BANKS' INTEREST RATE RISK EXPOSURE UNDER LOW RATES

TRACING EXPOSURE FROM BALANCE SHEET POSITIONS

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Banks' Interest Rate Risk Exposure Under Low Rates: Tracing Exposure from Balance Sheet Positions

Abstract:

Has the risk exposure of banks changed in response to low interest rates? We construct simple factor portfolios using the fair values of positions held by the U.S. banking sector in order to trace the interest rate exposure of individual positions on banks' balance sheets between 2001-2019. We find that the U.S. banking sector is more exposed to interest rate risk in the years after the financial crisis, a period characterised by low interest rates. The increased exposure can be observed across the majority of positions on the balance sheet. In particular, we distinguish trends of more long-term maturity contracts and more high-risk loans. We also find that the U.S. banking sector holds more assets and liabilities across the entire balance sheet, which contributes to increased exposure.

Keywords:

Banks, Interest rate exposure, Low interest rates, Risk-taking

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1 Introduction

Banks are a central part of a functioning financial system. As proven by the financial crisis of 2008, states are prepared to go to great lengths in order to prevent the banking sector from collapsing. The crisis led to new regulations, such as Basel III and the Dodd-Frank Act, with the purpose of improving bank risk management. However, Sarin and Summers (2016) find no evidence to support that banks would be safer today than before the crisis. On the contrary, they suggest that the opposite is true. The nature and business model of banks make them exposed to macroeconomic risks, such as interest rate risk and credit risk. In order to ensure the financial stability of the banking sector, it is important to understand how banks would be affected by changes in these macroeconomic factors.

Interest rates have been lowered since the crisis, at times to near zero levels. This raises the question of how the risk exposure of banks changes as rate levels nears the zero lower bound (ZLB), the point at which the capacity of monetary policy is limited. Bailey and Matyáš (2019) find that the bank stock sensitivity to the interest rate risk factor has changed since the crisis and explain this by an increased sensitivity to the slope of the yield curve. They hypothesize that increased sensitivity indicates an inability of banks to, under low rates, hedge against the interest rate risk resulting from maturity transformation. At the same time, a large section of the literature suggests that the lower interest rates that have prevailed since the crisis could incentivise increased risk-taking (Maddaloni and Peydró, 2011; Dell'Ariccia and Marquez, 2013; Adrian et al., 2014; Bologna, 2018). Increased risk-taking, combined with the inability to hedge, could pose a challenge to the banking sector.

Why are bank stock returns more sensitive to interest rate risk after the financial crisis of 2008? Many bank positions derive their return from maturity transformation and are thus commonly believed to be subject to interest rate risk. Changes in this factor will change the value of the position and consequently the value of the bank itself. We therefore propose to extend the study by Bailey and Matyáš (2019) by analysing from which positions on the balance sheet that the interest rate risk exposure originates.

To consider only the accounting measures provided by banks may prove insufficient in evaluating the exposure to macroeconomic risk. As pointed out by Begenau et al. (2015), a bank that holds many high-quality positions may be less exposed than a bank that holds few low-quality positions. Instead, we apply their proposed method of using simple factor portfolios to evaluate the effect of risk exposures on fixed income positions. We first construct an interest rate risk factor and a credit risk factor. We then compute exposure coefficients by regressing instrument-returns on these factors. Finally, we construct factor portfolios by applying our exposure coefficients to bank positions.

The interest rate risk factor is the return on a 5-year zero coupon swap. Swaps are considered safe bonds since they are collateralised which means that the return, and consequently our interest rate risk factor, depend only on changes in the yield curve. Our credit risk factor is computed by isolating the credit risk of a BBB bond. We do so by regressing the return of the BBB bond on our interest rate risk factor. Since the regression shows how much of the BBB bond return that can be explained by the safe interest rate risk factor, the remaining value is explained by the risk premium. In other words, our credit risk factor is the residual from regressing the return of a BBB bond on the interest rate risk factor.

Next, we recursively regress the returns of various instruments on our risk factors. We use instruments of different maturities and qualities in order to capture the different instruments held by banks. Each regression results in a beta coefficient that measures the exposure of the instrument to the risk factor. In other words, a one-unit change in the risk factor will change the instrument's return by the value of beta.

Finally, we multiply the fair value of positions held by banks with the corresponding risk exposure coefficient. For example, the reported fair value of treasuries with a maturity of one year is multiplied with the beta coefficient obtained when regressing treasuries with maturity of one year on our risk factors. The result is a simple factor portfolio that will, over the next quarter, react to interest rate risk and credit risk in the same way as the position held by the bank.

Since we want to capture how risk exposures affect the value of positions, we need instruments to be expressed in terms of fair values. For treasuries and mortgage-backed securities (MBS), banks report fair values. Loans, other borrowed money and deposits are reported in face value and therefore need to be converted into fair values before the factor portfolios can be constructed. Fair values are computed by discounting all future payment streams. Adjustments also need to be made to trading assets and liabilities, even though banks report fair values of these. The possibility of offsetting positions means that banks may not be exposed to the full extent suggested by the reported fair value. Instead, we compute fair values as the present value of the bid-ask spread plus the net gains from trading on own account.

We find that banks' exposure to interest rate risk has increased since the beginning of our sample. The contribution of each position to aggregate interest rate risk exposure has changed since the crisis; whereas the exposure of derivatives caused a sharp increase in exposure in the years leading up to the crisis, derivatives play a less important role in following years. In contrast, all other positions are more exposed after than before the crisis.

By considering individual positions, we try to explain why each position is more exposed to interest rate risk by examining the risk factor and the maturity and quality distributions. We find that banks hold more contracts of longer maturities as well as, in the case of loans, of lower quality. Banks also hold higher fair values across the entire balance sheet. We find that increased exposure contributes to higher typical gains or losses in response to changes in the interest rate factor post-crisis. This indicates increased sensitivity to changes in the yield curve.

This paper is structured in the following way. Section 2 discusses related literature. Section 3 outlines data processing and methodology for constructing factor portfolios. Section 4 presents the results. Finally, in Section 5 we conclude our study and propose potential areas for future research.

2 Related literature

The purpose of this paper is to understand banks' increased exposure to interest rate risk after the financial crisis, as found by Bailey and Matyáš (2019) by regressing bank stock return on the interest rate risk factor. It is common in the literature to measure banks' exposure to macroeconomic risk factors by considering bank performance, such as bank stock returns (Flannery and James, 1984; English et al., 2018) or the income gap (English, 2002; Gomez et al., 2020). Alternatively, Meiselman et al. (2020) apply the argument of high risk, high return to use high profits as an indicator of high systematic risk, whereas Sarin and Summers (2016) examine volatility as a sign of risk-taking.

Rather than using a performance measure, we measure exposure to risk by considering the banks' assets and liabilities. We are thus able to trace how the exposure of different positions held by banks reacts to changes in the interest rate, and to pin down possible causes of the increased sensitivity to the slope of the yield curve. We analyse the positions held by banks by constructing simple factor portfolios, following the methodology of Begenau et al. (2015). By replicating this paper, we do not only obtain factor portfolios used to analyse the exposure of fixed income positions to interest rate risk, we also aim at confirming the validity of their findings. Furthermore, their study contains data up to 2014. We extend the sample period to include data up to the final quarter of 2019. In doing so, our sample contains more data from after the 2008 recession and we are consequently better equipped to trace the long-term evolution of banks' risk exposure since the financial crisis.

In order to understand banks' increased sensitivity to the yield curve since the crisis, we have to consider the low-rate environment that has prevailed since. There is a long tradition of analysing banks' behaviour in response to changes in the interest rate as a way of measuring the transmission of monetary policy (Bernanke and Blinder, 1992; Drechsler, 2017). The existence of a risk-taking or risk premium channel has also been examined, under which changes in the interest rate can not only be used to influence the amount of loans, but also the quality of them.

Drechsler et al. (2014) find that banks hold liquid assets as buffers in order to prevent costly fire sales in the event of a funding shock. Lower rates imply cheaper liquidity premia, which allow a larger buffer to be kept and consequently more risk-taking. Another section of the literature finds that low rates increase risk-taking by negatively affecting bank profitability. Firstly, banks are forced to lower loan rates due to competition or contractual repricing but are hesitant to lower deposit rates, which leads to reduced net interest margins (NIM). Secondly, a flatter yield curve negatively affects the return from banks' maturity transformation (Borio et al., 2015; Busch and Memmel, 2015; Claessens et al., 2018). Reduced profitability could incentivise banks to increase risk-taking by lowering lending standards or by increasing the maturity mismatch in their maturity transformation (Maddaloni and Peydró, 2011; Dell'Ariccia and Marquez, 2013; Adrian et al., 2014; Bologna, 2018). By tracing the changes in the composition of banks' balance sheets, we are able to analyse how and why the exposure of individual positions have changed since the crisis. For example, we can map the quality of loans held and their contribution to interest rate risk exposure, and from this infer whether banks are more willing to take risk since the crisis.

Our contribution to the literature consists of two main parts. Firstly, we confirm the validity of the findings of Begenau et al. (2015) by replicating their study, something which is of high demand in the field of finance today. Secondly, we are able to trace the historical evolution of risk exposure of individual positions on the banks' balance sheets, and thus analyse whether the banking sector is more exposed to interest rate risk under the low-rate environment since the financial crisis of 2008.

3 Data and empirical strategy

3.1 Data sources

We retrieve data from four sources: FFIEC, the Chicago Fed, WRDS and ICE. A closer description of how data from each source is used, as well as a discussion of their limitations, follow below.

3.2 Bank data

Our sample covers all domestic top-tier bank holding companies (BHCs) in the U.S. between 2001:Q1 and 2019:Q4. We therefore eliminate all BHCs that is owned by another BHC and all BHCs that have a foreign parent. We infer that BHCs with an RSSD9348 variable of zero are top holders. This variable identifies the top holder in the organization hierarchy. When identifying BHCs, we also include financial holding companies (FHD), which is a type of bank holding company. By including these two entity types, we exclude foreign intermediate holding companies (IHCs). This is an attempt to as closely as possible recreate the sample used by Begenau et al. (2015). We further decide to follow their example of excluding Goldman Sachs and Morgan Stanley from our sample since they have only been classified as BHCs since the crisis.

BHC data is collected from the FR Y-9C report, retrieved from the Federal Reserve Bank of Chicago, which provides quarterly data for all domestic holding companies on a consolidated basis. The report has been updated on multiple occasions during our sample period, with updates such as new codes for variables as well as the addition and transformation of variables. We trace these changes by comparing historical reports. By doing so, we produce a list of relevant variables for each quarter of our sample.[1]

One limitation of the FR Y-9C report is that it does not require banks to report maturity distributions for all their assets and liabilities. Maturity distributions are central to our analysis since we expect the length of the contract to influence its sensitivity to changes in the interest rate. For the sake of our analysis, the FR Y-9C report only provides sufficient information regarding maturity distribution for trading assets and liabilities. In order to circumvent this issue, we use complementary data from the FFIEC 031 and 041 reports for commercial banks, retrieved from the FFIEC Central Data Repository's Public Data Distribution website. For each quarter of our sample, we aggregate the relevant maturity variables for all commercial banks that belong to the same BHC, using variable RSSD9348 in the FFIEC 031 and 041 reports to identify the top holder. Because structural information is not included in the commercial bank data from the FFIEC, we use the Bank Regulatory database on WRDS to access variable RSSD9348 for each commercial bank. We then compute maturity distributions expressed as percentages of the total value of an instrument (e.g. treasuries), which are applied to the total instrument value of the BHC in the FR Y-9C report. A few of our BHCs do not have commercial banks. For these, we use the average position maturity distribution for that quarter.

Ideally, the aggregated position value of the commercial banks would equal the position value of their BHC. This would allow us to use the maturity distributions of the commercial banks as perfect substitutes for the BHC data and thus proceed with the analysis without applying the maturity distribution to the BHC. This method is used by Begenau et al. (2015). However, we observe deltas when comparing aggregated commercial bank data to BHC data. Proceeding with commercial bank data would therefore result in a reduction in the value of BHC assets and liabilities. We therefore consider our best option to be to use the average maturity distribution of all commercial banks belonging to the same BHC at a particular date as an estimation of the actual maturity distribution of that BHC at that date.

Finally, the FFIEC makes a distinction between banks with domestic and foreign offices and banks with domestic offices only. Banks with domestic and foreign offices file the FFIEC 031 report while banks with domestic offices only file the FFIEC 041 report. When selecting variables from the FFIEC data files, we sum the variables that are denoted with the different series in the two reports. For these variables, RCFD denotes

[1] Appendix B lists the variables we used from the FR-Y-9C and FFIEC 031 and 041 forms.

consolidated foreign and domestic data (FFIEC 031) and RCON denotes domestic data (FFIEC 041).

3.3 Returns and risk exposure by instrument

We consider two risk factors. The first one is the interest rate risk factor, computed as the return of a safe bond. We use the ICE BofA 5 Year US Dollar Tradeable Zero Coupon Swap Index, collected from ICE, for the safe zero coupon bond return. Our second risk factor is the credit risk factor, computed as the residual when regressing the return of a risky bond on the safe interest rate risk factor. This allows us to isolate the credit risk. We use the ICE BofA 3-5 Year BBB US Corporate Index, also collected from ICE, for the higher risk bond return.

We want our instruments to cover the different pay-off structures, credit qualities and maturities of bank positions. We therefore collect returns for treasuries, bonds (AAA to CCC and below), swaps and MBS for all quarters in our sample from ICE in order to estimate risk exposure by instrument. For every category, Bank of America Merrill Lynch provides return indices for various maturities. We use these returns and our factors to recursively run exposure regressions using

$$R_i^t = \alpha_i + \beta_i^{INT} R_t^{INT} + \beta_i^{CR} R_t^{CR} + u_t^i \quad (1)$$

where R_i^t is the return of instrument i, such as the return of a short term AAA rated security. R_t^{INT} is the interest rate risk factor and R_t^{CR} is the credit risk factor. The betas are the factor exposure coefficients and show how much the return of instrument i moves with a change in the return of the risk factor. This allows us to compute factor portfolios for banks by multiplying bank positions with our risk exposure coefficients. The residual in (1) captures the part of the return of instrument i that cannot be explained by our two risk factors. A possible extension would be to include more macroeconomic risk factors or risk factors specific to an instrument in the regression.

In order to understand why recursive regressions are used, it is useful to recall that the risk factors in (1) originate from bond returns. Because there will exist some co-movement between the return of instrument i and the bond returns used for risk factors, we can use historical co-movements to predict how much the return of instrument i will move over the next quarter as the risk factor moves. We further expect the level of co-movement between bond returns in (1) to vary for each quarter. Since we want to capture the expectations for the next quarter that was prevailing during each period in our sample, we run regressions using data up to that point in time.

Positions with maturities shorter than one quarter are treated as riskless. Therefore, we do not apply our risk exposure coefficients on these positions. Among banks' balance sheet positions, these include cash, Fed funds and repo positions, and short deposits, which all have typical maturities below one quarter. Furthermore, we treat all non-interesting bearing deposits as short deposits.

The result from the exposure regressions in (1), using quarterly returns from the full period 1997:Q1 and 2019:Q4, can be seen in Table 1. Columns 1 and 2 show which instrument is being considered. Columns 3 and 4 report the mean and standard deviation per quarter. Longer maturities typically mean higher returns and more volatility. Comparison between instruments shows that lower quality instruments, such as CCC and lower rated bonds, have higher returns and are more volatile than highly rated bonds.

Column 5 and 6 relate to the interest rate factor. We observe that highly rated bonds have a positive exposure to the interest rate factor. This means that the bond returns co-move positively with the interest rate factor and thus co-move negatively with the level of the yield curve. This makes intuitive sense: bond prices rise when the yield curve falls, which results in higher returns. Equivalently, positions with a positive exposure to the interest rate risk factor decrease in value when yields rise. For low quality bonds we observe the opposite; they are less exposed to the interest rate factor. Finally, longer maturities result in more interest rate risk exposures for all instruments but CCC and below, where we observe an increasingly negative exposure.

Column 7 and 8 relate to the credit risk factor. Highly rated bonds show only limited exposure to the credit-risk factor. Most coefficients are not significant. Low quality bonds, on the other hand, are highly exposed to the credit-risk factor, with significant coefficients. When credit spreads widen, a holder of a position with positive exposure to the credit risk factor loses money as risky bond prices fall.

In column 9, we see that the factors capture variation in returns well, with most R^2s above 70%. Finally, column 10 shows that a factor model with only the interest rate factor can explain returns for highly rated bonds.

Table 1. Exposure Regressions

		mean (in %)	vol (in %)	β^{INT}	t-stat	β^{CR}	t-stat	R^2	R^2_{INT}
Treasuries	short	0.79	0.93	0.29	14.13	0.02	0.75	0.69	0.69
	medium	1.29	2.56	0.93	40.55	-0.04	-1.25	0.95	0.95
	long	1.57	3.65	1.24	20.53	-0.08	-1.09	0.83	0.82
Swap	short	0.88	1.15	0.38	17.13	0.02	0.67	0.77	0.77
	medium	1.31	2.68	1.00	>100	0.00	-0.41	1.00	1.00
	long	2.25	7.35	2.47	20.98	-0.55	-3.66	0.84	0.81
AAA	short	0.95	1.05	0.30	12.35	0.15	4.92	0.66	0.57
	medium	1.48	2.56	0.83	17.73	0.23	3.83	0.79	0.75
	long	1.77	4.07	1.24	13.36	-0.18	-1.49	0.67	0.66
BBB	short	1.16	1.47	0.03	1.75	0.67	30.70	0.91	0.00
	medium	1.64	2.85	0.16	6.27	1.31	41.37	0.95	0.02
	long	1.95	3.22	0.41	7.96	1.31	19.83	0.84	0.12
CCC and lower	short	2.14	6.90	-0.81	-3.97	1.94	7.47	0.45	0.10
	medium	2.05	9.05	-1.47	-8.50	3.28	14.87	0.77	0.19
	long	4.37	21.80	-2.35	-2.99	3.56	3.61	0.21	0.09
MBS	short	0.98	0.86	0.23	10.18	0.11	3.93	0.57	0.50
	medium	1.14	1.22	0.41	20.36	0.10	3.84	0.83	0.80
	long	1.14	1.30	0.44	20.74	0.11	3.96	0.83	0.80

Note: The sample is quarterly data from 1997:Q1 to 2019:Q4. Columns 1 and 2 refer to the instrument being considered. For treasuries, AAA rated bonds, BBB rated bonds and CCC and lower rated bonds, "short" maturities refer to 1-3 years, "medium" maturities to 5-7 years and "long" maturities to 10-15 years. For swaps, 2 years, 5 years and 15 years are used. For MBS, 0-3 years, 3-5 years and 15 years are used. Column 3 and 4 are the mean and standard deviation per quarter. Columns 5-9 show the results from exposure regressions. Column 10 shows the R^2 from regressions on only the interest rate factor.

3.4 Rates

The fair value of an instrument is defined as the present value of all future payment streams. The computation of fair values therefore requires interest rates, both to compute interest payments and to discount payment streams. For each BHC, we estimate different interest rates for different instruments. This allows us to capture different terms offered by different banks. Apart from swap and loan rates, the methods discussed below all use data from the FR Y-9C report.

Loans

We infer loan rates by using the fact that a loan can be considered a portfolio of zero coupon bonds: the amortisations and interest rate payments of a loan occur at regular intervals and are of equal sizes, and each payment stream can therefore be replicated by the principal payment of a zero coupon bond. It is therefore possible to use the rates of securities to compute the fair value of loans.

We apply the risk weights provided in schedule HC-R on the aggregate face value held by a bank in order to divide the position into different credit rating categories. Based on the risk weights, we categorise the loans as follows: risk weight of 0% to treasuries, risk weight of 20% to AAA, risk weight of 50% to A, and risk weight of 100% or more to BBB. The rate used for a loan of a particular quality and maturity is then approximated as the yield curve for that quality. The yield curve data is collected from ICE.

Other borrowed money and deposits

The annual interest rate on deposits and other borrowed money are estimated as the quotient of the interest income and the total value of the corresponding liability. For example, the annual deposit rate is computed as interest income on deposits divided by total interest-bearing deposits. Because the banks report values in year-to-date, we find the annual rate of year *t* by looking at the report of Q4 for year *t*. The annual rate is then divided by four to find the quarterly rate.

Our method implies the simplifying assumption that banks do not use different rates for different maturities. In the real world, we would expect rates to vary along this parameter. Taking maturities into account when computing rates would therefore give a more accurate output.

Swap rates

Historical data on swap rates are used to calculate payment streams of derivatives. Data on bid and ask prices as well as bid-ask spread is collected from ICE, using the swap rate for the 3-month LIBOR rate. In order to match the maturities of derivatives in call reports, we retrieve data on one-year, three-year and five-year maturities.

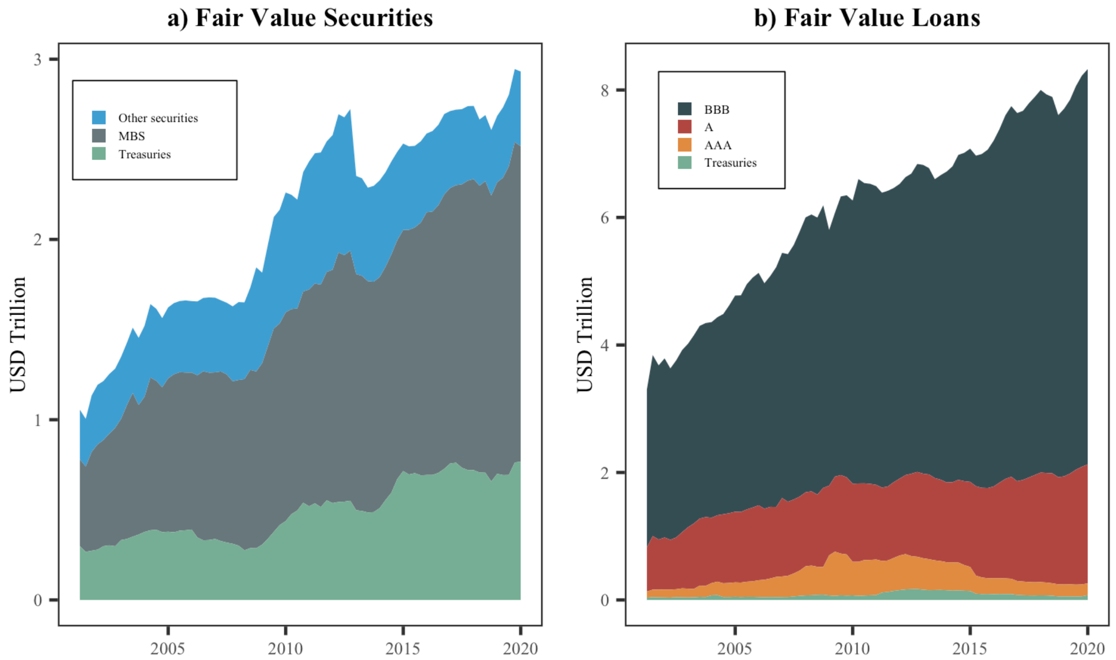
Finally, we use the 3-month LIBOR from ICE, in combination with net gains on derivatives, to infer trading direction. Because the 3-month LIBOR reports Q1 as 1 April rather than 31 March, as is the case with other data used, the dates are transformed by subtracting one day.

3.5 Securities

Banks report securities in fair values, which means that our risk exposure coefficients can be directly applied once the data has been categorised. We split securities into treasuries, MBS and other securities. We begin by applying the relevant maturity distributions from commercial banks to BHC data, as described in Section 3.2. For each of our instruments, we obtain maturities of less than three months, three to twelve months, one to three years, five to fifteen years, and more than fifteen years.

Other securities include all variables other than treasuries (including government obligations) and MBS. Since we do not have maturity distributions for other securities, we use those of MBS as an approximation. Similarly, the risk exposure coefficients for MBS is used as an estimate for other securities. As with loans, it would be possible to further break down securities into different risk classes using schedule HC-B and HC-R. For example, it would be possible to use schedule HC-B to make a distinction between agency MBS and other MBS and schedule HC-R to infer the risk distribution of other securities.

Figure 1. Fair values of security and loan holdings of aggregate U.S. banking sector by risk class



Note: Fair value held between 2001:Q1 and 2019:Q4, expressed in USD trillion. Fair value maturity distributions are available in appendix A.1. Left panel: Securities. As mentioned in Section 3.5, it would be possible to split other securities into different risk categories. Right panel: Loans. The categories represent the risk weights allocated from schedule HC-R. Fair value is computed by discounting all future payments streams of amortisations and interest rate payments.

The left panel in Figure 1 shows the fair value of securities held from 2001 to 2019. The total amount held has more than doubled since the beginning of the sample. We observe an increase between 2001-2005, followed by a flat period until the crisis. The post-crisis years are characterised by a sharp increase in the fair value held, that after a dip in around 2013 begins to climb again. As for individual positions, MBS have seen the largest growth. Whereas the level of short-term MBS has been relatively constant at a low level, both medium- and long-term contracts increases until 2013, after which the former begins to decline. The fair value of long-term MBS, however, increases even more after 2013. The fair value of treasuries has also increased, despite a period of reduced values leading up to the crisis. This increase is fairly proportionate across all maturities (appendix A.1.).

The fair values of securities held is comparable to the result of Begenau et al. (2015). They show a similar trend of growth that peaks around 2013, followed by a drop just before the end of their sample. However, their results do not show the stagnation of growth in the years before the crisis, but rather displays constant growth, to a large extent driven by the increase in long maturities. Finally, we observe that the fair values reported by Begenau et al. (2015) are higher: they show a peak in 2013 of almost USD 4 trillion, whereas ours is closer to USD 3 trillion.

3.6 Loans

Maturity distributions are computed using commercial bank data and then applied to BHC data as described in Section 3.2. Loans are reported in face value, which needs to be converted into fair value before the risk exposure coefficients can be applied. The fair value will differ from the face value if the interest rate, used for both interest rate payments and discounting, has changed since issuance. We therefore need to infer the issuance of new loans in order to compute all interest payments and amortisations associated with that loan.

Inferring the issuance of new loans

We assume that the full face value observed in the first period of our sample was issued in that period. This follows the assumption made by Begenau et al. (2015). They justify this by claiming that "the results are not particularly sensitive to initial conditions since many loans are short term and outstanding loans grow exponentially over time".[2]

With this assumption, we have new loans = face value in the first quarter. Next, we calculate the remaining value at period t as the sum of new loans from period 1 to $t - 1$, minus the cumulative sum of all amortisations. We assume equal amortisations, which will depend on the maturity of the loan. For example, a six months loan issued at period t will be amortised by half its value in period $t + 1$ and by the remaining half in period $t + 2$. Equivalently, a two-year loan will be amortised by 1/8th of its value each period for two years.

Finally, new loans are computed as the difference between the reported face value and the remaining value. The sign of new loans indicates the direction, such that a positive value implies issuance of new loans, and a negative value implies the termination of loans.

In some instances, we observe a period of face values equal to zero between periods of non-zero face values. This is interpreted as the bank selling all loans in period $t - 1$ to achieve a face value of zero in period t. As a result, the bank will not receive any future amortisations or interest payments associated with the sold loans, and the fair value will thus be zero until new loans are issued and the reported face value deviates from zero.

[2] Begenau et al. (2015), p. 29

Computing fair value

By running the iteration above, we find information on new loans issued as well as amortisation streams. We assume that new loans are issued at a fixed rate of the interest rate prevailing on that day. We further assume that the interest rate payment of date t depends on the remaining value of the loan at date t after amortisation. This implies that the interest rate payment at the date of the final amortisation will be zero. One implication of this simplifying assumption is that no interest will be paid on loans with a maturity of three months, since these loans will be fully amortised by the first period. This will have limited effect on our analysis since we, like Begenau et al. (2015), treat all instruments with maturities of three months or less as short-term assets or liabilities that can be converted to cash. As such, they are considered risk-less and are not subject to our analysis (see Section 3.3).

The fair value held on date t is found by discounting the future interest rate payments and amortisations on all loans outstanding on this date, using the interest rate of date t. The loans issued on date t will still have all future payment streams left, whereas older loans will have fewer payment streams left due to previous interest rate payments and amortisations.

The right panel in Figure 1 shows the aggregate fair value of loans held by the U.S. banking sector between 2001-2019. The total value held has been increasing throughout the sample period, to a large extent driven by the increase in BBB rated loans, which is also by far the largest risk category held. An increase can also be seen in the fair value of A rated loans, which after keeping a relatively constant level began to grow in 2015. 2015 also marks a decline in safer loans held; the fair value of AAA loans had been growing since the start of the sample whereas treasuries saw a short period of increase between 2011-2015. The majority of loans held are of short maturity, a category which has been growing at a relatively constant rate since 2001. The values of medium- and long-term loans are constant until the crisis, after which they increase slightly. This trend is particularly noticeable for the latter (appendix A.1.). The trend shown in Figure 1 is almost identical to that found by Begenau et al. (2015), both in terms of shape and values.

3.7 Deposits and other borrowed money

The maturity distributions of deposits and other borrowed money are approximated using the method in Section 3.2. BHCs report both deposits and other borrowed money in face value, which we convert into fair values using a method similar to that of loans in Section 3.6. We assume that neither deposits nor other borrowed money are amortised but rather repaid as a full principal at the end of the maturity, following the method used by Begenau et al. (2015). The computation of fair values will thus consist of the discounting of a stream of interest payments followed by a principal.

Risk factor portfolios are constructed by multiplying the fair values with the treasury exposure coefficients. A safe bond is chosen because neither deposits nor other borrowed money are exposed to the risk of default. Unlike loans, for example, the bank would not lose future payments streams if the other party defaults. The bank is, however, exposed to interest rate risk; the interest payments that the bank is obliged to pay depend on the interest rate. Following this logic, the risk factor portfolios for deposits and other borrowed money only reflect different maturities.

3.8 Trading assets and liabilities

For trading assets and liabilities, all relevant data is provided in the FR Y-9C report. Banks report gross notional amounts on interest rate, foreign exchange, equity derivative and commodity and other contracts, as well as credit derivatives. For the sake of our analysis, we consider only interest rate contracts, for which we also access gross positive and negative fair values. These variables are reported both for derivatives held for trading and held for purposes other than trading. In measuring the exposure of trading assets and liabilities to interest rate risk, we look only at those held for trading. Derivatives held for purposes other than trading are considered other assets or liabilities, depending on the sign of the position. Following the method of Begenau et al. (2015), we treat all interest rate derivatives as swaps in order to simplify computations.

Schedule HC-R provides information on maturity distributions for notional amounts of derivative contracts. Maturities are available for less than one year, one to five years, and over five years. The report further specifies whether the contract is over-the-counter or centrally cleared. Our analysis sums these as one type of derivative. Because the maturity distribution does not make the distinction between derivatives held for trading and held for other purposes, we compute each maturity as a percentage which is then applied to the amount held for trading. This approximation assumes that banks' decision on which maturities to hold does not depend on whether the derivatives is held for trading or other purposes.

Even though banks report the fair value of derivatives, the possibility of offsetting positions prevents us from directly applying our risk exposure coefficients. If a bank were to hold exclusively offsetting positions, and thus be a pure intermediary, they would be committed to in one position pay the fixed and receive the floating rate, and in the other position pay the floating and receive the fixed rate. This means that the bank is not exposed to changes in these rates, and it would therefore be misleading to estimate risk exposure from the bank's total notional values.

Even as a pure intermediary, the bank can have positive fair values. In practice, the bank does not set a textbook swap rate such as to achieve an initial fair value of zero, but instead earns money by adjusting the rate by integrating the bid-ask spread. For the purpose of our analysis, we incorporate the same adjustment as used by Begenau et al. (2015), and thus assume that the bank sets a swap rate of $s = \bar{s} - \varphi z$, where $\bar{s}$ is the textbook swap rate that sets fair value to zero, φ is the direction of the trade (1 for pay-fixed, -1 for pay-floating) , and z is half the bid-ask spread. This assumption is motivated by the fact that banks typically sets the swap rate on a pay-fixed swap lower than the rate that sets fair value to zero, whereas the rate on pay-floating swaps tends to be higher.

Because we assume that the bank makes these adjustments by incorporating half the bid-ask spread, a pure intermediary with a total notional of USD 1 would only have payment streams equal to half the spread (z). The fair value can then be found by considering at which price the bank could sell its positions, that is, the bid price that buyers are willing to pay. Consequently, the fair value of derivatives held by a pure intermediary depends only on the present value of bid-ask spread.

The bank can also trade on own account. It will then hold non-offsetting positions and not be a pure intermediary. In order to deal with this, we consider the fair value to be the sum of the present value of the bid-ask spread and the net gains from trading on own account:

$$FV_t = \sum_m N_t^m z_t^m \sum_{j=1}^{m} P_t^{(j)} + \sum_{\phi,m} \widehat{N}_t^{\phi,m} \phi F_t\left(s_t^{-\phi,m}, m\right) \qquad (2)$$

Because of assumptions made when computing the fair value of trading on own account (see below), we will not follow the method previously used when computing fair values for each maturity. Instead, the fair value of each quarter t will be computed by accounting for all maturities.

Computing Rent

When computing rent, we use information on bid-ask spreads and gross notionals. We first infer new swaps bought or sold on each date by using the same method as for loans, deposits and other borrowed money (see Section 3.6). It is necessary to separate new swaps from total notionals in order to determine the value of the bid-ask spread held by the bank at each date.

We proceed by computing the average bid-ask spread at each date, weighted by total notionals (z). Consider a swap with a maturity of six months. The new swap issued at *t = 1* will remain as a notional for two quarters. Total notionals at *t = 1* will consist only of the new swap$_{(t=1)}$, whereas total notionals at *t = 2* will be the sum of new swap$_{(t=1)}$ and new swap$_{(t=2)}$. Each of these new swaps will be associated with half the bid-ask spread of *t = 1* and *t = 2*, respectively. Furthermore, the overall effect of the bid-ask spread of a particular date on the bank will depend on the size of the notional of that date. We therefore weigh the spreads for the maturity of six months accordingly:

$$z_t^{6m} = Spread_{t-1}^{6m} \times (New\ swapst_{t-1}^{6m} \div Total\ notionals_t^{6m}) + Spread_t^{6m} \times (New\ swapst_t^{6m} \div Total\ notionals_t^{6m}) \qquad (3)$$

By multiplying the average bid-ask spread of a maturity with the total notionals of that maturity held, we obtain the total value of spreads held by the bank. We find the fair value of this position by multiplying with the bid price. This process is repeated for all maturities. Finally, we sum the fair value of all maturities.

Computing net gains from trading on own account

In order to compute the second part of the fair value, we make further simplifying assumptions. Like Begenau et al. (2015), we assume that the maturity distributions of notionals and the locked in mid-market rates are independent of the direction of the position, and that the net gain at the average maturity is a suitable approximation of the average gain. These assumptions allow us to rewrite the second part of (2):

$$FV_t^{own} \approx \left(\widehat{N}_t^1 - \widehat{N}_t^{-1}\right) F_t(\overline{s_t}, \overline{m_t}) \qquad (4)$$

Begenau et al. (2015) further proves that the assumptions made allow, given a sufficiently small bid-ask spread, gross fair value to be written as:

$$GV_t \approx \widehat{N}_t F_t(\overline{s_t}, \overline{m_t}) \qquad (5)$$

Rearranging (5), we can express fair value as gross fair value divided by vintage notionals. We substitute this expression into (4). We also rewrite the expression for net notionals invested in pay fixed swaps as the difference between total gross fair value and the fair value of rent. This gives the gross fair value earned from trading on own account. In order to transform this expression into net values, we multiply with direction of the trade:

$$sign(FV_t - FV_t^{rent})\frac{GV_t}{N_{t-1}} \qquad (6)$$

Since the direction of trade is not reported by banks, this needs to be inferred. To do so, we use information on cumulative gains and interest rate history.

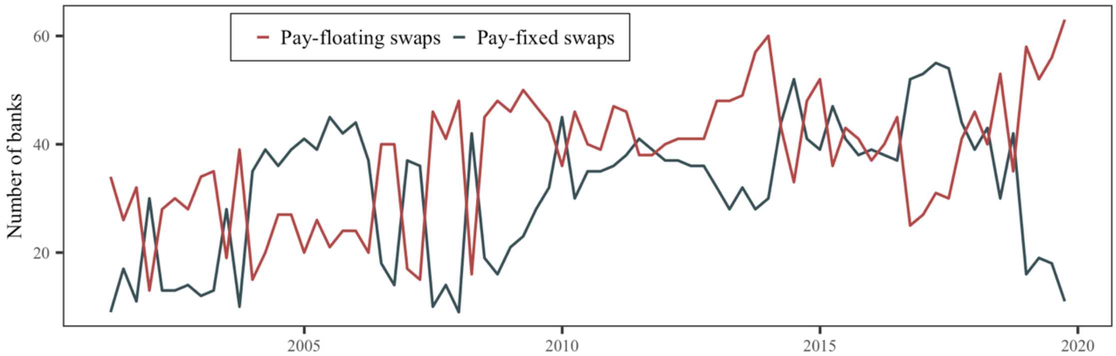
We depart from the method by Begenau et al. (2015) in inferring the direction of trade because we are unable to replicate their method. We find the direction of trade by looking at how changes in the LIBOR 3-month rate impact the reported gross positive and gross negative fair values. Changes in the interest rate will affect the value of both pay-fixed and pay-floating positions, but in opposite directions. For example, a decline in the interest rate will reduce the value of the pay-fixed position and thus contribute to the bank's reported gross fair negative value, and simultaneously increase the value of the pay-floating position which will contribute to the gross positive value. Because these effects will be of equal size for any offsetting positions, they will cancel out. Therefore, we compute the net effect by subtracting gross negative fair value from gross positive fair value. The resulting value indicates whether the bank's *overall* position is predominantly positive or negative.

Once again, we utilise the assumption that all positions are new in period 1. Consider a gross positive fair value (a) and a gross negative fair value (b) observed in quarter 2. These values will be the result of the new positions locked in at quarter 1 and the change of the interest rate from quarter 1 to 2. New positions entered in period 2 will not affect the fair value, since they are locked in at the current rate.

Because (a) and (b) react to the same change in interest rate, but (a) has a positive gross fair value whereas (b) has a negative, we know that they must be opposite positions. By computing the difference between (a) and (b), we can thus infer which position the bank predominantly entered into in the first period. For example, imagine that we observe a net positive fair value in quarter 2. We also observe that the interest rate has risen since quarter 1. This indicates that the bank at quarter 1 locked in more pay-fixed than pay-floating positions and is in our analysis considered to have pursued a pay-fixed strategy in quarter 1.

As we move to period 3, the gross fair values observed will depend on changes in the interest rate relative to rates locked in for positions in period 1 and 2. However, our logic of observing overall positions still apply. If, for example, we know that a pay-fixed position was taken in quarter 1 and we observe a falling rate between quarter 2 and 3, we know that the effect of our vintage position would be negative. If we then observe that (a) is larger than (b) in quarter 3, we can deduce that positions were taken in period 2 as to provide enough positive effect on fair value has to outweigh the negative effect of our vintage position from quarter 1. We would therefore infer that the bank entered more pay-floating than pay-fixed positions in quarter 2.

Figure 2. Inferred direction of trade for derivative contracts



Note: The direction of trade taken by banks between 2001:Q1 and 2019:Q4. The y-axis measures the number of banks pursuing a pay-floating or pay-fixed contract at a particular date. The red line represents pay-floating contracts and the grey line represents pay-fixed contracts.

Figure 2 shows the result of the inferred direction of trade. The y-axis measures the number of banks pursuing a pay-floating or pay-fixed contract at a particular date. The red line represents pay-floating contracts and the grey line represents pay-fixed contracts. Overall, the trend is highly volatile, contradicting Begenau et al.'s (2015) assumption that the direction of trade taken by banks exhibit a degree of persistence.

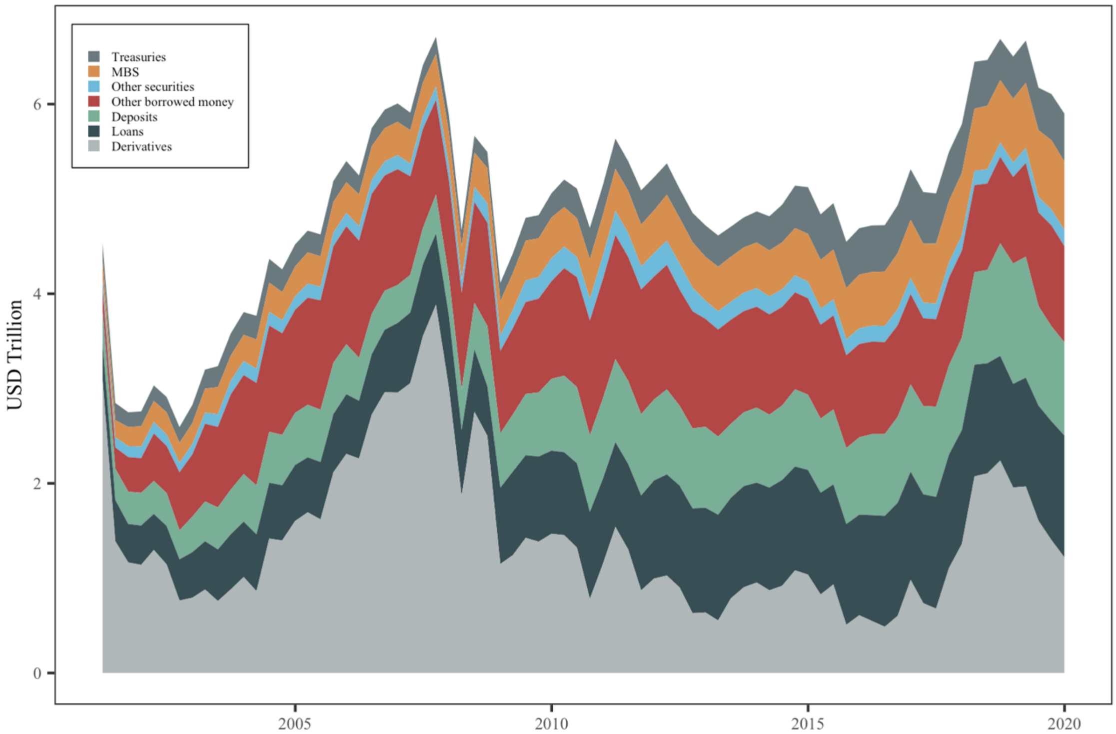
The fact that we do not use the method of Begenau et al. (2015) when inferring direction of trade could lead to different aggregate risk exposures. The direction will determine whether the exposure of a particular date and BHC will be added to or subtracted from the total, since pay-fixed is denoted as positive whereas pay-floating is negative in (6). This could affect the comparability of the two results.

4 Results

4.1 Risk exposure over time

By following the method outlined in Section 3, we derive the historical evolution of the interest rate in the U.S. banking sector between 2001 and 2019. As shown in Figure 3, exposure to interest rate risk increases sharply in the years leading up to the financial crisis of 2008. This peak is mainly driven by the exposure of derivatives, whose sharp increase is found also by Begenau et al. (2015).

Figure 3. Interest rate risk exposure of aggregate U.S. banking sector by position



Note: Aggregate interest rate risk for the U.S. banking sector, Q1:2001-Q4:2019. Each colour represents the total exposure of an instrument on the balance sheet, computed by multiplying the interest rate risk factor with the fair value of the instrument.

The shape of Figure 3 is comparable to that presented by Begenau et al. (2015). The main difference is that our values are higher; they show a peak of just over USD 4 trillion during the 2008 crisis, whereas ours is just over USD 6 trillion. This difference could be the result of different samples. Although both studies aim at including only top-tier domestic BHCs not owned by a foreign parent, we found it necessary to make assumptions in our attempt to replicate their sample of BHCs (see Section 3.2). It is therefore possible that our sample contains banks not considered by Begenau et al. (2015) because of our decision to include FHDs. However, we also find that our fair value of loans is similar to theirs, whereas we find lower fair values for securities (Figure 1). Based on this, we would expect our sample to result in similar or lower exposures. Alternatively, our sample contains banks with balance sheet compositions that result in similar fair values for some positions, while leading to higher values for others.

Another possible reason for the different values obtained could lie in the computation of fair values for derivatives, where we depart from their method. Because we compute direction of trade differently, the notation of pay-fixed positions as positive values and pay-floating as negative is likely to lead to different aggregated values (see Section 3.8). Although largely similar in shape, the difference in values means that our results may be better suited for considering general trends rather than absolute levels. This will be the foundation of our analysis. Finally, our data shows a sharp decline from previously high levels in the exposure of derivatives in 2001:Q1 which is not found in their study.

Even though our sample contains only a few years before 2008, we can observe that exposure did not fall back to pre-crisis levels after the crisis. An increased exposure is in line with the findings of Bailey and Matyáš (2019): banks are more sensitive to interest rate risk since the financial crisis. They theorise that banks were able to hedge the interest rate risk associated with maturity transformation before the crisis, similar to research by Drechsler et al. (2018), whereas they are unable to do so after the crisis due to the low-rate environment. Indeed, by considering the breakdown of aggregate interest risk exposure by position in Figure 3, we observe that all positions but derivatives carry more risk since the crisis. However, to attribute this increase only to banks' inability to hedge against interest rate risk misses the interesting aspects of changed willingness to take risk since the crisis.

In fact, the increased risk exposure observed also resonates with research that finds that lower rates incentivise increased risk-taking (Dell'Ariccia and Marquez, 2013; Adrian et al., 2014; Drechsler et al., 2014; Bologna, 2018), commonly motivated by a reduction of profitability (Borio et al., 2015; Busch and Memmel, 2015; Claessens et al., 2018). This could be traced to the composition of the balance sheet, where trends of longer maturities and reduced qualities could signal increased risk-taking. The following section examines possible causes of the change in risk exposure over the sample period for individual positions by considering changes in (1) the risk factor exposures, (2) the maturity distribution, and (3) quality of positions held.

4.1.1 Treasuries

The interest rate risk exposure of treasuries has been somewhat volatile with a general trend of growth. We observe a decline in the exposure between 2005 and 2008, after which a significant increase can be seen (Figure 4). The interest rate risk exposure coefficient for treasuries has been relatively constant over time (appendix A.2.). The exception is the coefficient for the maturity of over 15 years, where we observe an increase after the crisis. This means that each dollar held in contracts of maturities of over 15 years will contribute more to the overall exposure after the crisis. Approximately one third of treasuries held by the banking sector is classified as long-term, a fraction that has been constant throughout the sample period (appendix A.1.). Based on these observations, we conclude that some of the increased exposure could come from the change in the 15-year maturity risk exposure coefficient.

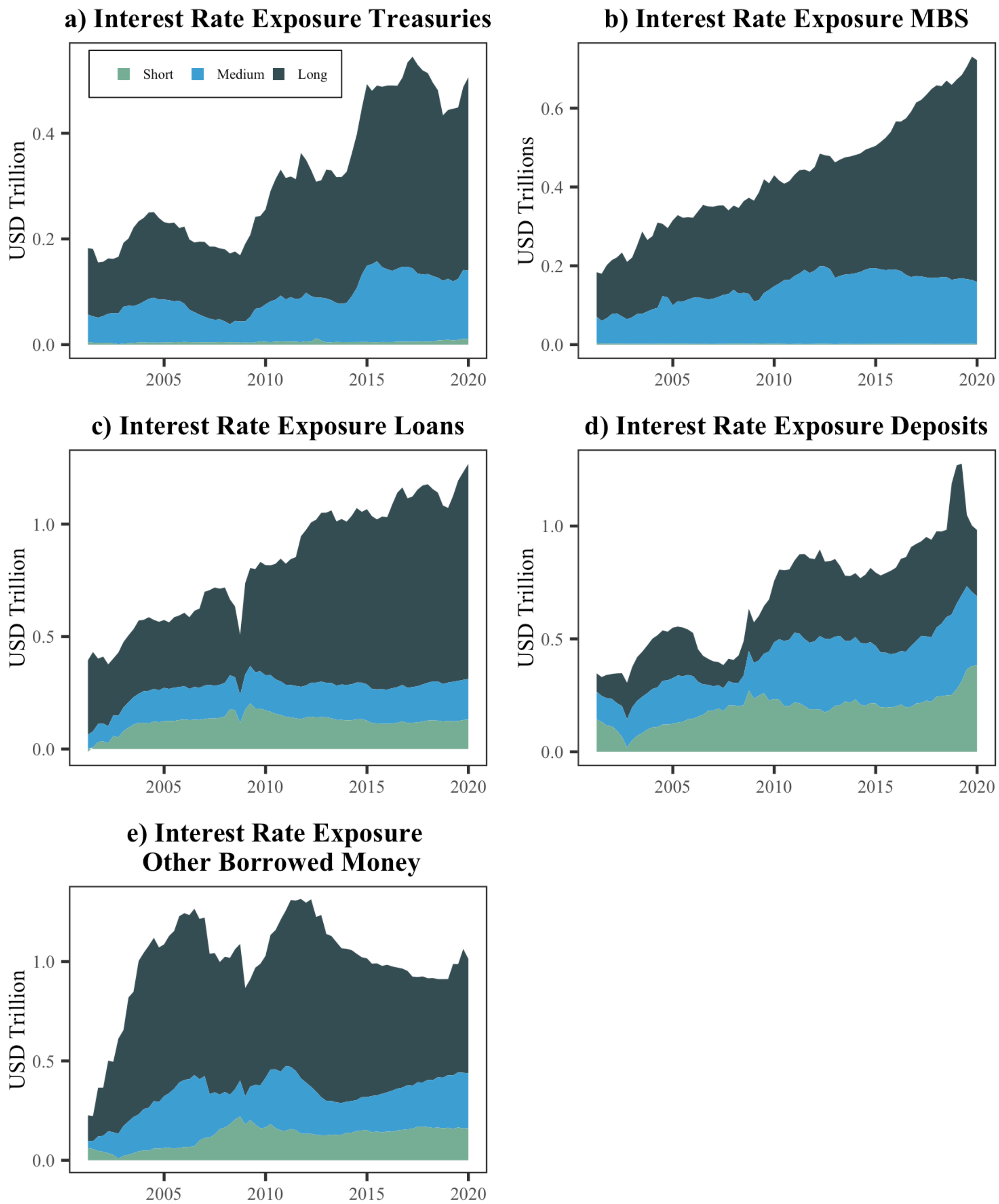
Even though we find that banks hold an approximately equal division of fair values derived from short-, medium-, and long-term contracts throughout the sample period,

Figure 4 shows that the majority of the exposure can be attributed to contracts of long maturities. This example illustrates the effect that the length of a contract has on interest rate risk exposure: longer contracts imply more risk. This becomes particularly evident when considering that although one third of the fair value held by banks is derived from short maturity contracts, the exposure of this category can hardly be seen in Figure 4. Finally, we expect the fact that banks have increased their overall holding of treasuries to affect the exposure (Figure 1). As the fair value held increases, the bank is more exposed to the interest rate risk factors (unless the beta coefficient is negative, see Section 3.3).

4.1.2 MBS

The interest rate risk exposure of MBS has been increasing at a constant rate since the beginning of our sample (Figure 4). Unlike treasuries, 2008 does not mark a noticeable shift in exposure. On the other hand, appendix A.1. shows a shift in the maturity distribution of banks around 2012 towards holding a higher amount of fair value derived from long-term contracts. This is mirrored in the interest rate risk exposure of MBS.

Figure 4. Interest rate risk exposure of aggregate U.S. banking sector by position



Note: Interest rate risk exposure by instrument and maturity, expressed in USD trillion. Top left panel: Treasuries. Top right panel: MBS. Middle left panel: Other borrowed money. Middle right panel: Deposits. Bottom left panel: Loans.

4.1.3 Other borrowed money

The interest rate risk exposure of other borrowed money increases sharply from 2001 to 2007. Following a decline, it once again increases to reach a slightly higher peak in 2012-2013. The exposure has since been declining but remains high. As discussed in Section 3.7, the exposure of other borrowed money is computed using the risk factors for treasuries. Given that other borrowed money only has maturity buckets of less than one year, one to three years and more than three years, the coefficient of the longest maturity that is applied is the 3-5 treasuries coefficient. Since we observe that the coefficients of lower maturities have been relatively stable, we infer that little of the increased exposure is derived from changes in the risk coefficients. Instead, we trace some of the increased exposure to the increase in long-term contracts between 2001-2007 (appendix A.1.). As with treasuries and MBS, long maturities are once again the main source of interest rate risk exposure. Finally, we observe that banks have increased their holdings of total other borrowed money across all maturities. This increases risk exposure following the reasoning in 4.1.1.

4.1.4 Deposits

Unlike other borrowed money, deposits exhibit a clear increase of interest rate risk exposure after the financial crisis. Exposure increases temporarily in the years leading up to the crisis but drops as the crisis hit. It has since been growing, with a sudden peak just before the end of our sample (Figure 4). Neither the dip during the crisis nor the peak in the late 2010s can be seen in the fair values held (appendix A.1.). Since deposits and other borrowed money have the same maturity buckets and coefficients, we do not expect changes in the risk exposure to be caused by changes in the risk coefficients.

Instead, we trace the dip to the maturity distribution of deposits held. In the years leading up to the crisis, banks gradually increase their holdings of all maturities, including long- and medium-term contracts. When the exposure drops, we simultaneously observe that banks reduce long- and medium-contracts while increasing short-term contracts. The positive relationship between exposure and the length of contracts held could therefore explain the drop.

After the crisis, banks increase their holding of all maturities. Although this include short-term contracts, Figure 4 shows that this category only contributes marginally to the increased exposure since the crisis. The increase is rather caused by long- and medium-maturities, consistent with the discussion in 4.1.1.

4.1.5 Loans

The interest rate risk exposure of loans has been increasing since the beginning of our sample, despite a sharp drop during the crisis (Figure 4). The temporary decline can be explained by the drop in the risk exposure coefficients for both AAA and BBB rated bonds. Although the effect is larger for long maturities, this can be seen for contracts of all lengths (appendix A.2.). The coefficients have been relatively stable after the crisis. For longer maturities of AAA quality, we first observe a sharp increase after the crisis to a level higher than the pre-crisis value, after which they continue to grow at a slow rate. A similar trend can be seen for long maturities for the BBB quality, whereas the exposure of medium maturities has fallen below the pre-crisis level.

Figure 4 shows that most of the exposure by maturity comes from long-term contracts, while appendix A.3 shows that the majority of risk exposure by quality comes from risky loans. When considering the composition of the balance sheet, we can see that banks' quality distribution is dominated by risky loans (Figure 1), whereas the maturity distribution is dominated by short-term contracts (appendix A.1.). The contribution of risky loans to the risk exposure is expected to be even larger after 2015, when banks reduce safe loans and increase risky loans. Indeed, appendix A.3. shows that this is the case. As with the positions discussed above, banks have been increasing their holdings of total fair value of loans across all maturities. The implications of increased fair values are discussed in 4.1.1.

Loans further illustrate how accounting measures can be misrepresentative of risk exposures. In Figure 1, we observe that loans have a fair value of around USD 7 trillion towards the end of our sample, while the fair value of securities is USD 3 trillion. Despite the fact that the fair value of loans is more than twice as large, loans have the same interest rate exposure as treasuries and MBS combined.

4.2 Findings

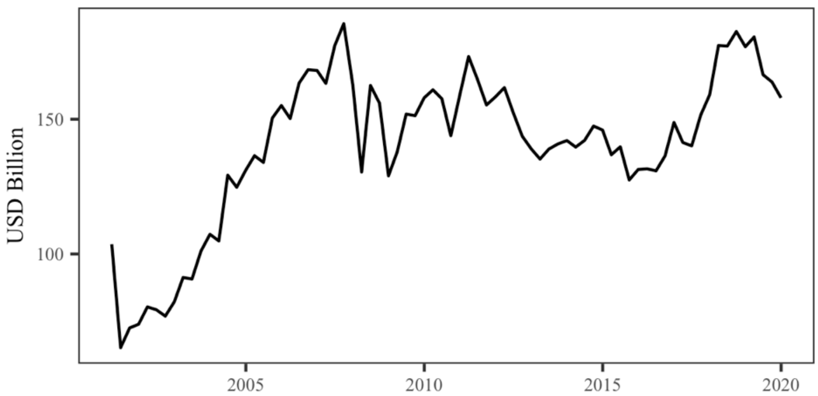
The analysis of interest rate risk exposure by instrument reveals a number of interesting trends. First, only a few examples of changes in the risk factor can be observed. The most notable changes can be seen in the risk factors for treasuries, AAA and BBB rated bonds, where the exposure of longer maturities increases after the crisis. This means that the majority of the instruments are expected to derive little of their increased sensitivity to interest rate risk from the risk factor.

It therefore seems that most of the increase in exposure of banks to interest rate risk cannot be attributed to changes in the risk factors. Instead, we trace the increased exposure to more risky loans, the maturity of contracts, and an increase in total assets and liabilities. We find that banks have added risk to their assets by holding more risky loans, in line with research that finds that low interest rates can incentivise increased risk-taking

(Dell'Ariccia and Marquez, 2013; Adrian et al., 2014). The presence of more risky loans could indicate reduced lending standards, as found by Maddaloni and Peydró (2011). It also resonates with the negative relationship between interest rates and the probability of successful loan applications found by Jiménes et al. (2012).

Risk can also be added by holding more contracts of longer maturities, a trend which can be observed across all instruments. We can also observe that the U.S. banking sector holds larger amounts across the entire balance sheet. This contributes to interest rate risk exposure, since exposure is computed in such a way that a higher fair value almost always leads to higher exposure.

Figure 5. Typical gain or loss U.S. banking sector



Note: Typical gains or losses of the U.S. banking sector in response to a standard deviation realisation of the interest rate risk factor, expressed in USD billion.

As mentioned, changes in the interest rate factor will change the value of a banks' position and thus the value of the bank itself. Using this logic, we construct Figure 5, which shows the typical gains or losses of the U.S. banking sector in response to a standard deviation realisation of the interest rate risk factor. It is derived from our position exposures and the recursively estimated interest rate factor volatilities, which has been relatively stable over our sample period (appendix A.4.). The constant levels of the factor volatilities explain why the shape of Figure 5 is similar to that of Figure 3. The fact that we observe higher typical gains and losses after the 2008 supports the notion that banks are indeed more sensitive to changes in the interest rate factor post-crisis.

5 Conclusions

By expressing banks' balance sheets in terms of simple factor portfolios, we show a number of interesting trends of how banks' exposure to interest rate risk has changed since 2001. We find that the banking sector as a whole is more sensitive to interest rate risk in the aftermath of the financial crisis. We are able to trace this change to individual positions and the factors that the exposure of these positions depends on. We find that little of this shift can be explained by differences in our risk factor exposures since they are relatively stable over time. The increase can in part be linked to the growth of the U.S. banking sector, but we also find that shifs in the maturity and quality compositions of banks' positions can explain some of the increased exposure.

There are multiple ways in which future research could extend our study. First, the accuracy of the study could be improved by a more detailed categorisation of securities into different risk categories. Furthermore, there are positions on the banks' balance sheets that are not included in our study. Including these would improve the results. Using instruments that better reflects their corresponding balance sheet position would also serve to make our results more accurate. Finally, successful replication of the computation of the fair value of interest rate derivatives used by Begenau et al. (2015) would improve comparability between the two studies.

Second, our analysis focuses on the banking sector as a whole. It would be interesting to examine the cross-section of banks, which could reveal heterogeneity in banks' risk exposure. For example, does the exposures of banks with a larger maturity mismatch differ from those with a smaller mismatch? Are high deposit banks more exposed than low deposit banks? This has, to the best of our knowledge, not been studied using the method of Begenau et al. (2015).

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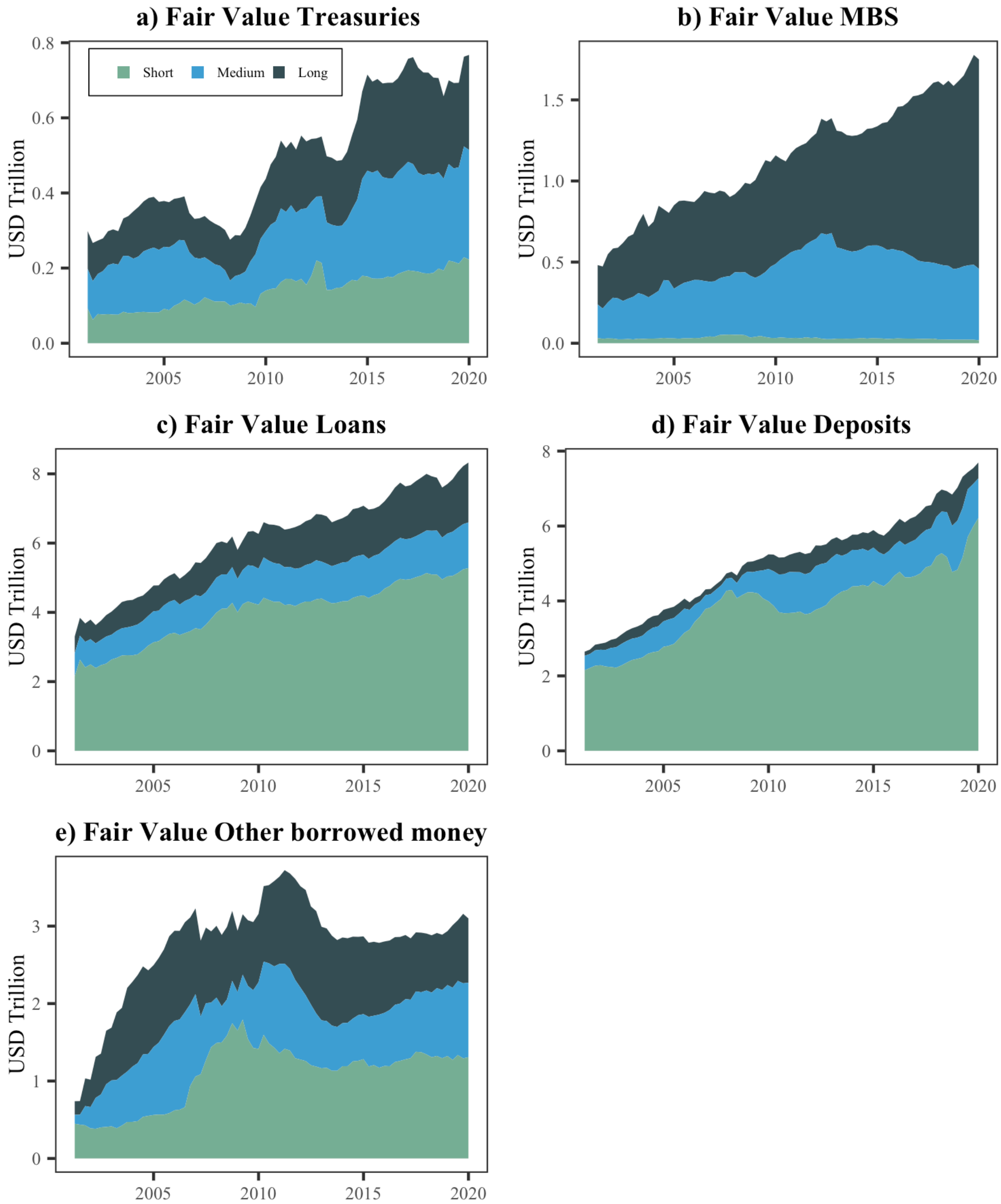
Appendix

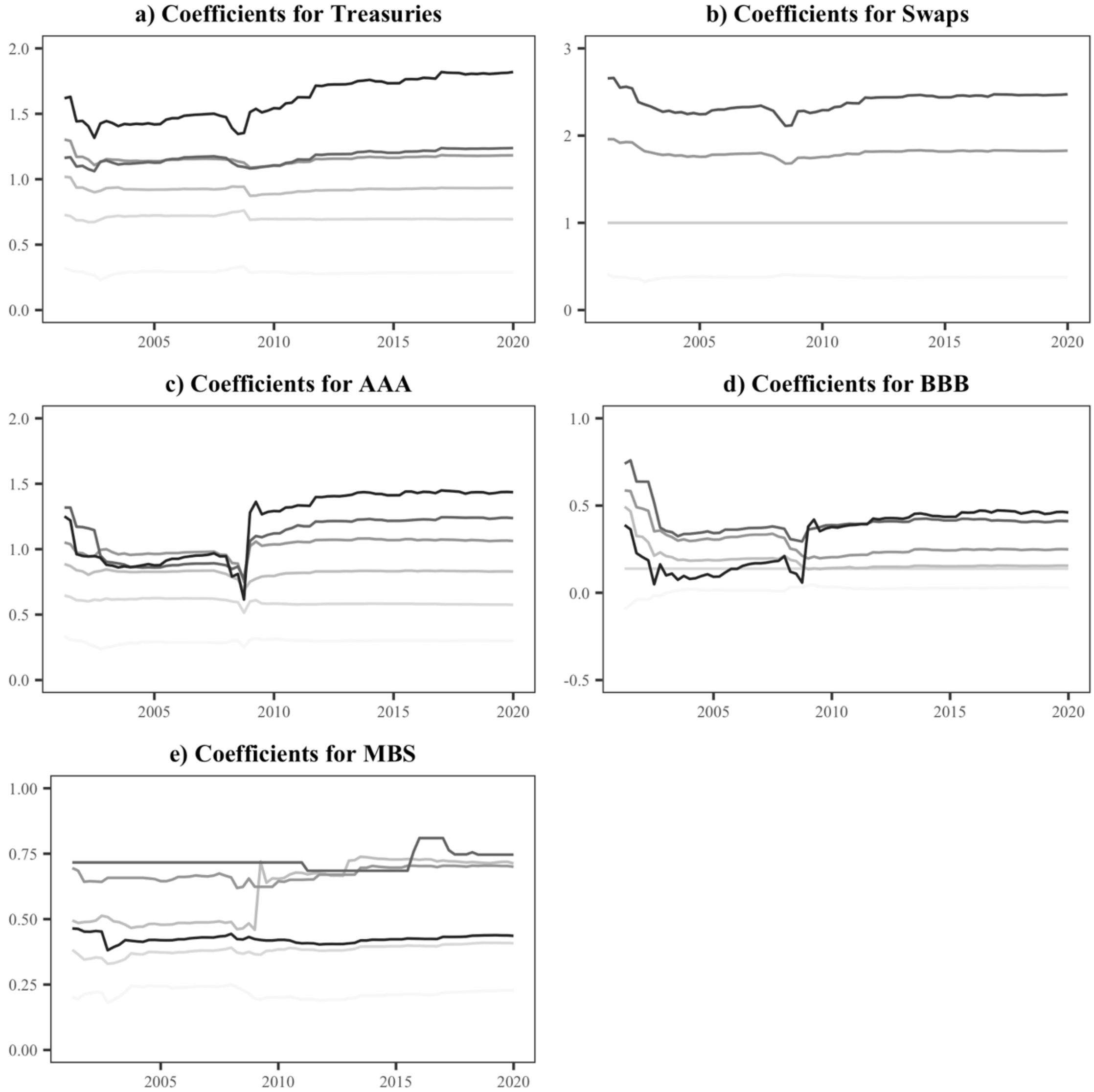
A. Additional figures

Figure A.1. Position fair value holdings of aggregate U.S. banking sector by maturity



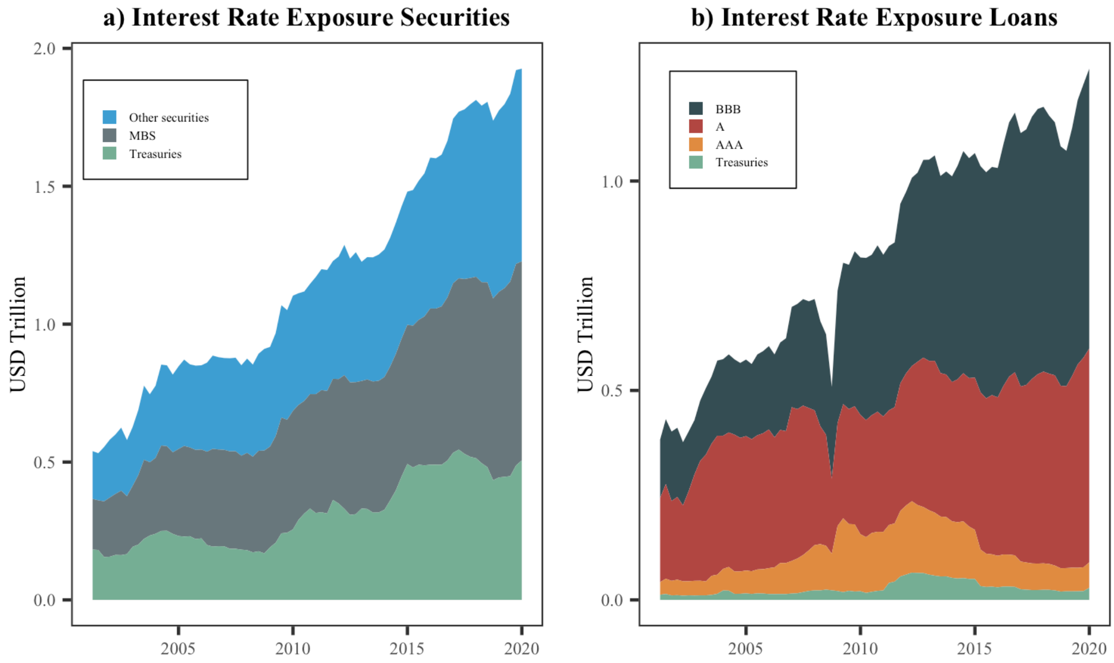
Note: Fair value of positions on the balance sheet, aggregated for the U.S. banking sector and expressed in USD trillions. Green shows short maturities, blue shows medium maturities and grey shows long maturities.

Figure A.2. Time variation in interest rate risk exposure by instrument



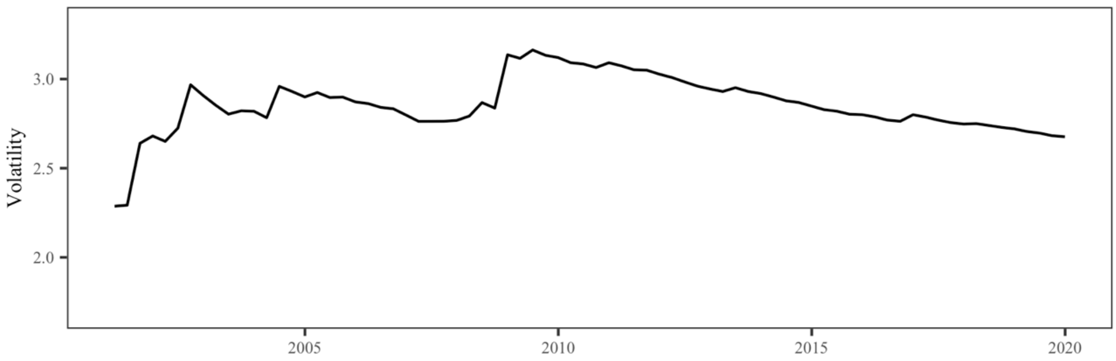
Note: The lines represent different maturities and darker lines imply longer maturities. For treasuries, AAA and BBB, we use maturities of 1-3, 3-5, 5-7, 7-10, 10-15 and 15+ years. For swaps, we use 2, 5, 10 and 15 years. Finally, for MBS, we use 0-3, 3-5, 5-7, 7-10, 10-15 and 15 years.

Figure A.3. Interest rate risk exposure for securities and loans holdings of aggregate U.S. banking sector by risk class



Note: Interest rate exposure aggregated for the U.S. banking sector, expressed in USD trillion. Left panel: Interest rate exposure for securities. Blue shows other securities, grey shows MBS and green shows treasuries. Right panel: Interest rate exposure for loans by credit quality. Grey represents BBB rated loans, red shows A rated loans, orange shows AAA rated loans and green shows loans with treasury quality.

Figure A.4. Volatility interest rate risk factor



Note: Recursively estimated volatility of the interest rate factor.

Appendix B. Variables used to form consistent time series data

This appendix shows what variables we use to form consistent time series in our data.

Commercial bank level data (FFIEC 031 and 041)

Treasury (RCFD/RCON):

2001:03-2019:12: A549, A550, A551, A552, A553, A554

MBS (RCFD/RCON):

2001:03-2019:12: A555, A556, A557, A558, A559, A560, A561, A562

Loans and leases (RCON):

2001:03-2019:12: A564, A565, A566, A567, A568, A569, A570, A571, A572, A573, A574, A575, A247

Time deposits (RCON):

2001:03-2016:12: A579, A580, A581, A582, A584, A585, A586, A587

2017:03-2019:12: HK07, HK08, HK09, HK10, HK12, HK13, HK14, HK15

Other borrowed money (RCFD/RCON):

2001:03-2006:09: F055, F056, F057, F058, F060, F061, F062, F063

2006:09-2019:12: 2651, B565, B566, B571, B567, B568

Bank holding company level data (FR Y-9C)

Treasuries:

2001:03-2018:03: BHCK0213, BHCK1290, BHCK1295, BHCK8497, BHCK1287, BHCK1293, BHCK1298, BHCK8499

2018:06-2019:12: BHCK0213, BHCKHT51, BHCK8497, BHCK1287, BHCKHT53, BHCK8499

MBS:

2001:03-2009:03: BHCK1699, BHCK1705, BHCK1710, BHCK1715, BHCK1719, BHCK1734, BHCK1702, BHCK1707, BHCK1713, BHCK1717, BHCK1732, BHCK1736

2009:06-2010:12: BHCKG301, BHCKG305, BHCKG309, BHCKG313, BHCKG317, BHCKG321, BHCKG303, BHCKG307, BHCKG311, BHCKG315, BHCKG319, BHCKG323, BHCKG325, BHCKG329, BHCKG327, BHCKG331

2011:03-2019:12: BHCKG301, BHCKG305, BHCKG309, BHCKG313, BHCKG317, BHCKG321, BHCKG303, BHCKG307, BHCKG311, BHCKG315, BHCKG319, BHCKG323, BHCKK143, BHCKK147, BHCKK151, BHCKK155, BHCKK145, BHCKK149, BHCKK153, BHCKK157

Other securities:

2001:03-2017:12: BHCK1771, BHCK1773

2018:03-2019:12: BHCKJA22, BHCK1771, BHCK1773

Loans:

2001:03-2019:12: BHCK5369, BHCKB528

Risk weights loans:

2001:03-2014:12: BHC05369, BHC0B528, BHC25369, BHC2B528, BHC55369, BHC5B528, BHC95369, BHC9B528

2015:03-2016:12: BHCKH173, BHCKH174, BHCKS425, BHCKS433, BHCKH178, BHCKH179, BHCKS451, BHCKS459, BHCKS415, BHCKH175, BHCKS426, BHCKS434, BHCKS441, BHCKH180, BHCKS452, BHCKS460, BHCKS416, BHCKH176, BHCKS427, BHCKS435, BHCKS442, BHCKH181, BHCKS453, BHCKS461, BHCKS417, BHCKH177, BHCKS428, BHCKS436, BHCKS443, BHCKH182, BHCKS454, BHCKS462, BHCKS421, BHCKS429, BHCKS437, BHCKS447, BHCKS455, BHCKS463

2017:03-2019:12: BHCKH173, BHCKH174, BHCKS425, BHCKS433, BHCKH178, BHCKH179, BHCKS451, BHCKS459, BHCKHJ78, BHCKHJ80, BHCKHJ82, BHCKHJ84, BHCKHJ79, BHCKHJ81, BHCKHJ83, BHCKHJ85, BHCKS415, BHCKH175, BHCKS426, BHCKS434, BHCKS441, BHCKH180, BHCKS452, BHCKS460, BHCKS416, BHCKH176, BHCKS427, BHCKS435, BHCKS442,

BHCKH181, BHCKS453, BHCKS461, BHCKS417, BHCKH177, BHCKS428, BHCKS436, BHCKS443, BHCKH182, BHCKS454, BHCKS462, BHCKS421, BHCKS429, BHCKS437, BHCKS447, BHCKS455, BHCKS463

Interest-bearing deposits:

2001:03-2019:12: BHDM6636, BHFN6636

Interest on deposits:

2001:03-2016:12: BHCKA517, BHCKA518, BHCK6761, BHCK4172

2017:03-2019:12: BHCKHK03, BHCKHK04, BHCK6761, BHCK4172

Other borrowed money (including total trading liabilities):

2001:03-2019:12: BHCK3190, BHCK3548, BHCK4185

Interest-rate derivatives:

2001:03-2014:12: BHCKA126, BHCK8733, BHCK8737, BHCK3809, BHCK8766, BHCK8767

2015:03-2019:12: BHCKA126, BHCK8733, BHCK8737, BHCKS582, BHCKS583, BHCKS584, BHCKS603, BHCKS604, BHCKS605