Loan Market Power and Monetary Policy Passthrough under Low Interest Rates

Mengbo Zhang*

UCLA

Job Market Paper

November 20, 2020

Click here for the latest version

Abstract

Is monetary policy less effective in a low interest-rate environment? To answer this question, I study how the passthrough of monetary policy to banks' deposit rates has changed, during the secular decline in interest rates in the U.S. over the last decades. In the data, the passthrough increased (decreased) for banks who started with a low (high) passthrough. I explain this observation in a model where banks have market power over loans and face capital constraints. In the model, when interest rates are low, the passthrough falls as policy rates fall, only in markets where loan competition is high. Hence, the overall passthrough depends on the distribution of loan market power. I confirm the model's prediction using the branch-level data of U.S. banks. This channel also impacts the transmission of monetary policy to bank lending under low interest rates.

JEL Classification: E52, E58, G12, G21, D43.

Keywords: Monetary Policy, Low Interest Rates, Banking, Market Power.

*Department of Economics, University of California, Los Angeles, E-mail: mbzhangucla@g.ucla.edu. I am grateful to my advisors, Pierre-Olivier Weill, Andrew Atkeson, and Saki Bigio for their invaluable guidance and continuous support. I thank, for fruitful discussions and suggestions, Paula Beltran, Huifeng Chang, Lee Ohanian, Shihan Shen, Jonathan Vogel, and participants at the UCLA Macroeconomics Proseminar and the UCLA Macro-Finance workshop. I am indebted to Tsz-Nga Wong for many insightful conversations all throughout the development of this paper. I gratefully acknowledge the support of the Lewis L. Clark Graduate Fellowship. All errors are my own.

1 Introduction

During recent decades, advanced economies have experienced a secular decline in nominal interest rates. It is thought that this environment will persist as policy makers renew their efforts to stimulate these economies. However, the previous research has observed that bank profitability may fall in a low-interest-rate environment (e.g. Jackson, 2015; Bech and Malkhozov, 2016; Claessens et al., 2018). This observation is a source of concern because it is thought that low bank profitability may actually impair banks' intermediation between deposits and loans (Bindseil, 2018). This impact can further weaken the transmission of monetary policy, which is usually measured as a lower passthrough from monetary policy rates to bank deposit rates, i.e. the extent to which commercial banks increase deposit rates in response to an increase in the monetary policy rate.[1] As motivated by the concern, this paper provides an empirical and theoretical investigation on how the passthrough of monetary policy rates to deposit rates changes, as an economy transitions to a low-interest-rate environment.

On the empirical front, I study how the monetary policy passthrough changed for individual banks. I measure passthrough as the regression coefficient of the change in bank deposit rate on the change in Fed funds rate. I document that as the U.S. transitioned to a low interest rate environment, the monetary policy passthrough changed for most banks. However, the direction of change is not the same for every bank. For some banks, the passthrough increased whereas for others it decreased. In particular, for banks that started with a high passthrough before the global financial crisis, their passthrough declined after the crisis. For banks that started with a low passthrough, their passthrough increased. An interpretation of this evidence is that banks with an initially lower passthrough were banks that had greater market power. Hence, for banks that started with greater market power, the passthrough has actually increased. This observation is important because it showcases that the concern that the overall passthrough of monetary policy will decline with lower rates depends on the distribution of bank market power.

On the theoretical front, I build a model of bank competition to explain why the passthrough for banks with low initial passthrough increases as an economy transitions to a low-interest-rate environment. The model has the following features: First, the economy consists of a finite number of banks that raise deposits and invest the funds, together with equity, in loans and fixed-income bonds. Second, in both loan and deposit markets, banks engage in monopolistic competition by setting loan rates over loans, and deposit rates over deposits. For loan and deposit demand schedules, the elasticities of substitution across individual banks are both greater than one, and the aggregate deposit demand has unit elasticity. Third, both banks and depositors can invest in the bonds and

[1] For related discussion, see Brunnermeier and Koby (2018), Wang (2018), Balloch and Koby (2019), and Ulate (2019).

earn a competitive rate of return set by the central bank, i.e. the Fed funds rate. The Fed funds rate thus also represents the nominal interest rate and equals the marginal cost of bank loans, and the difference between the Fed funds rate and deposit rate—the deposit spread—represents the cost of holding deposits. Finally, each bank is subject to a capital constraint, which says that a bank's deposit liabilities cannot exceed a multiple of bank profits. With these ingredients, I find that the change of a bank's passthrough under a lower interest rate depends on the degree of loan market concentration. As the interest rate falls, the monetary policy passthrough increases for banks that locate in concentrated loan markets, but decreases for banks that locate in competitive loan markets.

The model's mechanism works as follows. First, since banks can invest in bonds, the optimization on loans is independent of the deposit market, and the loan profit is a function of the nominal interest rate and the number of banks in loan market. Specifically, the loan profit is decreasing in the nominal rate, due to loan demand elasticity larger than one, and also decreasing in the number of banks in the loan market. More importantly, the loan profit decreases more in nominal rate if the loan market is more concentrated, i.e., the loan market has fewer banks. On the other hand, the return on bonds is increasing in the nominal rate. This implies that a bank's profits on assets are non-monotonic in the nominal interest rate: the profit on loans is decreasing in the nominal interest rate, and the return on bonds is increasing in the nominal interest rate. Moreover, the decreasing effect on loan profits is stronger if the loan market is more concentrated.

Second, the non-monotonic effect of nominal interest rate on asset profits is passed to the deposit side through the capital constraint. Due to the unit-elastic aggregate deposit demand, the capital constraint is always binding. This results in an equilibrium deposit spread that depends on a bank's profits on assets: When the nominal interest rate is low, for banks in concentrated loan markets, a lower interest rate induces a large increase in loan profits, which actually expands bank profits on assets. This allows banks to take more deposits at lower deposit spreads, thereby improves the passthrough. However, for banks in competitive loan markets, the profits on loans are not sensitive to the nominal rate. With a lower nominal rate, the profits on assets decreases due to the decline of return on bonds. As a consequence, banks have to take less deposits at higher deposit spreads, which weakens the passthrough.

The theoretical model has the following testable predictions. First, when the nominal interest rate is below (above) a threshold, the passthrough of monetary policy rates to deposit rates is increasing (decreasing) in bank's loan market concentration. Second, as the interest rate falls, the passthrough increases if the bank's loan market concentration is sufficiently high, and decreases otherwise. The third testable prediction states that the threshold value of interest rate, which is mentioned in the first prediction, is decreasing in bank equity.

I test the model predictions using a panel dataset of U.S. bank branches. The main identification issue is that banks' lending and deposit opportunities simultaneously affect their decisions on deposit rates. In order to ensure that banks face similar deposit opportunities, I compare the deposit rates and deposit growth across branches within the same county, but belonging to different parent banks. This within-county estimation has two identifying assumptions. First, a bank can raise deposits at one branch and lend them at another, which implies that the impact of loan competition on a bank's deposit rates is determined by the average loan concentration of its braches. Second, bank competition over deposits and loans is localized in a banking market, and county is taken to be the unit of banking market. As a result, the branches within the same county, but belonging to different banks, are faced with similar deposit opportunities and different loan market concentration.[2]

Moreover, the measurement of key variables is as follows. First, to account for the term premia, the measure of nominal interest rate, which follows Wang (2018), is the yield rate of a treasury portfolio that replicates the repricing maturity of banks' loan portfolio. Second, the proxy for a bank's loan market concentration is the average Herfindahl index of home mortgage loans in counties, weighted by the bank's home mortgage lending across counties. Third, the proxy for a bank's equity is the ratio of total equity to total assets.

The empirical results support the theoretical predictions. First, when the nominal interest rate is zero and the Fed funds rate increases by 100 bps, banks that make loans in a monopoly market increase their deposit rates by 282 bps more than banks that make loans in a perfectly competitive market. At the same time, the corresponding growth of deposits is 266 bps larger at the banks that make loans in a monopoly market. This differential effect shrinks as the interest rate rises, and vanishes to zero when the nominal interest rate reaches a threshold. Second, as the interest rate falls, the passthrough to deposit rates increases if a bank's Herfindahl index of loans is higher than 0.21. Third, the threshold value of nominal interest rate, below which the passthrough increases in banks' loan market concentration, is decreasing in a bank's equity-assets ratio. For the banks with the average equity-assets ratio, the threshold value is between 2.5% and 3.0%, depending on the deposit product in regression.

I conduct several robustness tests of my findings. First, the results are robust if I control different fixed effects and bank characteristics. Second, the results are robust for large banks. Third, the results are robust for alternative measures of nominal interest rate, such as the Fed funds rate and 1-year Treasury yield rate. Fourth, I re-run the regressions with data before the global financial crisis of 2008, and obtain similar estimation results.

Next, I explore how this passthrough channel affects the response of banks' balance sheet to monetary policy. First, I verify that all of the branch-level regression results hold at the bank level

[2] This identification assumption has been used in related empirical analysis on bank market power and passthrough, such as Drechsler et al. (2017), Drechsler et al. (2019), Li et al. (2019).

using Call Reports data for U.S. banks. Second, I find that at a low interest rate, the impact of loan market power on the monetary policy transmission to deposit growth also transmits to other balance sheet components: when the interest rate is low, an increase in the monetary policy rate induces higher growth of loans, securities and assets, for banks with higher loan market concentration.

The above theoretical and empirical analysis shows that the level of nominal interest rates affects the monetary policy passthrough to deposit rates. However, my empirical analysis only identifies loan market competition as one determinant, but omits other potential determinants. To estimate the effects of nominal interest rate on the passthrough comprehensively, I propose a new measure of monetary policy passthrough using the Call Reports data. This measure is a pair of betas: zero beta and slope beta. For deposit rates, the zero beta measures the passthrough of monetary policy rates to deposit rates when the nominal interest rate is zero; the slope beta measures the change in the passthrough when the nominal rate increases by 100 bps. Hence, a negative (positive) slope beta means the passthrough increases (decreases) with a lower nominal interest rate.

The estimates suggest that the betas differ substantially across banks. First, the two betas are also highly negative correlated. This implies that banks with a high zero beta, i.e. a high passthrough to deposit rates at zero nominal rate, experience a decline in the passthrough as the nominal rate increases. However, for banks with a low zero beta at zero nominal rate, their passthrough actually increases with the nominal rates. This is consistent with the theoretical predictions. Second, the share of banks with a negative slope beta is 24.6%, implying that low interest rate improves the passthrough for about about a quarter of banks in the sample. The share is even larger, which is 32.4%, for the largest 5% banks by assets. These numbers imply that whether the overall passthrough decreases with a lower interest rate depends on the distribution of market power. By weighting the slope betas by bank assets, I find that the average slope beta is about zero, implying that the overall passthrough does not significantly decrease with a lower interest rate. This is in contrast with the findings in the previous literature, which finds that a lower interest rate weakens passthrough by using models of representative banks.

To evaluate how the new measure of passthrough accounts for the impact of nominal interest rate on monetary policy transmission, I estimate the analogous pair of betas for the growth of individual bank deposits, loans, securities and assets. These betas measure the bank balance sheet's sensitivity to the policy rate at zero nominal rate, and the change of the sensitivity when the nominal rate increases by 100 bps. I find that the betas of deposit rates are significantly positive correlated with the betas of balance sheet growth. This implies that the impact of nominal rates on the passthrough to deposit rates can explain the effects of nominal interest rates on monetary policy transmission to bank balance sheets.

Related literature. This paper contributes to the literature on monetary policy transmission through banks.[3] Specifically, my paper highlights the role of bank market power as in Drechsler et al. (2017) and Scharfstein and Sunderam (2016), where Drechsler et al. (2017) demonstrates the role of deposits market power, and Scharfstein and Sunderam (2016) documents the role of market power in loan markets. Different from the previous literature, my work considers market power over deposits and loans simultaneously, and shows that the interplay between them reveals a new channel which impacts the response of bank deposits to monetary policy. In a recent paper, Wang et al. (2018) also studies bank market power over deposits and loans jointly. But their paper focuses on comparing the quantitative effect of market power on monetary transmission versus the traditional channels, and does not discuss theoretical implications of the interplay between deposit and loan competition.

Second, this paper relates to the recent literature on the effects of low interest rates (Krugman et al., 1998; Eggertsson and Woodford, 2004; Brunnermeier and Koby, 2018; Balloch and Koby, 2019; Ulate, 2019; Wang, 2018; Eggertsson et al., 2019; Bigio and Sannikov, 2019).[4] They argue that the usual transmission channels of monetary policy will be weakened or break down under very low interest rates, and short-run interest rate cuts or long-run low interest rate policy could be contractionary for aggregate bank lending. My paper differs from these research by focusing on the heterogeneous effects of low interest rates on the cross section of banks. I find that low interest rate impacts banks heterogeneously: while a lower interest rate weakens the monetary policy passthrough for some banks, it can actually improve the passthrough for others. Moreover, a key determinant of the heterogeneity is banks' market power. This implies that the aggregate effect of low interest rate on monetary policy transmission really depends on the distribution of bank market power. In a related paper, Sá and Jorge (2019) investigates the validity of the deposit market power channel of monetary policy under low interest rates. They find that a low interest rate environment may turn this channel off.

Third, this paper is related to the literature studying the passthrough efficiency of monetary policy rates to deposit rates (Berger and Hannan, 1989; Hannan and Berger, 1991; Diebold and

[3] Conventionally there is a large body of literaure on monetary policy transmssion through banks. The literature mostly focuses on two channels: the bank reserve channel and bank capital channel. In the bank reserve channel, monetary policy controls the size of bank reserves, which determines the size of bank deposits and hence bank lending. The related literature includes Bernanke (1983), Bernanke and Blinder (1988), Bernanke and Blinder (1992), Kashyap et al. (1993), Kashyap and Stein (1994), Kashyap and Stein (1995) Kashyap and Stein (2000), Jiménez et al. (2014). The bank capital channel argues that a surprise rise in interest rate reduces bank assets by more than liabilities due to maturity mismatch, thus decreases bank capital and compresses their lending capacity. The related literature includes Bemanke and Gertler (1989), Kiyotaki and Moore (1997), Gertler and Kiyotaki (2010), He and Krishnamurthy (2013), Brunnermeier and Sannikov (2014), Brunnermeier and Koby (2018), Van den Heuvel et al. (2002), Bolton and Freixas (2000), Brunnermeier and Sannikov (2016).

[4] Early research in this strand of literature focuses on the effects of zero lower bound, while recent literature studies more on the effects of negative interest rates.

Sharpe, 1990; Neumark and Sharpe, 1992; Driscoll and Judson, 2013; Yankov, 2014; Drechsler et al., 2017; Duffie and Krishnamurthy, 2016). This literature shows the adjustment of deposit rate to interest rate changes is slow and asymmetric, and interpret it as evidence of price rigidities or deposit market power. My work contributes to this literature by showing that the passthrough efficiency depends on the level of nominal interest rate, and is heteregeneous across banks.

Finally, this paper contributes to the literature on the economic consequences of banking sector concentration. The effects of imperfect competition and market power in banking sector, which arises from the rising bank concentration, has been an active strand of research during past decades. Several papers find that the markups in global and U.S. banking industry have risen greatly during past four decades (De Loecker et al., 2020; Diez et al., 2018). Others provide quantitative analysis on the economic consequences of the rising bank concentration and related regulations (Corbae and D'Erasmo, 2019). There are also papers that focus on the theoretical interactions between competition, financial fragility, and monetary policy (Corbae and Levine, 2018). My paper focuses on the role of loan market concentration on monetary policy passthrough, and provides new insights on how the rising bank concentration would affect the real effects of monetary policy.

Outline. The remainder of the paper is as follows. Section 2 describes the motivating evidence. Section 3 presents the static model that rationalizes the motivating facts, as well as illustrates the key mechanism at play. Section 4 describes the data. Section 5 presents the empirical results that support the theoretical predictions, and proposes the new measure of monetary policy passthrough. The final section 6 concludes the paper.

2 Motivating Evidence

This section presents the empirical facts that motivate this paper. I find that for U.S. banks, a lower interest rate can change the passthrough to deposit rates heterogeneously. Specifically, for banks with a low (high) level of passthrough in the period of high interest rates, their passthrough is strengthened (weakened) in the period of low interest rate.[5]

I start with the analysis by estimating the passthrough to a banks' deposit rate. Following Drechsler et al. (2020), I use the balance sheet data for U.S. banks from the Call Reports between

[5] As documented in the previous literature, the aggregate passthrough of policy interest rates to deposit rates is incomplete in advanced economies (e.g. Drechsler et al., 2017, Wang, 2018, Balloch and Koby, 2019). That is, a 100 bps increase in the policy interest rate leads to less than 100 bps increase in aggregate bank deposit rate. As suggested by Drechsler et al. (2017), bank market power in the retail markets is a key driving force. In the presence of market power, an increase in the policy interest rate allows banks to raise the markups between the policy interest rate and deposit rate, since the opportunity cost of holding cash is higher.

1997Q1 and 2019Q4,[6] and run the following time-series regression for each bank j:

$$\Delta\text{Deposit Rate}_{jt} = \alpha_j + \sum_{\tau=0}^{3} \beta_{j,\tau} \Delta\text{Fed Funds Rate}_{t-\tau} + \varepsilon_{jt}, \tag{1}$$

where t is a quarter, ΔDeposit Rate$_{jt}$ is the change in bank j's deposit rate from period $t-1$ to t, ΔFed Funds Rate$_t$ is the contemporaneous change in the Fed funds rate, and α_j are bank fixed effects. The deposit rate is the total quarterly interest expenses on domestic deposits divided by total domestic deposits and then annualized. It measures the average rate of interest expenses on deposits cumulated from the existing deposits, thus I add three lags of the Fed funds rate changes to capture the cumulative effect of Fed funds rate changes over one year. The coefficients β's measure the sensitivity of banks' deposit rates on the (current and past) nominal interest rate changes. Thus our estimate of passthrough to deposit rate is the sum of $\beta_{j,\tau}$ coefficients in (1), i.e. $\beta_i^{Dep} = \sum_{\tau=0}^{3} \beta_{i,\tau}$.

To examine the impact of low interest rate on the passthrough, I split the data into two subperiods: the period before 2008 global financial crisis (1997Q1-2007Q4) and after the crisis (2010Q1-2019Q4), and estimate the deposit rate passthrough in each subperiod. The first subperiod represents the time of normal interest rates, during which the average quarterly Fed funds rate is 3.93%. The second subperiod represents the time of low interest rates, during which the average quarterly Fed funds rate is 0.62%.[7] The banks included are required to have at least 30 quarters of data in each subperiod, which yields 4,596 banks.

Figure 1 shows the relationship between a bank's deposit rate betas over two subperiods in a graphical representation. The left panel presents a bin scatter plot which sorts all banks into 100 bins by their pre-crisis passthrough (winsorized at 1% level) and plots the average post-crisis passthrough for the banks within each bin. The right panel presents the analogous bin scatter plot for the largest 10% of banks by assets and groups them into 20 bins. While the full sample provides useful variation, the large banks are the economically important group, accounting for 88% of total assets.

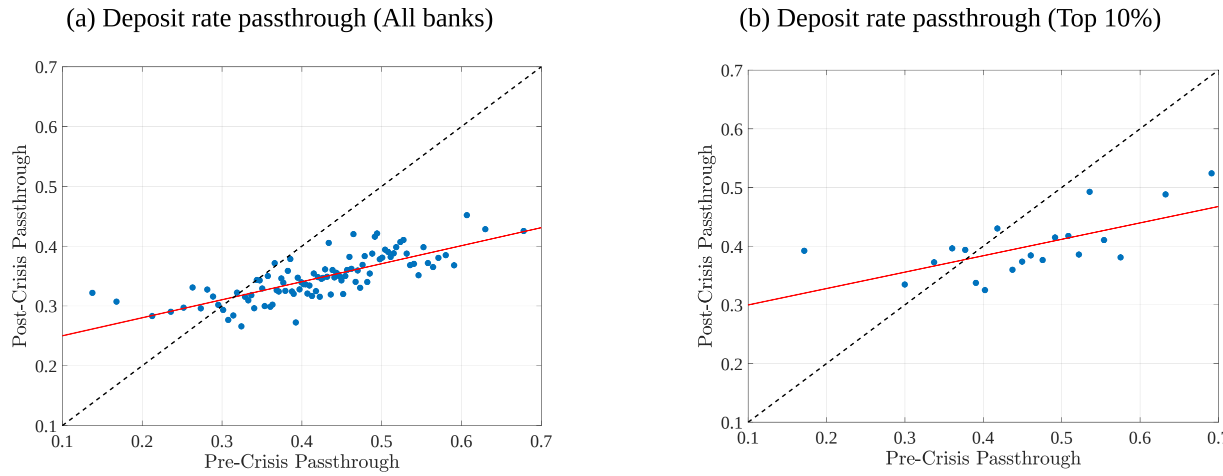
The bin scatter plots show the following results. First, there is a strong positive correlation between the deposit rate betas in two subperiods, with the slope of the linear fit significantly less than one: the estimated slopes are 0.301 for all banks and 0.278 for large banks.[8] This implies the distribution of passthrough to deposit rates across U.S. banks is more concentrated in the period of low interest rate. Second, the changes in passthrough are heterogeneous and depend on the banks'

[6] The details of data description are in Section 4.

[7] The quarterly Fed funds rates are always below 0.2% between 2010Q1 and 2015Q4, and gradually increased the level above 1.5% between 2016Q1 and 2019Q4. Removing the latter periods in the estimation does not change the main results.

[8] For both panels, the F-test of the linear fit rejects the null hypothesis that the slope is equal to 1 at 1% level.

Figure 1: Deposit rate passthrough comparison



Notes: This figure shows bin scatter plots for the passthrough of Fed funds rate to individual banks' deposit rates. The passthrough is estimated by regressing the quarterly change of a bank's deposit rate on the quarterly changes of the Fed funds rate over the contemporaneous quarter and past three quarters. The estimation is splitted into two subperiods: 1997Q1-2007Q4 and 2010Q1-2019Q4. Only banks with at least 30 quarterly observations in each subperiod are included. The estimates are winsorized at the 1% level for each subperiod. The bin scatter plot in panel (a) groups all banks into 100 bins by the deposit rate passthrough in the first subperiod and plots the average deposit rate passthrough in the second subperiod within each bin. The bin scatter plot in panel (b) groups the top 10% banks into 20 bins by the deposit rate passthrough in the first subperiod and plots the average deposit rate passthrough in the second subperiod within each bin. The top 10% of banks are those whose quarterly average inflation-adjusted total assets over the sample are in the top 10th percentile. The underlying data are from FRED and the Call Reports. The sample period is from 1997Q1 to 2019Q4.

pre-crisis passthrough. For banks started with a low passthrough, their passthrough increased after the crisis. However, for banks started with a high passthrough, their passthrough decreased. It implies that the change in the concentration of deposit rate passthrough is driven by two forces: the passthrough to deposit rates of banks with low pre-crisis passthrough is strengthened after crisis, but the passthrough of banks with high pre-crisis passthrough is weakened after crisis. Following Drechsler et al. (2017), an interpretation of this evidence is that banks with an initially low passthrough were banks that had great market power. Hence, for banks that started with greater market power, the passthrough has actually increased.

I also run analogous regressions to (1) for banks' interest expense rate (the annualized quarterly interest expenses on liabilities divided by total assets), loan income rate (the annualized quarterly interest income on domestic loans divided by total domestic loans), and interest income rate (the annualized quarterly interest income on assets divided by total assets), and calculate the corresponding passthroughs for two subperiods. Comparing these passthroughs over two subperiods allows me to investigate whether the heterogeneous change of passthrough to deposit rates is transmitted to the other bank balance sheet variables. The two panels in Figure 4 report the bin scatter plots for the loan rate passthrough, and Figure 5 shows the figures for the passthroughs of interest expense rate and interest income rate. Since the deposit interest expenses are the largest part of banks' interet expenses, the bin plots for interest expense rates exhibit the same patterns as in deposit rates. Moreover, the cross-sectional change of passthrough to interest expenses on liabilities is largely transmitted to the interest income on loans and assets. The estimated passthroughs of both loan rates and interest income rates show the same patterns of cross-sectional change as we have documented above.

3 Baseline Model

In this section I build a partial equilibrium model to study the impact of bank market power on the passthrough of Fed funds rates to deposit rates. The model is simplified to capture only the main economic force and allows for an analytical solution.

The economy lasts for one period and consists of three types of agents: (i) a unit mass of representative savers that demand deposits for transaction services; (ii) a mass μ of representative borrowers that demand loans for consuming final goods; (iii) N banks of mass $1/N$ that engage in monopolistic competition over loans and deposits by setting the loan rates and deposit rates.[9] At the same time, the savers and banks can invest in or borrow from a class of fixed-income assets, which are called bonds. The bonds do not provide liquidity convenience and are traded in a competitive market with a common rate of return, which is exogenous and set by the central bank monetary policy. I refer to the rate of return as the Fed funds rate and denote it by i.[10] Moreover, I set the final goods consumed by borrowers as the numeraire. The deposits, loans and bonds are all measured in the units of final goods.

3.1 Demand for Deposits

The demand for deposits is derived from the savers' utility maximization problem. The representative saver's utility function is

$$u^s(y, D) = y + \theta_d \cdot \ln(D), \tag{2}$$

[9] Assuming the mass of a bank to be $1/N$ is to guarantee that increasing the number of banks does not affect the equilibrium outcomes by mechanically increasing the total volume of loans and deposits, but through the extent of bank competition. This setup follows Drechsler et al. (2017) and Li et al. (2019).

[10] The maturity structure is not important for our main theoretical results. Thus we can think of the bonds as the Fed funds plus 3-month treasury bills, and the rate of return as the Fed funds rate that is used by the Federal Reserve to influence bank lending and deposit creation.

where y is the consumption of final goods and D is the aggregate deposits that represents transaction services from deposit holdings.[11] The deposit aggregate D is a CES aggregate of bank deposits D_j from bank $j \in \{1, 2, ..., N\}$ with elasticity of substitution $\sigma_d > 1$:[12]

$$D = \left(\frac{1}{N} \sum_{j=1}^{N} D_j^{\frac{\sigma_d - 1}{\sigma_d}} \right)^{\frac{\sigma_d}{\sigma_d - 1}}. \tag{3}$$

I denote the deposit interest rate paid by bank j as i_j^d and let $s_j^d \equiv i - i_j^d$ be the spread between the Fed funds rate and the deposit rate. Since the household can invest in bonds, deposit spread is the opportunity cost of holding deposits.

The representative household is initially endowed with final goods y_0. It chooses the deposit holdings $\{D_j\}_{j=1}^N$ to maximize the utility function (2) subject to the budget constraint

$$y = (1+i)\left(y_0 - \frac{1}{N} \sum_{j=1}^{N} D_j \right) + \frac{1}{N} \sum_{j=1}^{N} \left(1 + i_j^d\right) D_j = (1+i)\, y_0 - \frac{1}{N} \sum_{j=1}^{N} s_j^d D_j, \tag{4}$$

where I replace i_j^d with $i - s_j^d$ in the second equality. Thus the deposit spread s_j^d is the price of bank j's deposits in the budget constraint.

Note that the household's problem is equivalent to the following two-step problem. First, since the CES aggregator of deposits (3) is constant returns to scale, the household selects the deposit holdings across banks to minimize the unit cost of aggregate deposits. The minimized unit cost is the average deposit spread given by[13]

$$s^d \equiv \min_{\{D_j\}_{j=1}^N} \frac{1}{N} \sum_{j=1}^{N} s_j^d D_j \text{ s.t. } D\left(\{D_j\}_{j=1}^N \right) = 1 \tag{5}$$

$$= \left[\frac{1}{N} \sum_{j=1}^{N} \left(s_j^d \right)^{1-\sigma_d} \right]^{\frac{1}{1-\sigma_d}}, \tag{6}$$

where $D\left(\{D_j\}_{j=1}^N \right)$ denotes the deposit aggregator (3). Second, the representative household maximizes the utility over consumption and aggregate deposits according to the following problem:

$$\max_{D,y} y + \theta_d \cdot \ln(D) \tag{7}$$

[11] See Section 3.4 for the interpretation of demand for deposits.

[12] Note that D_j formally represents the amount of deposits when the mass of bank j is scaled to one. Since the mass of a bank is $1/N$, the real amount of bank j's deposits held by the household is $\frac{1}{N} D_j$. In the rest part of the model, the amounts of loans, bonds and equity of an individual bank are defined in an analogous way.

[13] The derivations for the baseline model are provided in the Appendix A.1.

subject to

$$y = (1+i)\, y_0 - s^d \cdot D. \tag{8}$$

Solving the above problem (5) and (7), I obtain that the demand for aggregate deposits is a function of the average deposit spread:

$$D\left(s^d\right) = \frac{\theta_d}{s^d}, \tag{9}$$

and the demand for bank j's deposits is

$$D_j\left(s_j^d; s_{-j}^d\right) = \left(\frac{s^d}{s_j^d}\right)^{\sigma_d} D\left(s^d\right), \tag{10}$$

where s_{-j}^d denotes the deposit spread of all banks except j. Note that the competitors' deposit spread determines bank j's deposit demand since the average deposit spread s^d, which is given by (6), is a function of $\left\{s_j^d\right\}_{j=1}^N$. Thus a change in s_j^d affects not only the individual demand D_j, but also the aggregate demand D through changing s^d. Moreover, the demand elasticity for individual bank deposits is:

$$\epsilon_j^d = -\frac{\partial \log\left(D_j\right)}{\partial \log\left(s_j^d\right)} = \sigma_d + \frac{1}{N}\left(1-\sigma_d\right)\left(\frac{s_j^d}{s^d}\right)^{1-\sigma_d}. \tag{11}$$

Note that the individual demand elasticity is increasing in N due to $\sigma_d > 1$. This implies that the individual deposit demand is more elastic if there are more banks in the deposit market. Moreover, if all the banks set the same deposit rate, the individual deposit spread s_j^d is equal to the average deposit spread s^d. Then the demand for individual deposits becomes identical, i.e. $D_j = D\left(s^d\right)$, and the individual demand elasticity becomes a constant, i.e. $\epsilon_j^d = \epsilon^d(N) \equiv \sigma_d + \frac{1}{N}\left(1-\sigma_d\right) > 1$.

3.2 Demand for Loans

The demand for loans is derived from the borrowers' utility maximization problem. The representative borrowers have a quasi-linear utility over final goods consumption and labor supply:

$$u^b\left(c^b, h\right) = \frac{\left(c^b\right)^{1-\nu} - 1}{1-\nu} - \theta_h \cdot h, \tag{12}$$

where c^b represents the consumption of final goods, h represents the amount of labor supply. The parameter θ_h the disutility of labor supply, and $\nu < 1$ is the parameter of CRRA utility. The borrowers have access to a production technology that produces one unit of final goods for each unit of labor supply. However, the demand for final goods consumption arrives before the production, and the borrowers have no initial endowment.[14] Then the consumption demand must be financed by the aggregate bank loans L, which is a CES aggregate of individual bank loans L_j with the elasticity of substitution $\sigma_l > \frac{1}{\nu}$:

$$L = \left(\frac{1}{N} \sum_{j=1}^{N} L_j^{\frac{\sigma_l - 1}{\sigma_l}} \right)^{\frac{\sigma_l}{\sigma_l - 1}}. \tag{13}$$

Thus the representative borrowers' optimization problem is to maximize (12) subject to (13) and

$$c^b \leq L \text{ and } \frac{1}{N} \sum_{j=1}^{N} \left(1 + i_j^l\right) L_j \leq h, \tag{14}$$

where i_j^l is bank j's loan interest rate. Similar to the savers' problem, the borrowers' problem can also be solved in two steps. First, since the loan aggregator (13) is constant returns to scale, the borrowers distribute loans across banks to minimize the unit cost of aggregate loans. The minimized unit cost is the average loan rate i^l that is given by

$$1 + i^l \equiv \min_{\{L_j\}_{j=1}^{N}} \frac{1}{N} \sum_{j=1}^{N} \left(1 + i_j^l\right) L_j \text{ s.t. } L\left(\{L_j\}_{j=1}^{N}\right) = 1 \tag{15}$$

$$= \left[\frac{1}{N} \sum_{j=1}^{N} \left(1 + i_j^l\right)^{1-\sigma_l} \right]^{\frac{1}{1-\sigma_l}}. \tag{16}$$

Second, the buject constraints in (14) must be binding at optimum. Thus the borrowers maximize the utility by solving

$$\max_{L} \frac{L^{1-\nu} - 1}{1 - \nu} - \theta_h \cdot \left(1 + i^l\right) L. \tag{17}$$

The optimal solution to the demand for aggregate loans and individual bank loans are given by

$$L\left(i^l\right) = \mu \cdot \theta_h^{-\frac{1}{\nu}} \left(1 + i^l\right)^{-\frac{1}{\nu}}, \tag{18}$$

where μ is the mass of borrowers, and

$$L_j\left(i_j^l; i_{-j}^l\right) = \left(\frac{1 + i^l}{1 + i_j^l} \right)^{\sigma_l} L\left(i^l\right). \tag{19}$$

[14] This is a simple way to model the demand for loans. See Section 3.4 for detailed discussions of the assumption.

Table 1: Bank balance sheet

Assets	Liabilities
Loans (L)	Deposits (D)
Bonds (A)	Equity (E_0)

Moreover, the demand elasticity of individual bank loans is

$$\epsilon_j^l = -\frac{\partial \log (L_j)}{\partial \log \left(1+i_j^l\right)} = \sigma_l + \frac{1}{N}\left(\frac{1}{\nu} - \sigma_l\right)\left(\frac{1+i_j^l}{1+i^l}\right)^{1-\sigma_l}. \tag{20}$$

Note that the demand elasticity is increasing in N due to $\sigma_l > \frac{1}{\nu}$. With a higher N, the loan market is more competitive, and the loan demand curve of an individual bank becomes more elastic. Moreover, if all banks sent the same loan rate, the demand for individual bank loans is identical, i.e. $L_j = L\left(i^l\right)$, and the individual demand elasticity becomes $\epsilon_j^l = \epsilon^l(N) \equiv \sigma_l + \frac{1}{N}\left(\frac{1}{\nu} - \sigma_l\right) > 1$.

3.3 The Bank's Problem

Each bank is endowed with an identical equity E_0, which is a constant and independent of the Fed funds rate.[15] The banks raise deposits D_j, and invests the funds in loans L_j and bonds A_j. Thus the balance sheet identity is given by

$$L_j + A_j = D_j + E_0, \tag{21}$$

and Table 1 displays the structure of a bank balance sheet.

Moreover, each bank is subject to a capital constraint that restricts the amount of assets it can hold on the balance sheet:

$$\psi\left(L_j + A_j\right) \leq N_j. \tag{22}$$

The parameter ψ is the risk weight and N_j denotes bank j's net worth at the end of the period:

$$N_j = \left(1+i_j^l\right)L_j + (1+i)A_j - \left(1+i_j^d\right)D_j. \tag{23}$$

Taking the individual demand function for loans and deposits as given, banks simultaneously set loan rates and deposit spreads to maximize their own net worth. By using the balance sheet

[15] We can assume the equity is decreasing in the Fed funds rate due to maturity mismatch. However, our results do not change as long as $|\partial E_0/\partial i|$ is bounded.

identity ([21](#)), we can replace A_j with $D_j + E_0 - L_j$ and write an individual bank's problem as

$$\max_{i_j^l, s_j^d} N_j = \left(i_j^l - i\right) L_j \left(i_j^l; i_{-j}^l\right) + s_j^d D_j \left(s_j^d; s_{-j}^d\right) + (1+i) E_0 \tag{24}$$

subject to

$$\psi \left[D_j \left(s_j^d; s_{-j}^d\right) + E_0\right] \leq N_j, \tag{25}$$

where $\left(i_j^l - i\right) L_j$ is the profit of loans, $s_j^d D_j$ is the profit of deposits, and $(1+i) E_0$ is the gross gain of investing equity in bonds.

Two-step problem. An important feature of banks' problem is that banks' optimal decisions of loan rates are independent of the deposit market and the capital constraint. To see this, note that banks can substitute loans for bonds without changing the total amount of assets. This implies that the marginal funding cost for loans is the Fed funds rate i, even though a bank can raise deposits. Therefore, we can solve the equilibrium in two steps. First, banks simultaneously choose loan rates to maximize their profits on loans:

$$\Pi_j^l = \max_{i_j^l} \left(i_j^l - i\right) L_j \left(i_j^l; i_{-j}^l\right), j = 1, 2, ..., N \tag{26}$$

Without loss of generality we focus on the equilibria where the individual loan rate i_j^l is non-negative. The following lemma characterizes the loan problem solution:

Lemma 1 *There exists a unique equilibrium to the loan problem. In this equilibrium, banks set identical loan rates*

$$1 + i_j^l = 1 + i^l = \frac{\epsilon^l (N)}{\epsilon^l (N) - 1} (1+i), \tag{27}$$

and earn identical loan profits

$$\Pi_j^l = \Pi^l (i, N) = \mathcal{C}_l (N) \cdot (1+i)^{-\frac{1-\nu}{\nu}}, \tag{28}$$

where

$$\mathcal{C}_l (N) \equiv \mu \cdot \theta_h^{-\frac{1}{\nu}} \frac{\left[\epsilon^l (N) - 1\right]^{\frac{1-\nu}{\nu}}}{\left[\epsilon^l (N)\right]^{\frac{1}{\nu}}} \tag{29}$$

is a decreasing function in N.

Proof. See the Appendix. ■

This lemma shows that due to the symmetry of individual bank loans in the loan aggregator ([13](#)), the symmetric equilibrium is the unique equilibrium of banks' loan problem. The equilibrium loan rate is a markup over the Fed funds rate, where the markup is a function of demand elasticity $\epsilon^l(N)$. The markup is decreasing in N since $\epsilon^l(N)$ is increasing in N. In the loan profit function $\Pi^l(i,N)$, the function $\mathcal{C}_l(N)$ is defined as the loan concentration index, which decreases with the number of banks N and the elasticity of substitution σ_l. Thus the loan profit $\Pi^l(i,N)$ also decreases in N. Intuitively, a larger N means a more competitive loan market, thus banks are less able to charge markup and earn monopolistic profits. On the other hand, $\Pi^l(i,N)$ is also decreasing in the interest rate i. This is because the individual loan demand elasticity is greater than 1, which implies that an increase in the loan rate induces larger reduction in the loan quantity. Importantly, loan profits decrease less in i for a higher N. This implies that a bank's profits on loans is less sensitive to nominal rate if the loan market is more competitive.

Another important implication of Lemma 1 is that bank's earnings on assets are non-monotonic in the Fed funds rate: the loan profits $\Pi^l(i,N)$ is decreasing in i, and the return on bonds $(1+i)A_j$ is increasing i. The non-monotonicity means that when the Fed funds rate is low (high), a bank's earnings on assets is decreasing (increasing) in the Fed funds rate. Moreover, the non-monotonicity depends on the degree of loan market competition: when the Fed funds rate is low, an increase in the Fed funds rate induces larger decrease in a bank's asset earnings if it locates in a more concentrated loan market. As is shown below, the non-monotonic effect is then passed to the liability side through the capital constraint, and explains the pattern of passthrough documented in the data.

The second step is to solve the problem of deposits. Given the equilibrium solution to the loan problem, banks simultaneously set deposit spreads to maximize their deposit profits:

$$\Pi_j^d = \max_{s_j^d} \left\{ s_j^d D_j\left(s_j^d; s_{-j}^d\right) \right\} \tag{30}$$

subject to

$$\psi D_j\left(s_j^d; s_{-j}^d\right) \leq W(i,N) + s_j^d D_j\left(s_j^d; s_{-j}^d\right) \tag{31}$$

where

$$W(i,N) = \Pi^l(i,N) + (1+i-\psi)E_0. \tag{32}$$

The deposit problem shows that the capital constraint is actually a Kiyotaki-Moore constraint: a bank's liabilities cannot exceed a multiple of future profits to ensure incentive compatibility. The future profits consist of two parts: $W(i,N)$ represents the effective profits on bank assets, and $s_j^d D_j\left(s_j^d; s_{-j}^d\right)$ represents the profits on deposits. The non-monotonic effect of nominal interest rate on banks' asset earnings impacts the equilibrium spread through changing the shadow cost of the capital constraint. Without loss of generality we focus on the equilibria with finite deposit spreads. The following lemma summarizes the equilibrium solution to the deposit spreads.

Lemma 2 *There exists a unique equilibrium to the deposit problem. In this equilibrium, the capital constraint is always binding, and banks set identical deposit spreads*

$$s_j^d = s^d\left(W\left(i,N\right)\right) = \frac{\psi\theta_d}{\mathcal{C}_l\left(N\right)\cdot\left(1+i\right)^{-\frac{1-\nu}{\nu}} + \left(1+i-\psi\right)E_0 + \theta_d} \tag{33}$$

and earn constant and identical deposit profits

$$\Pi_j^d = \theta_d. \tag{34}$$

Therefore, the bank's problem (24) and (25) has a unique equilibrium that is described by (27), (28), (33) and (34).

Proof. See the Appendix. ■

This lemma has the following results. First, since the aggregate demand of deposits has a unit elasticity, an equilibrium without capital constraint has zero deposit spreads. This implies banks' deposit liabilities are infinite. However, the unit demand elasticity also implies constant profits on deposits. Hence, the capital constraint must be binding in equilibrium, and the equilibrium deposit spread is an increasing function in the shadow cost of the constraint. This means that the aggregate supply of deposits by banks is given by the binding capital constraint, i.e.

$$D^s\left(s^d\right) = \frac{\mathcal{C}_l\left(N\right)\cdot\left(1+i\right)^{-\frac{1-\nu}{\nu}} + \left(1+i-\psi\right)E_0}{\psi - s^d}, \tag{35}$$

where the average spread s^d represents the price of deposits. Then the equilibrium average deposit spread is given by the equating the deposit supply and the deposit demand $D^d\left(s^d\right) = \frac{\theta_d}{s^d}$. Another important implication of this result is that the passthrough is one if the capital constraint is non-binding, and any incomplete passthrough in this model must come from the binding constraint.

Second, the equilibrium deposit spreads $s^d\left(W\left(i,N\right)\right)$ is a decreasing function in asset earnings $W\left(i,N\right)$. This is intuitive because a higher $W\left(i,N\right)$ makes the capital constraint less binding, thereby lowers the shadow cost of the capital constraint.

3.4 Discussion of model assumptions

Demand for liquidity. Incorporating liquidity services in the utility is the simplest way to generate a demand for assets with dominated return, such as deposits. An interpretation of this setup is that transactions are subject to frictions, such as cash in advance or frictions that arise from anonymous transaction and lack of commitment. Alternative ways would be to explicitly model these frictions, but models with these frictions produce similar utility functions as assuming liquidity in utility.[16] Moreover, the imperfect substitution between individual bank deposits captures the heterogeneous proximity, switching costs, tastes, or asymmetric information for depositors.

In general, modelling liquidity in utility usually incorporates currency and deposits as two substitutable forms of liquidity through an aggregator (Chetty 1969; Poterba and Rottemberg 1987; Nagel 2016; Tella and Kurlat 2020; Drechsler et al. 2017). However, the liquidity demand for currency is not necessary in this model. The main trade-off is the substitution between deposits and bonds, generating a comovement between the Fed funds rate and deposit rate. Thus in the baselien model I drop currency in utility to eliminate the impact of deposit competition on passthrough, which allows for an analytic solution for evaluating the impact of loan competition on passthrough.

Demand for loans. In this model, the demand of loans by borrowers arises from the arrival of consumption demand prior to the time when borrowers earn income. One can build a richer model with two subperiods. Borrowers prefer to consume more in the first subperiod, but have more income in the second period. Thus borrowers use bank loans to smooth the consumption across two subperiods. For individual banks, each bank produces a differentiated loan product that matures in one period. The heterogeneity of bank loans is motivated by factors such as geographic location and industry expertise. The maturity of loans will play no particular role in the qualitative mechanism of this model. Ulate (2019) provides a microfoundation of loan demand that nests the above characteristics, and it can also be applied in my model.

A decreasing loan profit in nominal interest rate is the key feature of this model. The related empirical evidence has been documented in Scharfstein and Sunderam (2016) and Fuster et al. (2020). This feature generates a non-monotonic effect of interest rate on bank profitability, which is able to explain the impact of low interest rate on passthrough.

Capital constraint. It is useful to note that the capital constraint arises from multiple reasons. First, banks are subject to regulatory constraints, such as Basel III, which requires sufficient bank equity to support lending. Our constraint, which is based on Brunnermeier and Koby (2018), is a simple form that delivers the same requirement on bank balance sheet.[17] We can also motivate the constraint with multiple microfoundations that reflects banks' endogenous risk-taking behavior and agency problems, such as Holmstrom and Tirole (1997) and Gertler and Kiyotaki (2010). Second, the constraint can be replaced with a smooth convex leverage cost, such as Piazzesi and Schneider (2018).

To present the simplest model without losing the main mechanism, we do not introduce any other balance sheet frictions which are commonly used in other banking models, such as the reserve

[16] See, for example, Feenstra (1986) and Williamson (2012).

[17] For alternative forms of capital constraints, see, for example, Begenau et al. (2019) and Wang (2018).

constraint, liquidity coverage constraint or the cost of non-reservable borrowing. These frictions do not change the qualitative results of the model.

3.5 Impacts of Loan Market Power on Passthrough

This section presents the comparative statics of loan market power and nominal interest rate on the passthrough of policy rate to deposit rate. Using the results of Lemma 2, the equilibrium deposit rate is given by

$$i^d(i, N) = i - s^d(W(i, N)). \tag{36}$$

Hence, the passthrough to deposit rates is defined as

$$\frac{\partial i^d(i, N)}{\partial i} = 1 - \frac{\partial s^d(W(i, N))}{\partial i} = 1 - \frac{\partial s^d(W(i, N))}{\partial W} \cdot \frac{\partial W(i, N)}{\partial i}. \tag{37}$$

Note that when the interest rate is low, the passthrough is incomplete, i.e. $\frac{\partial i^d(i,N)}{\partial i}$ is less than one, because $\frac{\partial s^d(W(i,N))}{\partial W} < 0$ and $\frac{\partial W(i,N)}{\partial i} < 0$. The following proposition describes the conditions needed for this result.

Proposition 1 *The passthrough of Fed funds rate to deposit rate* $\frac{\partial i^d}{\partial i}$ *is less than one iff* $i < i_0(\mathcal{C}_l, E_0)$, *where*

$$i_0(\mathcal{C}_l, E_0) \equiv \left(\frac{1-\nu}{\nu}\frac{\mathcal{C}_l}{E_0}\right)^{\nu} - 1. \tag{38}$$

Proof. See Appendix A. ■

This proposition states that the passthrough is incomplete when the nominal interest rate is below a threshold. This is because when the interest rate is low, an increase in interest rate depletes bank profit, thereby tightens the capital constraint and increases spread. Since an incomplete passthrough is consistent with the data of U.S. banks, we will focus on $i < i_0(\mathcal{C}_l, E_0)$ in the following analysis. This means all the propositions below are based on the following assumption, which guarantees a positive $i_0(\mathcal{C}_l, E_0)$:

Assumption 1 $\mathcal{C}_l > \frac{\nu}{1-\nu} E_0$.

As described in the following proposition, our first result is about the impact of loan market concentration on equilibrium deposit rate and passthrough: that, when the interest rate is sufficiently low, banks with higher market power set higher deposit rates than those in less concentrated markets.

Proposition 2 *(i) The equilibrium deposit rate increases in loan market concentration, i.e.*

$$\frac{\partial i^d}{\partial \mathcal{C}_l} > 0. \tag{39}$$

(ii) Given $\mathcal{C}_l$ and E_0, there exists a unique threshold $i_1(\mathcal{C}_l, E_0)$, which is smaller than $i_0(\mathcal{C}_l, E_0)$, such that the passthrough of Fed funds rate to deposit rate increases with loan market concentration iff $i < i_1(\mathcal{C}_l, E_0)$. That is,

$$\frac{\partial^2 i^d}{\partial i \partial \mathcal{C}_l} > (<)\, 0 \text{ iff } i < (>)\, i_1(\mathcal{C}_l, E_0). \tag{40}$$

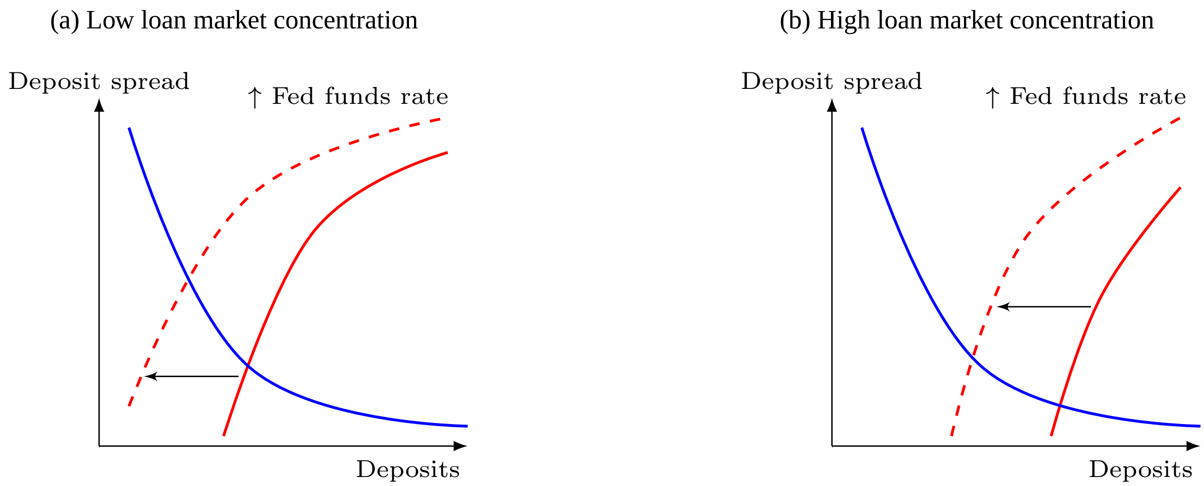
(iii) The threshold $i_1(\mathcal{C}_l, E_0)$ is increasing in $\mathcal{C}_l$ and decreasing in E_0. Moreover, it is positive iff $\mathcal{C}_l > \theta_d + \frac{1+\nu}{1-\nu}E_0$.

Proof. See Appendix A. ■

It is useful to illustrate the intuition of Proposition 2 in graphics, as plotted in Figure 2. This figure plots the demand (blue) and supply (red) curves of aggregate deposits for high loan concentration and low loan concentration. First, the deposit rate is increasing in loan concentration because the loan profits increases with loan concentration. This increases bank's total profit and makes the capital constraint less binding. As a result, banks are able to take more deposits at lower deposit spreads. The solid red curves in Figure 2 show this result. Second, when the interest rate is sufficiently low, the location of deposit supply curve is determined by bank's loan market concentration. In this case, the supply curve of banks with higher loan concentration interacts with the demand curve in the more elastic part. As a consequence, when the interest rate increases, the deposit spread increases less with a higher loan market concentration. Third, the threshold interest rate $i_1(\mathcal{C}_l, E_0)$ represents the cutoff rate below which the effect of loan concentration on passthrough dominates. A higher loan concentration implies a stronger effect of loan concentration on passthrough, while a higher equity implies a stronger effect of bond earnings on passthrough. This implies that the threshold value $i_1(\mathcal{C}_l, E_0)$ is increasing in $\mathcal{C}_l$ and decreasing in E_0.

Next we examine the net effect of low interest rate on passthrough efficiency through our loan market competition channel. We are interested in whether a lower interest rate improves or weakens a bank's passthrough to deposit rate, and its relationship with loan market power. The literature documents that low interest rate environment weakens the aggregate passthrough (e.g. Wang (2018)). However, the following proposition shows that the impact differs across banks. Specifically, a lower interest rate strengthens the deposit rate passthrough for banks with sufficiently large loan market concentration, but weakens otherwise.

Figure 2: Graphic Representation of Passthrough under Different Loan Market Concentration



Notes: This figure plots the passthrough of Fed funds rate to deposit rate for banks with low and high loan market power. The red curves are the supply of deposits, the blue curves are the demand of deposits.

Proposition 3 *Suppose $\nu < \frac{1}{2}$. (i) Given $\mathcal{C}_l$ and E_0, there exists a unique threshold $i_2(\mathcal{C}_l, E_0)$, which is smaller than $i_0(\mathcal{C}_l, E_0)$, such that a lower interest rate improves passthrough if $i < i_2(\mathcal{C}_l, E_0)$, i.e.*

$$\begin{aligned} \frac{\partial^2 i^d}{\partial i^2} &< 0 \text{ if } i < i_2(\mathcal{C}_l, E_0), \\ \frac{\partial^2 i^d}{\partial i^2} &> 0 \text{ if } i \in (i_2(\mathcal{C}_l, E_0), i_0(\mathcal{C}_l, E_0)). \end{aligned}$$

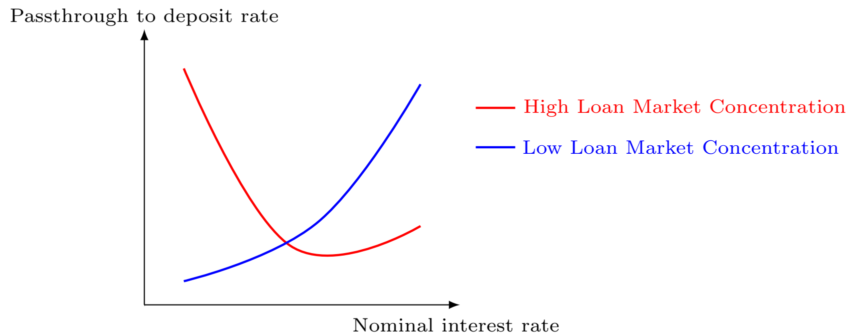
(ii) Given E_0, there exists a unique threshold $\widehat{\mathcal{C}}_l(E_0) > 0$ such that $i_2(\mathcal{C}_l, E_0)$ is positive iff $\mathcal{C}_l > \widehat{\mathcal{C}}_l(E_0)$.

(iii) The threshold $\widehat{\mathcal{C}}_l(E_0)$ is increasing in E_0; the threshold $i_2(\mathcal{C}_l, E_0)$ is increasing in $\mathcal{C}_l$ and decreasing in E_0.

Proof. See Appendix A. ■

A graphic representation of Proposition 3 is plotted in Figure 3. The intuition is as follows. According to Proposition 2, a higher loan market concentration improves passthrough when the interest rate is low. This effect increases with a lower interest rate if and only if the sensitivity of loan profits to interest rates also increases with lower interest rate. This requires $\nu < \frac{1}{2}$ and a sufficiently large $\mathcal{C}_l$. The main implication of this proposition is that a lower interest rate can improve passthrough for banks with high loan concentration, while weakens passthrough if the loan market is competitive.

Figure 3: Interest Rate Passthrough under Different Loan Market Concentration



Notes: This figure plots the theoretical prediction on the relationship between deposit spreads and nominal interest rates for banks with low loan market concentration (small $\mathcal{C}_l$) and high loan market concentration (large $\mathcal{C}_l$).

In sum, the above propositions imply the following testable predictions. First, the following equation summarizes the main results of Proposition 2:

$$\frac{\partial i^d}{\partial i} = \left(\underset{+}{\beta_1} + \underset{-}{\beta_2} \times i + \underset{-}{\beta_3} \times E_0\right) \times \text{loan market concentration} + \text{other terms}, \tag{41}$$

As predicted by the propositions, we expect that $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 < 0$. A positive β_1 represents that the passthrough to deposit rates increases in loan concentration under low interest rate. A negative β_2 implies that this relationship reverses under a high nominal rate. A negative β_3 means that with a higher bank equity, it is less likely that the deposit rate beta increases in bank concentration due to a more relaxed capital constraint. Note that the threshold value of interest rate $i_1(\mathcal{C}_l, E_0) = \frac{1}{-\beta_2}(\beta_1 + \beta_3 \times E_0)$ is decreasing in E_0, which is consistent with Proposition 2.

The second testable prediction is derived from Proposition 3:

$$\frac{\partial i^d}{\partial i} = \left(\underset{+}{\beta_4} + \underset{-}{\beta_5} \times \text{loan market concentration}\right) \times i + \text{other terms}, \tag{42}$$

We expect that $\beta_4 > 0$ and $\beta_5 < 0$. The signs of coefficients imply that if the loan market concentration is larger than $\frac{\beta_4}{-\beta_5}$, then the passthrough increases with a lower interest rate. Otherwise, the passthrough decreases with a lower interest rate.

4 Data

This section describes the data sources and the construction of main variables.

4.1 Data Sources

Branch deposits. The data on branch-level deposit volumes are from the Federal Deposit Insurance Corporation (FDIC). The data cover the universe of U.S. bank branches at an annual frequency from June 1994 to June 2019. The information on branch characteristics, such as the parent bank, address, and geographic location, are also available. I use the FDIC branch identifier to match the FDIC data with other datasets.

Branch deposit rates. The data on retail interest rates are provided by Ratewatch. Ratewatch surveys bank branches across the U.S. and collects weekly branch-level deposit rates by products. I use the sample from January 2001 to December 2019. Compared with the branch information from the FDIC, the data cover 54% of all U.S. branches as of 2019. Following Drechsler et al. (2017), I restrict the data sample to the branches that actively set retail rates, which cover approximately 30% of all unique branches. Moreover, my analysis focuses on the following deposit products: 25K money market accounts (the money market deposit accounts with an account size of $25,000) and 10K CDs with 3-month, 6-month and 12-month maturities (the certificates of deposits with an account size of $10,000 and mature in 3 months, 6 months and 12 months). These products are commonly offered across U.S. branches, and are representative of savings and time deposit products. The Ratewatch data also report the FDIC branch identifier, thus I use it to match the Ratewatch data with the FDIC data.

Bank data. The bank data are from the U.S. Call Reports provided by the Federal Reserve Bank of Chicago and the Federal Financial Institutions Examination Council (FFIEC). The data contain quarterly income statements and balance sheets of all U.S. commercial banks. Our sample is from 1997Q1 to 2019Q4. I use the FDIC bank identifier to merge the bank-level Call Reports data with the branch-level FDIC and Ratewatch data.

Home mortgage loans. I collect the administrative data on residential mortgage loans from the Home Mortgage Disclosure Act (HMDA) dataset. The dataset covers the loan-level information on residential mortgages originated or purchased by most mortgage lending institutions in the U.S. at an annual frequency. In particular, it reports the amount of mortgage loans issued by a financial institution in a given county in a given year. My data sample goes from 2000 to 2019. In the main sample I remove GSE loans, i.e. the mortgages subsidized by the Federal Housing Authority, the U.S. Department of Veterans Affairs, or other government programs. For the bank institutions in this dataset, I use the RSSD identifier to merge their home mortgage loan data with the Call Reports.[18]

County data. I collect data on county population, employment, and median household income from the U.S. Bureau of Labor Statistics, Bereau of Economic Analysis (BEA) and the Census Bureau. I match the data to other datasets using the county fips code as the identifier. Information on local business activities such as two-digit-industry level employment and number of establishments is provided by the County Business Patterns.

Monetary policy data. The quarterly data of effective Fed funds rates and treasury yield rates are obtained from the Federal Reserve Economic Data (FRED). For identification issue, I also adopt the series for policy news shocks from Nakamura and Steinsson (2018) and information shocks from Jarociński and Karadi (2020) as instruments for the Fed funds rate.[19] The sample is all regularly scheduled FOMC meetings from January 2000 to December 2019, excluding the peak of the financial crisis from July 2008 to June 2009. Following Romer and Romer (2004), I convert the shocks data to quarterly frequency by summing up the shocks within the same quarter.

4.2 Variable Definition

This section presents the definition of main variables for the empirical analysis. Table 2 in Appendix C lists the additional variables as well as their summary statistics.

Nominal interest rate. In my theoretical model, the nominal interest rate is the marginal cost of loans. The model assumes it is equal to (or at least influenced by) the policy rate set by the central bank. However, since bank loans have longer maturity than wholesale funding, the marginal cost of loans is not necessarily equal to the policy interest rate in the data due to term premia. To account for the term premia, I follow Wang et al. (2018) to construct a Treasury portfolio, which replicates the repricing maturity of the aggregate loan portfolio of U.S. banks as reported in the Call Reports.[20] I use the weighted average yield rate of this portfolio as banks' effective nominal

[18] The RSSD identifier is provided by Robert Avery from the Federal Housing Finance Agency (available at https://sites.google.com/site/neilbhutta/data).

[19] I use the updated series by Acosta and Saia over January 2000 to December 2019. The shock series is the first principal component across surprise changes of five futures contracts around scheduled policy announcements: the one with respect to the Fed funds rate immediately following a meeting by the Federal Open Market Committee (FOMC), the expected federal funds rate immediately following the next FOMC meeting, and expected three-month eurodollar interest rates at horizons of two, three, and four quarters.

[20] Since banks can also invest deposit funds in the replicating portfolio, we can think of the yield rate of this portfolio as marginal return of deposits. The repricing and maturity data for loans are reported in the Memoranda of Schedule RC-C Part I of the Call Reports. The schedule divides a bank's loan portfolio by the remaining maturity into six categories: 3 months or less, 3 months to 12 months, 1 to 3 years, 3 to 5 years, 5 to 15 years and over 15 years. I

interest rate. This yield rate is a better measure of nominal interest rate than the Fed funds rate, since the Fed funds rate is not informative on banks' marginal cost of capital after the 2008 global financial crisis.[21]

The top panel of Figure 6 plots the time series of the yield rate of the aggregate replicating portfolio. It shows that the yield rate is highly correlated with the effective Fed funds rate, for both the periods before and after the global financial crisis. Moreover, although banks differ in their individual loan portfolio, the yield rate of the replicating portfolio does not have a large variation across banks. In the bottom panel of Figure 6, I calculate the yield rate of the replicating portfolio for each individual bank based on its loan maturity structure and plot the time series of quartiles. The difference between the quartiles is stable and close to 0 over time.

Loan market concentration. In our empirical analysis, the primary proxy for the loan market concentration is the concentration of residential mortgage loans, which is measured as the standard Herfindahl index (HHI) of the home mortgage loans from the HMDA data. It is calculated by summing up the squared loan-market shares of all financial institutions that originate or purchase home mortgage loans in a given county in a given year. I assign to each bank branch in a given year the HHI of the county in which it is located, and refer to it as the Branch-HMDA-HHI. Then for each bank in a given year, I take the weighted average of Branch-HMDA-HHI across its branches, using branch mortgage loan volume as weights, and refer to it as the Bank-HMDA-HHI.

The measure of loan market concentration deserves specific discussions. First, the ideal construction of HHI in local banking markets should use the information on all types of bank loans. However, only the data of home mortage loans (HMDA) and small business loans (Community Reinvestment Act, CRA) are publicly available at the bank-county-year level. I use the mortgage loan data instead of small business loan data for two reasons. First, mortgages loans account for the most substantial part of bank loans, while the share of small business loans is small. Mankart et al. (2020) use the 2010 Call Reports data and find that mortgages account for between 62% and 72% of all bank loans, while the share of commercial & industrial loans is about 10%. Thus the level of mortgage market concentration is an important determinant of a bank's overal loan market concentration. The second reason is that the number of banks reporting CRA data is much less than that of HMDA reporting banks. When matched with the Call Reports data, the fraction

assign to each category the yield rate of treasury that has the closest maturity, and compute the weighted average of the treasury yield rate. This procedure follows English et al. (2018). Similar calculation is adopted in Wang (2018), Begenau et al. (2019) and Drechsler et al. (2020).

[21] Due to the unconventional monetary policy adopted by the Federal Reserve, domestic banks are flushed with excess reserves after the financial crisis, and the main participants of the Fed funds market are government sponsored enterprises and foreign bank organizations. The effective Fed funds rate falls below IOER due to regulatory arbitrage (e.g. Duffie and Krishnamurthy, 2016; Armenter and Lester, 2017; Afonso et al., 2019).

of bank-year pairs with unmissing loan observations is 13% for CRA data, and 39% for HMDA data.[22]

Second, I define banking markets in this paper to be counties, which are the primary administrative divisions for most states. Although other market definitions, such as state or metropolitan statistical area, have been used in some existing empirical research on the U.S. banking industry, many on bank market power have considered county as their measure of geographic market (e.g. Drechsler et al., 2017; Chen et al., 2017; Scharfstein and Sunderam, 2016; Aguirregabiria et al., 2019).

Deposit growth. The branch-level deposit growth is obtained from the FDIC data. Since the data are reported annually, a branch's deposit growth is equal to the log difference of its deposit volume in a year. The bank-level deposit growth is obtained from the Call Reports, which is reported at quarter frequency. A bank's deposit growth is the log difference of the bank's total domestic deposits in a quarter.

Deposit rates. The branch-level and bank-level deposit rates are measured at quarterly frequency. At branch level, for each deposit product, a branch's quarterly deposit rate is equal to the quarterly average of the branch's weekly deposit rates in Ratewatch. The bank-level deposit rates are calculated from the Call Reports data. It is equal to the annualized quarterly interest expenses on domestic deposits divided by total domestic deposits.

Bank equity. The measure of bank equity is calculated from the Call Reports data. It is equal to a bank's total equity capital divided by total assets in a quarter. This is an equivalent measure of bank leverage as documented in English et al. (2018).

4.3 Summary statistics

Table 2 in Appendix C provides the summary statistics of the main variables. It reports the statistics over the full sample, as well as the subperiods before 2010 (the period before low interest rate) and after 2010 (low interest rate period). Panel A presents the summary statistics for the quarterly

[22] There are some restrictions on loan reporting in both data. Under CRA, all banks with assets greater than $1 billion (before 2005, it is $250 million) are required to disclose annual tract-level data on the number and dollar volume of loans originated to businesses with gross annual revenues less than or equal to $1 million. Under HMDA reporting criteria, financial institutions required to disclose are banks, credit unions and savings associations that have at least $43 million in assets, have a branch office in a metropolitan statistical area or metropolitan division, originated at least one home purchase loan or refinancing of a home purchase loan in the preceding calendar year, and are federally insured or regulated. However, as reported in Greenstone et al. (2020), the CRA data still account for 86% of total lending in the small business loans, and the HMDA data account for at least 83% of the population lived in an MSA region during the sample period.

changes of branch deposit rates. For each deposit product, the quarterly changes of deposit rates are negative on average, which is due to the long-run decline of nominal interest rate. Moreover, the deposit rates before 2010 decrease more and are more volatile than the deposit rates after 2010. This is because the nominal interest rate is less volatile in the low-interest rate period.

Panel B reports the summary statistics of the annual deposit growth of U.S. branches. We can observe that the average growth rate is higher before 2010 than after 2010. This is because the nominal interest rate decreases more on average before 2010 than after 2010.

Panel C presents the summary statistics for the home mortgage loan HHI of counties with at least one bank branch. The average HHI is low, implying that the home mortgage loan markets are quite competitive on average. However, the standard deviation is close to the mean value, which implies a large variation of HHI across counties. These results are also reflected in Figure 7, which plots the map of Branch-HMDA-HHI across counties in the United States. Moreover, the average HHI of home mortgage loan markets increases from 0.08 in the first subperiod to 0.12 in the second subperiod, with a slight reduction in the standard deviation.

Panel D reports the sumamry statistics for bank characteristics. Similar to the summary statistics of branch deposit rates, the quarterly changes of bank deposit rate is negative on average. The bank deposit rates decrease more and are more volatile before 2010 than after 2010. The bank-level average home mortgage loan HHI (Bank-HMDA-HHI) is smaller on average and less volatile than the measures at county level. The distribution of bank equity-assets ratio is concentrated and quite stable across periods. Finally, there is a large reduction in the number of banks across periods due to the waves of bank failure and mergers and acquisitions.

Panel E presents the summary statistics of the yield rate on the aggregate replicating portfolio. Consistent with the trend of Fed funds rate, the yield rate is lower and less volatile over the years after 2010 than the period before 2010.

5 Empirical Analysis

This section presents the empirical tests of our model. The analysis starts with branch-level regressions that identify the theoretical mechanism, and then provides bank-level estimation that documents the impact of our channel on bank balance sheets.

5.1 Branch-level Estimation

The branch-level estimation aims to verify the testable predictions (41) and (42). The detailed description of identification strategy and empirical results are presented below.

5.1.1 Identification Assumption

The first part of our empirical analysis is to identify the causal effect of loan market competition on the passthrough to deposit rates under low interest rate. The main identification issue is that the changes in deposit rates and volumes depend on the loan and deposit opportunities simultaneously. In order to guarantee that banks are faced with similar deposit opportunities, I compare the deposit rates and deposit volume growth across branches in the same county but belong to different parent banks.[23] This identification strategy assumes that banks can raise deposits at one branch and lend them at another to equalize the marginal returns of lending across branches. It implies that the impact of loan market competition on a bank's deposit rate is determined by the average loan market concentration of its branches. Therefore, the within-county estimation is able to control for the branches' deposit market power and identify the effect of loan market competition on the passthrough to deposit rates. The identifying assumption is empirically justified by Drechsler et al. (2017), who show that a bank's lending in a given county is not related to local deposit-market concentration. The related empirical evidence is also documented in the banking literature, which shows that banks reallocate deposit fundings to areas with high loan demand (Gilje et al., 2016). Moreover, the within-county estimation allows me to control any other local market characteristics that can affect the equilibrium deposit rates.

5.1.2 Preliminary Analysis

The preliminary analysis investigates if the relationship between passthrough and loan market concentration is different, when the nominal interest rate is high versus low. To do this, I split the data sample into two subperiods: the quarters before 2010Q1 and the quarters after 2010Q1, and run the following regression:

$$\begin{aligned}\Delta y_{j,t} \quad = \quad & \alpha_j + \gamma_{b(j)} + \delta_{c(j),t} + \beta_1 1\{t < \text{2010Q1}\} \times HHI_{b(j),t-1} \times \Delta i_t \\ & +\beta_2 1\{t \geq \text{2010Q1}\} \times HHI_{b(j),t-1} \times \Delta i_t + \beta_3 HHI_{b(j),t-1} + \boldsymbol{\gamma} \cdot \mathbf{x}_{b(j),t-1} + \varepsilon_{j,t},\end{aligned} \tag{43}$$

where j denotes a branch, $b(j)$ denotes the parent bank, $c(j)$ denotes the county of branch j and t is the time index (quarter). I include county-time fixed effect $\delta_{c(j),t}$ to implement the within-county estimation, and branch fixed effect α_j and bank fixed effect $\gamma_{b(j)}$ to control the unobserved time-invariant characteristics of branches and parent banks.[24] The variable $y_{j,t}$ is either the deposit rate or the log of deposits of branch i in period t, and $\Delta y_{j,t}$ is the change of $y_{j,t}$ from period

[23] This identification is similar to the within-county estimation on the impact of deposits concentration on small business lending in Drechsler et al. (2017).

[24] Some branches change their ownership structure due to merger and acquisitions during the sample period. I introduce bank fixed effect to control the potential time-invariant effect of this ownership change.

$t-1$ to t. The variable Δi_t is the contemporaneous change in the Fed funds rate. The variable $HHI_{b(j),t}$ is the measure of bank-level loan market concentration, i.e. Bank-HMDA-HHI. The indicator functions $1\{t < \text{2010Q1}\}$ and $1\{t \geq \text{2010Q1}\}$ represent the dummies of two subperiods. The interaction terms capture the heterogeneous impact of loan market concentration on the deposit rate passthrough.[25] I use quarterly data for deposit rates from Ratewatch and annual data for deposit growth from FDIC. I focus on the sample of counties with at least two different banks for identifying β_1 and β_2. In addition to the fixed effects, the regression also includes a set of bank characteristics $\mathbf{x}_{b(j),t-1}$ to control the factors potentially correlated with $HHI_{b(j),t}$.[26]

Table 3 and 4 report the results of preliminary specification (43) for deposit rates and deposit growth, respectively. The deposit rates include savings deposits ($25K money market account) and time deposits ($10K 3-month, 6-month and 12-month CDs). The deposit growth is the annual growth rate of a branch's aggregate deposits. The results of Table 3 show that in the period after 2010Q1, the passthrough of Fed funds rate to deposit rate is increasing in bank's loan market HHI. The results are significant for the three products of time deposits, and also produce the correct signs of coefficients for the savings deposits. However, in the period before 2010Q1, the passthrough is decreasing in bank's loan market HHI. These results are consistent with Proposition 2. Moreover, the magnitude of estimation is also considerable. The estimated coefficients imply that, for example, when the Fed funds rate rises by 100 bps after 2010Q1, banks in high-concentration loan markets (HHI=1) raise deposit rates by 79 bps more than banks in low-concentration loan markets (HHI=0). Note that the results are robust for various specifications on fixed effects and bank controls. For the regressions on deposit growth, Table 4 confirm that the deposit growth increases (decreases) in loan market HHI in the period after (before) 2010Q1, when the Fed funds rate increases. This means that during the period of low interest rate, banks in high-concentration loan markets experience smaller deposit outflows than banks in low-concentration loan markets.

Equation (43) provides an intuitive split of the data sample to investigate the heterogeneous impact of loan market competition on the passthrough to deposit rates. However the specification is subject to several disadvantages. First, the heterogeneous impact could be driven by other factors that took place simultaneously with low interest rate. Due to the global financial crisis, there could be structural changes in banking sector that arise from changes in the bank regulations. Second, the specification cannot provide an estimate of the threshold value of nominal interest rate, below which the deposit rate passthrough increases in loan market concentration. Thus in the following

[25] The results are robust if the term $\beta_3 HHI_{b(j),t-1}$ is replaced with $\beta_3 1\{t < \text{2010Q1}\} \times HHI_{b(j),t-1} + \beta_4 1\{t \geq \text{2010Q1}\} \times HHI_{b(j),t-1}$ to capture the heterogeneous direct effect of loan market concentration on the changes of deposit rates over two subperiods.

[26] The controls include one-period lag of bank-level average deposits HHI, its interaction with Δi_t, one-period lag of the deposit rate, and one-period lags of bank characteristics: bank size (log of assets), loan-assets ratio, share of non-performing loans, repricing maturity, core deposit share, equity-assets ratio and noninterest net income to assets ratio.

section, I extend the preliminary regression to the baseline regression that explicitly takes into account the effect of nominal interest rate, as well as tesing the role of bank equity.

5.1.3 Baseline Estimation

Our baseline regression, which is designed for testable prediction (41), takes on the following specification:

$$\begin{aligned}\Delta y_{j,t} \;\; = \;\; & \alpha_j + \gamma_{b(j)} + \delta_{c(j),t} + \beta_1 HHI_{b(j),t-1} \times \Delta i_t + \beta_2 HHI_{b(j),t-1} \times i_{t-1} \times \Delta i_t \\ & + \beta_3 HHI_{b(j),t-1} \times E_{b(j),t-1} \times \Delta i_t + \beta_4 E_{b(j),t-1} \times \Delta i_t + \beta_5 HHI_{b(j),t-1} \times i_{t-1} \\ & + \beta_6 E_{b(j),t-1} \times i_{t-1} + \beta_7 E_{b(j),t-1} \times HHI_{b(j),t-1} + \beta_8 HHI_{b(j),t-1} \\ & + \beta_8 E_{b(j),t-1} + \boldsymbol{\gamma} \cdot \mathbf{x}_{b(j),t-1} + \varepsilon_{j,t},\end{aligned} \tag{44}$$

where i_t is the yield rate on the replicating treasury portfolio, and $E_{b(j),t}$ represents the bank equity-assets ratio. All the other variables are defined in the same way as in equation (43).

Equation (44) addresses the disadvantages of (43). First, the two-way interaction $HHI_{b(j),t-1} \times \Delta i_t$ and the three-way interaction $HHI_{b(j),t-1} \times i_{t-1} \times \Delta i_t$ capture that the effect of loan market concentration on passthrough depends on the level of nominal interest rate. The coefficient β_1 captures the sensitivity of passthrough to loan market concentration when the interet rate is zero. The coefficient β_2 measures the the change of the sensitivity when the nominal interest rate increases by 100 bps. Moreover, the term $HHI_{b(j),t-1} \times E_{b(j),t-1} \times \Delta i_t$ represents that the effect of loan market concentration on passthrough also depends on the level of bank equity. As predicted by the model, we expect $\beta_1 > 0$ and $\beta_2, \beta_3 < 0$. This means when the nominal interest rate is sufficiently low (high), the deposit rate passthrough is increasing (decreasing) in banks' loan market concentration. The threshold value of i_{t-1} is equal to $-\frac{\beta_1}{\beta_2} - \frac{\beta_3}{\beta_2} E_{b(j),t-1}$, which is decreasing in bank equity. I also add all the other two-way interactions among the main regressors, i.e., $HHI_{j(i),t-1}$, Δi_t, i_{t-1}, and $E_{j(i),t-1}$, as long as they are not absorbed by fixed effects. The standard errors are clustered at the county level.

The estimation in first differences performed in the equation (44) is preferable to estimation in levels in our empirical analysis. The main reason is that we focus on the passthrough of policy rates to deposit rates, which is the sensitivity of deposit rates to policy rate shocks.[27] Therefore, regression in first differences is the direct counterpart of Proposition 2. Thus I adopt the first-difference estimation in line with the previous literature.

[27] Another reason of estimating in first differences is documented in Drechsler et al. (2017), which implicitly assumes that bank retail rates adjust concemporaneously to changes in the Fed funds rate. This is preferable to estimation in levels from an identification standpoint because it controls for other factors that might vary with monetary policy over longer periods of time or with a lag.

The estiation results of branch deposit rates are reported in Table 5. Column (1), (4) (7) and (10) only include the two-way interaction $HHI_{b(j),t-1} \times \Delta i_t$ to estimate the average effect of loan market concentration on the passthrough to deposit rates. All the four columns report insignificant β_1, implying that an insignificant average impact. Column (2), (5), (8) and (11) reports the baseline specification, which include the interaction terms $HHI_{b(j),t-1} \times \Delta i_t$ and $HHI_{b(j),t-1} \times i_{t-1} \times \Delta i_t$. Although the estimates in column (2) are insignificant, column (5), (8) and (11) confirm that the passthrough of Fed funds rate to time deposit rates is increasing in the loan market concentration, when the nominal interest rate is low. The differential effect vanishes as the nominal interest rate is higher. For example, when the nominal interest rate is zero and the Fed funds rate increases by 100 bps, banks in high-concentration loan markets (HHI=1) raise the deposit rates of 12-month CD accounts by 201 bps more than banks in low-concentration loan markets (HHI=0). The differential effect becomes zero when the nominal interest rate increases to 2.95%. Also notice that the absolute value of β_1's in colum (5), (8) and (11) is larger for products with longer maturity, meaning that the differential effect at zero nominal rate is stronger for longer-maturity products. Column (3), (6), (9) and (12) present the results of the full specification. The estimation demonstrates the role of bank equity. Column (3) reports a significantly positive β_1 and a significantly negative β_3, meaning that the differential effect at zero interest rate also exists for savings deposits, and the effect is weakened by a larger bank-equity ratio. It also implies that the insignificant coefficients in column (2) are due to omitted variables. Moreover, column (6) and (12) also report an significant and negative β_3, which demonstrates the role of bank equity in generating the differential effect of loan market concentration on deposit rate passthrough.

Next I present the results that verify testable prediction (42). Specifically, I replace the county$\times$time fixed effects with county fixed effects in equation (44), and add Δi_t, i_{t-1} and $\Delta i_t \times i_{t-1}$ to capture the aggregate effect of low interest rate on deposit rate passthrough. I also includes a set of controls for robustness of estimation.[28] Table 12 reports the estimation results for branch deposit rates. The coefficient of $\Delta i_t \times i_{t-1}$ is positive, which implies that for banks in perfectly competitive loan market, a lower interest rate weakens the deposit rate passthrough. This is consistent with the empirical result of Wang et al. (2018). On the other hand, the coefficient of $HHI_{j(i),t-1} \times i_{t-1} \times \Delta i_t$ is negative and significant for time deposit products. Moreover, the absolute value of the coefficient of $HHI_{j(i),t-1} \times i_{t-1} \times \Delta i_t$ is larger than that of $\Delta i_t \times i_{t-1}$. This implies that when a bank's loan market concentration is sufficiently large, a lower nominal interest rate actually improves the deposit rate passthrough. The estimated coefficients reveal that a lower nominal rate can improve the passthrough of all the time deposit products, if the bank's loan market HHI is above 0.21. These

[28] The set of controls includes 4-quarter lags of retail and treasury rates, 4-quarter lags of unemployment and real GDP growth, one-year lag of Branch-Dep-HHI, county share of population aged 65 or older, log of county-level population, log of county-level median household income and county share of population with a college degree. I also add linear and quadratic time trends, and the interactions of these controls with the monetary shock.

estimation results show that the impact of low interest rate on passthrough is heterogeneous and depends on banks' loan market power.

Table 13 presents within-county estimates for deposit volume growth. Column (1) to (3) verify testable prediction (41): when the nominal interest rate is zero, an increase in the Fed funds rate leads to smaller outflows for the banks in more concentrated loan markets. The differential effect shrinks at a higher nominal interest rate. Column (3) shows that the threshold nominal interest rate is decreasing in bank equity-assets ratio. For banks with average equity-assets ratio, a 100 bps Fed funds rate increase from zero generates 389 bps less deposit outflows if the bank locates at high-concentration loan markets (HHI=1) than at low-concentration loan markets (HHI=0). Moreover, column (8) reports the results of testable prediction (42). I find that a lower interest rate increases the sensitivity of deposit growth to Fed funds rate for banks in high-concentration loan markets, but decreases the sensitivity for banks in low-concentration loan markets.

5.1.4 Other determinants of the Channel

The theoretical model and empirical results show that the threshold value of nominal interest rate, below which the deposit rate passthrough increases in loan market concentration, is decreasing in bank equity-assets ratio. In this section I investigate if other bank characteristics also affect the threshold value of nominal interest rate.[29] Specifically, I run the following regression:

$$\begin{aligned}\Delta y_{j,t} \quad = \quad & \alpha_j + \gamma_{b(j)} + \delta_{c(j),t} + \beta_1 HHI_{b(j),t-1} \times \Delta i_t + \beta_2 HHI_{b(j),t-1} \times i_{t-1} \times \Delta i_t \\ & + \beta_3 HHI_{b(j),t-1} \times i_{t-1} + \beta_4 HHI_{b(j),t-1} + \boldsymbol{\theta}_1 \cdot HHI_{b(j),t-1} \times \mathbf{x}_{b(j),t-1} \times \Delta i_t \\ & + \boldsymbol{\theta}_2 \cdot \mathbf{x}_{b(j),t-1} \times \Delta i_t + \boldsymbol{\theta}_3 \cdot \mathbf{x}_{b(j),t-1} \times i_{t-1} + \boldsymbol{\theta}_4 \cdot \mathbf{x}_{b(j),t-1} \times HHI_{b(j),t-1} \\ & + \boldsymbol{\gamma} \cdot \mathbf{x}_{b(j),t-1} + \varepsilon_{j,t},\end{aligned} \tag{45}$$

where I replace $E_{b(j),t-1}$ with a full set of bank characteristics $\mathbf{x}_{b(j),t-1}$. The set of bank characteristics include equity-assets ratio, log of bank assets, loan-assets ratio, core deposit share in total liabilities, maturity gap, nonperforming share of loans in total loans, the share of other assets in total interest-earning assets, the share of other liabilities in total liabilities. The computation of maturity gap follows English et al. (2018). The variables "other assets" and "other liabilities" represent the assets and liabilities with no repricing or maturity information. Including these three variables aims to investigate the impact of bank's maturity structure on the threshold value of nominal interest rate.

[29] The potential determinants reflect other financial frictions that link banks' loan pricing strategy to deposits pricing. Such frictions include borrowing cost in wholesale funding market due to asymmetric information, regulatory requirement on reserves, capital and liquid assets. See Wang et al. (2018) for a quantitative evaluation on the role of each friction in monetary transmission.

Table 15 reports the estimated vector of coefficients $\boldsymbol{\theta}_1$ for branch deposit spreads. Consistent with the baseline estimation, the coefficients of three-way interaction $HHI_{j(i),t-1} \times E_{j(i),t-1} \times \Delta i_t$ are still significant for money market accounts, 3-month CDs and 12-month CDs in this table. This confirms that our theoretical mechanism through capital constraint is significant for linking loan market concentration and deposit pricing, and bank equity is one of the most important determinants for the threshold value of nominal interest rate. The effects of other bank characteristics are as follows. First, the loan market concentration has a significantly more pronounced positive impact on larger banks' deposit rate passthrough, as evidenced by the large positive coefficient of bank size. This implies that the threshold value of nominal interest rate is increasing in bank assets. This is possibly due to stronger regulatory capital constraint on larger banks. Second, as indicated by the positive coefficients of nonperforming loan share, loan market concentration also improves the deposit passthrough more on banks with a larger share of nonperforming loans. A possible reason is that higher nonperforming loan share implies higher risk of bank assets, which induces a more strict capital constraint or higher cost of external financing. Thus the threshold value of nominal interest rate is also increasing in nonperforming loan share.

5.1.5 Robustness Checks

This section presents the robustness checks of the empirical results. First, the results are robust for alternative fixed effects and controls. Table 6 and 7 report the robustness checks for deposit rates, and column (4)-(7) in Table 13 report the robustness checks for deposit growth. Second, the results are similar if the measure of nominal interest rate is the Fed funds rate or the 1-year treasury yield rate. Table 8 and 9 report the estimation results for deposit rates, and column (1)-(4) in Table 14 report the results for deposit growth. Third, restricting the data sample to the pre-financial crisis period (until the end of 2008Q2) produces consistent signs of coefficients, but slightly reduces the significance level. This is because the nominal interest rate was not extremely low. The results are reported in Table 10 for deposit rates, and column (5) and (6) in Table 14 for deposit growth. Fourth, the robustness tests run the original regressions of (44) for banks with the largest 25% banks, which are sorted by the inflation-adjusted annual average assets, and obtain consistent results. The regression results are reported in Table 11 for deposit rates, and column (7) and (8) in Table 14 for deposit growth.All these results are availalbe upon request.

5.2 Bank-level Estimation

To deepen the understanding of the economic consequences of low interest rate and bank market power on the passthrough, I now turn to banks' income and balance sheet variables. In particular, I investigate whether the results of branch-level regressions also hold at the bank level, and how the impact of loan market competition on deposit passthrough affects the associated dynamics of bank balance sheets.[30] This provides a more detailed picture of how banks with different loan market power respond differently to interest rate changes in the low-interest environment. The empirical analysis uses the Call Report data over 1997Q1 to 2019Q4.

The analysis studies the impact of loan market concentration on the sensitivity of bank balance sheet components to monetary policy, under different levels of nominal interest rates. Formally, I estimate the following bank-quarter regression:

$$\begin{aligned} y_{b,t+h} - y_{b,t-1} &= \alpha_{b,h} + \eta_{t,h} + \beta_{1,h} HHI_{b,t-1} \times \Delta i_t + \beta_{2,h} HHI_{b,t-1} \times i_{t-1} \times \Delta i_t \\ &+ \beta_{3,h} HHI_{b,t-1} \times E_{b,t-1} \times \Delta i_t + \beta_{4,h} E_{b,t-1} \times \Delta i_t \\ &+ \beta_{5,h} HHI_{b,t-1} \times i_{t-1} + \beta_{6,h} E_{b,t-1} \times HHI_{b,t-1} \\ &+ \beta_{7,h} HHI_{b,t-1} + \beta_{8,h} E_{b,t-1} + \boldsymbol{\gamma}_h \cdot \mathbf{x}_{b,t-1} + \varepsilon_{b,t,h}, \end{aligned} \tag{46}$$

where $h = 0, 1, 2, ..., 8$, b represents a bank and t is a quarter. The dependent variable $y_{b,t+h}$ is an accounting measure of a bank balance sheet variable in quarter $t + h$. The bank concentration $HHI_{b,t}$ is the bank-level loan market HHI, i.e. Bank-HMDA-HHI. The interest rate changes Δi_t is the shocks to Fed funds rate. To control the potential endogeneity between the Fed funds rate changes and the unobserved factors at the bank level, I use two sequences of monetary policy shocks: the policy news shocks of Nakamura and Steinsson (2018) and the information shocks of Jarociński and Karadi (2020). The monetary policy shocks are normalized to generate +100 bps change in the Fed funds rate. I present the results using each sequence and show the robustness. The nominal interest rate i_t and bank equity $E_{b,t}$ are defined in the same way as before. I control the horizon-specific bank fixed effect $\alpha_{j,h}$ and time fixed effect $\eta_{t,h}$, as well as bank-level controls $\mathbf{x}_{b,t-1}$.[31] The inclusion of bank controls is intended to absorb non-monetary policy drivers of bank balance sheet. I cluster standard errors at bank level. The estimation follows the local projection method of Jordà (2005). I plot the sequence of estimated coefficients $\left\{\hat{\beta}_{1,h}, \hat{\beta}_{2,h}, \hat{\beta}_{3,h}\right\}$, $h = 0, 1, ..., 8$, which traces out the cumulative response of bank-level variables to a policy-induced change in the Fed funds rate as a function of bank loan market concentration, level of nominal interest rate and bank equity.

Results on Deposit Rates. Figure 8 plots the estimated responses of average bank deposit rates using the policy news shocks of Nakamura and Steinsson (2018). The bank deposit rate is equal to the annualized quarterly interest expenses on domestic deposits divided by total domestic deposits.

[30] I focus on the dynamic responses because the banks' income and balance sheet reflect income and expense flows accruing from past assets and liabilities. The impacts of interest rate shocks can be reflected on the data with lags.

[31] The bank controls include the same set of balance sheet variables as in the branch regressions. We also include two lags of $y_{b,t}$ to control the seasonality of dependent variables. The full results are available upon request.

Panel (a)-(c) depict the sequences of $\left\{\hat{\beta}_{1,h}\right\}$, $\left\{\hat{\beta}_{2,h}\right\}$ and $\left\{\hat{\beta}_{3,h}\right\}$ respectively. Consistent with the branch-level estimation, the impact of loan market concentration and nominal interest rate is significant persistent on the passthrough to deposit rate at bank level. As shown in panel (a), when there is a +100 bps change in the nominal interest rate from zero-lower bound, banks which has zero equity and operates in a high-concentration loan market (HHI=1) increase their deposit rates by an average of 203 bps more than banks which has zero equity and locates in a low-concentration loan market (HHI=0), during the subsequent four quarters. The estimate is similar in magnitude to the branch-level estimation of Table 5. Panel (b) shows that the differential response vanishes by an average of 29.6 bps if the level of nominal interest rate increases by 100 bps, which is slightly smaller than the magnitude estimated in the branch regression. Panel (c) shows that the differential response vanishes by about 12.9 bps if the bank equity-to-assets ratio increases by 1%. The estimates imply that the threshold level of nominal interest rate, below which banks with a higher loan market concentration have more efficient passthrough, is about 1.89%. The number is lower than the estimate values on time deposits in the branch regressions, which is because the bank average deposit rates also include savings and demand deposits. Moreover, when the nominal interest rate is equal to 3.93%, i.e. its pre-crisis average (over 1997Q1 to 2007Q4), then the banks with average equity-assets ratio and high loan market concentration (HHI=1) raise deposit rates by an average of 60.4 bps less than those with average equity-assets ratio and low loan market concentration (HHI=0). All these numbers imply that the magnitudes of the responses under both normal and low interest rates are economically meaningful compared to the standard deposits channel.[32] All these estimates are significant at least 5% level for a horizon of four quarters, and gradually shrink to zero over the following quarters. This implies that our channel on the short-run passthrough lasts about four quarters, which is consistent with the fact that the maturities of bank deposit products are mostly below 12 months. Moreover, the results are robust and significant if I use the information shocks from Jarociński and Karadi (2020) as monetary policy shocks. As show in Figure 12, the estimated coefficients of $\left\{\hat{\beta}_{1,h}, \hat{\beta}_{2,h}, \hat{\beta}_{3,h}\right\}$ are of the correct signs and significant for the first two quarters.

Results on Balance Sheet Growth and Structure. Now I turn to estimate the impact of our channel on the dynamics of bank balance sheet variables. The analysis focuses on estimating the responses of the growth of bank deposits, loans, securities and assets, as well as the loan-security ratio and the core deposit share in total liabilities. For deposits, loans, securities and assets, which is denoted as $Y_{j,t}$, I define the dependent variable $y_{j,t+h}$ at horizon h as the symmetric growth rate

[32] For a more reasonable comparison, the banks with average equity-assets ratio raise deposit rates by 6.1 bps more and 1.8 bps less if their loan market HHIs are higher by one standard deviation, when the interest rate increases by 100 bps from zero and the pre-crisis average, respectively. The corresponding number estimtated in Drechsler et al. (2017) is by 1.1 bps less if the banks' deposit HHIs are one standard deviation higher.

of $Y_{j,t}$ between $t-1$ and $t+h$, i.e. $y_{j,t+h} = \frac{Y_{j,t+h}-Y_{j,t-1}}{0.5\left(Y_{j,t+h},Y_{j,t-1}\right)}$.[33] The symmetric growth rate is able to accomodate changes in bank balance sheet variables from a starting level of zero, and bound the changes between -2 and 2 for all impulse response horizons and therefore avoids the possibility of extreme outliers. All the other specifications stay the same with (46).

Figure 9 reports the estimation results using the monetary policy shocks of Nakamura and Steinsson (2018). It shows that the our channel has significant impact on the dynamics of bank balance sheets. As plotted in panel (a), the effects of loan market concentration and bank equity are both significant and of the correct signs over the second and third quater after the interest rate shock, and the effect of the level of nominal interest rate is negative and significant over the quarter 0 and 1. Panel (b) to (d) show that banks with higher loan market concentration absorb this expansion by increasing their loans and securities more, when the nominal interest rate is zero. For the growth of bank loans, the level of nominal interest rate does not have significant impact on the passthrough. However, the level of nominal interest rate has a significant impact on the passthrough to assets and security holdings growth in the contemporaneous quarter when the interest rate shocks take place. Moreover, the results with the shocks of Jarociński and Karadi (2020) show that the level of nominal interest rate does have significant impact on the growth of bank balance sheets. As reported in Figure 13, this effect is significant with at least 5% level for the growth of deposits, assets and securities over two quarters after the interest rate shock, and for the loan growth over the third and fourth quarter after the interest rate shock. One reason is that the shocks of Nakamura and Steinsson (2018) rely more on the yield rate curves with shorter maturity than the shocks of Jarociński and Karadi (2020), thus does not fully reflect the shocks to the cost of bank capital.

Finally, the composition of bank balance sheet is also impacted by our passthrough channel. Figure 9 and 13 report the responses of a bank's loan-assets ratio and the share of core deposits in liability. In response to an increase in the Fed funds rate from zero, banks with higher loan market concentration experience larger increase in both loan-assets ratio and core deposit share. The differential response of core deposit share is due to the differential effect of loan market competition on deposit passthrough. Banks with higher loan market concentration are able to raise more deposits, which gives rise to a higher share of core deposits. Since the cost of raising core deposits is lower than other funds, these banks are able to supply loans at lower average and marginal costs. Then they obtain an advantage of issuing new loans and experience an increase in the share of loans in assets.

[33] The symmetric growth rate is the second-order approximation of the log-difference for growth rates around zero and has been used in a variety of contexts such as establishment-level employment growth rates (e.g. Decker et al. (2014)) but also credit growth rates (e.g., Gomez et al., 2020 and Greenwald et al., 2020).

Results on Profitability. A major concern of low interest rate is that it narrows bank profitability and thereby reduces bank lending through the leverage constraints.Thus I investigate the impact of the reversed deposits channel on the dynamics of the measures of bank profitability. Specifically, I run the regression of (46) on the equity-assets ratio and net interest margin. The net interest margin is equal to the annualized quarterly interest income on assets minus quarterly interest expense on liabilities, and then divided by bank assets. The results are plotted in Figure 11 and 15. In both figures, the level of nominal interest rate has negative and persistent effect on the dynamics of bank equity-assets ratio through loan market competition. For example, in Figure 11, at zero nominal interest rate, there is no significant heterogeneity in the response of equity-assets ratio to interest rate shocks for banks with different loan market concentration. However, when the nominal interest rate is equal to 1%, the equity-assets ratio of banks with high loan market concentration (HHI=1) reduces more than banks with low loan market concentration (HHI=0) to positive interest rate shocks, and this additional reduction persists and accumulates to 0.03% in two years after the shock. The magnitude is considerable since the standard deviation of equity-assets ratio is 0.07%.

Moreover, the differential effect of loan market concentration and nominal interest rate also exists for the net interest margin. As shown in panel (b) of both figures, banks with higher loan market concentration experience larger change of net interest margin in response to interest rate shocks when the nominal rate is zero. The differential response vanishes as the nominal rate gets higher. This is consistent with the responses of loan-assets ratio and equity-assets ratio: since the loan-assets ratio increases more for the banks with higher loan market concentration, these banks gain more interest income on new loans, which offsets the loss on deposits. This increases the banks' net interest margin and then the bank equity. When the interest rate shock takes place at a high level of nominal interest rate, banks are not able to gain more on loan interest income, thus the contribution of loan market concentration on profitability is weakenend. This gives rise to a decreasing response of bank equity and net interest margin over the level of nominal interest rates.

5.3 State-Dependent Exposure to Monetary Policy

The above analysis shows that the passthrough of monetary policy to deposit rates depends on the level of nominal interest rate. The theoretical model shows that this dependence operate through loan market competition. Yet the dependence could also derive from other sources. Moreover, the bank-level regressions suggest that this dependence is passed through to the responses of bank balance sheets upon interest rate shocks. In this section, I propose a state-dependent measure of passthrough, which comprehensively evaluates the impact of nominal interest rate on monetary policy transmission through bank balance sheets.

The measure builds on the deposit spread beta in Drechsler et al. (2017). Specifically, I assume the passthrough of monetary policy to deposit rate is a linear function in the nominal interest rate. This is done by running the following time series regression for each bank in the Call Reports data:

$$\Delta \text{Deposit Rate}_{bt} = \alpha_b + \sum_{\tau=0}^{3} \beta_{0,b,\tau} \Delta i_{t-\tau} + \sum_{\tau=0}^{3} \beta_{1,b,\tau} i_{t-\tau-1} \times \Delta i_{t-\tau} + \varepsilon_{bt}, \tag{47}$$

where b denotes a bank, t denotes quarter, ΔDeposit Rate$_{bt}$ is the change in the deposit rate of bank b from period $t-1$ to t, i_t is the Fed funds rate in period t, Δi_t is the change in the Fed funds rate from period $t-1$ to period t.[34] Similar to Equation (1), I control 3 lags of interest rate shocks to account for the cumulative effects over a full year. However, this regression equation differs from the former by adding the interaction terms $\sum_{\tau=0}^{3} \beta_{1,b,\tau} i_{t-\tau-1} \times \Delta i_{t-\tau}$, which takes into account the dependence on the nominal rate. Our estimate of the passthrough to deposit rates consists of two betas: $\beta_{0,b} = \sum_{\tau=0}^{3} \beta_{0,b,\tau}$ and $\beta_{1,b} = \sum_{\tau=0}^{3} \beta_{1,b,\tau}$. The first beta $\beta_{0,b}$ measures the passthrough when the nominal rate is zero, thus I call it "zero beta". The second beta $\beta_{1,b}$ measures the change in the passthrough when the nominal rate increases by 100 bps, thus I call it "slope beta". Since our dependent variable is the changes in deposit rates, a positive slope beta means the passthrough is lower at a lower interest rate, and a negative slope beta means the passthrough is higher at a lower nominal rate. For the robustness of estimation, I focus on the banks which have at least 60 quarters of data over 1997Q1 to 2019Q4, excluding the periods of global financial crisis (2008Q3 to 2009Q2), and winsorize the estimated betas at the 10% level to remove the impact of outliers.

Our estimates suggest that the deposit rate passthrough at zero nominal rate is substantially low and the passthrough is quite sensitive to the nominal interest rate. For all of the banks included in the estimation, the average values of zero beta and slope beta are 0.259 and 0.030, respectively. That is, on average banks raise deposit rates by 25.9 bps per 100 bps increase in the Fed funds rate, when the initial Fed funds rate is zero. This amount increases to 37.9 bps per 100 bps in the Fed funds rate if the initial Fed funds rate increases to 4%. This implies that on average, the passthrough efficiency is lower at lower interest rate. However, the betas also differ substantially in the cross section. The standard deviations of zero beta and slope beta are 0.140 and 0.038, respectively. The fraction of banks with a negative slope beta is 24.6% (1203 out of 4885). This means that low interest rate improves the passthrough efficiency to deposit rates for a quarter of banks in our sample. For comparison, the 10th and 90th percentiles of the slope beta distribution are -0.032 and 0.090. This implies a large cross-sectional heterogeneity in the change of passthrough: when the initial Fed funds rate reduces from 4% to 0, the banks at the 10th percentile are able to raise deposit rates by 36 bps more per 100 bps increase in the Fed funds rate, while those at the 90th percentile are able to raise deposit rates by 12.8 bps less. A more striking result is that the size-weighted

[34] Alternatively, one can replace the Fed funds rate changes with the monetary policy shocks, or replace the lag of Fed funds rate with the lag of the yield rate of replicating portfolio. All the specifications produce similar results.

average slope beta, with the size equal to average bank assets, is about 0. This implies that the aggregate effect of nominal interest rate on passthrough is actually zero, if we take into account the heterogeneity of bank passthrough.

Moreover, I also relate the deposit rate slope beta to deposit zero beta. Panel (a) of Figure 16 reports the bin scatter plots, which sort banks into 100 bins by their zero betas and plot the average slope beta within each bin. The slope between two betas is significantly negative. This is consistent with our channel of loan market competition, which argues that banks with lower passthrough at high nominal rate is expected to have a higher passthrough at zero nominal rate.

Cross-sectional Effects on Bank Balance Sheets. Next I show that the zero beta and slope beta of deposit rates are related to the sensitivity of bank balance sheets to monetary policy. I measure the sensitivity by re-running regression (47) with the symmetric growth rates of deposits, assets, securities, and loans as dependent variables. The corresponding betas are called flow zero betas and flow slope betas. I present the relationship by first showing the bin scatter plots of flow zero beta vs deposit rate zero beta and flow slope beta vs deposit rate slope beta, respectively, for the growth of deposits and loans. The slope of this relationship measures the impact of increased sensitivity of deposit rates to policy rates on the various components of bank balance sheets. The results are reported in Figure 17. All the panels show a strong positive relationship between the deposit rate betas and the flow betas. In particular, the effect of nominal interest rate on the exposure of bank balance sheet components through deposit rate passthrough is large: when the initial level of Fed funds rate reduces from 4% to 0, the banks at the 10th percentile of the deposit rate slope beta distribution are predicted to have a 114 bps less outflow of deposits for every 100 bps increase in the Fed funds rate; however, banks at the 90th percentile are predicted to have a 320 bps more outflow of deposits the same amount increase in the Fed funds rate. The effects are similar for total assets, securities, and loans.[35] Panel A and B of Table 16 report the formal estimates from cross-sectional regressions of flow betas on deposit rate betas for all the banks in our sample. The estimates are significant with large magnitudes. The estimates of zero beta can be interpreted as the semi-elasticities of bank balance sheet components to deposit rates at zero nominal rate, while the estimates of slope beta can be interpreted as the sensitivity of semi-elasticities to the nominal interest rate. These results show that the impact of nominal rate on deposit rate passthrough strongly influences the sensitivity of bank balance sheets to monetary policy.

Aggregate Effects. I use the estimation on large banks to calculate the aggregate impact of nominal interest rate on the deposit rate passthrough over the cross section of banks, and the corre-

[35] The corresponding numbers for total assets are 88 bps less at 10th percentile and 248 bps more at 90th percentile; for securities, the numbers are 160 bps less at 10th percentile and 450 bps more at 90th percentile; for loans, the numbers are 60 bps less at 10th percentile and 169 bps more at 90th percentile.

sponding impact on bank balance sheets. Our analysis focus on the largest 5% banks by assets. The summary statistics of zero beta and slope beta for deposit rates are similar to the full sample. For these banks, the averages of zero beta and slope beta of deposit rates are 0.334 and 0.022, respectively. Their standard deviations are 0.198 and 0.053, and the fraction of large banks with a negative slope beta is 32.4% (79 out of 244). This implies that even for the large banks, a lower interest rate improves the deposit rate passthrough for a significant fraction of banks, but weakens the group on average. Panel (b) of Figure 16 show that the two betas are still negatively correlated for the large banks. Moreover, Figure 18 report the bin scatter plots between flow betas and deposit spread betas for the growth of deposits and assets of large banks. All the panels confirm a positive relationship. Panel C and D of Table 16 report the formal estimates of this positive relationship from cross-sectional regressions of flow betas on deposit rate betas for large banks. The estimates are all significant and have overally larger magnitudes than the estimates for full sample. Thus the passthrough to deposit rates and its dependence on the level of nominal interest rate have stronger impacts on the exposure of bank balance sheets to monetary policy, which implies a strong aggregate effect since the large banks represent most of assets, deposits and loans in the U.S. banking sector.

6 Conclusion

This paper documents that the level of nominal interest rate affects the passthrough of monetary policy rates to deposit rates heterogeneously across banks: with a lower nominal interest rate, the deposit rate passthrough is higher (lower) if a bank starts with a low (high) passthrough. I argue that this relationship is due to banks' loan market power and capital constraints. With market power on loans, a bank's loan profit is decreasing in nominal interest rate, and its total profit is a U-shape function in nominal interest rate. The capital constraint says a bank's deposit liabilities cannot exceed its total profits. Therefore, when the nominal interest rate is low, for banks in concentrated loan markets, a lower interest rate induces larg increase in bank profits. This allows banks to take more deposits at lower deposit spreads, thereby improves the passthrough. However, for banks in competitive loan markets, a lower interest rate still depletes bank profits, which weakens the passthrough.

I test the empirical evidence of this theoretical channel using branch-level data of U.S. banks. I control for the impacts of banks' deposit market characteristics by comparing branches of different banks located in the same local banking market. I find that when the nominal interest rate is sufficiently low, branches of banks located in more concentrated loan markets raise their deposit rates by more, and experience less deposit outflows in response to increases in policy interest rates.

Since deposits are the main source of stable funding for banks, I show that this channel also affects the response of bank balance sheet components to interest rate shocks under low interest rate. Specifically, when the nominal rate is low enough, banks in more concentrated loan markets contract their balance sheet components, such as assets, securities and lendings, by less in response to policy rate increases. Moreover, these banks also experience relative increase in profitability measured by net interest margin.

Finally I extend this channel to construct a general measure of monetary policy passthrough to deposit rates, taking into account the dependence on the level of interest rate. My estimates suggest that nominal interest rate impacts banks' passthrough heterogeneously. Specifically, a lower interest rate improves the passthrough efficiency to deposit rates for a signficant share of banks, while weakens the passthrough for the others. Further estimation shows that the dependence of passthrough efficiency on nominal interest rates can account for the effects of nominal interest rates on the monetary policy transmission through bank balance sheets.

References

Afonso, G., Armenter, R., and Lester, B. (2019). A model of the federal funds market: yesterday, today, and tomorrow. *Review of Economic Dynamics*, 33:177–204. 24

Aguirregabiria, V., Clark, R., and Wang, H. (2019). The geographic flow of bank funding and access to credit: Branch networks, local synergies, and competition. 25

Armenter, R. and Lester, B. (2017). Excess reserves and monetary policy implementation. *Review of Economic Dynamics*, 23:212–235. 24

Balloch, C. and Koby, Y. (2019). Low rates and bank loan supply: Theory and evidence from japan. Technical report, Working paper, London School of Economics. 1, 5, and 6

Bech, M. L. and Malkhozov, A. (2016). How have central banks implemented negative policy rates? *BIS Quarterly Review March*. 1

Begenau, J., Bigio, S., Majerovitz, J., and Vieyra, M. (2019). Banks adjust slowly: Evidence and lessons for modeling. *Available at SSRN 3394601*. 17 and 24

Bemanke, B. and Gertler, M. (1989). Agency costs, net worth, and business fluctuations. *American Economic Review*, 79(1):14–31. 5

Berger, A. N. and Hannan, T. H. (1989). The price-concentration relationship in banking. *The Review of Economics and Statistics*, pages 291–299. 5

Bernanke, B. S. (1983). Nonmonetary effects of the financial crisis in the propagation of the great depression. *The American Economic Review*, 73(3):257–276. 5

Bernanke, B. S. and Blinder, A. S. (1988). Credit, money, and aggregate demand. *The American Economic Review*, 78(2):435–439. 5

Bernanke, B. S. and Blinder, A. S. (1992). The federal funds rate and the channels of monetary transmission. *The American Economic Review*, 82(4):901–921. 5

Bigio, S. and Sannikov, Y. (2019). A model of credit, money, interest, and prices. *Working Paper, University of California, Los Angeles*. 5

Bindseil, U. (2018). *Financial stability implications of a prolonged period of low interest rates*. BIS. 1

Bolton, P. and Freixas, X. (2000). Equity, bonds, and bank debt: Capital structure and financial market equilibrium under asymmetric information. *Journal of Political Economy*, 108(2):324–351. 5

Brunnermeier, M. K. and Koby, Y. (2018). The reversal interest rate. Technical report, National Bureau of Economic Research. 1, 5, and 17

Brunnermeier, M. K. and Sannikov, Y. (2014). A macroeconomic model with a financial sector. *American Economic Review*, 104(2):379–421. 5

Brunnermeier, M. K. and Sannikov, Y. (2016). The i theory of money. Technical report, National Bureau of Economic Research. 5

Chen, B. S., Hanson, S. G., and Stein, J. C. (2017). The decline of big-bank lending to small business: Dynamic impacts on local credit and labor markets. Technical report, National Bureau of Economic Research. 25

Chetty, V. K. (1969). On measuring the nearness of near-moneys. *The American Economic Review*, 59(3):270–281. 17

Claessens, S., Coleman, N., and Donnelly, M. (2018). âĂIJlow-for-longâĂİ interest rates and banksâĂŹ interest margins and profitability: Cross-country evidence. *Journal of Financial Intermediation*, 35:1–16. 1

Corbae, D. and D'Erasmo, P. (2019). Capital requirements in a quantitative model of banking industry dynamics. Technical report, National Bureau of Economic Research. 6

Corbae, D. and Levine, R. (2018). Competition, stability, and efficiency in financial markets. *Unpublished manuscript*. 6

De Loecker, J., Eeckhout, J., and Unger, G. (2020). The rise of market power and the macroeconomic implications. *The Quarterly Journal of Economics*, 135(2):561–644. 6

Decker, R., Haltiwanger, J., Jarmin, R., and Miranda, J. (2014). The role of entrepreneurship in us job creation and economic dynamism. *Journal of Economic Perspectives*, 28(3):3–24. 35

Diebold, F. X. and Sharpe, S. A. (1990). Post-deregulation bank-deposit-rate pricing: The multivariate dynamics. *Journal of Business & Economic Statistics*, 8(3):281–291. 5

Diez, M. F., Leigh, M. D., and Tambunlertchai, S. (2018). *Global market power and its macroeconomic implications*. International Monetary Fund. 6

Drechsler, I., Savov, A., and Schnabl, P. (2017). The deposits channel of monetary policy. *The Quarterly Journal of Economics*, 132(4):1819–1876. 3, 5, 6, 8, 9, 17, 22, 25, 27, 29, 34, and 36

Drechsler, I., Savov, A., and Schnabl, P. (2019). How monetary policy shaped the housing boom. Technical report, National Bureau of Economic Research. 3

Drechsler, I., Savov, A., and Schnabl, P. (2020). Banking on deposits: Maturity transformation without interest rate risk. *The Journal of Finance*, forthcoming. 6 and 24

Driscoll, J. C. and Judson, R. (2013). Sticky deposit rates. *Available at SSRN 2241531*. 6

Duffie, D. and Krishnamurthy, A. (2016). Passthrough efficiency in the fedâĂŹs new monetary policy setting. In *Designing Resilient Monetary Policy Frameworks for the Future. Federal Reserve Bank of Kansas City, Jackson Hole Symposium*, pages 1815–1847. 6 and 24

Eggertsson, G. B., Juelsrud, R. E., Summers, L. H., and Wold, E. G. (2019). Negative nominal interest rates and the bank lending channel. Technical report, National Bureau of Economic

Research. 5

Eggertsson, G. B. and Woodford, M. (2004). Optimal monetary and fiscal policy in a liquidity trap. Technical report, National Bureau of Economic Research. 5

English, W. B., Van den Heuvel, S. J., and Zakrajšek, E. (2018). Interest rate risk and bank equity valuations. *Journal of Monetary Economics*, 98:80–97. 24, 25, and 31

Feenstra, R. C. (1986). Functional equivalence between liquidity costs and the utility of money. *Journal of Monetary Economics*, 17(2):271–291. 17

Fuster, A., Hizmo, A., Lambie-Hanson, L., Vickery, J., and Willen, P. (2020). Mortgage credit supply during the covid-19 pandemic. 17

Gertler, M. and Kiyotaki, N. (2010). Financial intermediation and credit policy in business cycle analysis. In *Handbook of monetary economics*, volume 3, pages 547–599. Elsevier. 5 and 17

Gilje, E. P., Loutskina, E., and Strahan, P. E. (2016). Exporting liquidity: Branch banking and financial integration. *The Journal of Finance*, 71(3):1159–1184. 27

Gomez, M., Landier, A., Sraer, D., and Thesmar, D. (2020). BanksâĂŹ exposure to interest rate risk and the transmission of monetary policy. *Journal of Monetary Economics*. 35

Greenstone, M., Mas, A., and Nguyen, H.-L. (2020). Do credit market shocks affect the real economy? quasi-experimental evidence from the great recession and" normal" economic times. *American Economic Journal: Economic Policy*, 12(1):200–225. 25

Greenwald, D. L., Krainer, J., and Paul, P. (2020). The credit line channel. Federal Reserve Bank of San Francisco. 35

Hannan, T. H. and Berger, A. N. (1991). The rigidity of prices: Evidence from the banking industry. *The American Economic Review*, 81(4):938–945. 5

He, Z. and Krishnamurthy, A. (2013). Intermediary asset pricing. *American Economic Review*, 103(2):732–70. 5

Holmstrom, B. and Tirole, J. (1997). Financial intermediation, loanable funds, and the real sector. *the Quarterly Journal of economics*, 112(3):663–691. 17

Jackson, H. (2015). The international experience with negative policy rates. Technical report, Bank of Canada. 1

Jarociński, M. and Karadi, P. (2020). Deconstructing monetary policy surprisesâĂŤthe role of information shocks. *American Economic Journal: Macroeconomics*, 12(2):1–43. 23, 33, 34, 35, 61, 63, 64, and 65

Jiménez, G., Ongena, S., Peydró, J.-L., and Saurina, J. (2014). Hazardous times for monetary policy: What do twenty-three million bank loans say about the effects of monetary policy on credit risk-taking? *Econometrica*, 82(2):463–505. 5

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American economic review*, 95(1):161–182. 33, 56, 58, 59, 60, 61, 63, 64, and 65

Kashyap, A. K. and Stein, J. C. (1994). Monetary policy and bank lending. In *Monetary policy*, pages 221–261. The University of Chicago Press. 5

Kashyap, A. K. and Stein, J. C. (1995). The impact of monetary policy on bank balance sheets. In *Carnegie-Rochester conference series on public policy*, volume 42, pages 151–195. Elsevier. 5

Kashyap, A. K. and Stein, J. C. (2000). What do a million observations on banks say about the transmission of monetary policy? *American Economic Review*, 90(3):407–428. 5

Kashyap, A. K., Stein, J. C., and Wilcox, D. W. (1993). Monetary policy and credit conditions: Evidence from the composition of external finance. *The American Economic Review*, pages 78–98. 5

Kiyotaki, N. and Moore, J. (1997). Credit cycles. *Journal of political economy*, 105(2):211–248. 5

Krugman, P. R., Dominquez, K. M., and Rogoff, K. (1998). It's baaack: Japan's slump and the return of the liquidity trap. *Brookings Papers on Economic Activity*, 1998(2):137–205. 5

Li, W., Ma, Y., and Zhao, Y. (2019). The passthrough of treasury supply to bank deposit funding. *Columbia Business School Research Paper*. 3 and 9

Mankart, J., Michaelides, A., and Pagratis, S. (2020). Bank capital buffers in a dynamic model. *Financial Management*, 49(2):473–502. 24

Nagel, S. (2016). The liquidity premium of near-money assets. *The Quarterly Journal of Economics*, 131(4):1927–1971. 17

Nakamura, E. and Steinsson, J. (2018). High-frequency identification of monetary non-neutrality: the information effect. *The Quarterly Journal of Economics*, 133(3):1283–1330. 23, 33, 35, 56, 58, 59, and 60

Neumark, D. and Sharpe, S. A. (1992). Market structure and the nature of price rigidity: evidence from the market for consumer deposits. *The Quarterly Journal of Economics*, 107(2):657–680. 6

Piazzesi, M. and Schneider, M. (2018). Payments, credit and asset prices. 17

Poterba, J. and Rottemberg, J. (1987). Money in the utility function: An empirical implementation, new approaches to monetary economics: Proceedings of the second international symposium in economic theory and econometrics. 17

Romer, C. D. and Romer, D. H. (2004). A new measure of monetary shocks: Derivation and implications. *American Economic Review*, 94(4):1055–1084. 23

Sá, A. I. and Jorge, J. (2019). Does the deposits channel work under a low interest rate environment? *Economics Letters*, 185:108736. 5

Scharfstein, D. and Sunderam, A. (2016). Market power in mortgage lending and the transmission of monetary policy. *Unpublished working paper. Harvard University*. 5, 17, and 25

Tella, S. D. and Kurlat, P. (2020). Why are banks exposed to monetary policy? *American Economic Journal: Macroeconomics*, forthcoming. 17

Ulate, M. (2019). Going negative at the zero lower bound: The effects of negative nominal interest rates. Federal Reserve Bank of San Francisco. 1, 5, and 17

Van den Heuvel, S. J. et al. (2002). The bank capital channel of monetary policy. *The Wharton School, University of Pennsylvania, mimeo*, pages 2013–14. 5

Wang, O. (2018). Banks, low interest rates, and monetary policy transmission. *Available at SSRN 3520134*. 1, 3, 5, 6, 17, 19, and 24

Wang, Y., Whited, T. M., Wu, Y., and Xiao, K. (2018). Bank market power and monetary policy transmission: Evidence from a structural estimation. *Available at SSRN 3049665*. 5, 23, 30, and 31

Williamson, S. D. (2012). Liquidity, monetary policy, and the financial crisis: A new monetarist approach. *American Economic Review*, 102(6):2570–2605. 17

Yankov, V. (2014). In search of a risk-free asset. 6

Appendices

A Proofs and Derivations

A.1 Derivations of the model

A.1.1 Deposit demand block

Given banks' deposit spreads $\left\{s_j^d\right\}_{j=1}^N$, the average deposit spread is defined as

$$s^d \equiv \min_{\{D_j\}_{j=1}^N} \frac{1}{N}\sum_{j=1}^N s_j^d D_j \text{ s.t. } \left(\frac{1}{N}\sum_{j=1}^N D_j^{\frac{\sigma_d-1}{\sigma_d}}\right)^{\frac{\sigma_d}{\sigma_d-1}} = 1.$$

To solve this problem, we write the following Lagrangian

$$\mathcal{L} = \frac{1}{N}\sum_{j=1}^N s_j^d D_j + \lambda\left[1 - \left(\frac{1}{N}\sum_{j=1}^N D_j^{\frac{\sigma_d-1}{\sigma_d}}\right)^{\frac{\sigma_d}{\sigma_d-1}}\right]$$

The first-order condition with respect to D_j is

$$\frac{\partial \mathcal{L}}{\partial D_j} = \frac{1}{N}s_j^d - \lambda\frac{1}{N}\left(\frac{1}{D_j}\right)^{\frac{1}{\sigma_d}} = 0 \Rightarrow D_j = \left(\frac{\lambda}{s_j^d}\right)^{\sigma_d},$$

where I apply $\left(\frac{1}{N}\sum_{j=1}^N D_j^{\frac{\sigma_d-1}{\sigma_d}}\right)^{\frac{1}{\sigma_d-1}} = 1$. Plugging the solution to D_j into the budget constraint implies

$$\lambda = \left[\frac{1}{N}\sum_{j=1}^N \left(s_j^d\right)^{1-\sigma_d}\right]^{\frac{1}{1-\sigma_d}}.$$

Therefore, plugging the solution of D_j and λ into the objective function, we obtain

$$s^d = \frac{1}{N}\sum_{j=1}^N s_j^d D_j = \frac{1}{N}\sum_{j=1}^N s_j^d \left(\frac{\lambda}{s_j^d}\right)^{\sigma_d} = \lambda = \left[\frac{1}{N}\sum_{j=1}^N \left(s_j^d\right)^{1-\sigma_d}\right]^{\frac{1}{1-\sigma_d}},$$

Moreover, since the deposit aggregator is constant returns to scale, the individual deposit demand is proportional to aggregate deposit demand:

$$D_j = \left(\frac{s^d}{s_j^d}\right)^{\sigma_d} D.$$

For the aggreate deposit demand, it is given by

$$\max_{D} \theta_d \cdot \ln(D) - s^d \cdot D$$

The first-order condition implies that the solution is

$$D\left(s^d\right) = \frac{\theta_d}{s^d}.$$

Finally, the demand elasticity of individual deposits is

$$\epsilon_j^d = -\frac{\partial \ln(D_j)}{\partial \ln\left(s_j^d\right)} = \sigma_d + (1-\sigma_d)\frac{\partial \ln\left(s^d\right)}{\partial \ln\left(s_j^d\right)} = \sigma_d + \frac{1-\sigma_d}{N}\left(\frac{s_j^d}{s^d}\right)^{1-\sigma_d}.$$

Q.E.D.

A.1.2 Loan demand block

The derivations of the average loan rate i^l and individual loan demand have the same steps as those of average deposit spread by relabelling. The aggregate loan demand is given by the following problem:

$$\max_{c^b,h,l} \frac{\left(c^b\right)^{1-\nu} - 1}{1-\nu} - \theta_h \cdot h$$

subject to

$$c^b \leq l \text{ and } \left(1+i^l\right) l \leq h.$$

The budget constraints are both binding at optimum, thus we have $c^b = l$ ahd $h = \left(1+i^l\right) l$. Then the first-order condition for l is

$$l^{-\nu} = \theta_h \cdot \left(1+i^l\right),$$

which implies

$$l = \left[\theta_h \cdot \left(1+i^l\right)\right]^{-\frac{1}{\nu}}.$$

The aggregate loan demand is

$$L\left(i^l\right) = \mu \cdot l = \mu\left[\theta_h \cdot \left(1+i^l\right)\right]^{-\frac{1}{\nu}}.$$

Q.E.D.

A.2 Proof of Lemma 1

First we derive the optimal response function of a bank's loan rate. This is given by maximizing a bank's profit on loans:

$$\max_{i_j^l} \left(i_j^l - i\right) L_j \left(i_j^l; i_{-j}^l, i\right)$$

The first-order condition implies that

$$1 = \left(1 - \frac{1+i}{1+i_j^l}\right) \left[\sigma_l + \frac{1}{N}\left(\frac{1}{\nu} - \sigma_l\right) \left(\frac{1+i_j^l}{1+i^l}\right)^{1-\sigma_l}\right].$$

Denote $x \equiv \left(1+i^l\right)/(1+i)$ and $x_j \equiv \left(1+i_j^l\right)/(1+i)$. Since we focus on the equilibria with non-negative loan rates, the first-order condition implies that $x_j > 1$. Then the first-order condition can be written as

$$\frac{x_j^{\sigma_l}}{x_j - 1} - \sigma_l x_j^{\sigma_l - 1} = \frac{1}{N}\left(\frac{1}{\nu} - \sigma_l\right) x^{\sigma_l - 1}.$$

Denote the left-hand side of the above equation as $F\left(x_j\right)$. By taking first-order derivative we can get

$$F'\left(x_j\right) = x_j^{\sigma_l - 2}\left[\sigma_l \frac{x_j}{x_j - 1} - \left(\frac{x_j}{x_j - 1}\right)^2 - \sigma_l\left(\sigma_l - 1\right)\right].$$

Note that $x_j > 1$ implies $\frac{x_j}{x_j - 1} \geq 1$. Since $\sigma_l > 1$, one can show that the function $g(y) = \sigma_l \cdot y - y^2 - \sigma_l\left(\sigma_l - 1\right) < 0$ for any $y > 1$. To show this, note that $g(y)$ is maximized at $y = \frac{\sigma_l}{2}$, and $g\left(\frac{\sigma_l}{2}\right) = \frac{3}{4}\sigma_l\left(\frac{4}{3} - \sigma_l\right)$. Moreover, we have $g(1) = -\left(\sigma_l - 1\right)^2 < 0$. If $\sigma_l < 2$, then $g(y) < 0$ for any $y \geq 1$. If $\sigma_l > 2$, then $g\left(\frac{\sigma_l}{2}\right) < 0$, which also implies $g(y) < 0$ for any $y \geq 1$. Therefore, we must have $F'\left(x_j\right) < 0$ for any $x_j > 1$, which implies that $F\left(x_j\right)$ is decreasing in x_j. Moreover, note that $F(1) = +\infty$ and $F(+\infty) = -\infty$, thus there exists a unique solution of x_j to the first-order condition. This solution is identical for any j, which implies that banks must set the same loan rate in equilibrium. By replacing i_j^l with i^l in the first-order condition, we obtain the equilibrium loan rate stated in the lemma. The corresponding profit function is calculated by plugging the equilibrium loan rate into the objective function of loan problem. **Q.E.D.**

A.3 Proof of Lemma 2

First we show that the capital constraint must be binding in a symmetric equilibrium. Suppose there is a symmetric equilibrium where the constraint is not binding, then the first-order condition for individual deposit spread is

$$D_j + s_j^d D_j' = D_j\left[1 - \epsilon_j^d\right] = 0$$

which implies that

$$s_j^d = N^{\frac{1}{1-\sigma_d}} s^d.$$

Thus all banks set the same deposit spread. In this case, the equilibrium deposit spread must be zero. Otherwise, by the definition of s^d, we have

$$s^d = \left[\frac{1}{N}\sum_{j=1}^{N}\left(s_j^d\right)^{1-\sigma_d}\right]^{\frac{1}{1-\sigma_d}} = N^{\frac{1}{1-\sigma_d}} s^d \Rightarrow s^d = 0,$$

which is a contradiction. This implies that in a symmetric equilibrium with non-binding constraint, banks set zero deposit spreads, and the individual loan demand is $\frac{\theta_d}{0} = +\infty$. However, the deposit profit is a constant θ_d due to unit elastic aggregate demand. This violates the capital constraint, thus the constraint must be binding in equilibrium.

Therefore, the equilibrium deposit spread is given by the binding capital constraint, which gives the solution described in the lemma. **Q.E.D.**

A.4 Proof of Proposition 1

Taking the first-order derivative of s^d with respect to i, we have

$$\frac{\partial s^d}{\partial i} = \frac{\psi\theta_d}{\left[\mathcal{C}_l\left(1+i\right)^{-\frac{1-\nu}{\nu}} + \theta_d + \left(1+i\right)E_0\right]^2}\left\{\frac{1-\nu}{\nu}\mathcal{C}_l\left(1+i\right)^{-\frac{1}{\nu}} - E_0\right\}.$$

This implies that $\frac{\partial s^d}{\partial i} > 0$ if and only if $\frac{1-\nu}{\nu}\mathcal{C}_l\left(1+i\right)^{-\frac{1}{\nu}} - E_0 > 0$, which is equivalent to $i < i_0\left(\mathcal{C}_l, E_0\right) \equiv \left[\frac{1-\nu}{\nu}\frac{\mathcal{C}_l(N)}{E_0}\right]^{\nu} - 1$. **Q.E.D.**

A.5 Proof of Proposition 2

For the first part of the proposition, note that $i^d = i - s^d$ and s^d is decreasing in $\mathcal{C}_l$. It is straightforward that i^d is increasing in $\mathcal{C}_l$. For the second part of the proposition, take the second-order cross derivative of s^d with respect to i and $\mathcal{C}_l$:

$$\begin{aligned}\frac{\partial^2 s^d}{\partial i\partial\mathcal{C}_l} = \; & \frac{\psi\theta_d}{\left[\mathcal{C}_l\left(1+i\right)^{-\frac{1-\nu}{\nu}} + \theta_d + \left(1+i\right)E_0\right]^2}\frac{1-\nu}{\nu}\left(1+i\right)^{-\frac{1}{\nu}} \\ & - \frac{2\psi\theta_d}{\left[\mathcal{C}_l\left(1+i\right)^{-\frac{1-\nu}{\nu}} + \theta_d + \left(1+i\right)E_0\right]^3}\left\{\frac{1-\nu}{\nu}\mathcal{C}_l\left(1+i\right)^{-\frac{1}{\nu}} - E_0\right\}\left(1+i\right)^{-\frac{1-\nu}{\nu}}.\end{aligned}$$

For $\frac{\partial^2 i^d}{\partial i \partial \mathcal{C}_l} > 0$ it is equivalent to prove $\frac{\partial^2 s^d}{\partial i \partial \mathcal{C}_l} < 0$. This condition holds if and only if

$$(1-\nu)\,\theta_d + (1+i)\,E_0\,(1+\nu) < (1-\nu)\,\mathcal{C}_l\,(1+i)^{-\frac{1-\nu}{\nu}} \Leftrightarrow i < i_1\left(\mathcal{C}_l, E_0\right). \tag{48}$$

Note that the left-hand side of (48) is increasing in i and increases to infinity, and the right-hand side is decreasing in i and decreases to 0, then there exists a unique value $i_1\left(\mathcal{C}_l, E_0\right)$ below which the above inequality holds. The threshold value $i_1\left(\mathcal{C}_l, E_0\right)$ has following properties. First, it is smaller than $i_0\left(\mathcal{C}_l, E_0\right)$, since $\left.\frac{\partial^2 s^d}{\partial i \partial \mathcal{C}_l}\right|_{i=i_0(\mathcal{C}_l, E_0)} > 0$. Second, if $(1-\nu)\,\theta_d + E_0\,(1+\nu) < (1-\nu)\,\mathcal{C}_l$, then $i_1\left(\mathcal{C}_l, E_0\right)$ is greater than zero. Third, since the right-hand side of (48) is increasing in $\mathcal{C}_l$, and the left-hand side is increasing in E_0, by implicit function theorem we can get that $i_1\left(\mathcal{C}_l, E_0\right)$ increases in $\mathcal{C}_l$ and decreases in E_0. **Q.E.D.**

A.6 Proof of Proposition 3

The second-order derivative of s^d with respect to i is

$$\begin{aligned}\frac{\partial^2 s^d}{\partial i^2} &= \frac{\psi\theta_d}{\left[\mathcal{C}_l\,(1+i)^{-\frac{1-\nu}{\nu}} + \theta_d + (1+i)\,E_0\right]^2}\left\{-\frac{(1-\nu)\,\mathcal{C}_l}{\nu^2}\,(1+i)^{-\frac{1}{\nu}-1}\right\}\\ &\quad+\frac{2\psi\theta_d}{\left[\mathcal{C}_l\,(1+i)^{-\frac{1-\nu}{\nu}} + \theta_d + (1+i)\,E_0\right]^3}\left\{\frac{1-\nu}{\nu}\mathcal{C}_l\,(1+i)^{-\frac{1}{\nu}} - E_0\right\}^2.\end{aligned}$$

It implies that $\frac{\partial^2 s^d}{\partial i^2} > 0$ if and only if function $G\left(i; \mathcal{C}_l, E_0\right) > 0$, where

$$G\left(i; \mathcal{C}_l, E_0\right) \equiv \frac{(1-\nu)\,(1-2\nu)}{\nu^2}\frac{\mathcal{C}_l}{(1+i)^{\frac{1}{\nu}}} + 2E_0^2\frac{(1+i)^{\frac{1}{\nu}}}{\mathcal{C}_l} - \frac{1-\nu}{\nu^2}\left[\frac{\theta_d}{1+i} + (1+4\nu)\,E_0\right].$$

The function $G(i)$ has following properties. First, we have $G\left(i_0\left(\mathcal{C}_l, E_0\right); \mathcal{C}_l, E_0\right) < 0$. This is directly proved from that $\left.\frac{\partial^2 s^d}{\partial i^2}\right|_{i=i_0(\mathcal{C}_l, E_0)} < 0$. Second, $G\left(i; \mathcal{C}_l, E_0\right)$ is a U-shape function over $i \geq -1$. This is proved by taking first-order derivative of G with respect to i. One can show that the first-order derivative is positive if and only if

$$\frac{2E_0^2}{\nu\mathcal{C}_l}\,(1+i)^{\frac{1}{\nu}+1} + \frac{1-\nu}{\nu^2}\theta_d > \frac{(1-\nu)\,(1-2\nu)}{\nu^3}\mathcal{C}_l\,(1+i)^{-\frac{1-\nu}{\nu}}.$$

In this inequality, the left-hand side is increasing in i and is positive at $i = -1$. Since $\nu < \frac{1}{2}$, the right-hand side decreases from infinite to zero as i increases from -1 to infinite. Thus there exists a unique value of i below (above) which G is decreasing (increasing) in i.

Third, $G(i;\mathcal{C}_l,E_0)$ is increasing $\mathcal{C}_l$ for any $i < \left(\frac{\mathcal{C}_l}{\nu E_0}\right)^{\nu}\left[\frac{(1-\nu)(1-2\nu)}{2}\right]^{\frac{\nu}{2}} - 1$. The threshold value is given by taking the first-order derivative of G with respect to $\mathcal{C}_l$ and letting the derivative to be positive. Moreover, the value of G at this threshold is negative, i.e.

$$\begin{aligned}
& G\left(i = \left(\frac{\mathcal{C}_l}{\nu E_0}\right)^{\nu}\left[\frac{(1-\nu)(1-2\nu)}{2}\right]^{\frac{\nu}{2}} - 1;\mathcal{C}_l,E_0\right) \\
= \ & \frac{2E_0}{\nu}\sqrt{2(1-\nu)(1-2\nu)} - \frac{(1-\nu)(1+4\nu)}{\nu^2}E_0 - \frac{1-\nu}{\nu^2}\frac{\theta_d}{1+i} \\
< \ & \frac{(1-\nu)E_0}{\nu}\left[2\sqrt{2\frac{1-2\nu}{1-\nu}} - \frac{1+4\nu}{\nu}\right] < \frac{(1-\nu)E_0}{\nu}\left(2\sqrt{2}-4\right) < 0.
\end{aligned}$$

This implies that (i) when $\mathcal{C}_l \le \nu E_0\left[\frac{2}{(1-\nu)(1-2\nu)}\right]^{\frac{1}{2}}$, $G(i;\mathcal{C}_l,E_0)$ is negative for any $i \in [0, i_0(\mathcal{C}_l,E_0)]$; (ii) when $\mathcal{C}_l > \nu E_0\left[\frac{2}{(1-\nu)(1-2\nu)}\right]^{\frac{1}{2}}$, $G(0;\mathcal{C}_l,E_0)$ is increasing in $\mathcal{C}_l$. It implies that there exists a unique threshold value $\widehat{\mathcal{C}}_l(E_0)$, which is larger than $\nu E_0\left[\frac{2}{(1-\nu)(1-2\nu)}\right]^{\frac{1}{2}}$, such that $G(0;\mathcal{C}_l,E_0) > 0$ if and only if $\mathcal{C}_l > \widehat{\mathcal{C}}_l(E_0)$. The threshold value $\widehat{\mathcal{C}}_l(E_0)$ is increasing in E_0, because $G(0;\mathcal{C}_l,E_0)$ is decreasing in E_0 for any $\mathcal{C}_l > \nu E_0\left[\frac{2}{(1-\nu)(1-2\nu)}\right]^{\frac{1}{2}}$.

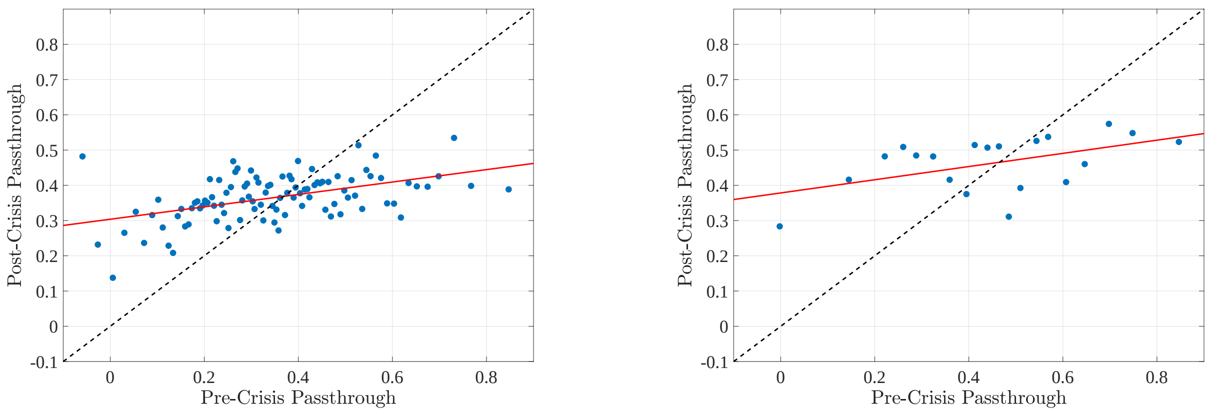
Finally, since G is a U-shape function in i, then there exists a unique threshold value $i_2(\mathcal{C}_l,E_0)$, which is smaller than $i_0(\mathcal{C}_l,E_0)$, such that $G(i;\mathcal{C}_l,E_0) > 0$ if $i < i_2(\mathcal{C}_l,E_0)$, and $G(i;\mathcal{C}_l,E_0) < 0$ if $i \in (i_2(\mathcal{C}_l,E_0), i_0(\mathcal{C}_l,E_0))$. The threshold value $i_2(\mathcal{C}_l,E_0)$ is positive if and only if $\mathcal{C}_l > \widehat{\mathcal{C}}_l(E_0)$. Moreover, whenever positive, $i_2(\mathcal{C}_l,E_0)$ is decreasing in E_0 and increasing in $\mathcal{C}_l$, due to $\mathcal{C}_l > \nu E_0\left[\frac{2}{(1-\nu)(1-2\nu)}\right]^{\frac{1}{2}}$. **Q.E.D.**

B Figures

Figure 4: Loan rate passthrough comparison

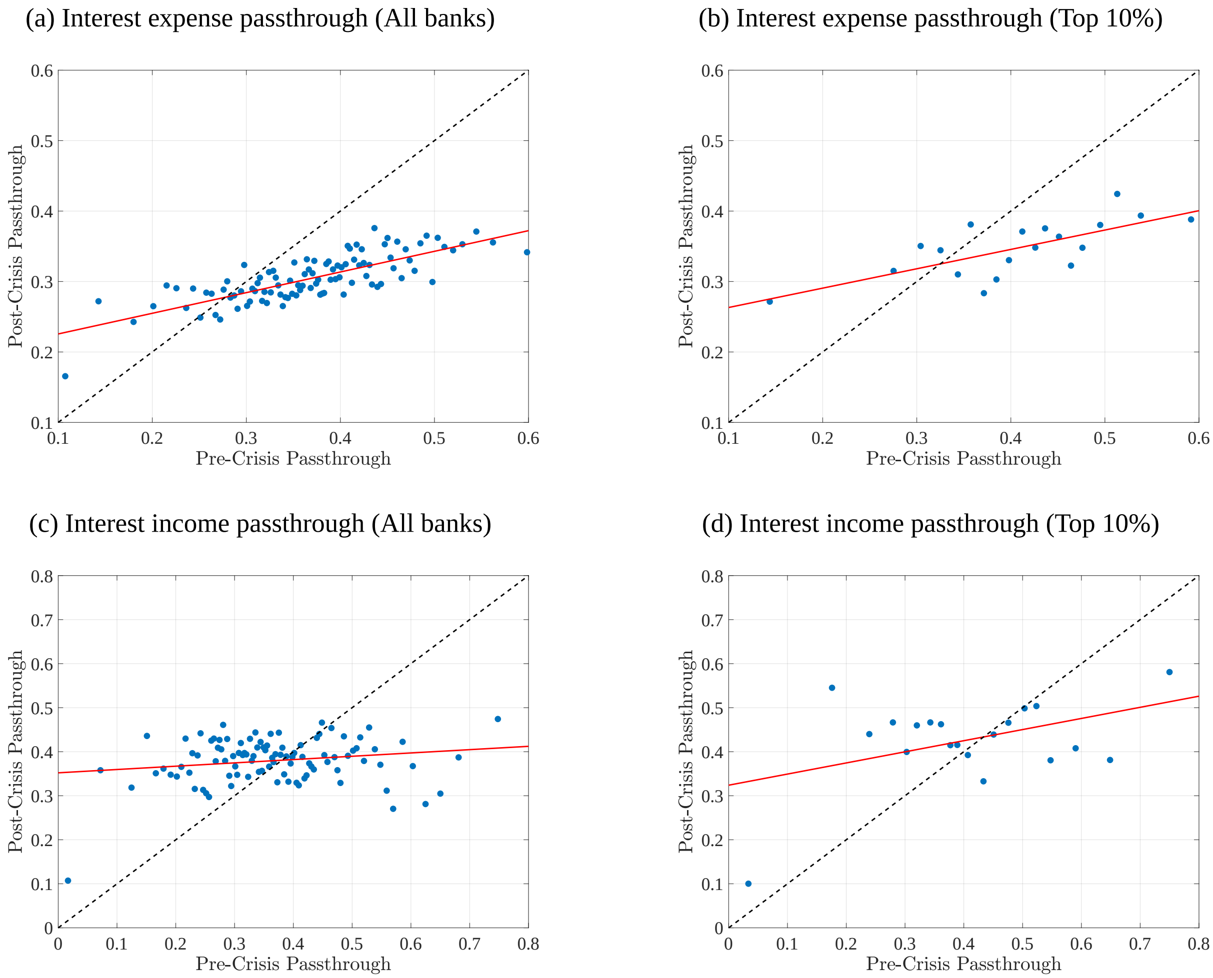
(a) Loan rate passthrough (All banks)

(b) Loan rate passthrough (Top 10%)



Notes: This figure shows bin scatter plots for the passthrough of Fed funds rate to individual banks' loan rates. The passthrough is estimated by regressing the quarterly change of a bank's loan rate on the quarterly changes of the Fed funds rate over the contemporaneous quarter and past three quarters. The estimation is splitted into two subperiods: 1997Q1-2007Q4 and 2010Q1-2019Q4. Only banks with at least 30 quarterly observations in each subperiod are included. The estimates are winsorized at the 1% level for each subperiod. The bin scatter plot in panel (a) groups all banks into 100 bins by the loan rate passthrough in the first subperiod and plots the average loan rate passthrough in the second subperiod within each bin. The bin scatter plot in panel (b) groups the top 10% banks into 20 bins by the loan rate passthrough in the first subperiod and plots the average loan rate passthrough in the second subperiod within each bin. The top 10% of banks are those whose quarterly average inflation-adjusted total assets over the sample are in the top 10th percentile. The underlying data are from FRED and the Call Reports. The sample period is from 1997Q1 to 2019Q4.

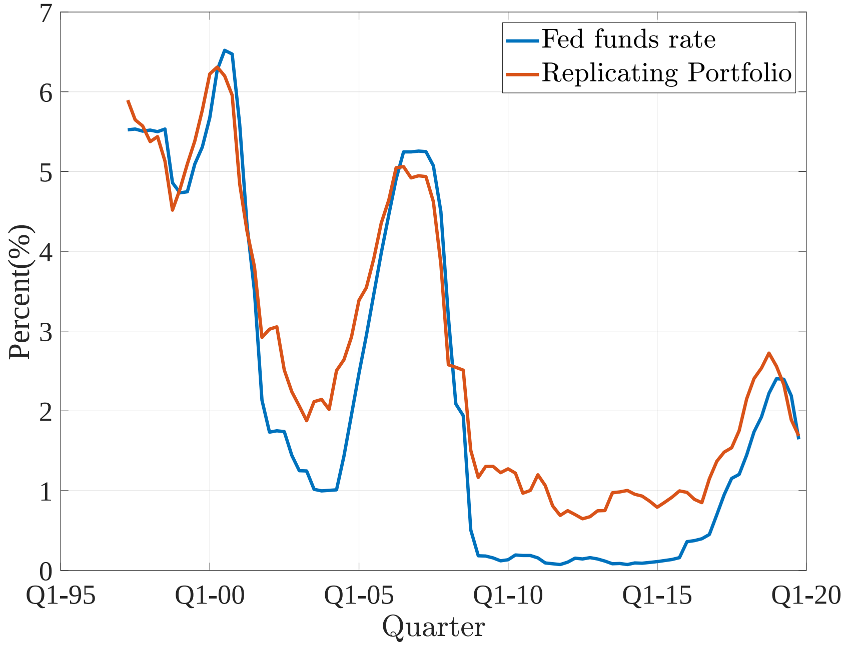
Figure 5: Interest passthrough comparison



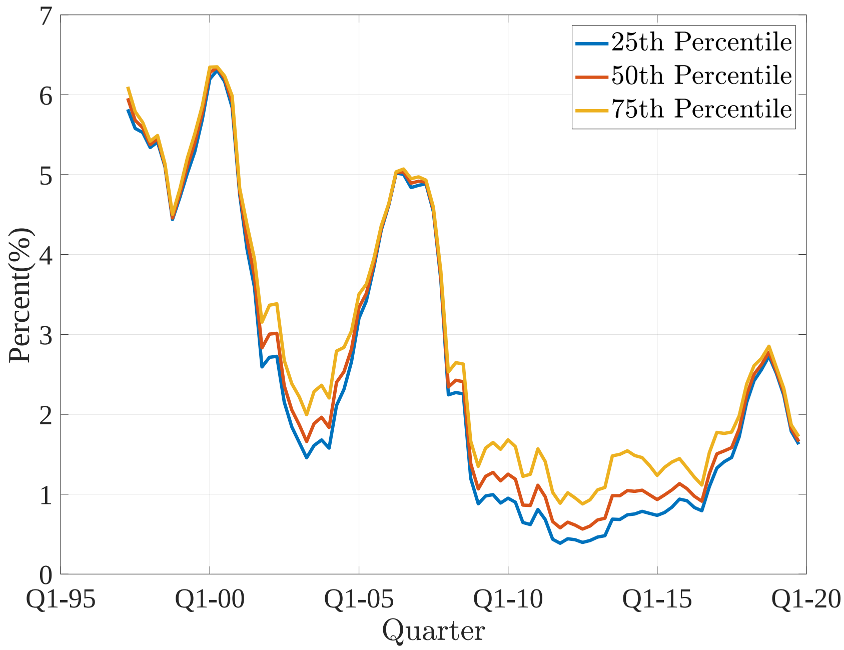
Notes: This figure shows bin scatter plots for the passthrough of Fed funds rate to individual banks' interest expense rates and interest income rates. The passthrough is estimated by regressing the quarterly change of a bank's interest expense rate or interest income rate on the quarterly changes of the Fed funds rate over the contemporaneous quarter and past three quarters. The estimation is splitted into two subperiods: 1997Q1-2007Q4 and 2010Q1-2019Q4. Only banks with at least 30 quarterly observations in each subperiod are included. The estimates are winsorized at the 1% level for each subperiod. The bin scatter plot in panel (a) groups all banks into 100 bins by the interest expense or interest income passthrough in the first subperiod and plots the average interest expense or interest income passthrough in the second subperiod within each bin. The bin scatter plot in panel (b) groups top 10% banks into 20 bins by the deposit rate or loan rate passthroughs in the first subperiod and plots the average interest expense or interest income passthrough in the second subperiod within each bin. The top 10% of banks are those whose quarterly average inflation-adjusted total assets over the sample are in the top 10th percentile. The underlying data are from FRED and the Call Reports. The sample period is from 1997Q1 to 2019Q4.

Figure 6: Replicating Portfolio

(a) Aggregate time series

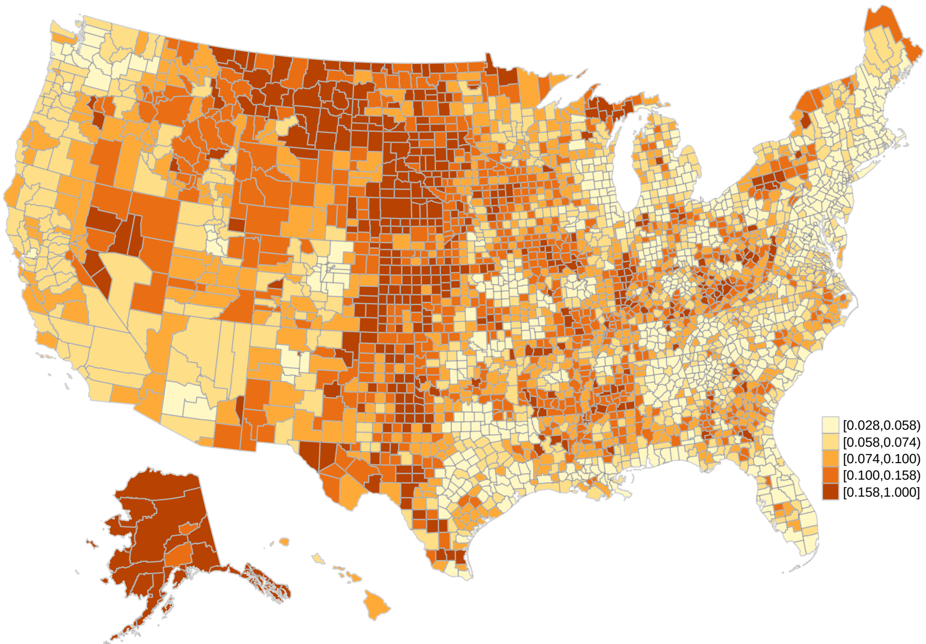


(b) Distribution of bank series



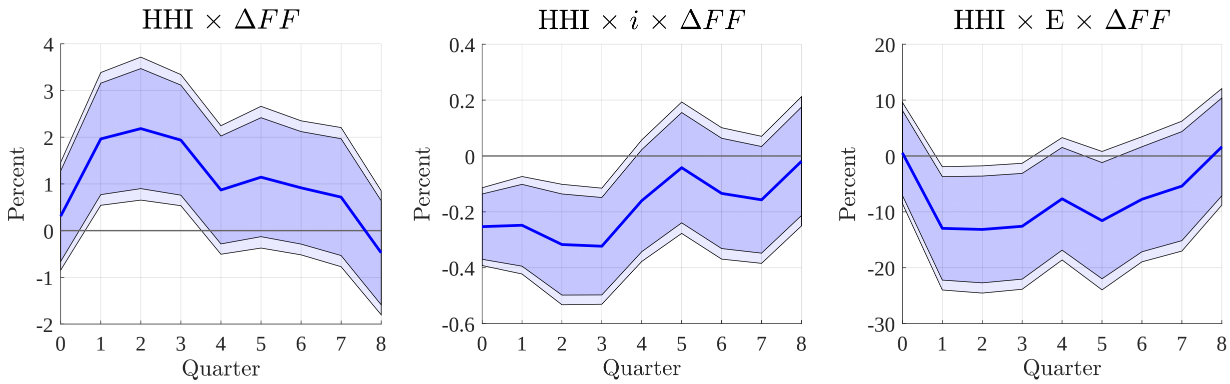
Note: This figure plots the time series of the yield rate on the replicating treasury portfolio. This portfolio replicates the repricing maturity structure of U.S. banks using the Call Reports data. Panel (a) plots the sequence of the aggregate replicating portfolio yield rate and the contemporaneous effective Fed funds rate. Panel (b) plots the quartiles of the yield rates on individual bank's replicating portfolio. The underlying data are from FRED and the Call Reports. The sample period is 1997Q1 to 2019Q4.

Figure 7: Home Mortgage Loan HHI in Local Banking Markets



Notes: This figure plots the yearly average Herfindahl index (HHI) of home mortgage loans by U.S. county. The HHI is calculated each year using the home mortgage loan market shares of all financial institutions that issue or purchase home mortgage loans in a given county, and then averaged over the period from 2000 to 2019. The underlying data are from the HMDA. The threshold values of colorbar in each panel are the quintiles of the HHI distribution.

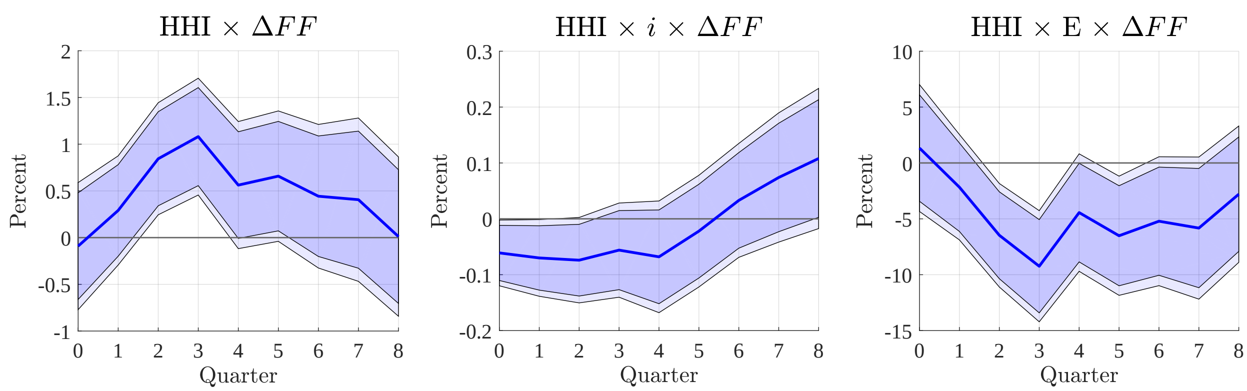
Figure 8: Cumulative response of deposit spread at Bank



Notes: This figure plots the dynamic responses of bank deposit rates to interest rate shocks through the impact of loan market concentration and nominal interest rate. The blue line plots the estimated coefficients $\{\beta_{1,h}, \beta_{2,h}, \beta_{3,h}\}$ of equation (46) for horizon $h = 0, 1, 2, ..., 8$ (quarters). The estimation uses the local projection method of Jordà (2005). 95 and 90 percent confidence intervals are plotted using the standard errors clustered by banks. The left panel plots the sequence of $\beta_{1,h}$, the middle panel plots the sequence of $\beta_{2,h}$, and the right panel plots the sequence of $\beta_{3,h}$. The underlying data are from the Call Reports, HMDA, FRED, and Nakamura and Steinsson (2018). The sample period is from 1997Q1 to 2019Q4,

Figure 9: Cumulative response of bank balance sheet components

(a) Deposits growth



(b) Loan growth

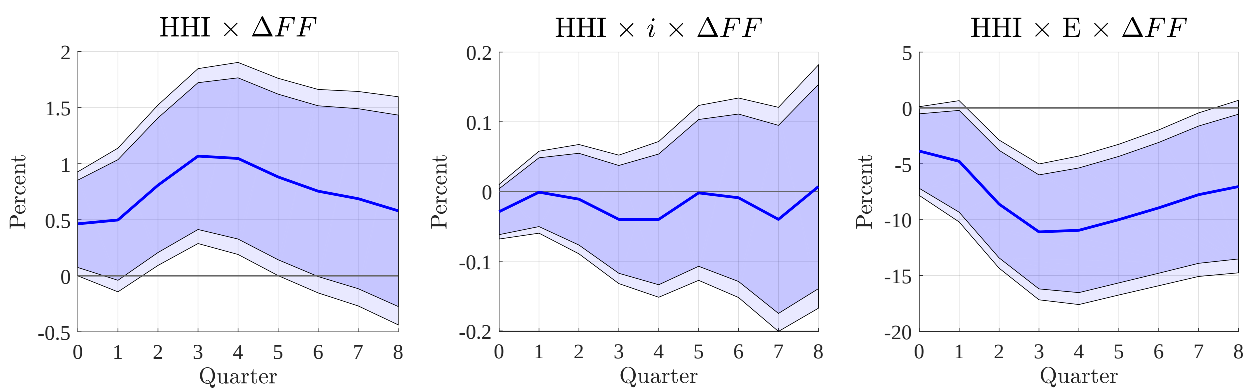
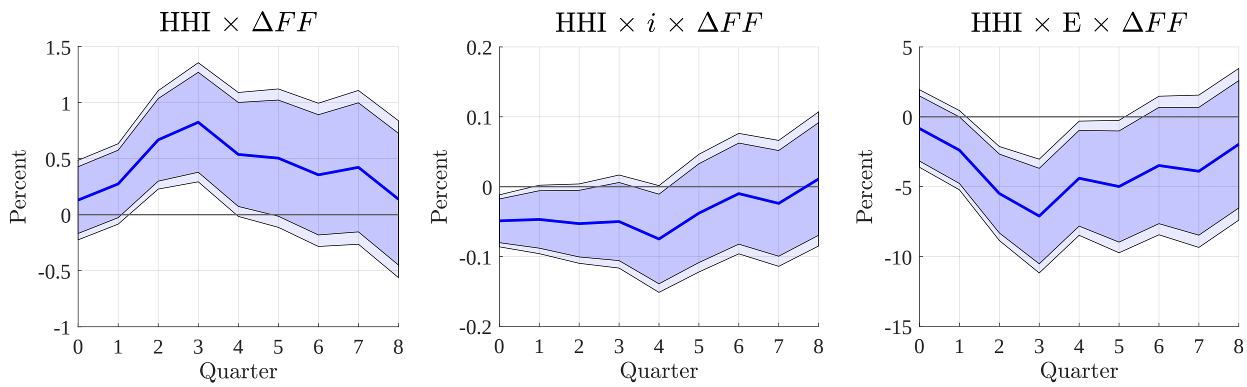
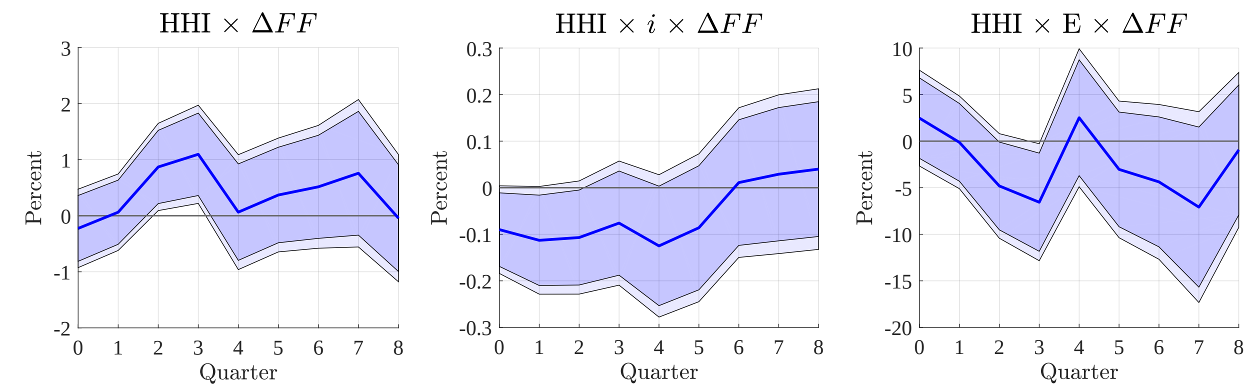


Figure 9: Cumulative response of bank balance sheet components (Cont.)

(c) Assets growth



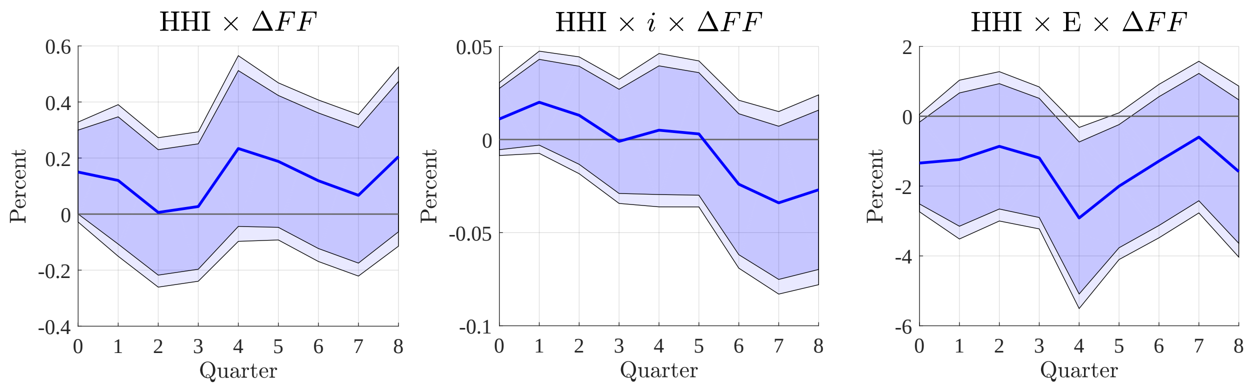
(d) Securities growth



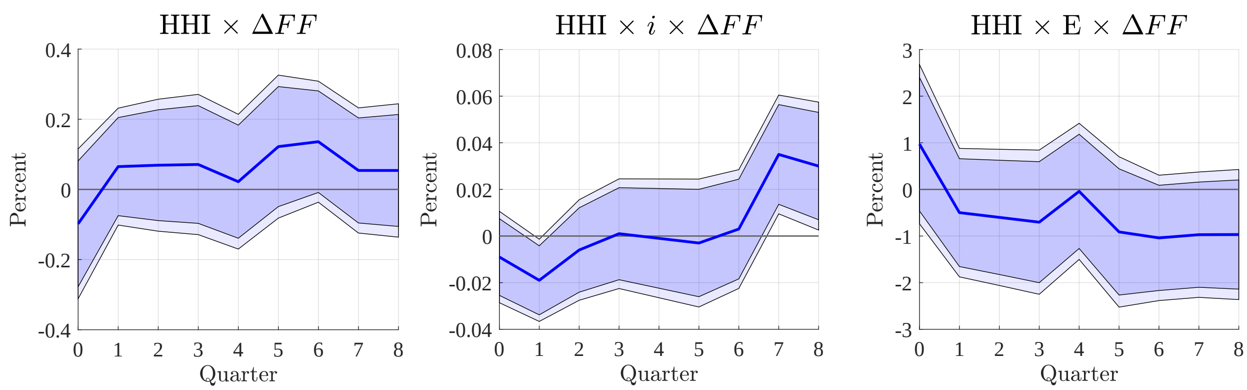
Notes: This figure plots the dynamic responses of the growth bank balance sheet components to interest rate shocks through the impact of loan market concentration and nominal interest rate. The blue line plots the estimated coefficients $\{\beta_{1,h}, \beta_{2,h}, \beta_{3,h}\}$ of equation (46) for horizon $h = 0, 1, 2, ..., 8$ (quarters). The estimation uses the local projection method of Jordà (2005). 95 and 90 percent confidence intervals are plotted using the standard errors clustered by banks. In each panel, the left figure plots the sequence of $\beta_{1,h}$, the middle figure plots the sequence of $\beta_{2,h}$, and the right figure plots the sequence of $\beta_{3,h}$. The underlying data are from the Call Reports, HMDA, FRED, and Nakamura and Steinsson (2018). The sample period is from 1997Q1 to 2019Q4,

Figure 10: Cumulative response of bank balance sheet structure

(a) Loan-Assets Ratio

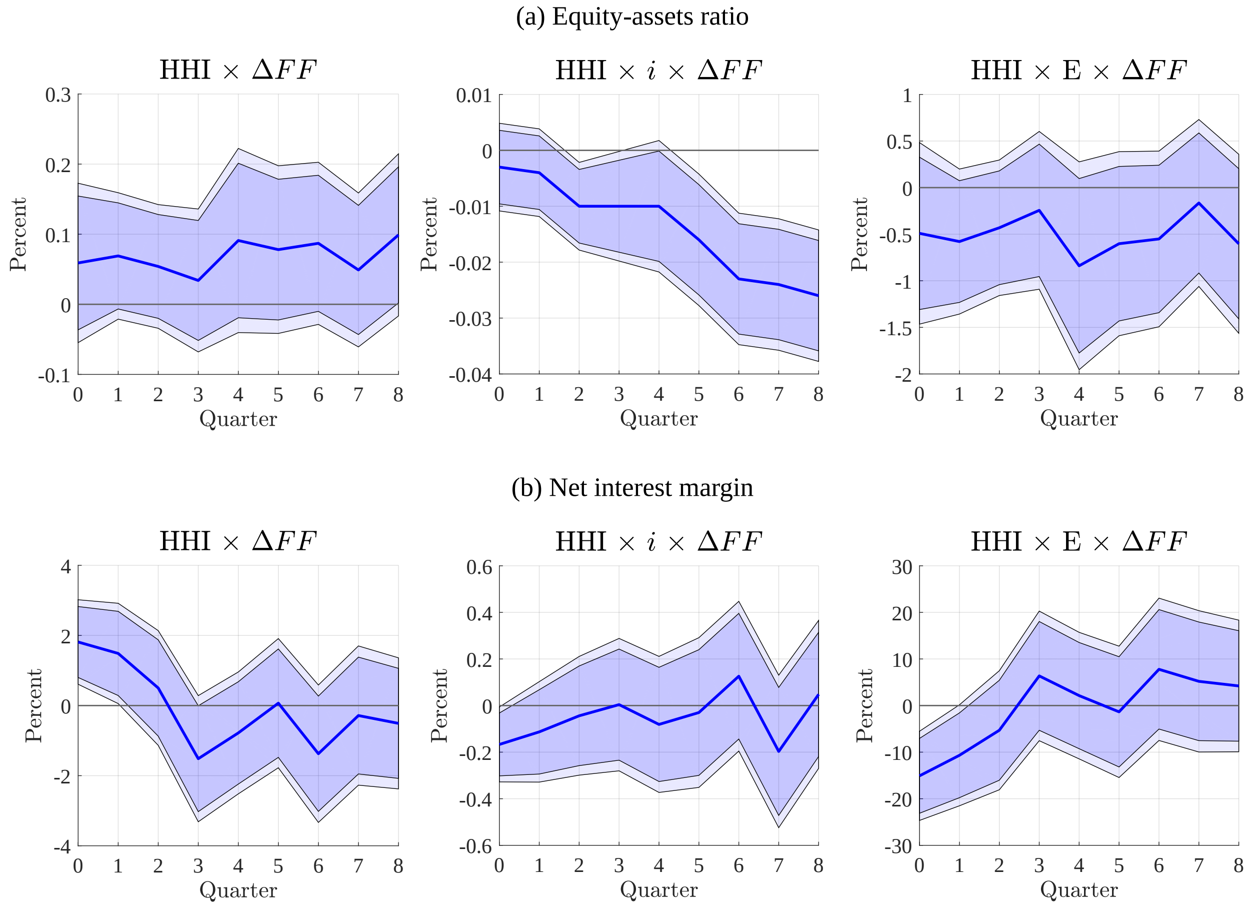


(b) Core Deposits Share



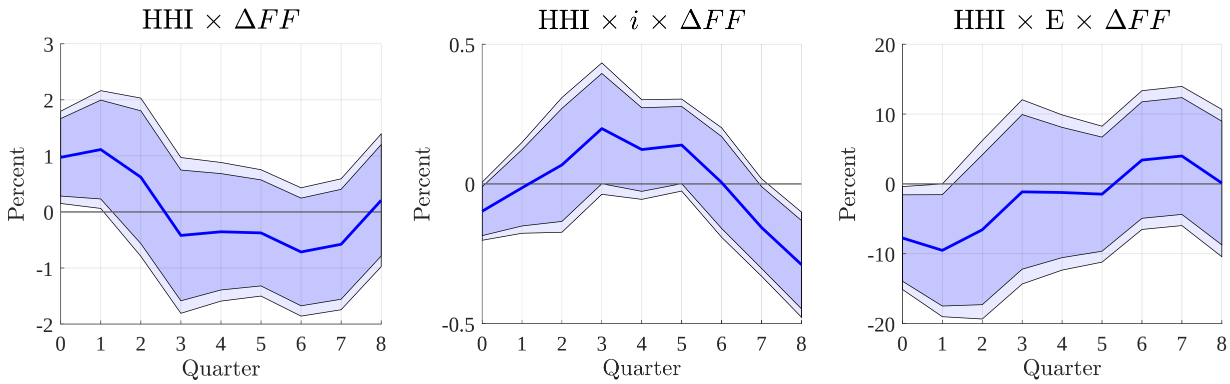
Notes: This figure plots the dynamic responses of bank balance sheet structure to interest rate shocks through the impact of loan market concentration and nominal interest rate. The blue line plots the estimated coefficients $\{\beta_{1,h}, \beta_{2,h}, \beta_{3,h}\}$ of equation (46) for horizon $h = 0, 1, 2, ..., 8$ (quarters). The estimation uses the local projection method of Jordà (2005). 95 and 90 percent confidence intervals are plotted using the standard errors clustered by banks. In each panel, the left figure plots the sequence of $\beta_{1,h}$, the middle figure plots the sequence of $\beta_{2,h}$, and the right figure plots the sequence of $\beta_{3,h}$. The underlying data are from the Call Reports, HMDA, FRED, and Nakamura and Steinsson (2018). The sample period is from 1997Q1 to 2019Q4,

Figure 11: Cumulative response of bank profitability



Notes: This figure plots the dynamic responses of bank profitability measures to interest rate shocks through the impact of loan market concentration and nominal interest rate. The blue line plots the estimated coefficients $\{\beta_{1,h}, \beta_{2,h}, \beta_{3,h}\}$ of equation (46) for horizon $h = 0, 1, 2, ..., 8$ (quarters). The estimation uses the local projection method of Jordà (2005). 95 and 90 percent confidence intervals are plotted using the standard errors clustered by banks. In each panel, the left figure plots the sequence of $\beta_{1,h}$, the middle figure plots the sequence of $\beta_{2,h}$, and the right figure plots the sequence of $\beta_{3,h}$. The underlying data are from the Call Reports, HMDA, FRED, and Nakamura and Steinsson (2018). The sample period is from 1997Q1 to 2019Q4,

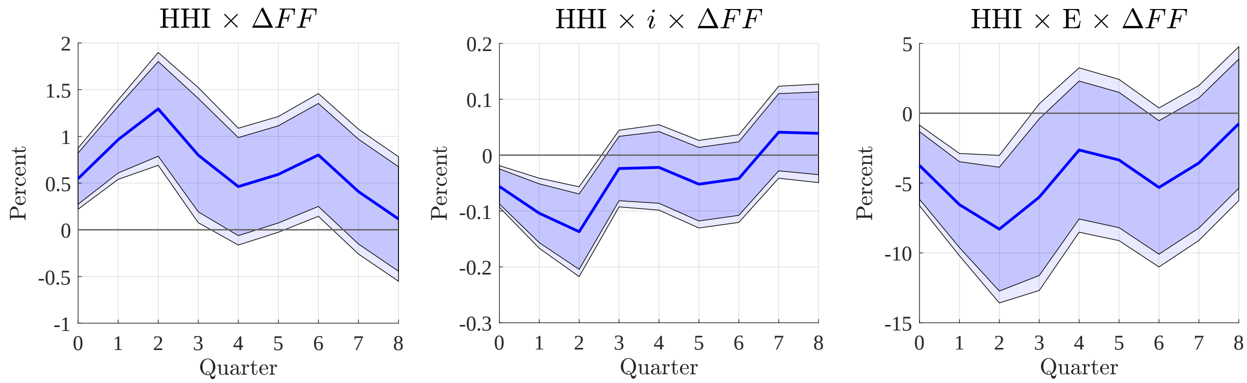
Figure 12: Cumulative response of deposit spread at Bank



Notes: This figure plots the dynamic responses of bank deposit rates to interest rate shocks through the impact of loan market concentration and nominal interest rates. The blue line plots the estimated coefficients $\{\beta_{1,h}, \beta_{2,h}, \beta_{3,h}\}$ of equation (46) for horizon $h = 0, 1, 2, ..., 8$ (quarters). The estimation uses the local projection method of Jordà (2005). 95 and 90 percent confidence intervals are plotted using the standard errors clustered by banks. The left panel plots the sequence of $\beta_{1,h}$, the middle panel plots the sequence of $\beta_{2,h}$, and the right panel plots the sequence of $\beta_{3,h}$. The underlying data are from the Call Reports, HMDA, FRED, and Jarociński and Karadi (2020). The sample period is from 1997Q1 to 2019Q4,

Figure 13: Cumulative response of bank balance sheet components

(a) Deposits growth



(b) Loan growth

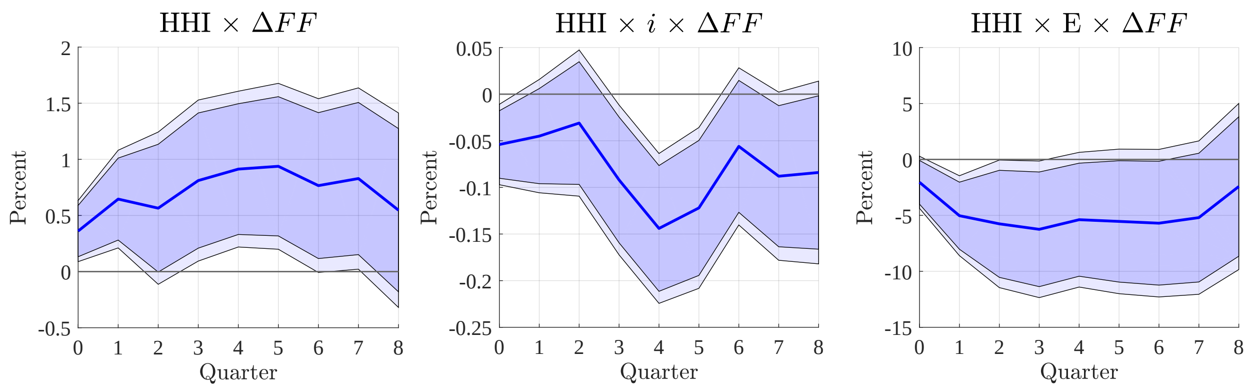
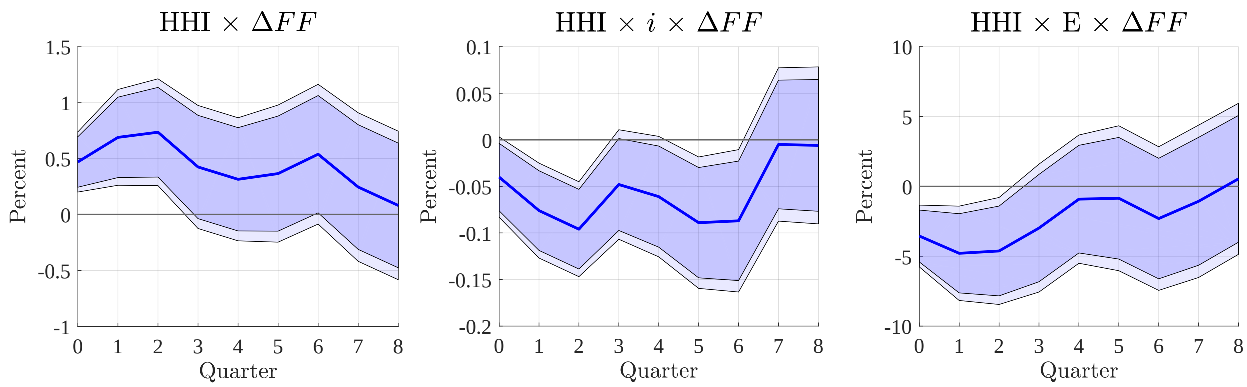
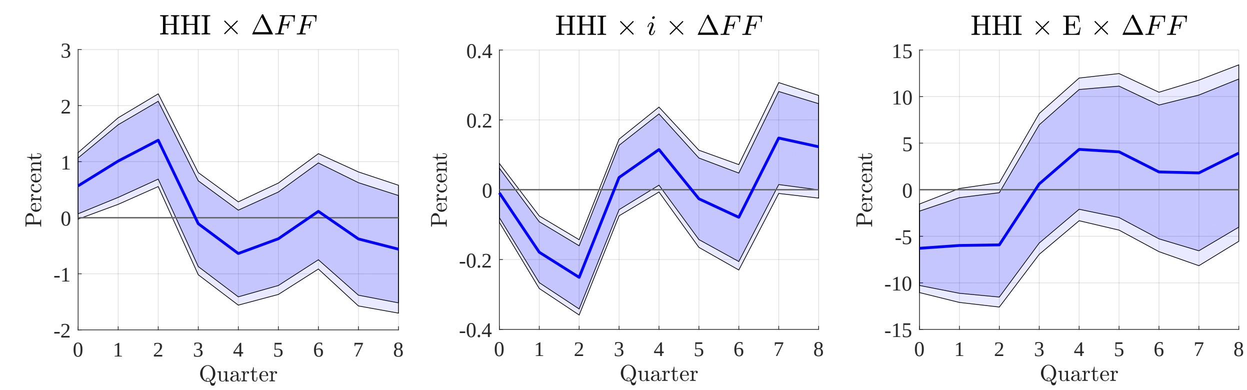


Figure 13: Cumulative response of bank balance sheet components (Cont.)

(c) Assets growth



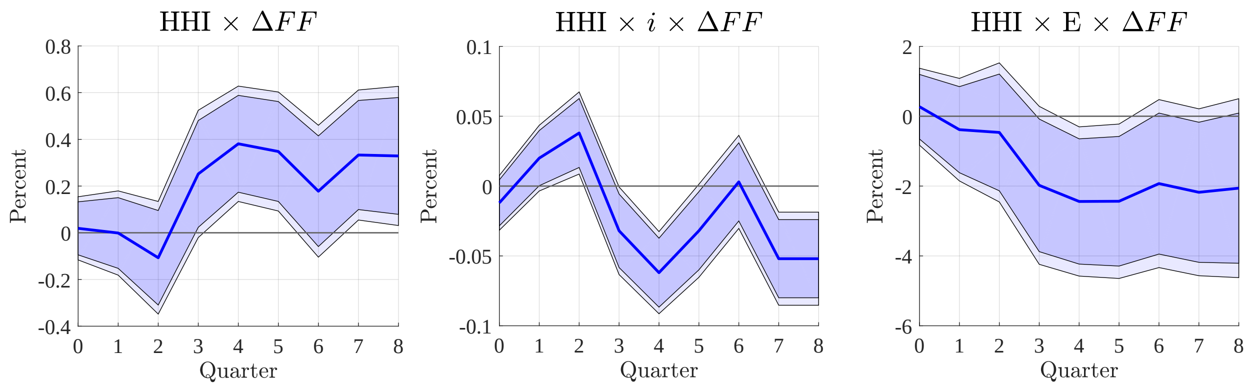
(d) Securities growth



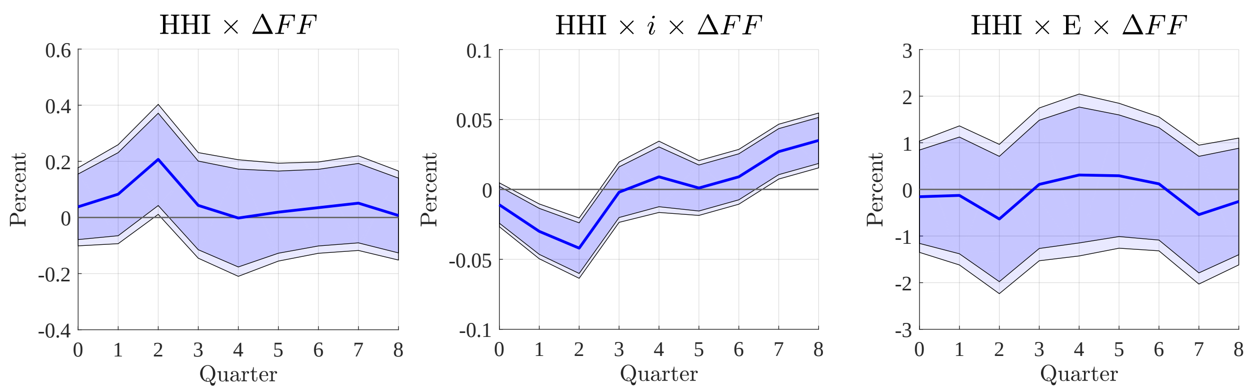
Notes: This figure plots the dynamic responses of the growth bank balance sheet components to interest rate shocks through the impact of loan market concentration and nominal interest rate. The blue line plots the estimated coefficients $\{\beta_{1,h}, \beta_{2,h}, \beta_{3,h}\}$ of equation (46) for horizon $h = 0, 1, 2, ..., 8$ (quarters). The estimation uses the local projection method of Jordà (2005). 95 and 90 percent confidence intervals are plotted using the standard errors clustered by banks. In each panel, the left figure plots the sequence of $\beta_{1,h}$, the middle figure plots the sequence of $\beta_{2,h}$, and the right figure plots the sequence of $\beta_{3,h}$. The underlying data are from the Call Reports, HMDA, FRED, and Jarociński and Karadi (2020). The sample period is from 1997Q1 to 2019Q4,

Figure 14: Cumulative response of bank balance sheet structure

(a) Loan-Assets Ratio



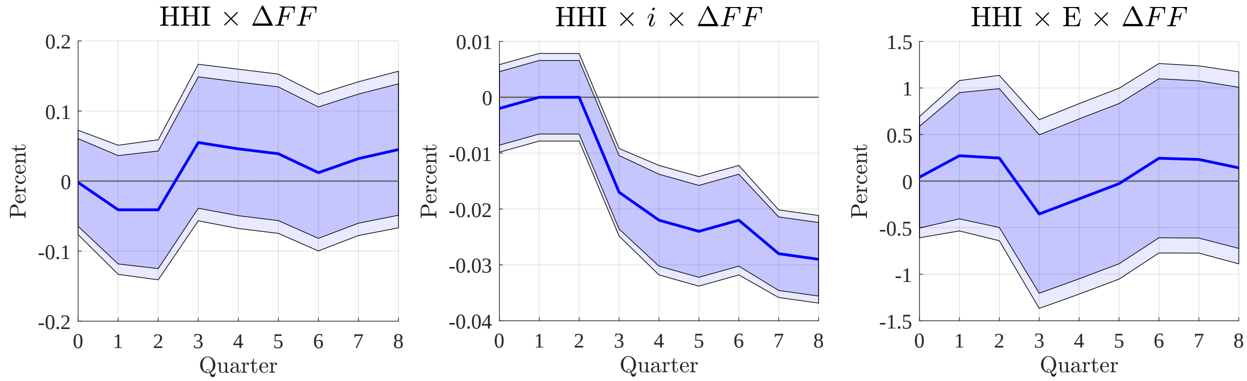
(b) Core Deposits Share



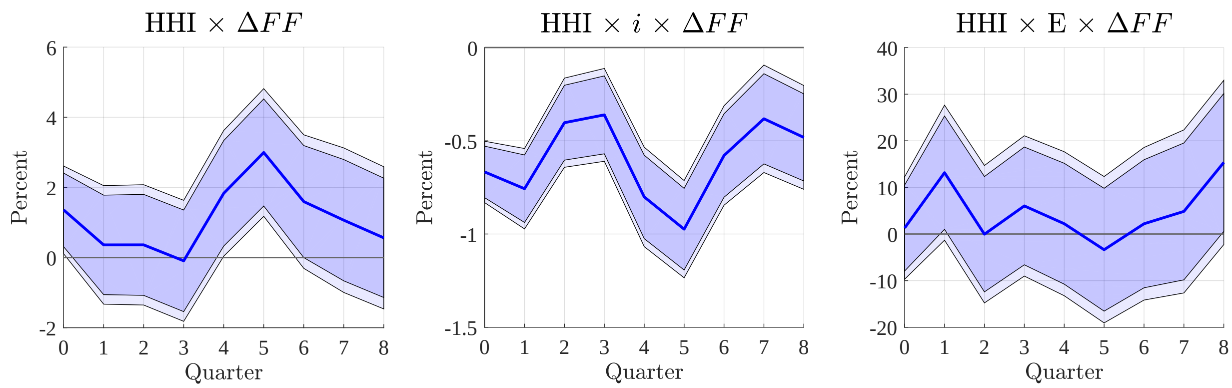
Notes: This figure plots the dynamic responses of bank balance sheet structure to interest rate shocks through the impact of loan market concentration and nominal interest rate. The blue line plots the estimated coefficients $\{\beta_{1,h}, \beta_{2,h}, \beta_{3,h}\}$ of equation (46) for horizon $h = 0, 1, 2, ..., 8$ (quarters). The estimation uses the local projection method of Jordà (2005). 95 and 90 percent confidence intervals are plotted using the standard errors clustered by banks. In each panel, the left figure plots the sequence of $\beta_{1,h}$, the middle figure plots the sequence of $\beta_{2,h}$, and the right figure plots the sequence of $\beta_{3,h}$. The underlying data are from the Call Reports, HMDA, FRED, and Jarociński and Karadi (2020). The sample period is from 1997Q1 to 2019Q4,

Figure 15: Cumulative response of bank profitability

(a) Equity-assets ratio



(b) Net interest margin

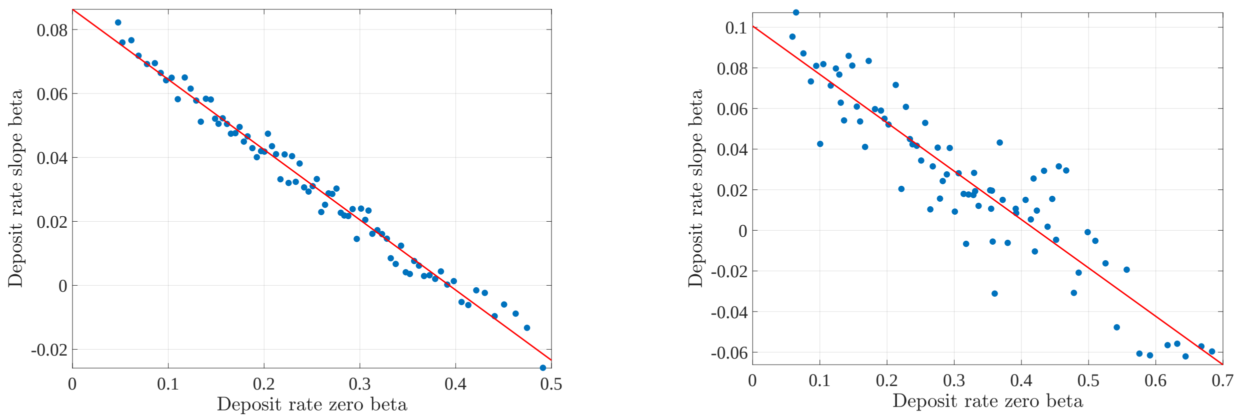


Notes: This figure plots the dynamic responses of bank profitability measures to interest rate shocks through the impact of loan market concentration and nominal interest rate. The blue line plots the estimated coefficients $\{\beta_{1,h}, \beta_{2,h}, \beta_{3,h}\}$ of equation (46) for horizon $h = 0, 1, 2, ..., 8$ (quarters). The estimation uses the local projection method of Jordà (2005). 95 and 90 percent confidence intervals are plotted using the standard errors clustered by banks. In each panel, the left figure plots the sequence of $\beta_{1,h}$, the middle figure plots the sequence of $\beta_{2,h}$, and the right figure plots the sequence of $\beta_{3,h}$. The underlying data are from the Call Reports, HMDA, FRED, and Jarociński and Karadi (2020). The sample period is from 1997Q1 to 2019Q4,

Figure 16: General deposit spread betas

(a) All banks

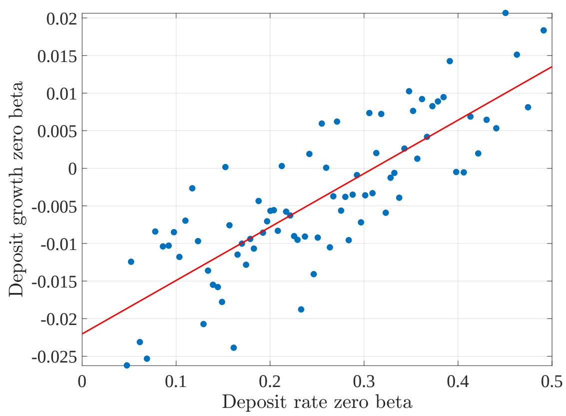
(b) Large banks



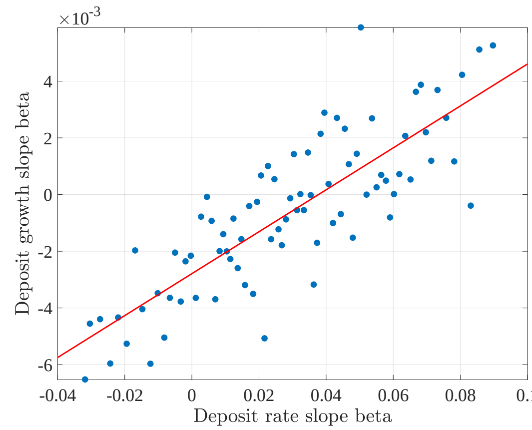
Notes: This figure shows scatter plots of average deposit rate slope betas over 100 bins of deposit rate zero beta. The zero beta measures the passthrough of Fed funds rate to individual bank's deposit rate when the Fed funds rate is zero. The slope beta measures the change in the passthrough when the Fed funds rate increases by 100 bps. Only banks with at least 60 quarterly observations are included. Both betas are winsorized at 10%. The left panel plots the results for all banks, and the right panel plots the results for largest 5% banks by assets. The sample is from 1997Q1 to 2019Q4.

Figure 17: Flow betas vs deposit rate betas (all banks)

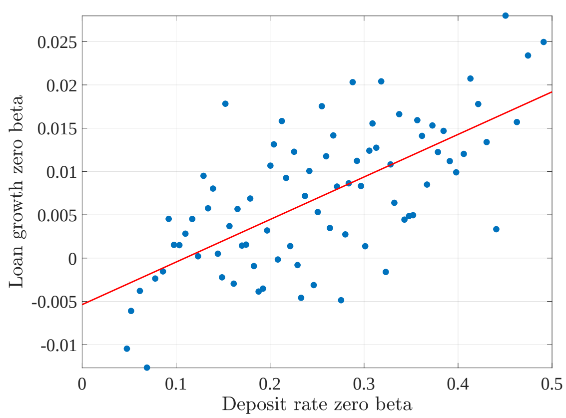
(a) Deposits, Zero beta



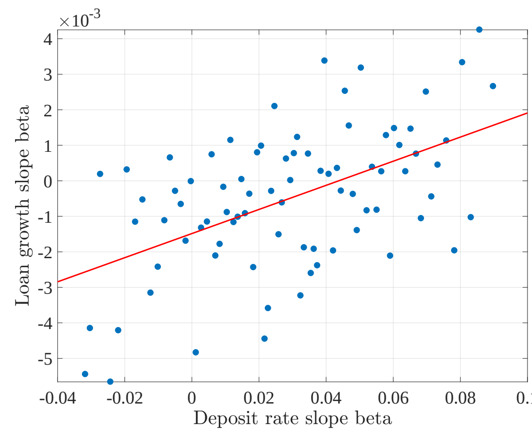
(b) Deposits, Slope beta



(c) Loans, Zero beta



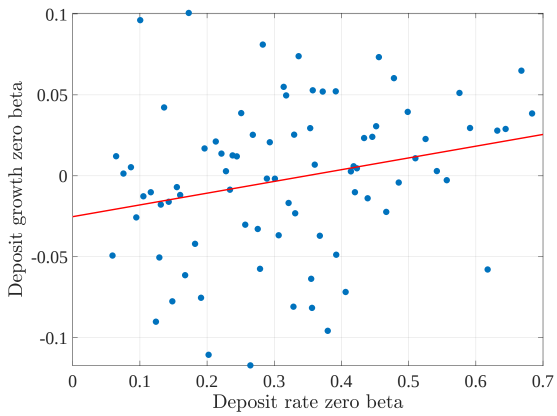
(d) Loans, Slope beta



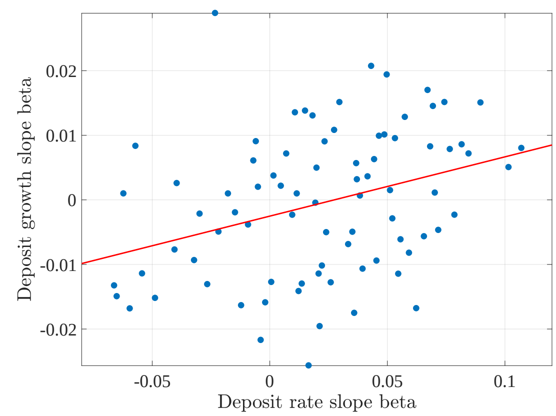
Notes: This figure shows scatter plots of average flow betas over 100 bins of deposit rate betas. Panel (a) is the bin scatter plot of deposit growth zero beta versus deposit rate zero beta. Panel (b) is the bin scatter plot of deposit growth slope beta versus deposit rate slope beta. Panel (c) is the bin scatter plot of loan growth zero beta versus deposit rate zero beta. Panel (d) is the bin scatter plot of loan growth slope beta versus deposit rate slope beta. The deposit rate zero beta measures the passthrough of Fed funds rate to a bank's deposit rate when the Fed funds rate is zero. The deposit rate slope beta measures the change in the passthrough when the Fed funds rate increases by 100 bps. The deposit (loan) growth zero beta measures the sensitivity of a bank's log deposits (loans) to the Fed funds rate when the Fed funds rate is zero. The deposit (loan) growth slope beta measures the change in the sensitivity when the Fed funds rate increases by 100 bps. Only banks with at least 60 quarterly observations are included. Both betas are winsorized at 10%. The panels plot the results for all banks. The sample is from 1997Q1 to 2019Q4.

Figure 18: Flow betas vs deposit rate betas (large banks)

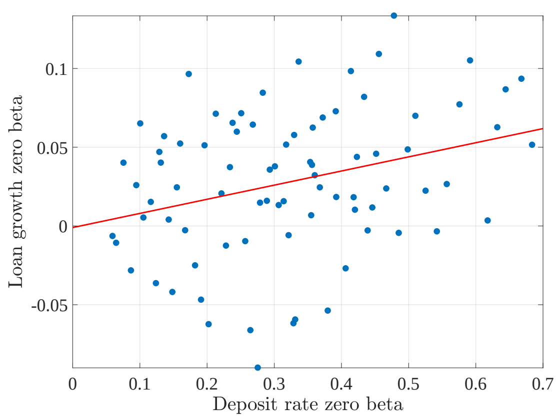
(a) Deposits, Zero beta



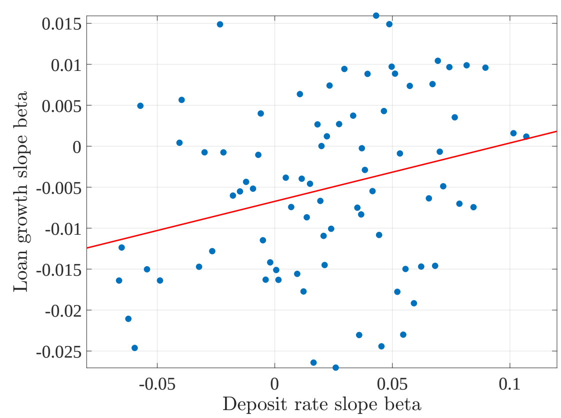
(b) Deposits, Slope beta



(c) Loans, Zero beta



(d) Loans, Slope beta



Notes: This figure shows scatter plots of average flow betas over 100 bins of deposit rate betas. Panel (a) is the bin scatter plot of deposit growth zero beta versus deposit rate zero beta. Panel (b) is the bin scatter plot of deposit growth slope beta versus deposit rate slope beta. Panel (c) is the bin scatter plot of loan growth zero beta versus deposit rate zero beta. Panel (d) is the bin scatter plot of loan growth slope beta versus deposit rate slope beta. The deposit rate zero beta measures the passthrough of Fed funds rate to a bank's deposit rate when the Fed funds rate is zero. The deposit rate slope beta measures the change in the passthrough when the Fed funds rate increases by 100 bps. The deposit (loan) growth zero beta measures the sensitivity of a bank's log deposits (loans) to the Fed funds rate when the Fed funds rate is zero. The deposit (loan) growth slope beta measures the change in the sensitivity when the Fed funds rate increases by 100 bps. Only banks with at least 60 quarterly observations are included. Both betas are winsorized at 10%. The panels plot the results for largest 5% banks by assets. The sample is from 1997Q1 to 2019Q4.

C Tables

Table 2: Summary statistics

	All		< 2010		≥ 2010	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Panel A: Branch Deposit Rates (Ratewacth)						
ΔRate (MM, %)	-0.04	0.21	-0.07	0.30	-0.01	0.07
ΔRate (3M CD, %)	-0.05	0.27	-0.09	0.38	-0.02	0.08
ΔRate (6M CD, %)	-0.05	0.30	-0.09	0.42	-0.02	0.11
ΔRate (12M CD, %)	-0.05	0.31	-0.09	0.42	-0.02	0.14
Obs. (product$\times$branch$\times$quarter)	2,883,416		1,381,701		1,501,715	
Panel B: Branch deposits (FDIC)						
Deposit growth (%)	7.66	26.66	8.94	29.54	6.09	22.57
Obs. (branch$\times$year)	1,944,437		1,068,767		875,670	
Panel C: County characterstics (FDIC and HMDA)						
Branch-HMDA-HHI	0.10	0.11	0.08	0.11	0.12	0.10
Obs. (counties)	3,225		3,219		3,216	
Panel D: Bank characteristics (Call Reports)						
Rate (deposits, %)	-0.04	0.32	-0.05	0.39	-0.02	0.14
Net interest margin (%)	3.69	0.85	3.84	0.85	3.44	0.77
Equity (%)	11.40	0.07	11.23	0.07	11.71	0.06
Assets (mill. $)	1,503	29,235	967	17,640	2,448	42,558
Bank-HMDA-HHI	0.06	0.03	0.04	0.03	0.07	0.03
# of banks	12,950		12,263		7,808	
Obs. (bank$\times$quarter)	699,744		446,418		253,326	
Panel E: Aggregate series						
Replicating portfolio yield rate (%)	2.70	1.78	3.83	1.56	1.25	0.59
Obs. (quarter)	91		51		40	

Notes: This table provides summary statistics at the branch, bank, county and aggregate levels. All panels provide a breakdown by subperiods over the quarters up to 2009Q4 and after 2010Q1. Panel A presents data on the quarterly changes of branch-level deposit rates of four deposit products. "MM" represents the 25K Money Market account. "3M CD", "6M CD" and "12M CD" represent the 10K CD accounts with 3-month, 6-month and 12-month maturity. The underlying data are from Ratewatch from January 2001 to December 2019. Panel B presents data on the annual growth of branch deposit volumes. The underlying data are from FDIC from 1994 to 2019. Panel C presents data on a county's Herfindahl index of home mortgage loans. The underlying data are from HMDA from 2000 to 2019. Panel D presents data on bank characteristics. The underlying data are from the Call Reports from 1997Q1 to 2019 Q4. Panel E presents data on the yield rate of the aggregate replicating treasury portfolio. The underlying data are from the Call Reports and FRED from 1997Q1 to 2019Q4.

Table 3: Identification of the channel: preliminary results on deposit rates

Dependent Variable:	Δbranch deposit rate (quarterly)							
Loan market power:	Bank-HMDA-HHI							
Deposit product:	Money Market Account				3M CD			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$1\{t < 2010\text{Q1}\} \times HHI \times \Delta i$	0.174	0.131	0.303	0.299	-0.601**	-0.472*	-0.047	-0.042
	(0.258)	(0.252)	(0.223)	(0.223)	(0.251)	(0.246)	(0.216)	(0.216)
$1\{t \geq 2010\text{Q1}\} \times HHI \times \Delta i$	0.205	0.209	0.123	0.141	0.378**	0.543***	0.400***	0.406***
	(0.166)	(0.162)	(0.110)	(0.109)	(0.186)	(0.183)	(0.153)	(0.152)
Obs	206,211	206,211	206,211	206,211	195,515	195,515	195,515	195,515
Adj R^2	0.789	0.788	0.782	0.787	0.708	0.707	0.685	0.694
Deposit product:	6M CD				12M CD			
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
$1\{t < 2010\text{Q1}\} \times HHI \times \Delta i$	-0.895***	-0.797***	-0.526***	-0.527***	-0.321*	-0.269	-0.484***	-0.494***
	(0.234)	(0.228)	(0.196)	(0.196)	(0.183)	(0.183)	(0.176)	(0.175)
$1\{t \geq 2010\text{Q1}\} \times HHI \times \Delta i$	0.484**	0.631***	0.478***	0.485***	0.790***	0.956***	0.608***	0.620***
	(0.197)	(0.194)	(0.174)	(0.174)	(0.227)	(0.233)	(0.192)	(0.191)
Obs	213,701	213,701	213,701	213,701	214,374	214,374	214,374	214,374
Adj R^2	0.669	0.668	0.641	0.650	0.670	0.668	0.639	0.648
Controls (all panels):								
Branch FE	Y	Y	Y	N	Y	Y	Y	N
Bank FE	Y	Y	Y	N	Y	Y	Y	N
County FE	N	N	Y	Y	N	N	Y	Y
Time FE	N	N	Y	Y	N	N	Y	Y
County$\times$time FE	Y	Y	N	N	Y	Y	N	N
Bank controls	Y	N	Y	Y	Y	N	Y	Y

Notes: This table presents the estimation of equation (43) for branch deposit rates. The dependent variable is the quarterly change of a branch's deposit rate on a deposit product. For the independent variables listed in the table, $1\{t < 2010Q1\}$ and $1\{t \geq 2010Q1\}$ are the indicators of whether the observation is before 2010Q1 or after 2010Q1. HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The deposit products include 25K money market accounts (Money Market Account) and 10K CD accounts with 3-month, 6-month and 12-month maturity (3M CD, 6M CD, 12M CD). The underlying data are from Ratewatch, Call Reports, HMDA and FRED. The sample period is from 2001Q1 to 2019Q4. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Identification of the channel: preliminary results on deposit growth

Dependent Variable	Δ log (Branch Deposits, Annual)			
Loan market power	Bank-HMDA-HHI			
	(1)	(2)	(3)	(4)
$1\{t < \text{2010Q1}\} \times HHI \times \Delta i$	-0.070***	-0.075***	-0.005	0.002
	(0.026)	(0.026)	(0.017)	(0.017)
$1\{t \geq \text{2010Q1}\} \times HHI \times \Delta i$	2.674***	2.093***	-0.407	-0.354
	(0.761)	(0.779)	(0.652)	(0.637)
Obs	1,284,427	1,284,427	1,284,427	1,284,427
Adj R^2	0.264	0.262	0.230	0.067
Controls (all panels):				
Branch FE	Y	Y	Y	N
Bank FE	Y	Y	Y	N
County	N	N	Y	Y
Time FE	N	N	Y	Y
County×time FE	Y	Y	N	N
Bank controls	Y	N	Y	Y

Notes: This table presents the estimation of equation (43) for branch deposit growth. The dependent variable is the annual log difference of a branch's total deposit volumes. For the independent variables listed in the table, $1\{t < 2010Q1\}$ and $1\{t \geq 2010Q1\}$ are the indicators of whether the observation is before 2010Q1 or after 2010Q1. HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The underlying data are from FDIC, Call Reports, HMDA and FRED. The sample period is from 1997 to 2019. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Identification of the channel: baseline results for deposit rates

Dependent Variable:	Δbranch deposit rate (quarterly)					
Loan market power:	Bank-HMDA-HHI					
Deposit product:	Money Market Account			3M CD		
	(1)	(2)	(3)	(4)	(5)	(6)
β_1: $HHI \times \Delta i$	0.120	-0.198	2.220***	-0.174	1.375***	2.736***
	(0.226)	(0.477)	(0.753)	(0.218)	(0.464)	(0.887)
β_2: $HHI \times i \times \Delta i$		0.103	-0.130		-0.489***	-0.520***
		(0.146)	(0.206)		(0.171)	(0.170)
β_3: $HHI \times E \times \Delta i$			-19.041***			-12.441*
			(6.525)			(6.813)
Obs	204,674	204,674	204,674	194,101	194,101	194,101
Adj R^2	0.988	0.988	0.988	0.973	0.973	0.973
Deposit product:	6M CD			12M CD		
	(7)	(8)	(9)	(10)	(11)	(12)
β_1: $HHI \times \Delta i$	-0.325	1.826***	2.308***	-0.269	2.010***	2.824***
	(0.201)	(0.441)	(0.695)	(0.190)	(0.452)	(0.635)
β_2: $HHI \times i \times \Delta i$		-0.658***	-0.677***		-0.682***	-0.705***
		(0.149)	(0.147)		(0.146)	(0.144)
β_3: $HHI \times E \times \Delta i$			-4.188			-7.116*
			(5.158)			(4.125)
Obs	212,418	212,418	212,418	212,824	212,824	212,824
Adj R^2	0.966	0.966	0.966	0.965	0.965	0.965
Controls (all panels):						
Branch FE	Y	Y	Y	Y	Y	Y
Bank FE	Y	Y	Y	Y	Y	Y
County$\times$time FE	Y	Y	Y	Y	Y	Y
Bank controls	Y	Y	Y	Y	Y	Y

Notes: This table presents the estimation of equation (44) for branch deposit rates. The dependent variable is the quarterly change of a branch's deposit rate on a deposit product. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. E is the bank equity-assets ratio. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The deposit products include 25K money market accounts (Money Market Account) and 10K CD accounts with 3-month, 6-month and 12-month maturity (3M CD, 6M CD, 12M CD). The underlying data are from Ratewatch, Call Reports, HMDA and FRED. The sample period is from 2001Q1 to 2019Q4. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Robustness checks: alternative fixed effects and controls for the regressions of deposit rates

Dependent Variable:	Δbranch deposit rate (quarterly)							
Loan market power:	Bank-HMDA-HHI							
Deposit product:	Money Market Account				3M CD			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_1: $HHI \times \Delta i$	-0.197	-0.272	0.007	0.025	1.400***	1.127***	0.990***	0.998***
	(0.477)	(0.238)	(0.224)	(0.223)	(0.464)	(0.313)	(0.289)	(0.287)
β_2: $HHI \times i \times \Delta i$	0.101	0.060	0.038	0.032	-0.497***	-0.383***	-0.269**	-0.271**
	(0.146)	(0.087)	(0.085)	(0.085)	(0.172)	(0.114)	(0.108)	(0.108)
Obs	204,674	204,674	204,674	204,674	194,101	194,101	194,101	194,101
Adj R^2	0.988	0.988	0.988	0.988	0.973	0.973	0.972	0.973
Deposit product:	6M CD				12M CD			
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
β_1: $HHI \times \Delta i$	1.834***	1.198***	1.267***	1.275***	2.055***	1.488***	1.443***	1.482***
	(0.441)	(0.280)	(0.260)	(0.260)	(0.455)	(0.287)	(0.263)	(0.263)
β_2: $HHI \times i \times \Delta i$	-0.662***	-0.434***	-0.392***	-0.397***	-0.693***	-0.593***	-0.518***	-0.521***
	(0.150)	(0.100)	(0.095)	(0.096)	(0.148)	(0.104)	(0.097)	(0.097)
Obs	212,418	212,418	212,418	212,418	212,824	212,824	212,824	212,824
Adj R^2	0.966	0.965	0.964	0.964	0.965	0.964	0.963	0.963
Controls (all panels):								
Branch FE	Y	Y	Y	N	Y	Y	Y	N
Bank FE	Y	Y	Y	N	Y	Y	Y	N
County FE	N	Y	Y	Y	N	Y	Y	Y
Time FE	N	N	Y	Y	N	N	Y	Y
County$\times$time FE	Y	N	N	N	Y	N	N	N
State$\times$time FE	N	Y	N	N	N	Y	N	N
Bank controls	N	Y	Y	Y	N	Y	Y	Y

Notes: This table presents the estimation of equation (44) for branch deposit rates with alternative fixed effects and bank controls. In the estimation the interaction terms with bank equity-assets ratio are not included. The dependent variable is the quarterly change of a branch's deposit rate on a deposit product. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The deposit products include 25K money market accounts and 10K CD accounts with 3-month, 6-month and 12-month maturity. The underlying data are from Ratewatch, Call Reports, HMDA and FRED. The sample period is from 2001Q1 to 2019Q4. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Robustness checks: alternative fixed effects and controls for the regressions of deposit rates

Dependent Variable:	Δbranch deposit rate (quarterly)							
Loan market power:	Bank-HMDA-HHI							
Deposit product:	Money Market Account				3M CD			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_1: $HHI \times \Delta i$	2.129***	1.622***	1.955***	1.995***	2.827***	1.911***	1.557***	1.487***
	(0.750)	(0.490)	(0.486)	(0.487)	(0.896)	(0.544)	(0.492)	(0.489)
β_2: $HHI \times i \times \Delta i$	0.033	0.005	-0.015	-0.025	-0.523***	-0.413***	-0.300***	-0.301***
	(0.146)	(0.087)	(0.085)	(0.085)	(0.171)	(0.114)	(0.107)	(0.107)
β_3: $HHI \times E \times \Delta i$	-20.678***	-17.006***	-17.583***	-17.676***	-13.252*	-6.895*	-4.720	-3.985
	(6.558)	(4.105)	(4.113)	(4.125)	(6.909)	(3.953)	(3.668)	(3.646)
Obs	204,674	204,674	204,674	204,674	194,101	194,101	194,101	194,101
Adj R^2	0.988	0.988	0.988	0.988	0.973	0.973	0.973	0.973
Deposit product:	6M CD				12M CD			
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
β_1: $HHI \times \Delta i$	2.387***	1.773***	1.352***	1.226***	2.987***	2.420***	1.932***	1.836***
	(0.704)	(0.474)	(0.464)	(0.465)	(0.641)	(0.486)	(0.480)	(0.481)
β_2: $HHI \times i \times \Delta i$	-0.679***	-0.450***	-0.395***	-0.403***	-0.714***	-0.612***	-0.526***	-0.532***
	(0.147)	(0.099)	(0.094)	(0.095)	(0.146)	(0.104)	(0.096)	(0.097)
β_3: $HHI \times E \times \Delta i$	-4.897	-5.249	-0.919	0.481	-8.344**	-8.511**	-4.553	-3.161
	(5.243)	(3.393)	(3.443)	(3.468)	(4.195)	(3.401)	(3.507)	(3.529)
Obs	212,418	212,418	212,418	212,418	212,824	212,824	212,824	212,824
Adj R^2	0.966	0.965	0.964	0.964	0.965	0.964	0.963	0.963
Controls (all panels):								
Branch FE	Y	Y	Y	N	Y	Y	Y	N
Bank FE	Y	Y	Y	N	Y	Y	Y	N
County FE	N	Y	Y	Y	N	Y	Y	Y
Time FE	N	N	Y	Y	N	N	Y	Y
County$\times$time FE	Y	N	N	N	Y	N	N	N
State$\times$time FE	N	Y	N	N	N	Y	N	N
Bank controls	N	Y	Y	Y	N	Y	Y	Y

Notes: This table presents the estimation of equation (44) for branch deposit rates with alternative fixed effects and bank controls. In the estimation the interaction terms with bank equity-assets ratio are included. The dependent variable is the quarterly change of a branch's deposit rate on a deposit product. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. E is the bank equity-assets ratio. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The deposit products include 25K money market accounts and 10K CD accounts with 3-month, 6-month and 12-month maturity. The underlying data are from Ratewatch, Call Reports, HMDA and FRED. The sample period is from 2001Q1 to 2019Q4. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 8: Robustness checks for deposit rate regressions: using Fed funds rate as the nominal rate

Dependent Variable:	Δbranch deposit rate (quarterly)							
Loan market power:	Bank-HMDA-HHI							
Deposit product:	MM		3M CD		6M CD		12M CD	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_1: $HHI \times \Delta i$	-0.030	2.091***	0.893***	2.298***	1.085***	1.584**	1.247***	2.025***
	(0.388)	(0.666)	(0.320)	(0.807)	(0.328)	(0.633)	(0.342)	(0.569)
β_2: $HHI \times i \times \Delta i$	0.052	0.015	-0.424***	-0.442***	-0.513***	-0.526***	-0.529***	-0.540***
	(0.122)	(0.121)	(0.137)	(0.138)	(0.120)	(0.120)	(0.120)	(0.120)
β_3: $HHI \times E \times \Delta i$		-19.892***		-13.081*		-4.363		-7.181*
		(6.643)		(6.881)		(5.141)		(4.157)
Obs	204,674	204,674	194,101	194,101	212,418	212,418	212,824	212,824
Adj R^2	0.988	0.988	0.973	0.973	0.966	0.966	0.965	0.965
Branch FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank FE	Y	Y	Y	Y	Y	Y	Y	Y
County$\times$time FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table presents the estimation of equation (44) for branch deposit rates, where the nominal interest rate is the Fed funds rate. In the estimation the interaction terms with bank equity-assets ratio are included. The dependent variable is the quarterly change of a branch's deposit rate on a deposit product. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. E is the bank equity-assets ratio. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The deposit products include 25K money market accounts (MM) and 10K CD accounts with 3-month, 6-month and 12-month maturity (3M CD, 6M CD, 12M CD). The underlying data are from Ratewatch, Call Reports, HMDA and FRED. The sample period is from 2001Q1 to 2019Q4. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 9: Robustness checks for deposit rate regressions: using 1-year Treasury yield rate as the nominal rate

Dependent Variable:	Δbranch deposit rate (quarterly)							
Loan market power:	Bank-HMDA-HHI							
Deposit product:	MM		3M CD		6M CD		12M CD	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_1: $HHI \times \Delta i$	-0.089	2.049***	1.056***	2.473***	1.329***	1.847**	1.429***	2.239***
	(0.400)	(0.702)	(0.367)	(0.837)	(0.356)	(0.651)	(0.372)	(0.584)
β_2: $HHI \times i \times \Delta i$	0.078	0.034	-0.438***	-0.461***	-0.564***	-0.579***	-0.557***	-0.571***
	(0.130)	(0.131)	(0.152)	(0.152)	(0.131)	(0.130)	(0.130)	(0.129)
β_3: $HHI \times E \times \Delta i$		-19.822***		-13.084*		-4.543		-7.436*
		(6.623)		(6.904)		(5.174)		(4.143)
Obs	204,674	204,674	194,101	194,101	212,418	212,418	212,824	212,824
Adj R^2	0.988	0.988	0.973	0.973	0.966	0.966	0.965	0.965
Branch FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank FE	Y	Y	Y	Y	Y	Y	Y	Y
County$\times$time FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table presents the estimation of equation (44) for branch deposit rates, where the nominal interest rate is the 1-year Treasury yield rate. In the estimation the interaction terms with bank equity-assets ratio are included. The dependent variable is the quarterly change of a branch's deposit rate on a deposit product. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. E is the bank equity-assets ratio. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The deposit products include 25K money market accounts (MM) and 10K CD accounts with 3-month, 6-month and 12-month maturity (3M CD, 6M CD, 12M CD). The underlying data are from Ratewatch, Call Reports, HMDA and FRED. The sample period is from 2001Q1 to 2019Q4. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 10: Robustness checks for deposit rate regressions: Pre-financial crisis results

Dependent Variable:	Δbranch deposit rate (quarterly)							
Loan market power:	Bank-HMDA-HHI							
Deposit product:	MM		3M CD		6M CD		12M CD	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_1: $HHI \times \Delta i$	-0.200	1.282***	2.405**	2.434	2.929***	3.577***	1.324	3.655***
	(1.036)	(1.372)	(0.951)	(1.708)	(0.836)	(1.282)	(0.868)	(1.248)
β_2: $HHI \times i \times \Delta i$	0.040	0.008	-0.865***	-0.816***	-0.950***	-0.965***	-0.687***	-0.675***
	(0.276)	(0.275)	(0.290)	(0.275)	(0.239)	(0.228)	(0.250)	(0.239)
β_3: $HHI \times E \times \Delta i$		-13.535		-2.557		-6.017		-23.586**
		(9.807)		(14.258)		(10.003)		(9.477)
Obs	65,104	65,104	61,773	61,773	67,250	67,250	67,300	67,300
Adj R^2	0.978	0.978	0.948	0.948	0.927	0.927	0.926	0.926
Branch FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank FE	Y	Y	Y	Y	Y	Y	Y	Y
County$\times$time FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table presents the estimation of equation (44) for branch deposit rates using the data before the 2008 global financial crisis (until June 2008). In the estimation the interaction terms with bank equity-assets ratio are included. The dependent variable is the quarterly change of a branch's deposit rate on a deposit product. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. E is the bank equity-assets ratio. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The deposit products include 25K money market accounts (MM) and 10K CD accounts with 3-month, 6-month and 12-month maturity (3M CD, 6M CD, 12M CD). The underlying data are from Ratewatch, Call Reports, HMDA and FRED. The sample period is from 2001Q1 to 2019Q4. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 11: Robustness checks for deposit rate regressions: Large banks

Dependent Variable:	Δbranch deposit rate (quarterly)							
Loan market power:	Bank-HMDA-HHI							
Deposit product:	MM		3M CD		6M CD		12M CD	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_1: $HHI \times \Delta i$	-0.715	0.589	1.499*	3.527***	1.636*	1.497	3.093***	3.239***
	(0.755)	(1.392)	(0.794)	(1.358)	(0.863)	(1.260)	(0.836)	(1.130)
β_2: $HHI \times i \times \Delta i$	0.484*	0.390	-0.504	-0.589*	-0.453	-0.453	-0.927***	-0.926***
	(0.292)	(0.302)	(0.321)	(0.331)	(0.340)	(0.338)	(0.309)	(0.306)
β_3: $HHI \times E \times \Delta i$		-9.712		-16.735*		2.668		0.119
		(9.449)		(9.544)		(8.789)		(7.206)
Obs	93,397	93,220	92,442	92,442	97,496	97,496	97,752	97,752
Adj R^2	0.986	0.987	0.970	0.970	0.962	0.962	0.961	0.961
Branch FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank FE	Y	Y	Y	Y	Y	Y	Y	Y
County$\times$time FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table presents the estimation of equation (44) for branch deposit rates using the data of the largest 25% banks by inflation-adjusted quarterly average assets. In the estimation the interaction terms with bank equity-assets ratio are included. The dependent variable is the quarterly change of a branch's deposit rate on a deposit product. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. E is the bank equity-assets ratio. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The deposit products include 25K money market accounts (MM) and 10K CD accounts with 3-month, 6-month and 12-month maturity (3M CD, 6M CD, 12M CD). The underlying data are from Ratewatch, Call Reports, HMDA and FRED. The sample period is from 2001Q1 to 2019Q4. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 12: Net effects of the channel: branch deposit rates

Dependent Variable:	Δbranch deposit rate (quarterly)			
Loan market power:	Bank-HMDA-HHI			
Deposit product:	MM	3M CD	6M CD	12M CD
	(1)	(2)	(3)	(4)
$HHI \times \Delta i$	0.541***	2.330***	2.637***	2.681***
	(0.185)	(0.244)	(0.222)	(0.227)
$HHI \times i \times \Delta i$	-0.071	-0.702***	-0.789***	-0.855***
	(0.074)	(0.092)	(0.083)	(0.084)
$i \times \Delta i$	0.061***	0.149***	0.170***	0.183***
	(0.005)	(0.006)	(0.006)	(0.006)
Obs	251,477	240,852	259,087	259,793
Adj R^2	0.988	0.973	0.965	0.963
Controls (all panels):				
Branch FE	Y	Y	Y	Y
Bank FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
Bank controls	Y	Y	Y	Y

Notes: This table presents the estimated net effects of loan market concentration and nominal interest rate on deposit rate passthrough using equation (44). The dependent variable is the quarterly change of a branch's deposit rate on a deposit product. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. E is the bank equity-assets ratio. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. The deposit products include 25K money market accounts (MM) and 10K CD accounts with 3-month, 6-month and 12-month maturity (3M CD, 6M CD, 12M CD). The underlying data are from Ratewatch, Call Reports, HMDA and FRED. The sample period is from 2001Q1 to 2019Q4. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 13: Identification of the channel: branch deposits growth

Dependent Variable	Δ log (Branch Deposits, Annual)							
Loan market power	Bank-HMDA-HHI							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_1: $HHI \times \Delta i$	-0.043*	0.073	0.266***	0.263***	0.268***	0.148**	0.176***	0.108***
	(0.023)	(0.064)	(0.085)	(0.086)	(0.068)	(0.059)	(0.059)	(0.042)
β_2: $HHI \times i \times \Delta i$		-0.059**	-0.059**	-0.054**	-0.065***	-0.045***	-0.037**	-0.038**
		(0.025)	(0.024)	(0.025)	(0.018)	(0.017)	(0.017)	(0.017)
β_3: $HHI \times E \times \Delta i$			-1.924***	-1.965***	-2.015***	-1.200**	-1.458***	
			(0.611)	(0.614)	(0.541)	(0.473)	(0.479)	
$i \times \Delta i$								0.006***
								(0.001)
Obs	1,108,167	1,108,167	1,108,167	1,108,167	1,108,167	1,108,167	1,108,167	1,108,167
Adj R^2	0.190	0.190	0.191	0.188	0.157	0.147	0.032	0.147
Controls (all panels):								
Branch FE	Y	Y	Y	Y	Y	Y	N	Y
Bank FE	Y	Y	Y	Y	Y	Y	N	Y
County	N	N	N	N	Y	Y	Y	Y
Time FE	N	N	N	N	N	Y	Y	N
County$\times$time FE	Y	Y	Y	Y	N	N	N	N
State$\times$time FE	N	N	N	N	Y	N	N	N
Bank controls	Y	Y	Y	N	Y	Y	Y	Y

Notes: This table presents the estimation of equation (44) for branch deposit growth. The dependent variable is the annual log difference of a branch's total deposit volumes. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. E is the bank equity-assets ratio. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. Deposit growth is equal to the symmetric growth rate of branch deposits at annual frequency. The underlying data are from FDIC, Call Reports, HMDA and FRED. The sample period is from 1997 to 2019. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 14: Robustness checks of regressions on deposits growth

Dependent Variable	$\Delta \log$ (Branch Deposits, Annual)							
Loan market power	Bank-HMDA-HHI							
Robustness test	Nominal Rate: FF		Nominal Rate: T-Bill		Pre-financial crisis		Large banks	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_1: $HHI \times \Delta i$	0.032	0.191***	0.057	0.206***	0.147	0.233	0.106	0.453***
	(0.038)	(0.065)	(0.042)	(0.067)	(0.180)	(0.207)	(0.083)	(0.114)
β_2: $HHI \times i \times \Delta i$	-0.052***	-0.050***	-0.057***	-0.054***	-0.095*	-0.086	-0.071**	-0.080**
	(0.018)	(0.018)	(0.019)	(0.019)	(0.057)	(0.057)	(0.032)	(0.032)
β_3: $HHI \times E \times \Delta i$		-1.605***		-1.515***		-1.119		-3.339***
		(0.559)		(0.552)		(0.871)		(0.828)
Obs	1,108,167	1,108,167	1,108,167	1,108,167	381,383	381,383	958,410	958,410
Adj R^2	0.198	0.198	0.198	0.198	0.322	0.323	0.203	0.204
Controls (all panels):								
Branch FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank FE	Y	Y	Y	Y	Y	Y	Y	Y
County$\times$time FE	Y	Y	Y	Y	Y	Y	Y	Y
Bank controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: This table presents the robustness tests on the branch deposit growth regression (44). In Column (1) and (2), the nominal interest rate is the yearly Fed funds rate. In Column (3) and (4), the nominal interest rate is the 1-year Treasury yield rate. In Column (5) and (6), the estimation uses data before the 2008 global financial crisis (until June 2008). In Column (7) and (8), the estimation uses data of largest 25% banks by inflation-adjusted annual average assets. The dependent variable is the annual log difference of a branch's total deposit volumes. For the independent variables listed in the table, HHI is the bank-level average Herfindahl index of home mortgage loans across counties (Bank-HMDA-HHI). i is the nominal interest rate. E is the bank equity-assets ratio. Δi is the quarterly change in the Fed funds rate. The sample consists of all U.S. counties with branches of at least two different banks for identification. Deposit growth is equal to the symmetric growth rate of branch deposits at annual frequency. The underlying data are from FDIC, Call Reports, HMDA and FRED. The sample period is from 1997 to 2019. Fixed effects are denoted at the bottom of the table. Standard errors clustered by county are reported in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 15: Determinants of the threshold nominal interest rate

Dependent Variable:	Δbranch deposit rate (quarterly)			
Deposit product:	MM	3M CD	6M CD	12M CD
Regressor x of $HHI \times x \times \Delta i$	(1)	(2)	(3)	(4)
Equity/assets	-20.282***	-13.426**	-3.949	-6.379*
	(7.077)	(6.438)	(4.921)	(3.844)
Bank size (log assets)	0.274***	0.345***	0.079	0.398***
	(0.086)	(0.094)	(0.100)	(0.085)
Loan/assets	0.067	-0.609	-1.098	0.965
	(1.222)	(1.310)	(1.354)	(1.200)
Core deposits/liabilities	4.769**	-2.215	-5.174**	-3.961**
	(2.271)	(2.001)	(2.082)	(1.819)
Maturity gap	-0.054	-0.102	-0.047	0.086
	(0.084)	(0.089)	(0.079)	(0.076)
Nonperforming loan share	18.133**	17.135	20.769**	24.602***
	(8.576)	(10.684)	(8.295)	(7.652)
Other assets	-0.284	2.132	-0.579	1.174
	(1.748)	(2.061)	(2.225)	(1.845)
Other liabilities	0.672	-0.729	-1.203	-2.348***
	(0.892)	(1.067)	(0.934)	(0.854)
Obs	204,674	194,101	212,148	212,824
Adj R^2	0.988	0.974	0.966	0.966
All FEs	Y	Y	Y	Y
Bank controls	Y	Y	Y	Y

Notes: This table reports the effects of bank characteristics on the threshold value of nominal interest rate, below which the passthrough monetary policy rate to deposit rate increases in a bank's loan market concentration. The vector of coefficients of $HHI \times x \times \Delta i$ are reported in the table, where x represents the following bank characteristics: equity-assets ratio, log of total assets, loan-assets ratio, core deposits share in total liabilities, maturity gap, the share of nonperforming loans in total loans, the share of other assets in total interest-earning assets, the share of other liabilities in total liabilities. The underlying data are from HMDA, Ratewatch, FRED and Call Reports. The sample period is 2001Q1 to 2019Q4.

Table 16: Regression on the state-dependent passthrough

Balance sheet component	Deposits	Assets	Securities	Loans	RE loans	C&I loans
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Zero beta, all banks						
Deposit rate	0.059***	0.049***	0.096***	0.026***	0.018	0.025**
	(0.008)	(0.007)	(0.015)	(0.009)	(0.020)	(0.011)
Obsevations	4,885	4,885	4,885	4,885	4,885	4,885
R^2	0.015	0.013	0.010	0.002	0.000	0.002
Panel B: Slope beta, all banks						
Deposit rate	0.089***	0.069***	0.125***	0.047***	0.059***	0.054***
	(0.005)	(0.005)	(0.011)	(0.006)	(0.014)	(0.007)
Observations	4,885	4,885	4,885	4,885	4,885	4,885
R^2	0.072	0.055	0.033	0.018	0.004	0.015
Panel C: Zero beta, large banks						
Deposit rate	0.105***	0.076***	0.056*	0.087***	0.116***	0.098***
	(0.022)	(0.020)	(0.034)	(0.021)	(0.031)	(0.026)
Obsevations	244	244	244	244	244	244
R^2	0.088	0.061	0.012	0.066	0.056	0.063
Panel D: Slope beta, large banks						
Deposit rate	0.106***	0.081***	0.088***	0.086***	0.120***	0.100***
	(0.021)	(0.019)	(0.033)	(0.019)	(0.032)	(0.024)
Observations	244	244	244	244	244	244
R^2	0.100	0.079	0.031	0.078	0.057	0.077

Notes: This table reports the relationship between the state-dependent passthrough of monetary policy rates to bank deposit rates and the state-dependent transmission of monetary policy rates to bank balance sheet components. The analysis covers all U.S. commercial banks in the Call Reports data with at least 60 quarters observations from 1997Q1 to 2019Q4, excluding the periods of global financial crisis (2008Q3 to 2009Q2). Panel A and B report the resutsl for all banks, Panel C and D report the results for the largest 5% of banks by assets. The passthrough of monetary policy rates to bank deposit rates is measured as the deposit rate zero beta and slope beta. The zero beta measures the sensitivity of a bank's deposit rate to the Fed funds rate when the Fed funds rate is zero. The slope beta measures the change in the sensitivity when the Fed funds rate increases by 100 bps. The state-dependent transmission of monetary policy rates to bank balance sheet components include the analogous zero betas and slope betas for the quarterly growth of a bank's deposits (column (1)), assets (column (2)), securities (column (3)), loans (column (4)), real estate loans (column (5)) and commercial and industrial loans (column (6)). Panel A and C report the coefficient of regressing a balance sheet component's zero beta on deposit rate zero beta. Panel B and D report the coefficient of regressing a balance sheet component's slope beta on deposit rate slope beta. All the betas are winsorized at 5%. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.