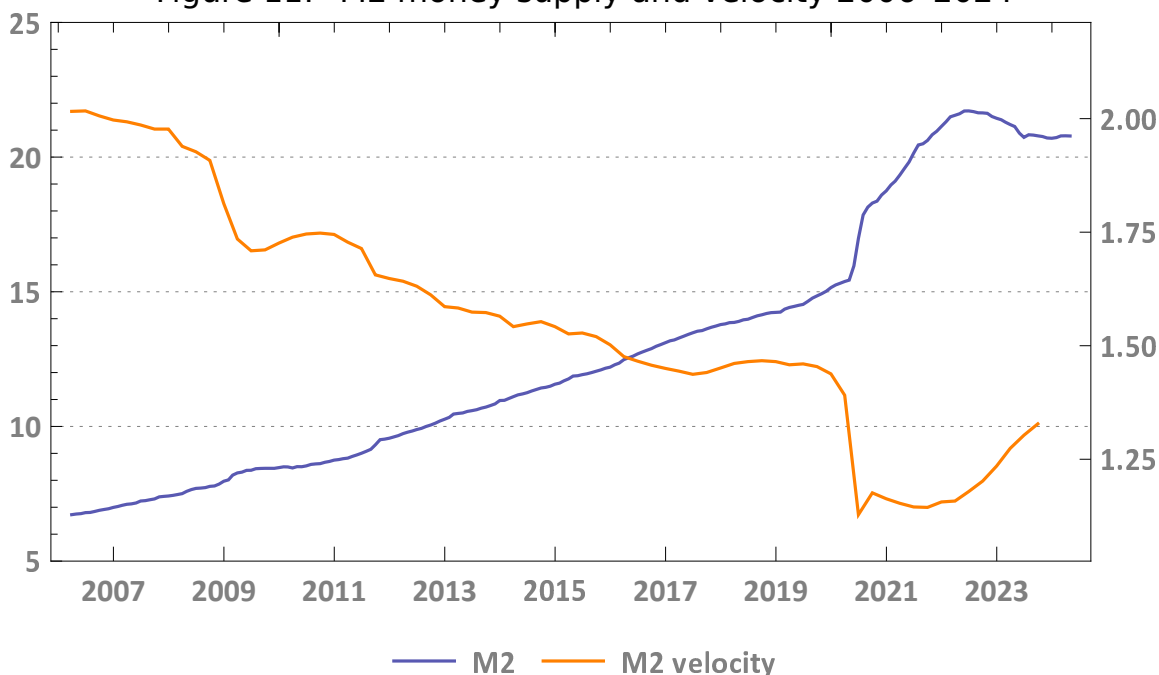
The US federal public debt has grown from about \$9.5 trillion in late 2008 to \$34 trillion at the end of 2023, with the most rapid increase from 2020. The government response to Covid included large direct transfers to households and businesses, in the form of direct payments or relief from tax and loan payment obligations for households, businesses and state and local governments, increased health care expenditures, and programs sponsoring loans to businesses that became grants if they documented having maintained their payrolls. Estimates of the Covid-related additional expenditure range from about \$4.5 to \$6.5 trillion.

The business and household direct payments were in large part initially added to demandable deposit accounts, resulting in a large immediate increase in the money supply, while transactions declined due to Covid and associated public-health policies. Eventually, as liquidity preference reverted and households had time to adjust, the deposits were reallocated to spending on goods and services, other forms of money, and investments, and inflation accelerated (see Figure 11).

Banks deployed the influx of deposits created through direct transfers into assets, initially loans and reserves at the Fed, but eventually a large increase in longer-term securities, most of it Treasuries and agency MBS. While these securities have little credit risk and high market liquidity, they are of long duration and have a great deal of interest rate risk.

Inflation rose from well below the Fed's 2 percent goal to well over 5 percent in the course of 2021. As inflation took off, long-term rates began to rise. With the Fed holding short-term rates unchanged through 2021, the yield curve did not initially flatten with rising rates but remained for a time steeply upward sloping. At the same time, rising long-term rates led to large mark-to-market losses on their securities portfolios. The Fed raised its target rates by 5.25 percent in 2022 and 2023, a record pace.

Figure 11: M2 money supply and velocity 2006–2024



M2 money stock, \$ trillion, monthly, Jan. 2006 to Feb. 2024, and velocity of M2 money stock, quarterly, Q1 2006 to Q3 2023, both seasonally adjusted. *Source:* Federal Reserve H.6 release and Federal Reserve Bank of St. Louis, via FRED.

The yield curve not only flattened but sharply inverted by the end of 2022.

Banks, apart from the largest ones, have had growing difficulty retaining deposits. The franchise value of a deposit base—the "stickiness" of deposits—has diminished as alternatives have become commonplace. Deposit beta is the sensitivity of rates paid on interest-bearing deposits to money market rates and to central bank target rates in particular. Deposit beta varies nonlinearly over time, generally low when rates have been low and rising as money market rates rise and depositors become more sensitive to returns. It is also lower for larger banks, and in regions with less competition between banks. Larger banks have an advantage from the stronger public-sector guarantees they enjoy, making them appear a safer repository for uninsured and large deposits. Smaller and

regional banks rely to a far greater extent on brokered deposits.⁹

Deposit betas were unusually low in early 2022, so NIM initially rose for most banks. Deposit costs and deposit betas rose throughout 2022, especially for midsize and regional banks. The volume of deposits declined as depositors began shifting to money funds and other higher-yielding alternatives, placing funding pressure on bank earnings just as losses were mounting on their securities holdings. Demand for bank loans together with rising short-term rates generated intense competition for funding among banks, and with money funds and other nonbank alternatives. Tightening liquidity was reflected in higher loan-to-deposit ratios, a measure of liquidity risk, and a sharp decline, following a rebound, in some short-term lending, such as stock market margin debt (Figure 12).¹⁰

Figure 12: US stock market margin debt 1997–2023



Debit balances in customers' securities margin accounts at Financial Industry Regulatory Authority (FINRA) member firms, month-end, January 1997 to February 2023, \$ billions Source: FINRA.

Competition for funding affected the Federal Reserve's balance sheet.

⁹Drechsler et al. (2017) define and estimate deposit betas.

¹⁰Kang-Landsberg et al. (2023) estimate deposit betas during the Fed tightening of 2022.

Its overnight reverse repurchase agreement program (ON RRP), previously used relatively sparingly to assist in controlling interest rates, grew rapidly in the first half of 2023. As bank holdings of reserves and deposits level off or decline, and with T-bills less available, investors seeking liquid short-term investments turn to money market funds, which invest in the ON RRP facility, and displace banks as holders of Fed liabilities. Reserves at the Fed must be funded by some liability, and the funding cost of deposits, the natural choice, had been rising particularly for smaller and regional banks, increasing their reluctance to maintain large reserve balances at the Fed. Large banks, in contrast, facing lower deposit beta pressure and deposit spreads, hold the bulk of the declining volume of reserves among domestic US banks. Discount window borrowing, normally a very small item on the Federal Reserve balance sheet, also became substantial in late 2022.

As rates rose, banks' realized and unrealized losses grew. The spring of 2023 saw three of the largest four bank failures in US history, preceded by runs on the banks' deposits. The failure of Silicon Valley Bank (SVB) was the second-largest in US history (after Washington Mutual Bank in 2008), with \$209 billion at the end of 2022, until it was displaced by the failure of First Republic Bank, with \$212 billion, over the weekend into May 1. Signature Bank (SBNY) was the fourth-largest (\$110 billion).¹¹ The episode illustrates the interaction of leverage and liquidity in bank stability, the evolution of run dynamics with communication technology, the limitations of regulation and supervision as substitutes for market scrutiny, and the instability induced by long periods of extremely low interest rates.

The bank failures originated in problems on both the asset and liability sides of the banks' businesses. Banks had treated forward guidance as credible and underestimated interest rate risk, extending credit and acquiring bonds at low interest rates between 2008 and 2021. Follow-

¹¹Chartered in Santa Clara, CA, San Francisco and New York, NY, respectively. The FDIC makes data on US failures available at <https://www.fdic.gov/resources/resolutions/bank-failures/>.

ing the rise in rates from 2022, banks owned a large volume of loans and debt securities with unrealized losses. While loans in the banking book could simply be held at amortized value, securities either had to be marked-to-market or the unrealized loss had to be reported publicly. One response was for banks to shift bonds into their HTM portfolios in 2022 and 2023 to stave off balance sheet markdowns.¹²

The increasing prevalence of remote work and online shopping undermined the credit quality of commercial real estate loans, many of which finance office building construction. The market values of real estate loans are also sensitive to interest rate changes. As a result, many banks announced or were presumed by the markets to have large unrealized losses. Banks' loan loss reserves rose from mid-2022.

On the liability side, many banks were vulnerable to an increase in funding costs and the liquidity risk of reliance on demandable deposits. Banks had experienced a large increase in deposits in consequence of Federal Reserve and US government policies during the Covid pandemic, much of it uninsured, and far in excess of transactions balances needed by firms and households. Uninsured deposits accounted for 43.5 percent of the total at US depository institutions at the end of 2022.¹³

The banks that failed in 2023 had both concentrated assets and funding. SVB had had an unusually large deposit influx stemming from the large increase in tech sector revenues over the preceding few years, and had tripled in size between 2019 and 2022. By 2022, uninsured and interest-bearing deposits that are more susceptible to runs accounted for nearly all its funding, while its share of stickier non-interest bearing deposits declined. Signature was reliant on real-estate and law firm deposit accounts.

SVB had lent primarily to venture capital and technology firms, which were also the core of its deposit base. Like many US banks, SVB de-

¹²See Sec. 3 above.

¹³Table L.110 of the Financial Accounts of the United States (<https://www.federalreserve.gov/releases/z1/>).

ployed its inflow of deposits, beginning in 2020, to acquire a portfolio of agency MBS, US Treasuries, and other long-term full-faith-and-credit bonds with high interest-rate sensitivities. SVB was unusual among US banks for the large share of its assets invested in securities compared to loans and its interest-rate market risk. Its portfolio was essentially a carry trade, with the thesis that interest rates would remain low for the foreseeable future.

First Republic Bank had a large portfolio of residential real estate loans issued at low interest rates that did not have to be marked to market, but did need to be funded. It was heavily reliant on deposit funding, and their outflow raised the possibility that loans would have to be liquidated at a loss. Silvergate Capital Corp (SI) provided banking services to and had a deposit base centered on the crypto industry, which was experiencing insolvency and illiquidity of exchanges and stablecoin issuers. It announced its voluntary liquidation on March 8.

During its period of rapid growth between 2020 and 2022, on-site supervisors had identified several Matters Requiring Attention (MRAs) and Matters Requiring Immediate Attention (MRIAs) at SVB, and in 2022 and early 2023 had placed some restrictions on SVB's activities due to its high duration risk and deficient risk management processes. SVB had 31 still outstanding at the time it failed, but none that obliged it to immediately address its risk of insolvency as interest-rates began rising. According to SVB's Pillar III disclosure, its risk-based Tier 1 capital ratio was 15.5 percent and its leverage ratios 8.11 percent at the end of 2022, well above regulatory minimums.¹⁴ While not large enough to be subject to the LCR, it had a substantial stock of US Treasuries that would have gone a considerable way toward meeting a 100 percent minimum LCR. Some elements of the capital rules, such as the exclusion of AOCI from the measurement of Tier 1 capital, permitted banks other than the largest ones to calculate and publicly disclose higher regulatory capital

¹⁴Available at <https://ir.svb.com/financials/Regulatory-Disclosures/default.aspx>.

ratios. Many banks would otherwise have had to raise additional equity funding to maintain Tier 1 capital ratios as unrealized losses grew.¹⁵

Throughout 2022, SVB experienced large unrealized losses on its bond portfolio, and announced large realized losses after liquidating a portion of it to meet deposit redemptions in early 2023. The fair value of its HTM securities had declined by \$21.1 billion in 2022, compared to its \$16.3 billion book value of equity. The losses and a subsequent failed attempt to raise additional equity capital triggered further redemptions. With concentrated deposits, these readily accelerated into a run on March 10, with \$42 billion withdrawn within hours.

Signature Bank, with assets concentrated in commercial real estate, failed at the same time. A few weeks later, First Republic Bank, with a concentrated uninsured deposit base as well, failed. Large depositors rather than on-site supervisors were responsible for finally pushing these banks into resolution and might have acted sooner, had they not been able to rely on an implicit guarantee of their uninsured deposits. The technology firm Roku disclosed just before SVB's collapse that it had \$487 million in uninsured deposits at SVB, over 25 percent of its total cash balances, an example of nonfinancial corporate reliance on implicit guarantees, retrospectively justified by the emergency response to SVB's failure.¹⁶

The 2023 episode, as was also the case during the 2008 and 2011 crises in the United States and Europe, differed from the standard run model in a crucial respect. They were not indiscriminate, but affected only banks that were known to be troubled, overly leveraged, and had serious realized and potential asset losses. Larger banks, although they also had large unrealized losses on their securities portfolios, at least benefited relatively from depositors turning away from smaller ones.

¹⁵The Fed's proposed capital rule of July 2023 limits the AOCI exclusion.

¹⁶Board of Governors of the Federal Reserve System (2023) is the Fed's report on its supervision of SVB and Federal Deposit Insurance Corporation (2023) the FDIC's report on its supervision of First Republic. SVB Financial Group (2023) presents SVB's financial results for the years leading up to its failure.

The FDIC and Federal Reserve actions on the weekend of March 11 and subsequently aimed to resolve the two failed banks, SVB and Signature, and allay public concerns about the safety of the banking system as a whole. Buyers could not be identified immediately, so after being taken into FDIC receivership, the FDIC established bridge banks to hold their assets and liabilities. Although neither bank was large enough to qualify as systemically important, or even to qualify as an Advanced Approaches bank, a "systemic risk" exception was made to the deposit insurance limits to cover their uninsured deposits. First Republic's assets were acquired by JPMorgan in a purchase and assumption agreement with the FDIC. The episode displayed evidence of politicization of the resolution process and has strengthened the implicit guarantee of all uninsured US bank deposits.¹⁷ Public officials subsequently discussed the possibility of raising the deposit insurance coverage limit from \$250,000 to as high as \$10 million.¹⁸

The Federal Reserve initiated several paths of emergency lending to banks. Discount window borrowing conditions were further eased and a new emergency lending program, the Bank Term Funding Program (BTFP) was created, extending loans of up to one year secured by Treasuries and agency debt and MBS. The program measures haircuts against the full par value of the collateral, so more than the market value of the collateral can in principle be lent, a further innovation in Federal Reserve lending programs that would be highly unusual in private markets.¹⁹ The Fed also lent to the bridge banks financing the purchase of the now-defunct bank holding companies' subsidiaries and assets.

The bank failures in the spring of 2023 illustrate the long-noted phe-

¹⁷Lobbying by politically influential nonfinancial firms that stood to lose on depositors potentially affected (see Alan Rappeport et al., "How Washington Decided to Rescue Silicon Valley Bank's Depositors," *New York Times*, March 14, 2023, <https://www.nytimes.com/2023/03/14/us/politics/inside-silicon-valley-bank-rescue.html>)

¹⁸<https://www.cbsnews.com/news/elizabeth-warren-face-the-nation-transcript-03-19-2023/>

¹⁹The BTFP does however, have a US Treasury backstop and, in contrast to several other Fed lending facilities, has recourse to the borrowing banks' other assets.

nomenon that regulation and supervision are backward-looking, and apparently unprepared for the next crisis. New and revised regulations follow each crisis, but it is in the nature of complex rules attempting to comprehensively anticipate future developments that subsequent crises display features for which they are unprepared.

Liquidity conditions eased from the second half of 2023. Demand remained high for safe short-term investments, Treasury bill issuance increased substantially, and TGA liabilities were built up, but the yield curve became somewhat less inverted. The ON RRP facility reverted to lower usage as short-term funding pressure on banks eased, the demand for reserve balances recovered and T-bill yields rose. The Fed felt able to continue the gradual runoff of its portfolio, though emphasizing in its announcements that reserves would remain ample. It has slowed the pace of Treasury securities runoff from May 2, 2024.²⁰

5 Conclusion

The banking turmoil of 2023 has brought interest-rate risk back into focus, after a long era of low interest rates in which it seemed to recede in importance. Losses have arisen from what had been viewed as some of the safest assets.²¹ The rise in yields has somewhat eased long-term funding concerns of pension funds and insurance companies. But banks, investors and regulators are now far more vigilant about interest-rate risk.

²⁰See the Implementation Note to the May 1, 2024, FOMC statement at <https://www.federalreserve.gov/newsevents/pressreleases/monetary20240501a1.htm>.

²¹Some long-term Republic of Austria nominal bonds and UK inflation-linked gilts, for example, have lost on the order of three-quarters of their value since the end of 2021. See Robin Wigglesworth, "Argentina vs Austria, the smackdown of the century (bonds)," *Financial Times*, October 10, 2023, <https://www.ft.com/content/1893d2e9-9548-4e47-92e7-ea3ceb873f9c>.

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