The Sovereign-Bank Nexus and the Inflation Channel

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JEL Codes: G21, H63, E31

Keywords: Sovereign Debt; Banks; Inflation

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Abstract

We show that the sovereign-bank nexus comprises an additional channel: inflation. When the sovereign attempts to resolve a sovereign debt crisis through debt monetization, the higher inflation induces a deterioration of banks' capital position because of the maturity mismatch of banks' assets and liabilities. Quantitative analysis reveals that the elasticity of banking capital to long-term inflation expectations is high, as a 1% increase to long-term inflation expectations leads to a 15% decrease in banks' Tier 1 capital.

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1 Introduction

Sovereign debt crises driven by unsustainable borrower debt burdens are typically resolved through use of two policy levers: reduction of the real debt burden through default; or reduction of the real debt burden through inflation. Since the European sovereign debt crisis of the 2010s, an emerging literature has explored the web of connections linking the fiscal health of the sovereign to the stability and health of the domestic banking sector, sometimes called the sovereign-bank nexus. This literature often focuses on mechanisms linked to use of the first policy lever - and for good reason, as banks often have substantial balance sheet exposures to domestic sovereign debt.

While bank balance sheet exposures to sovereign debt offer a clear vector of contagion by which fiscal unsustainability can threaten financial sector solvency, there is a second, subtler balance sheet exposure to sovereign debt crises: maturity mismatch. Since the duration of a financial sector's nominal assets are often far greater than that of its liabilities, changes in long-term nominal interest rates wrought through changes in inflation expectations can generate economically significant deteriorations in bank equity capital and, by extension, in financial stability. Furthermore, since adverse valuation effects influence all banks' nominal fixed-income holdings, the potential damage to a financial sector wrought through debt-driven inflation is not bounded by the sector's direct exposure to sovereign debt. A vivid example is the recent failure of Silicon Valley Bank (SVB) in March 2023, marking the second-largest bank failure in U.S. history. The immediate cause of the failure was a run on SVB, triggered by the announcement of significant losses resulting from the sale of its securities. These losses were prompted by an increase in interest rates, as a response by the Federal Reserve to counter rising inflation.[1]

This paper argues for the inclusion of debt-driven inflation as an important and overlooked contagion channel of the sovereign-bank nexus that would benefit from greater attention and study. We use bank balance sheet maturity data to quantitatively estimate the elasticity of banking capital to changes in inflation expectations. The US banking sector provides an ideal setting for our estimation, as it affords us rich maturity information on banks' fixed income positions. After using this maturity data to construct banks' sequence of future fixed income payment streams, we estimate the valuation changes to these fixed income streams driven by counterfactual changes to inflation expectations.

We find that the value of bank fixed income positions are economically sensitive to changes in inflation expectations: a 1% increase in long-term inflation expectations generates a decrease in Tier 1 capital of approximately 10-15%. These results are robust to controlling for bank size, systemically-important indicator status, and interest rate derivatives holdings.

Our work attempts to tie together related but distinct literatures. First, it relates to the work on the sovereign-bank nexus or "doom loop" that has emerged in recent years (Brunnermeier et al., 2016; Dell'Ariccia et al., 2018; Farhi and Tirole, 2018; Gennaioli et al., 2014). In particular, we argue that inflation merits consideration as a distinct channel of this nexus. In re-emphasizing this inflation channel, we draw on a separate literature going back to Calvo (1988) which recognizes inflation and default as strategic substitutes of a sovereign facing an unsustainable debt burden (Aguiar et al., 2013; Hurtado et al., 2023; Sunder-Plassman, 2020). In focusing on the inflation channel as a mechanism by which sovereign debt crises can erode financial stability, we draw from

[1]While most of the interest rate increase in this period was due to monetary policy, concerns about the federal budget deficit and the government's commitment to address it also contributed. This sentiment became apparent during the October 2023 bond market sell-off, pushing the yield on the 10-year U.S. Treasury note to 5%.

a broader literature that examines the interaction between inflation/monetary policy and financial stability (Smets, 2014; English et al., 2018; Gomez et al., 2021).

The paper unfolds as follows: section 2 discusses the data on banks' nominal positions and maturity mismatch; section 3 presents the conceptual framework used in our empirical analysis and describes the procedures to construct streams of future payments; section 4 presents the main results; section 5 concludes.

2 Data

2.1 Data on commercial banks' fixed income portfolios

We use the commercial banks' quarterly Call Reports (FFIEC 031 and 041) between 1997 Q2 - 2009 Q4 for information on the composition and maturity structure of banks' balance sheets. To account for the possibility that common ownership ties foster risk-sharing across bank subsidiaries, we aggregate bank-level Call Report data at the bank holding company (BHC) level. We drop from our sample banks with asset value smaller than $500 million in 2009 Q4 and restrict our attention to relatively large banks.[2] As we use recursive methods to construct synthetic payment streams from bank balance sheets, we drop a few banks whose observations are not continuous in the sample. Finally, to account for the M&A activity among banks and BHCs during this period, we use data on bank M&A activity from the Federal Reserve Bank of Chicago to identify affected banks. If institution A is acquired by institution B in date t, we add A's balance sheet positions to B and treat them as one institution prior to t.

2.2 Bank balance sheet maturity data

The Call Report information on bank maturity information for this period is surprisingly rich, covering approximately 70% of banks' assets and liabilities.

[2]$500 million is the threshold above which a BHC needs to file regulatory report FR Y-9C (after March 2006).

2.2.1 Maturity mismatch

The first two panels of Figure 1 plot the average maturity/repricing period of the key items on bank balance sheets.[3] On the asset side, pass-through mortgage-backed securities have the longest maturities, increasing from ten years at the beginning of the sample period to 15 years at the end of it. Treasury and agency securities have maturities of around 5 years. Loans and leases, as well as structured MBS, have shorter maturities of three to four years. On the liability side, time deposits and other borrowed money both have very short maturity of one to two years. By construction, savings and demand deposits have zero maturity.[4] The maturities of these items remain relatively stable over time.

To gauge the degree of maturity mismatch, we define maturity gap as the difference between the weighted-average maturity/repricing period of bank assets and liabilities, as in English et al. (2018). We plot cross-sectional asset-weighted mean and median maturity gap in the third panel of Figure 1. Both measures of maturity gap fluctuate around three to five years over the period.

3 Quantitative framework

Here, we provide a simple asset pricing framework to show how inflationary episodes can affect bank balance sheets. We first discuss the pricing of zero coupon bonds, noting that a more general fixed-income claim with coupon payments can be viewed as a portfolio of zero-coupon bonds with different maturities.

3.1 A simple asset-pricing model

We assume that the exogenous fundamentals of the economy at time t are functions of the state s_t. The history of the states from period 0 to t are denoted as the sequence $s^t = (s_0, ..., s_t)$. We assume that bonds represent pools on many independent borrowers whose repayment status at time t is determined by the history s^t. Given the borrower pool still making payments at the start of t

[3] We set the average maturity/repricing period within each bucket to the midpoint of that buckets' range. Claims with over 15 years to maturity or the next repricing date are assumed to have a maturity/repricing period of 20 years; those with over three years are assumed to have a period of five years.

[4] Interest rates on transaction deposits are de facto very sticky (Hannan and Berger, 1991); as such, their effective maturities may be considerably longer than their contractual maturity. Nevertheless, we follow the literature and treat their effective maturity as zero.

("remaining borrowers"), we denote the fraction of remaining borrowers that default in t by $h(s^t)$. We denote the gross inflation rate between periods t and $t+1$ in the continuation history s^{t+1} as $\pi_{t+1}(s^{t+1})$ and the real discount factor in history s^t for a payoff in s^{t+1} as $m_{t,t+1}(s^{t+1})$.

For tractability, we assume that the credit risk, characterized by the state-contingent haircut $h(s^t)$, and the real stochastic discount factor $m_{t,t+1}(s^{t+1})$ are both unaffected by changes in inflation expectations. Thus, we essentially restrict our attention to the partial equilibrium effect of inflation. We first consider the period-t price of a j-period zero-coupon bond issued in t that pays \$1 in $t+j$ in all possible continuation histories s^{t+j}:

$$w_j(s^t) = \sum_{s^{t+j}|s^t} \Pr(s^{t+j}|s^t) \prod_{k=0}^{j-1} \frac{\left(1 - h(s^{t+k+1})\right) m_{t+k,t+k+1}(s^{t+k+1})}{\pi_{t+k+1}(s^{t+k+1})} \equiv \frac{1}{(1 + i_{t,t+j}(s^t))^j}. \tag{1}$$

The second equality is simply the definition of the j-period zero-coupon yield $i_{t,t+j}(s^t)$. It depends on expected inflation, default risk and the real stochastic discount factor. Given a history s^t, consider a surprise period-t policy announcement by the government that permanently and immediately increases inflation expectations by $\Delta\pi$. When zero coupon yields $i_{t,t+j}(s^t)$ and the change in inflation rate $\Delta\pi$ are sufficiently small, we can approximate $\Delta w^j(s^t)$ by $\frac{1}{(1+i_{t,t+j}(s^t)+\Delta\pi)^j} - \frac{1}{(1+i_{t,t+j}(s^t))^j}$. Intuitively, changes to inflation expectations are priced into the nominal yield curves.[5]

General fixed income claims Now consider a more general financial claim which pays ν_j dollars in all states $s^{t+j}|s^t$ for $\forall j \geq 1$. By linearity, the decline in its value in a higher inflation scenario of $\Delta\pi$ is given as:

$$\Delta V(s^t) = \sum_j \left[\frac{1}{(1 + i_{t,t+j}(s^t) + \Delta\pi)^j} - \frac{1}{(1 + i_{t,t+j}(s^t))^j} \right] \nu_j. \tag{2}$$

In the rest of the paper, we estimate $\Delta V(s^t)$ for bank portfolios, in a scenario of a one percentage point permanent increase in inflation expectations ($\Delta\pi = 0.01$).

[5] This condition can be found in other works investigating the wealth effects of inflation (e.g., Doepke and Schneider, 2006).

3.2 Empirical framework

We want to generate estimates of inflation-induced valuation changes to banks' fixed income positions. The estimation involves three steps. First, we construct banks' fixed income payment streams $\{\nu_j\}_{j\geq 1}$ using balance sheet information on fixed income position sizes and maturities. Second, we estimate zero-coupon yield curves $\{i_{t,t+j}\}_{j\geq 1}$ that allow us to re-price future payment streams for different types of financial claims held by banks. Third, we estimate banks' gains and losses according to Equation (2).

3.2.1 Constructing payment streams

We follow a procedure similar to Doepke and Schneider (2006) to create payment streams for various categories of fixed-income instruments on the bank balance sheet. Specifically, we employ a recursive method to construct payment streams from loans, leases, MBS, and time deposits, distinguishing between claims issued in earlier periods with high interest rates and those issued in later periods with low interest rates. Further details about the construction can be found in the Online Appendix.

3.2.2 Yield curve estimation

To price a given payment stream generated by banks' portfolio at each date, we need to know the relevant zero-coupon yield curve for each asset class. We use the approach of Svensson (1994) to parametrically estimate two yield curves: that of Treasury securities and that of swap contracts. The former is used to discount banks' holdings of safe assets and liabilities; the latter, to discount privately issued securities, such as loans and leases. The Svensson (1994) yield curve is the most commonly used parametric form in central banks (Reppa, 2008). It is flexible enough to produce curves with two extrema, one maximum and one minimum. More details about the yield curve estimation can be found in the Online Appendix.

4 Results

4.1 Inflation-induced capital losses

The benchmark results are shown in Figure 2. For each sample year (fourth quarter), we compute gains and losses as a percentage of Tier 1 capital for each bank in the sample, and report the asset-weighted average statistics in the figure.

We find that a 1%-point increase in inflation expectations induce capital losses equivalent to a 10-15% reduction in banks' Tier 1 capital.[6] The effect size is remarkably stable throughout the sample period. As shown in Figure 2, fully 10%-points of capital losses are driven by write-downs of banks' loan and lease holdings, which represent 50-60% of banking assets on average. The longer durations of MBS make them the next largest source of capital losses ($\approx$ 3-5% of Tier 1 capital), despite only representing about 10% of bank assets. Treasury and agency securities cause an amount of capital loss which fluctuates around 1-2%-points. Simultaneously, the short maturities of banks' liabilities limit the capital gains from increases to inflation expectations to 5%-points.

The marked consistency of average inflation-induced capital losses over the sample period mask growing heterogeneity in the underlying capital loss distribution. The right panel of Figure 2 presents the cross-sectional distribution of capital losses at the beginning and the end of the sample period (1997Q2 and 2009Q4), showing increasing variation in the severity of capital losses. In 1997Q2, a 1%-point increase to inflation expectations would induce capital losses of greater than 20% for only 8.2% of banks; by 2009Q4, 23.3% of banks would bear a capital loss larger than 20%.

4.2 Maturity mismatch: a size phenomenon?

Clearly, maturity mismatch in banks' nominal fixed income positions represents a potent mechanism through which inflation shocks can propagate to the banking sector. By extension, we should expect that factors that influence banks' management of maturity mismatch to also influence their counterfactual capital losses in higher inflation equilibria. For instance, if larger banks are better at managing the risks of maturity mismatch, their capital losses could be less severe. Bearing this in mind, we re-present the results of the same inflation experiment according to the three size-classes

[6] This estimate is comparable with estimates of Japanese banks provided by Bank of Japan (2013).

of banks referenced earlier in Figure 3.

Overall, the sizes of losses are robust across the three groups of banks, which are around 10-15% percent of Tier 1 capital. If anything, banks with assets larger than $50 billion bear slightly larger losses than medium and small-sized banks in the second half of the sample (after 2003). Therefore, inflation causes a substantial loss to big banks which bear more systemic importance.

4.3 Bank risk hedging

Figure 4 breaks down the results of the inflation expectations experiment by bank interest rate derivative exposure. It is worth noting that, even at the end of our sample window, more than half of the banks do not hold any interest rate derivatives. While the gross capital loss profiles of banks with no or limited interest rate derivative positions are roughly similar and consistent with the story of a 10-15% capital loss, banks with derivative positions greater than 20% of total assets experience larger gross capital losses, which are particularly acute in the lead-up to the Great Recession. These results support the findings of Begenau et al. (2020) that banks incur similar exposures to interest rate risk through derivatives and other business activities.

5 Conclusion

Since at least Calvo (1988), it has been acknowledged that distressed sovereigns can resolve unsustainable real debt burdens through default or through debt monetization. If the sovereign chooses the latter, forward-looking, rational agents will adjust inflation expectations immediately and demand higher nominal interest rates in compensation for their savings, devaluing asset prices. This paper argued that inflation expectations constitute a separate and heretofore unacknowledged channel through which fiscal instability of the sovereign can turn into financial instability of the banking sector.

To investigate the quantitative implications of this channel, we generate synthetic payment streams for US banks from 1997 Q2 - 2009 Q4 using maturity characteristics from the balance sheet for the purposes of estimating portfolio values under counterfactual inflation expectations regimes. When we increase permanent inflation expectations by 1 percentage point, we find that the resultant net valuation losses to banks' balance sheets represent a 10-15% reduction in their

Tier 1 capital. In light of the fact that Manasse and Roubini (2018) use the inflation rate threshold of 10.5% to separate low-inflation and high-inflation sovereign debt crises, these results suggest that the bandwidth of the inflation channel to transmit instability from public bond markets to domestic banking markets is considerable and worthy of further research.

References

Aguiar, M., Amador, M., Farhi, E., and Gopinath, G. (2013). Crisis and commitment: Inflation credibility and the vulnerability to sovereign debt crises. *NBER Working Paper Series.*

Bank for International Settlements (2005). Zero-coupon yield curves: technical documentation. *BIS Papers No. 25.*

Bank of Japan (2013). Financial system report. *Bank of Japan Reports and Research Papers.*

Begenau, J., Piazzesi, M., and Schneider, M. (2020). Banks' risk exposures.

Brunnermeier, M., Garicano, L., Lane, P., Pagano, M., Reis, R., Santos, T., Thesmar, D., Van Nieuwerburgh, S., and Vayanos, D. (2016). The sovereign-bank diabolic loop and esbies. *American Economic Review: Papers & Proceedings*, (5):508–512.

Calvo, G. (1988). Servicing the public debt: The role of expectations. *American Economic Review*, pages 647–661.

Dell'Ariccia, G., Ferreira, C., Jenkison, N., Laeven, L., Martin, A., Minoiu, C., and Popov, A. (2018). Banks' exposure to interest rate risk and the transmission of monetary policy. *European Centeral Bank Working Paper Series.*

Doepke, M. and Schneider, M. (2006). Inflation and the redistribution of nominal wealth. *Journal of Political Economy*, 114(6):1069–1097.

English, W. B., Van den Heuvel, S. J., and Zakrajšek, E. (2018). Interest rate risk and bank equity valuations. *Journal of Monetary Economics*, pages 80–97.

Farhi, E. and Tirole, J. (2018). Deadly embrance. *Review of Economic Studies*, (3):1781–1823.

Gennaioli, N., Martin, A., and Rossi, S. (2014). Sovereign default, domestics banks, and financial institutions. *Journal of Finance*, (2):819–861.

Gomez, M., Landier, A., Sraer, D., and Thesmar, D. (2021). Banks' exposure to interest rate risk and the transmission of monetary policy. *Journal of Monetary Economics*, pages 1781–1823.

Gürkaynak, R. S., Sack, B., and Wright, J. H. (2007). The US Treasury yield curve: 1961 to the present. *Journal of Monetary Economics*, 54(8):2291–2304.

Hannan, T. H. and Berger, A. N. (1991). The rigidity of prices: Evidence from the banking industry. *The American Economic Review*, pages 938–945.

Hurtado, S., Nuño, G., and Thomas, C. (2023). Monetary policy and sovereign debt sustainability. *Journal of the European Economic Association*, (1):293–325.

Lesniewski, A. (2008). The forward curve. Lecture notes.

Manasse, P. and Roubini, N. (2018). "rules of thumb" for sovereign debt crises. *Journal of International Economics*, pages 192–205.

Reppa, Z. (2008). Estimating yield curves from swap, BUBOR and FRA data. Technical report, MNB Occasional Papers.

Smets, F. (2014). Financial stability and monetary policy: How closely interlinked. *International Journal of Central Banking*, (2):263–300.

Sunder-Plassman, L. (2020). Inflation, default and sovereign debt: The role of denomination and ownership. *Journal of International Economics.*

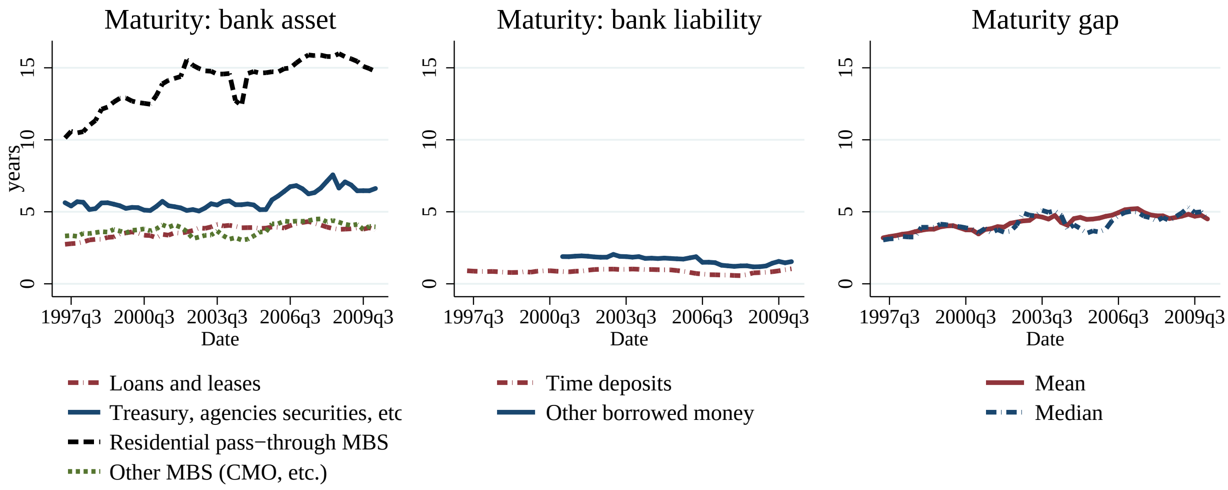
Svensson, L. E. (1994). Estimating and interpreting forward interest rates: Sweden 1992-1994. Technical report, National Bureau of Economic Research.

Table 1: Number of Bank Holding Companies

Year	Total	Large	Medium	Small
1997	774	22	33	719
1998	808	23	35	750
1999	854	23	39	792
2000	886	23	39	824
2001	913	24	41	848
2002	941	24	41	876
2003	960	24	44	892
2004	982	24	44	914
2005	1,005	24	44	937
2006	1,031	24	44	963
2007	1,054	25	44	985
2008	1,075	28	45	1,002
2009	1,079	29	45	1,005

Note: Large banks have assets larger than $50 billion in 2009Q4, medium banks have assets between $10-$50 billion in 2009Q4, and small banks have assets less than $10 billion in 2009Q4.

Figure 1: Maturity of bank assets and liabilities



Note: We compute statistics for each bank in the sample, and report the asset-weighted average statistics in the figure.

Figure 2: Inflation-induced capital losses

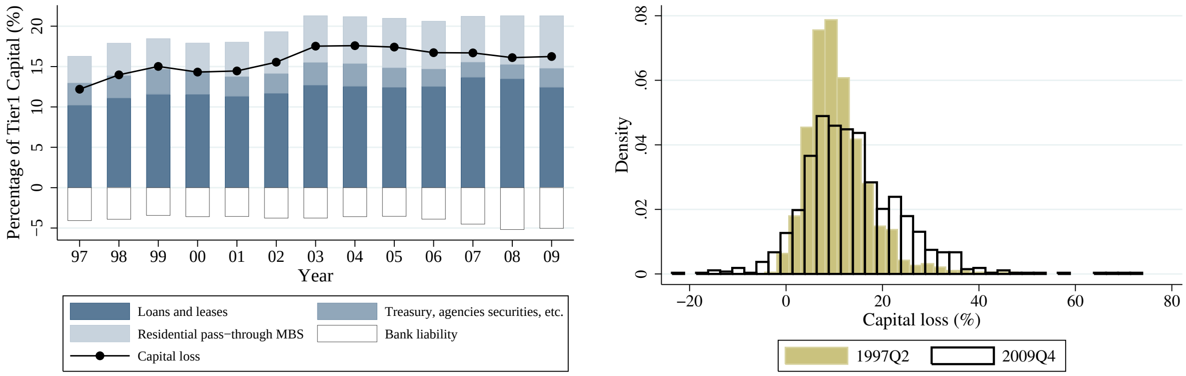
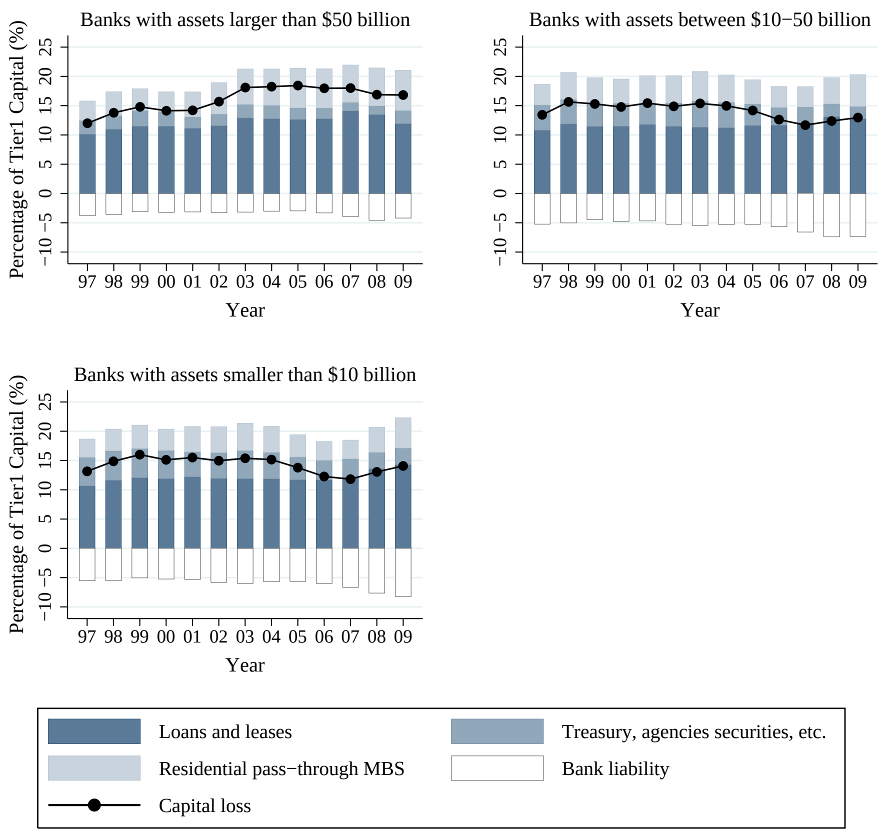
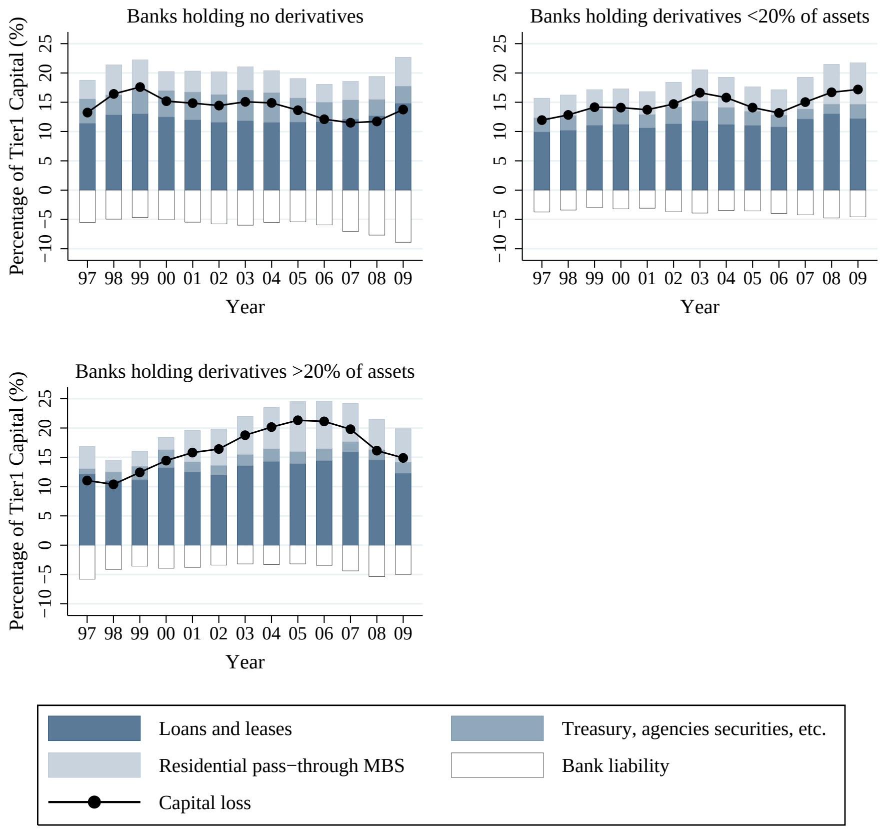


Figure 3: Gains and losses by bank size (total assets)



Note: We compute gains and losses for each bank in the sample, and report the asset-weighted average statistics in the figure.

Figure 4: Gains and losses by bank derivative holdings



Note: We compute gains and losses for each bank in the sample, and report the asset-weighted average statistics in the figure.

Online Appendix (not for publication)

A Estimating Yield Curves

To price a given payment stream generated by banks' portfolio at each date, we need to know the zero-coupon yield curve. In principal, asset classes differ in safety, liquidity and other features, and we want to estimate the yield curve for each asset class. Due to limitations on interest rate data, we estimate two yield curves: that of Treasury securities and that of swap contracts.[7] We use the yield curve of Treasury securities to discount banks' holding of safe assets and liabilities, e.g., Treasury and agency securities, and consumer deposits. We use the swap yield curve to discount privately issued securities, such as loans and leases.

We adopt parametric formulations of the yield curves in our estimation. In general, parametric formulations impose smoothness assumptions on the curve, and therefore is more suitable to study the macroeconomic forces that influence the shape of the curve. In contrast, Spline-based method is suited to better capture local behaviors of the yield curve.

We follow the standard approach proposed by Svensson (1994) and assume the following parametric form for the instantaneous forward curve at date t:

$$f_t(t+j) = \beta_{0,t} + \beta_{1,t} e^{-\frac{j}{\tau_{1,t}}} + \beta_{2,t} \frac{j}{\tau_{1,t}} e^{-\frac{j}{\tau_{1,t}}} + \beta_{3,t} \frac{j}{\tau_{2,t}} e^{-\frac{j}{\tau_{2,t}}}$$

where $f_t(t+j)$ denotes instantaneous forward rate j years ahead. Under the expectation hypothesis, the zero-coupon yield curve is given by $i_{t,t+j} = \frac{1}{j}\int_0^j f_t(t+u)du$. At a given point of time t, the zero-coupon yield curve $\{i_{t,t+j}\}_j$ is characterized by six parameters $\{\beta_{0,t}, \beta_{1,t}, \beta_{2,t}, \beta_{3,t}, \tau_{1,t}, \tau_{2,t}\}$.

The Svensson yield curve is the most commonly used parametric form in central banks (Reppa, 2008). It is flexible enough to produce curves with two extrema, one maximum and one minimum.

Treasury yield curve. We directly use the result of Gürkaynak et al. (2007), who estimate the Svensson yield curve for the entire maturity range spanned by outstanding Treasury securities from 1961 to present.[8] They show that their estimation is accurate for the entire maturity range,

[7] Swap interest rate is the rate of the fixed leg of a swap contract, calculated to make the net present value of the contract equal zero.

[8] Available at http://www.federalreserve.gov/pubs/feds/2006/200628/200628abs.html.

and the prediction error of bond yields lie within one basis point.

Swap yield curve. We use middle rate quotes of the UK-based inter-dealer broker ICAP, accessed through the Reuters database. The maturities of the contracts are 1-10, 12, 15, 20, 25 and 30 years.

In our estimation, we use the fact that a hypothetical bond paying a coupon rate equal to the swap interest rate is priced at par (Lesniewski, 2008). For each quarter of the sample period, we estimate $\{\beta_{0,t}, \beta_{1,t}, \beta_{2,t}, \beta_{3,t}, \tau_{1,t}, \tau_{2,t}\}$ by minimizing the weighted sum of squared deviations between actual bond prices and predicted bond prices. The weights are the inverse of the duration of each individual securities.[9]

The success at fitting the swap yields is repeated throughout the sample. Table A.1 shows the time-average absolute yield prediction error in different maturities. As can be seen, all of the errors are quite small over the entire sample, within several basis points.

Table A.1: Average absolute yield prediction errors by maturity

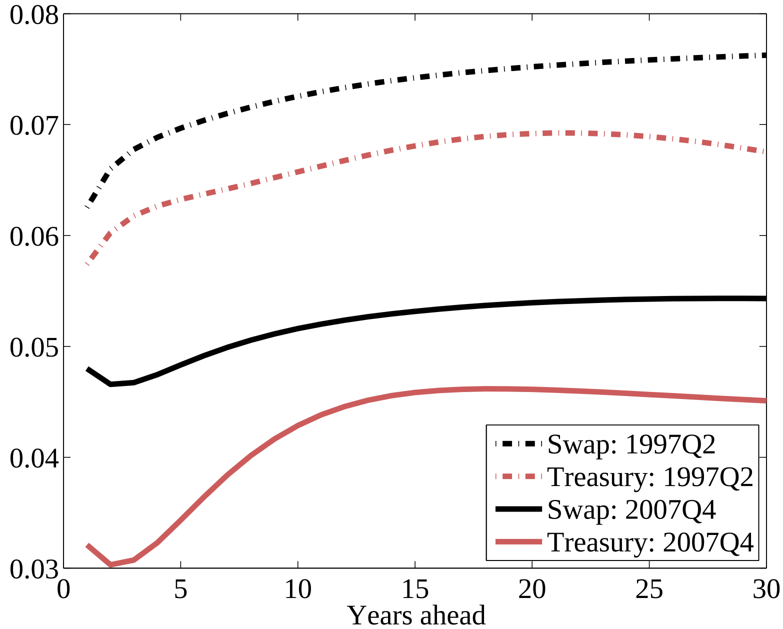
Maturity	1	2	3	4	5	6	7	8	9	10	12	15	20	25	30
Error (bps)	1.3	3.3	2.2	2.1	2.0	2.4	5.3	2.6	3.4	3.5	1.5	4.5	2.7	2.5	2.0

Note: Average absolute yield prediction error across time in different maturities.

As an example, we report estimated Treasury and swap yield curve at the beginning of the sample period (1997Q2) and before the crisis (2007Q4) in the appendix (Figure A.1). Two observations are worth noting. First, the Svensson parametric form is flexible enough to capture two humps in the Treasury yield curve in 2007Q4. Second, our sample period features a large decline in the overall level of interest rate. This pattern of data suggests that when constructing payment streams of long term loans, it is important to distinguish loans issued at earlier and later dates, since their yields may differ a lot. Therefore in the spirit of Doepke and Schneider (2006), we adopt a recursive method to construct payment streams for long-term loans and MBS, as described in the next subsection.

[9] Since a given change in the yield corresponds to a larger change in the price of a bond with a longer duration, fitting prices of each bond given an equal weight irrespective of its duration will lead to over-fitting of the long-term bond prices at the expense of the short-term prices. Therefore we follow the literature by weighting the price error of each bond by a value derived from the inverse of its duration (Bank for International Settlements, 2005). This procedure is approximately equivalent to minimizing the unweighted sum of squared deviations between the actual and predicted yields of securities.

Figure A.1: Estimated Yield Curve



B Constructing Payment Streams

We now describe the methods to construct payments streams of major categories of fixed-income instruments on bank balance sheet. In the construction we use size and maturity data on balance sheet positions, and yield curves estimated from the previous subsection.

For long-term fixed-income claims, it is important to distinguish between book value and fair value accounting. According to the guidelines of the Call Reports, most loans are recorded at face value, while most securities (Treasury or agency securities, or privately issued MBS) are recorded at fair value.

Since maturity data in the Call Reports are in the form of buckets. We assume that within each bucket the maturity is uniformly distributed, and that the maximal maturity is 20 years.

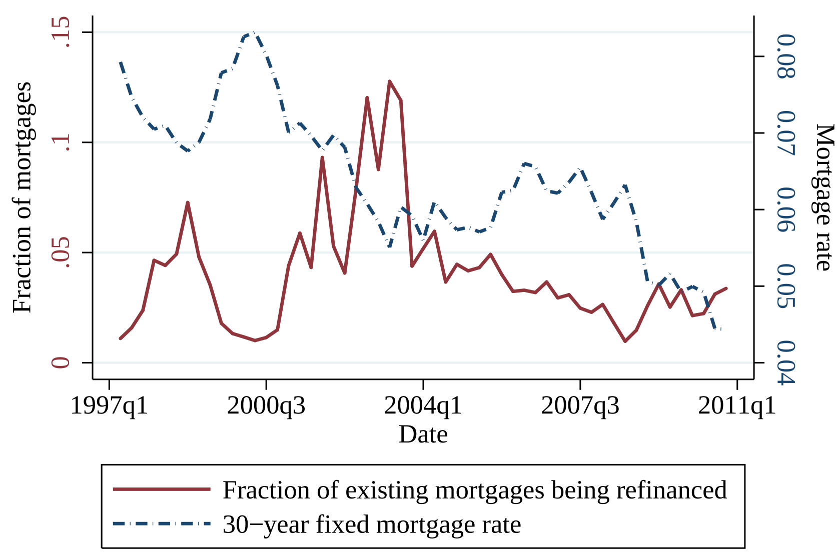
Loans and leases. We assume that all loans and leases are amortized according to the straight-line schedule, which features equal monthly payment until the maturity.

Since most loans and leases are held to maturity, we adopt a recursive method to construct payment streams. In the initial sample period (1997Q2), we assume that all loans were newly issued. For each maturity j, we observe the book value of the loan with maturity of j years. We construct the loan's payment stream $\{\nu_{t,m}\}_m$ according to the fact that, the discounted value of payment stream $\{\nu_{t,m}\}_m$ using the swap yield curve must equal their book value. We also determine the remaining face value of the initial vintage of loans in each subsequent sample period. This recursive method distinguishes between loans issued in earlier sample periods when interest rates were high and loans issued in later periods when interest rates were low.

For each subsequent sample period, we compute recursively the face value of new loans issued, as well as the expected payments and evolution of face value associated with that period's vintage.

We consider refinancing activities when constructing payment streams. In late 1990s and early 2000s, many homeowners took advantage of relatively low interest rates to refinance their mortgage loans. As shown in Figure A.2, 7-13% of outstanding mortgage loans were refinanced each quarter.[10] Therefore, when constructing payment streams after the initial sample period, we take into account that some existing loans are refinanced. We assume that when a mortgage loan is refinanced, the new loan has the same maturity as the remaining maturity of the old loan.

Figure A.2: Mortgage rate and refinancing activities



Note: The red line plots the (quarterly) percentage of existing mortgage loans being refinanced; the blue dash-dotted line plots the 30-year fixed mortgage rate.

[10] To construct the fraction of outstanding mortgage loans being refinanced, we use "mortgage refinance by one- to four-family residences" from Mortgage Banker Associations, and "mortgage debt outstanding by one- to four-family residences" from the FRED database.

Mortgage backed securities. We assume that all MBS are pass-through securities for which principal and interest payments are directly passed on to security holders from mortgage borrowers.[11] To construct payment streams, we adopt a recursive approach similar to that of loans and leases. The only difference is that MBS are recorded at fair value. Therefore, for each period we compute the fair value of previously issued securities using current interest rates.

Treasuries, agency-bond, other non-MBS. Because these securities are actively traded on the market instead of held to maturity, the previously mentioned recursive method is not appropriate in constructing payment streams. To proceed, we make two assumptions. First, all securities are newly issued and issued at par; second, a security is a zero-coupon bond if its maturity is less than 1 year, and a coupon bond otherwise. Then we compute coupon payments using the Treasury yield curve.

Time deposits and Other borrowed money. We also adopt the previously mentioned recursive method to construct payment streams for time deposits. The only difference is how payments are distributed across future periods. For time deposits, interests are accrued until maturity; for other borrowed money, we assume that it is in the form of coupon bonds, and their face values are not amortized.

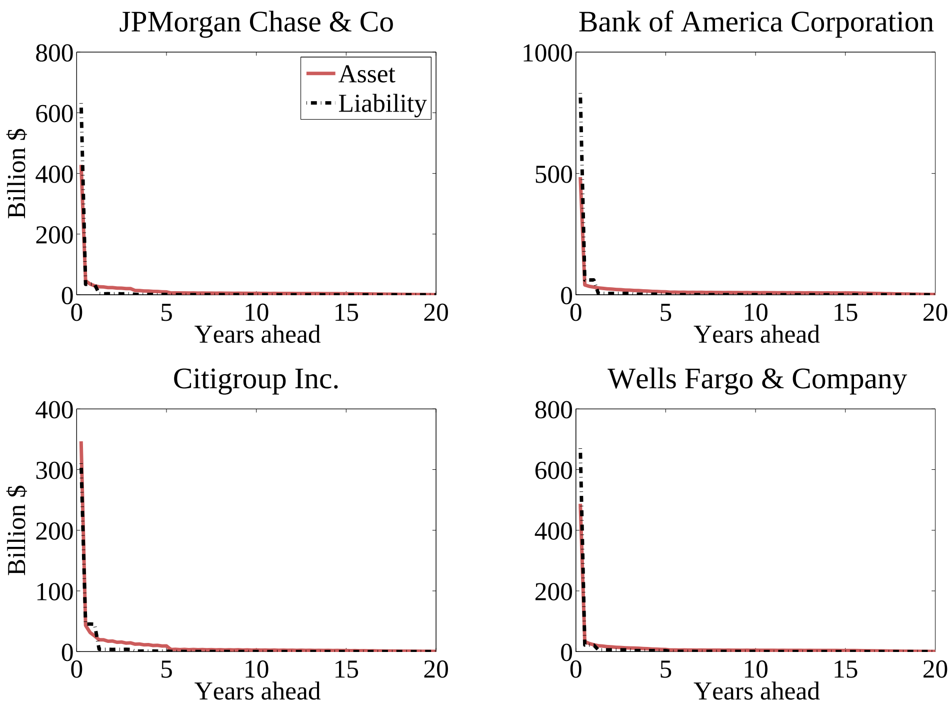
demand deposits and savings accounts. As discussed in the previous session, we assume that these deposits have maturity of a quarter and the interest rates paid on these deposits adjust in a quarter.

B.1 Constructed payment streams: examples

As an example, constructed quarterly payment streams for four largest bank holding companies are plotted in Figure A.3. On both asset and liability sides of bank balance sheets, future payments are very concentrated on short maturities within 5 years. Consistent with evidence of maturity mismatch discussed in the previous section, payments of bank assets are less concentrated on short maturities, comparing with payments of bank maturities.

[11] As in Figure A.4, the majority of MBS is pass-through securities.

Figure A.3: Constructed quarterly payment streams for four largest bank holding companies



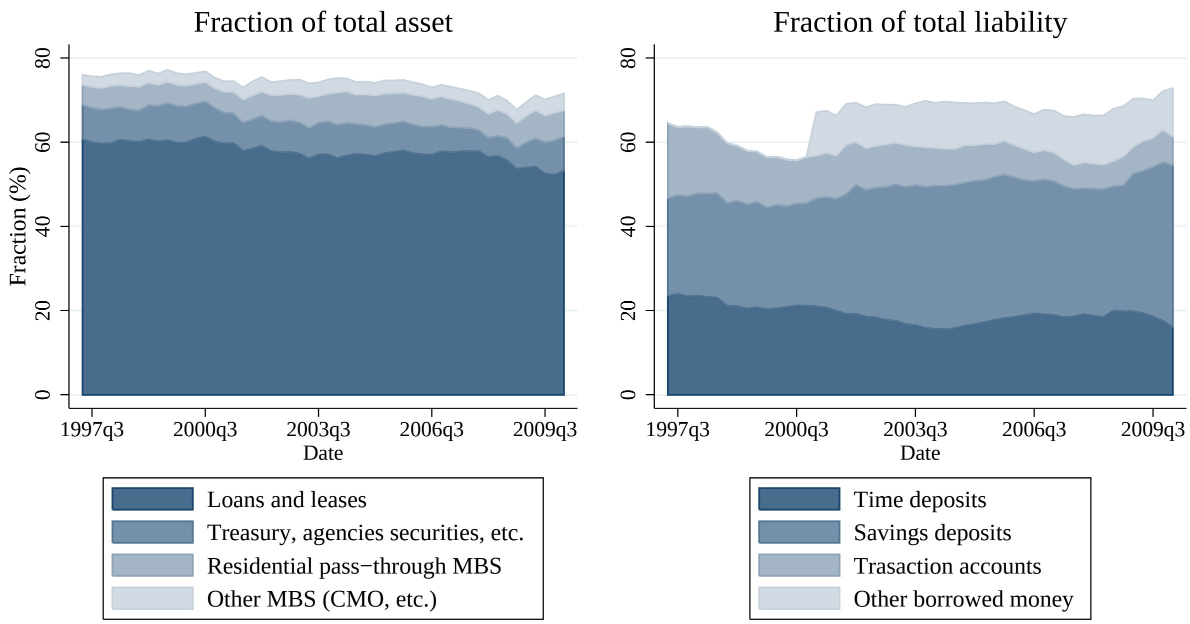
C Additional Details

C.1 Maturity breakdowns in the Call Reports

Table A.2: Maturity breakdowns in the Call Reports

Treasury and agency securities, Residential pass-through MBS, Loans and leases	1. Three months or less. 2. Over three months through 12 months. 3. Over one year through three years. 4. Over three years through five years. 5. Over five years through 15 years. 6. Over 15 years.
Time deposits, Other borrowed money	1. Three months or less. 2. Over three months through 12 months. 3. Over one year through three years. 4. Over three years.
Non pass-through MBS	1. Three months or less. 2. Over three months.

Figure A.4: Fraction of total assets and liabilities of which maturity breakdowns are reported



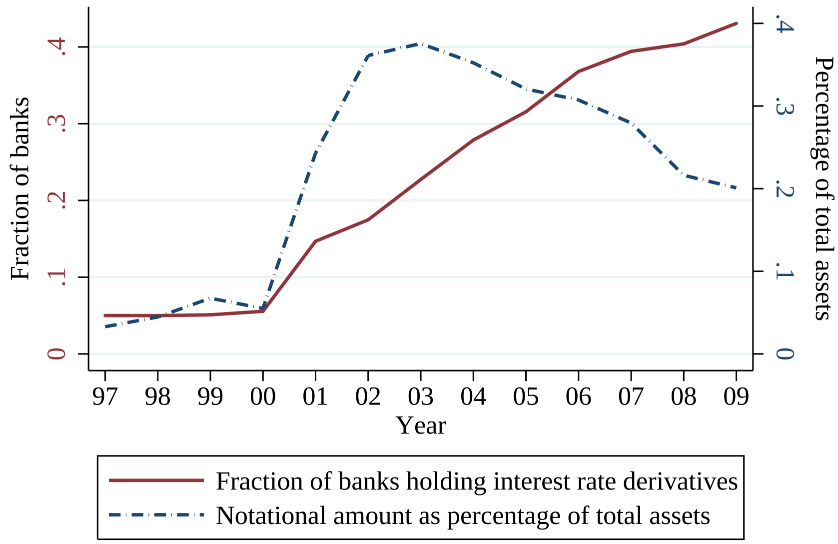
Note: We compute fractions for each bank in the sample, and report the asset-weighted average statistics in the figure.

C.2 Banks' Risk Hedging

The Call Reports record the notional value of interest rate derivatives and distinguish between derivatives "held for trading" or "held for purposes other than trading".[12] We assume that all derivatives "held for purposes other than trading" are due to trading on one's own account. According to accounting rules, the majority of positions due to market-making activity are recorded as "held for trading". We focus our attention on such derivative positions, as we are mostly interested in banks' behavior to hedge their own interest rate risks.

[12]Most interest rate derivatives are traded over the counter, and a few large dealers make the market. In particular, dealers intermediate between two parties by initiating, say, a pay-fixed swap with the first party as well as an offsetting pay-floating swap with the second party. Often one of the parties is another dealer.

Figure A.5: Fraction of banks holding interest rate derivatives and the size of their holdings



Note: the dash-dotted line shows the notational amount of interest rate derivatives as a percentage of total assets, conditional on positive holding. We compute the percentage for each bank in the sample, and report the asset-weighted average statistics in the figure.