Bank Market Power and Monetary Policy Transmission: Evidence from a Structural Estimation

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September 29, 2019

Abstract

We quantify the impact of bank market power on the pass-through of monetary policy to borrowers. To this end, we estimate a dynamic banking model in which monetary tightening increases banks' funding costs. Given their market power, banks optimally choose how much of a rate increase to pass on to borrowers. In the model, banks are subject to capital and reserve regulations, which also influence the degree of pass-through. Compared with the conventional regulation-based channels, we find that in the two most recent decades, bank market power explains a significant portion of monetary transmission. The quantitative effect is comparable in magnitude to the bank capital channel. In addition, the market power channel interacts with the bank capital channel, and this interaction can reverse the effect of monetary policy when the Federal Funds rate is low.

JEL Codes: E51, E52, G21, G28

Keywords: Monetary policy transmission, banking competition.

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1. Introduction

We examine the quantitative importance of bank market power as a transmission mechanism for monetary policy. This question is interesting given three decades of consolidation in the banking industry that has softened competitive pressure. Indeed, recent research offers evidence that bank market power is an important friction that affects the passthrough of monetary policy through the banking system to the supply of loans (Drechsler, Savov, and Schnabl 2017; Scharfstein and Sunderam 2016). In contrast, traditional analysis of monetary policy transmission focuses on regulatory constraints, such as reserve or capital requirements, as the central friction that influences monetary policy transmission (e.g. Bernanke and Blinder 1988; Kashyap and Stein 1995). Yet the qualitative nature of all of this evidence leaves open the question of the relative importance of traditional versus market-power channels for the transmission of monetary policy.

Our paper starts to fill this void by constructing and estimating a dynamic banking model with three important frictions: regulatory constraints, financial frictions, and imperfect competition. The estimation allows our data on commercial banks to discipline the model parameters and thus expose the relative magnitude of these three frictions. We find that in the current banking system, bank market power plays an important role in determining the degree of monetary transmission. In terms of magnitude, the effect of bank market power is comparable in magnitude to that of bank capital, while the effect of bank reserve requirements is negligible.

Our analysis produces two further results. First, we show that banks face nontrivial costs of accessing external financial markets. This friction plays a pivotal role in transmitting banks' deposit market power to their lending decisions, as external financing costs serve to connect banks' sources and uses of funds. Relatedly, we also show that these frictions help explain the between between big and small banks in terms of monetary policy transmission.

Second, we show that bank market power interacts with capital regulation to reverse the

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sign of monetary policy when the Federal Funds rate is very low. Specifically, we estimate that when the Federal Funds rate is below 2.27%, further cuts in the policy rates can be contractionary. Moreover, we find external validation of this reversal rate by showing in a simple regression framework that the relation between bank capital and interest rates switches sign at approximately this interest rate.

An understanding of the intuition behind these results requires a deeper description of the model. In the economy, banks act as intermediaries between borrowers and depositors. The lending decision is dynamic because deposits are short-term, while loans are long-term. Monetary policy enters the picture by changing the Federal Funds rate. In this setting, because banks are not price takers in the deposit and loan markets, they choose how much of a rate increase to pass on to depositors and borrowers. The degree of passthrough is influenced by the tightness of regulatory constraints, the degree of financial frictions, and the intensity of competition.

These frictions in our model map into four monetary policy transmission channels emphasized in the literature. The first is the bank reserve channel in which a high Federal Funds rate raises the opportunity cost of holding reserves (Bernanke and Blinder 1988; Kashyap and Stein 1995) and thus contracts deposit creation. The second is the bank capital channel in which a rise in the Federal Funds rate lowers bank capital because of a maturity mismatch, thus constraining banks' capacity to lend (Van den Heuvel 2002; Bolton and Freixas 2000; Brunnermeier and Sannikov 2016). The third is the deposit market power channel in which a rise in the Federal Funds rate allows banks to charge a higher markup on deposits, thus leading to a contraction in deposits and loanable funds (Drechsler, Savov, and Schnabl 2017). The fourth is the loan market power channel in which banks lower markup to mitigate the effect of falling loan demand when the Federal Reserve raises rates (Scharfstein and Sunderam 2016).

To gauge the quantitative importance of these transmission channels, we estimate our model using a panel of U.S. commercial banks. Our estimation combines methods used

in the industrial organization literature (Berry, Levinsohn, and Pakes 1995; Nevo 2001) with those used in the corporate finance literature (Hennessy and Whited 2005; Bazdresch, Kahn, and Whited 2018). As a first step, we use demand estimation techniques to obtain the elasticities of loans and deposits to interest rates. We then plug these estimates into our model and use simulated minimum distance to obtain estimates of parameters that quantify financial frictions and operating costs. The sequential use of these two techniques is a methodological advance that allows us to consider a rich equilibrium model that would otherwise be intractable to estimate.

To obtain our results on the relative importance of each transmission channel, we then use these parameter estimates to simulate counterfactual experiments in which we start with a model with all frictions as estimated and then subtract each channel from the model one at a time. These counterfactuals also produce our interesting result that rate cuts can be contractionary when rates are already low. Low interest rates depress bank profits by reducing bank market power in the deposit market, as the competition from cash becomes more intense. Lower profits then tighten the capital constraint and result in less lending. This result sheds light on the sluggish bank lending growth post crisis, as an ultra-low rate policy can unintentionally reduce bank profitability, and consequently constrain banks' capacity to lend. Overall, our results suggest that Federal Reserve actions can have complicated effects on bank lending depending on the level of policy rates, the amount of bank capital, and the industrial organization of the banking sector.

Our paper contributes to the literature studying the role of banks in transmitting monetary policy (Bernanke and Blinder 1988; Kashyap and Stein 1995; Van den Heuvel 2002; Drechsler, Savov, and Schnabl 2017; Scharfstein and Sunderam 2016; Brunnermeier and Sannikov 2016). It is the first to estimate a structural dynamic banking model to quantify various transmission channels.[1] Prior to our work, little has been known about the relative importance of different transmission channels, as this type of quantitative exercise is

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[1]Xiao (2018) also uses a structural approach, but the main focus is on shadow banks.

difficult to undertake using reduced-form methods. Moreover, the prior literature usually studies each transmission channel separately. For example, Drechsler, Savov, and Schnabl (2017) and Scharfstein and Sunderam (2016) study market power in the deposit and loan markets separately. However, little is known about the interaction between different channels. Thus, an important contribution of this paper is to provide a unified framework to study these interactions. For example, we show that the relative importance of the deposit and loan markets depends on the level of the Federal Funds rate. The deposit market is more important when the Federal Funds rate is low, while the loan market becomes more important when the Federal Funds rate is high.

Second, our paper is related to the literature that studies the effect of negative interest rate policies (Brunnermeier and Koby 2016; Eggertsson, Juelsrud, and Wold 2017; Wang 2019; Campos 2019). While the theoretical branch of this literature offers interesting insights, it typically treats the banking sector with a high level of abstraction. In comparison, we provide a model sufficiently realistic that it can be directly mapped to the micro data. Our paper also contributes to a set of empirical papers on negative interest policy (Heider, Saidi, and Schepens 2018; Basten and Mariathasan 2018; Demiralp, Eisenschmidt, and Vlassopoulos 2017). This literature show that negative interest rate policy can have perverse effects on bank lending. Our results suggest that such perverse effects can start to occur even before the policy rate turns negative because a near-zero policy rate compresses banks' deposit spreads. Therefore, in countries such as the United States where the policy rate has never gone negative, the banking sector could still be hurt by an ultra-low rate monetary policy.

Third, our paper is related to the literature on external financial frictions. Largely focused on industrial firms, this literature shows that financial frictions significantly affect corporate policies such as investment, cash holding, and dividend payout. In the banking literature, Romer and Romer (1990) argue that banks can easily replace deposits with external financing, so shocks to deposits are unlikely to affect bank lending. In contrast, Kashyap and Stein (1995) argues that external financing is costly for banks, so the quantity of deposits matters

for bank lending. Our study sheds new light on this debate, as the structural estimation approach allows us to infer the degree of bank financing costs from the relative size of their non-reservable borrowing and deposit taking. We find that the magnitude of this cost is economically significant and that frictions related to bank balance sheets play an important role in the transmission of monetary policy.

Finally, our paper contributes to the structural industrial organization literature on the banking system (Egan, Hortacsu, and Matvos 2017; Buchak, Matvos, Piskorski, and Seru 2018; Egan, Lewellen, and Sunderam 2017; Xiao 2018). While this literature usually features a static industrial equilibrium, we introduce dynamic adjustment in banks' balance sheets to study the role of maturity transformation and financial frictions. Our paper is also broadly related to the literature that uses quantitative dynamic banking models to study optimal capital regulation (Corbae and D'Erasmo 2013; Begenau 2018; Begenau and Landvoigt 2018; Elenev, Landvoigt, and Van Nieuwerburgh 2016). Our paper contributes to this literature in two ways. First, we estimate, rather than calibrate, all of our model parameters. More substantively, we extend this type of dynamic banking model by combining it with a structural industrial organization model in the spirit of Berry, Levinsohn, and Pakes (1995) to study the effect of imperfect competition on banking monetary policy transmission.

2. Data

Our main data set is the Consolidated Reports of Condition and Income, generally referred to as the Call Reports. This data set provides quarterly bank-level balance sheet information for U.S. commercial banks, including deposit and loan amounts, interest income and expense, loan maturities, salary expenses, and fixed-asset related expenses. We merge the Call Reports with the FDIC Summary of Deposits, which provides branch-level information for each bank since 1994 at an annual frequency. The resulting sample period is 1994–2017.

Our analysis requires data from several further sources. First, we retrieve publicly listed

bank returns from CRSP. We link the stock returns to bank concentration measures using the link table provided by the Federal Reserve Bank of New York. We obtain bank industry stock returns from Kenneth French's website. We collect the Federal Open Market Committee meeting dates from the FOMC Meeting calendar. Finally, we obtain the following time series from FRED (Federal Reserve Economic Data): NBER recession dates, the effective Federal Funds rate, the two-year and five-year Treasury yields, the aggregate amount of corporate bonds issued by U.S. firms, and the aggregate amount of cash, Treasury bonds, and money-market mutual funds held by households.

Table 1 provides summary statistics for this sample, which we use for our demand estimation.[2] The first two lines report the mean, standard deviation, and several percentiles of bank market shares in both the deposit and loan markets. We define the total size of the deposit market as the sum of deposits, cash, and Treasury bills held by all U.S. households. The total size of the loan market is defined as the sum of U.S. corporate and household debt. Interestingly, mean market shares in both the loan and deposit markets lie near the 90th percentile, indicating a very skewed distribution of market shares in which a few large banks dominate the market.

The next two lines report summary statistics for deposit and loan rates, which we impute by dividing total deposit interest expense by total deposits and total interest income by total loans. The next two lines report summary statistics for two non-rate bank characteristics used in the estimation: the number of branches and the number of employees per branch. While we see little variation in the number of employees per branch, we see both high variance and skewness in the number of branches per bank. The skewness is consistent with the skewness in market shares, as the number of branches is highly correlated with bank size. Lastly, we report summary statistics for the two supply shifters we use in our estimation: salaries and fixed asset expenses (Ho and Ishii 2011). Fixed asset expenses include all non-

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[2]We combine tiny local banks (banks with market shares less than 0.001% or fewer than ten domestic branches) as one observation for structural estimation because they have limited influence on the equilibrium but can substantially slow down the estimation.

interest expenses stemming from use of premises, equipment, furniture, and fixtures. We scale both supply shifters by total assets.

3. Stylized Facts

To motivate our study of the importance of bank market power for monetary policy transmission, we first examine the prices that banks charge on their deposits and loans. Panel A of Figure 1 shows a non-parametric relationship between the Federal Funds rate and the average deposit spread for U.S. banks. We define the deposit spread as the difference between the Federal Fund rate and the deposit rate. Because this latter rate measures the price that banks charge for their depository services, in the absence of market power or other frictions, one would expect a constant deposit spread that equals the marginal cost of providing depository services. However, we find a positive relation between the deposit spread and the Federal Funds rate, with this relation steepening when the Federal Funds rate is close to zero. In other words, banks charge higher prices for their depository services when the Federal Reserve raises interest rates. This pattern is consistent with the idea that banks have market power in the deposit market, as suggested by Drechsler, Savov, and Schnabl (2017). In presence of market power, a high Federal Funds rate allows banks to raise markups above marginal costs because an important outside option for depositors, cash, becomes more costly to hold. Therefore, banks make more profits in the deposit market when the Fed raises short-term rates. Naturally, this effect is particular strong when the Federal Funds rate is close to zero when deposits become less attractive relative to cash.

Panel B of Figure 1 shows a non-parametric relationship between the Federal Funds rate and the average loan spread for U.S. banks. We define the loan spread as the difference between the average lending rate and 5-year Treasury yields adjusted by the average loan loss provision. In this case, an higher the Federal Funds rate is associated with a lower loan spread. This pattern is consistent with Scharfstein and Sunderam (2016) who suggest that

banks may lower markups on loans when the Federal Reserve raise rates to mitigate the effect of falling demand.

In summary, Figure 1 shows that market power creates two wedges between bond market interest rates and the rates at which banks borrow and lend. Furthermore, the size of these wedges seems to depend on the stance of monetary policy. This suggests that bank market power may influence how monetary policy is transmitted to bank lending.

4. Model

While the facts documented in the previous section point to interesting interactions between bank market power and monetary policy, this time-series evidence cannot help us understand the underlying mechanisms that drive these patterns in the data. To move in this direction, we next consider an infinite-horizon, equilibrium model with three sectors: households, firms, and banks.[3] Figure 2 shows the flow of funds in the model. Banks act as intermediaries between households and firms by taking short-term deposits from households and providing long-term loans to firms. We model the households and firms as solving straightforward static discrete choice problems in which they choose from a variety of saving and financing vehicles. The richness of the model lies in the banking sector, as a variety of frictions imply that monetary policy affects the amount of intermediation that banks provide. These frictions are important because in a frictionless world, banks are simply pass-through entities and bond market interest rates summarize monetary policy. However, in presence of frictions in the banking system, the supply of bank deposits and loans matter for monetary policy in their own right.

Since Bernanke and Blinder (1988), researchers have identified many frictions that affect monetary transmission through banks. Our model incorporates the following prominent channels featured in the literature. First, competition in the deposit and loan markets is

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[3]Households should be broadly interpreted as savers and firms should be broadly interpreted as borrowers.

imperfect. With market power, banks strategically choose deposit and loan rates to maximize their profits. This profit maximizing behavior, in turn, determines how monetary policy transmits through the banking system. Second, banks are subject to reserve regulation and capital regulation. Reserve regulation links the opportunity cost of taking deposits to the prevailing Federal Funds. Capital regulation incentivizes banks to optimize their loan supply intertemporally with an eye to preserving excess equity capital as a buffer against future capital inadequacy. Third, access to non-deposit external financing is more costly than taking deposits. This friction implies that shocks to the quantity of deposits are transmitted to the supply of bank loans, as banks cannot costlessly replace deposits with non-reservable borrowing.

4.1 Households

At each time t, the economy contains W_t households, each of which is endowed with one dollar. Hereafter, we drop the time subscript for convenience, so aggregate household wealth is then W. Households choose among the following investment options for their endowments: cash, bonds, and deposits, where the deposits of each individual bank constitute a differentiated product. If we index each option by j, the households' choice set is given by $\mathcal{A}^d = \{0, 1, \ldots, J, J+1\}$, with option 0 representing cash, option $J+1$ representing short-term bonds, and options $1, \ldots, J$ representing deposits in each bank. We further assume that each depositor can choose only one option. This one-dollar, one-option assumption is without loss of generality. For example, we can interpret this setting as if households make multiple discrete choices for each dollar that they have, and the probability of choosing each of the options can be interpreted as portfolio weights.

Each option is characterized by a yield, r_j^d, and a vector of product characteristics, x_j^d, which captures the convenience of using each option to households. For instance, households may value the number of branches and the number of employees per branch when they choose which bank to deposit money. The yield on cash is 0, and the yield on bonds is the Federal

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Funds rate, f.

The problem of a household is to choose the best option to maximize its utility:

$$\max_{j \in \mathcal{A}^d} u_{i,j} = \alpha_i^d r_j^d + \beta^d x_j^d + \xi_j^d + \epsilon_{i,j}^d, \tag{1}$$

where $u_{i,j}$ is the utility for household i from choosing option j. α_i^d is the sensitivity to yield r_j^d. We allow households to exhibit different sensitivity to yields. This is to capture the idea that some depositors are less yield sensitive than others.[4] The types of households are indexed by $i \in 1, 2, \ldots, I$. ξ_j is the unobservable product-level demand shock. We model the distribution of depositors' yield sensitivity as a uniform distribution with a mean, α^d, and a standard deviation σ_α^d. β^d is the sensitivity to the non-rate product characteristics x_j^d. $\epsilon_{i,j}^d$ is a relationship specific shock for the choice of option j by household i. $\epsilon_{i,j}^d$ captures the horizontal differentiation across banks. For instance, if household i lives close to bank j, then $\epsilon_{i,j}^d$ is large, which makes household i more likely to choose bank j holding other characteristics constant. The optimal choice of household i is given by an indicator function:

$$\mathbb{I}_{i,j}^d = \begin{cases} 1 & \text{if } u_{i,j} \geq u_{i,k}, \text{ for } k \in \mathcal{A}^d \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

We aggregate the optimal choices across all the households to compute the market share of each bank j. Assuming $\epsilon_{i,j}^d$ follows a generalized extreme value distribution with a cumulative distribution function given by $F(\epsilon) = \exp(-\exp(-\epsilon))$, we can get the standard logit market share:[5]

$$\int \mathbb{I}_{i,j}^d dF(\epsilon) = s_j^d(r_j^d) = \sum_{i=1}^{I} \mu_i^d \frac{\exp(\alpha_i^d r_j^d + \beta^d x_j^d + \xi_j^d)}{\sum_{m \in \mathcal{A}^d} \exp(\alpha_i^d r_m^d + \beta^d x_m^d + \xi_m^d)} \tag{3}$$

where μ_i^d is the fraction of total wealth (W) held by households of type i. The demand

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[4]Xiao (2018) shows that the heterogeneity in yield sensitivity has an important impact on deposit rate setting.

[5]This distributional assumption is standard in the structural industrial organization literature and allows for a closed-form solution for the market shares.

function for deposits of bank j is then given by the market share multiplied by total wealth,

$$D_j \left(r_j^d \right) = s_j^d \left(r_j^d \right) W. \tag{4}$$

Firms

There are K firms, each of which wants to borrow one dollar, so aggregate borrowing demand is K. Firms can borrow by issuing long-term bonds or taking out bank loans. We assume that each individual bank is a differentiated lender, where this assumption is motivated by such factors as geographic location or industry expertise. Letting each option be indexed by j, the firms' choice set is given by $\mathcal{A}^l = \{0, 1, \ldots, J, J+1\}$, where option $J+1$ represents bonds, option $1, \ldots, J$ represents loans from each bank, and option 0 is the option not to borrow at all.[6]

For tractability, we assume that both bonds and bank loans have the following repayment schedule. Each period the firm has to pay back a fraction, μ, of its outstanding principal plus interest. For instance, if the firm borrow a one dollar with fixed interest of r, the repayment stream, starting in the next period, is $\mu+r, (1-\mu)\cdot(\mu+r), (1-\mu)^2\cdot(\mu+r), \ldots$. Accordingly, all firm debt has an average maturity of $\frac{1}{\mu}$ periods.

The long-term bond interest rates is given by an expected weighted average of future Federal Funds rates, $\bar{f}_t$, plus the expected default cost.

$$\bar{f}_t = \mu f_t + \mathbb{E}_t \left[\sum_{n=1}^{\infty} \mu(1-\mu)^n f_{t+n} \right] \tag{5}$$

Each of the firm's financing option's is characterized by a rate, r_j^l, and a vector of product characteristics, x_j^l, which captures the convenience of using each of the financing options. For instance, borrowers may value the number of branches and the number of employees per branch when they choose which bank to borrow from.

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[6]Our index choices recycle the notation i to index firms and j to index the firm's borrowing options.

The problem of a firm is to choose the best option to maximize its profit:

$$\max_{j \in \mathcal{A}^l} \pi_{i,j} = \alpha_i^l r_j^l + \beta^l x_j^l + \xi_j^l + \epsilon_{i,j}^l \tag{6}$$

where $\pi_{i,j}$ is the profit of firm i from choosing option j. α_i^l is the sensitivity sensitivity to the interest rate r_j^l, which follows a uniform distribution with a mean, α^l, and a standard deviation σ_α^l. β^l are the sensitivities to non-rate characteristics x_j^l. ξ_j^l is the unobservable product-level demand shock. $\epsilon_{i,j}^l$ is an idiosyncratic shock when a firm i borrows from bank j. The optimal choice of household i is given by an indicator function:

$$\mathbb{I}_{i,j}^l = \begin{cases} 1 & \text{if } \pi_{i,j} \geq \pi_{i,k}, \text{ for } k \in \mathcal{A}^l \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

We aggregate the optimal choices across all the firms to compute the market share of each bank j. Assuming $\epsilon_{i,j}^l$ follows a generalized extreme value distribution with a cumulative distribution function given by $F(\epsilon) = \exp(-\exp(-\epsilon))$, we can get the standard logit market share:

$$\int \mathbb{I}_{i,j}^l dF(\epsilon) = s_j^l(r_j^l) = \sum_{i=1}^{I} \mu_i \frac{\exp(\alpha_i^l r_j^l + \beta^l x_j^l + \xi_j^l)}{\sum_{m \in \mathcal{A}^l} \exp(\alpha_i^l r_m^l + \beta^l x_m^l + \xi_m^l)} \tag{8}$$

where μ_i^l is the fraction of type i firms. The demand function for loans is given by the market share multiplied by the total market size,

$$B_j(r_j^l) = s_j^l(r_j^l) K. \tag{9}$$

4.2 The Banking Sector

Given the Federal Funds rate, f_t, each bank simultaneously sets its deposit rate, $r_{j,t}^d$, and its loan rate $r_{j,t}^l$, thereby implicitly choosing the quantities of deposits to take from households and credit to extend to firms. For example, given each bank j's choice of $r_{j,t}^d$, households solve

their utility maximization problem described above, which yields the quantity of deposits supplied to bank j, $D_j(r_{j,t}^d)$. Because households have the outside option of holding zero-nominal return cash, banks face a zero-lower bound for the deposit rates.

$$r_{j,t}^d \geq 0 \tag{10}$$

Similarly, given each bank j's choice of $r_{j,t}^l$, firms solve their profit maximization problem, which yields the quantity of loans borrowed from bank j, $B_j(r_{j,t}^l)$. To simplify notation, in what follows, we suppress the dependence of loans and deposits on the relevant interest rates, denoting them simply as $D_{j,t}$ and $B_{j,t}$.

This lending activity involves a maturity transformation. Let $L_{j,t}$ denote the amount of loans that the bank currently holds. In each period, as in the case of bonds, a fraction, μ, of a bank's outstanding loans matures. This assumption about long-term loans captures a traditional maturity transformation role for banks, in which they convert one-period deposits into long-term bank loans with maturity $\frac{1}{\mu}$. As noted above, banks can also issue new loans with an annualized interest rate of $r_{j,t}^l$. The new loans, once issued, have the same maturity structure as the existing ones, and the interest rate is fixed over the entire life span of the new loans. From the bank's perspective, the present value of interest income equals to:

$$I_{j,t} = \sum_{n=0}^{\infty} \frac{(1-\mu)^n B_{j,t} r_{j,t}^l}{(1+\gamma)^n}, \tag{11}$$

where γ is the bank's discount factor. As such, a bank's outstanding loans evolve according to:

$$L_{j,t+1} = (1-\mu)\left(L_{j,t} + B_{j,t}\right). \tag{12}$$

We assume that a random fraction of loans, $\delta_t \in [0, \mu]$, falls delinquent in each period, with delinquency occurring when a loan comes due but the borrower fails to pay. Although we assume that delinquent payments are written off by the bank, with charge-offs equal

to $L_t \times \delta_t$, defaulting on a payment in one period does not exonerate the borrower from payments in future periods. Therefore, delinquency does not affect the evolution of loans in (12).

We summarize the rest of the bank's activities in the balance sheet given in Table 2, where we suppress the subscript for bank identity, j, for convenience. Here, we see that the banks assets consist of existing plus new loans, reserves, and holdings of government securities. Its liabilities consist of deposits and borrowing that is not subject to reserve requirements. The difference is then bank equity. We now go through these items in detail.

In each period, the bank can rely on deposits or internal retained earnings to finance its loans. When the supply of funds falls short of loan demand, the bank can also borrow via non-reservable securities, N_t. A typical example of non-reservable borrowing is large denomination CDs. As argued by Kashyap and Stein (1995), because non-reservable borrowing is not insured by FDIC deposit insurance, purchasers of this debt must concern themselves with the default risk of the issuing bank. These considerations make the marginal cost of non-reservable borrowing an increasing function of the amount raised, and motivate our next assumption, which is that non-reservable borrowing incurs a quadratic financing cost beyond the prevailing Federal Funds rate, as follows:

$$\Phi^N(N_t) = \phi^N \frac{N_t^2}{D_t}. \tag{13}$$

This cost of non-reservable borrowing represents an important friction because in its absence, banks could always raise wholesale funding to compensate for the shortfall of deposits. This activity would disconnect banks' deposit taking decisions from their lending decisions, so changes in the Federal Funds rate would not have an impact on lending.

Banks also incur costs to serve depositors, such as hiring tellers and managers. We assume

that costs are linear in the amount of deposits:

$$\Phi^d(D_t) = \phi^d D_t. \tag{14}$$

Similarly, we also assume that lending activity itself incurs separate costs, such as the labor input necessary to screen loans or maintain client relationships. Again, we assume a linear functional form as follows:

$$\Phi^l(B_t) = \phi^l B_t. \tag{15}$$

In addition to variable cost, banks may also incur some fixed operating cost. Outside of their loan portfolio, banks may also earn a noninterest income. We assume both the fixed operating cost and the noninterest income are independent of the deposit taking and the lending decision. We use a parameter ψ to represent the difference between the fixed operating expense and noninterest income per unit of the steady state assets, $\bar{A}$. Therefore, the net fixed operating cost each period is $\psi \bar{A}$.

If the total supply of funds exceeds the demand from the lending market, the bank can invest in government securities, G_t, where the return is the Federal Funds rate, f_t. The bank's holdings of loans, government securities, deposits, reserves, and non-reservable borrowing must satisfy the standard condition that assets equal liabilities plus equity:

$$L_t + B_t + R_t + G_t = D_t + N_t + E_t, \tag{16}$$

where R_t denotes bank reserves and E_t is the bank's begin-of-period book equity. E_t itself evolves according to:

$$E_{t+1} = E_t + \Pi_t \times (1 - \tau) - C_{t+1} \tag{17}$$

where τ denote the linear tax rate, and Π_t is the bank's total operating profit from its deposit taking, security investments, and lending decisions. This identity ends up being a central ingredient in the model, as it links bank competition, which is reflected in profits, with bank

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capital regulation.

The profits in (17) are in turn given by:

$$\Pi_t = I_t - D_t \times r_t^d + G_t \times f_t - \Phi^l(B_t) - \Phi^d(D_t) - N_t \times f_t - \Phi^N(N_t) - L_t \times \delta_t - \psi \bar{A}, \quad (18)$$

Finally, C_{t+1} in equation (17) represents the cash dividends distributed to the bank's shareholders. We assume that a bank can only increase its inside equity via retained earnings, that is, there is no new equity issuance, so:

$$C_{t+1} \geq 0 \quad \forall t. \quad (19)$$

This constraint reflects a bank's limited liability, which prevents it from obtaining any external equity financing from shareholders. This constraint implies that banks cannot raise equity capital to replace deposits or non-reservable borrowing. In Section 7, we find allowing for equity issuance only has limited impacts on the results because banks' equity issuances are both tiny and rare.

We now introduce the capital requirement and the reserve requirement:

$$E_{t+1} \quad \geq \quad \kappa \times L_{t+1} \quad (20)$$

$$R_t \quad \geq \quad \theta \times D \quad (21)$$

Equation (20) implies that the bank's book equity at the beginning of the next period has to be no smaller than a fraction, κ, of the loans outstanding. Equation (21) is the bank's reserve requirement, which says that the bank has to keep θ of its deposits in a non-interest bearing account with the central bank. Zero interest on reserves implies that the bank has no incentive to hold excess reserve, so equation (21) holds with equality.[7]

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[7]The Federal Reserve starts to pay interests on reserves since October 2008. In section 6, we show that paying interest on reserves has a limited impact on the equilibrium.

4.3 Monetary policy

Monetary policy is modeled as a process of the Federal Funds rates determined by the central bank. Since our focus is on the banking sector, we assume that monetary transmission in the bond market is simply pinned down by the expectations hypothesis, i.e., the long-term bond yield equals to the average of expected future short rates. By doing so, we assume away frictions in the bond market which may drive the long-term bond yield away from the expectations hypothesis benchmark. Formally, define f_t^n as n-year yield at time t.[8] We have

$$f_t^n = \frac{1}{n}E[f_t + f_{t+1} + ... + f_{t+n}] \tag{22}$$

Monetary policy affects banks in two ways. First, by setting the short rate, monetary policy affects the marginal funding cost of banks in the non-reservable funding market. Second, by setting the short rate and influencing the long rate through expectations, monetary policy affects the relative attractiveness of various saving and financing vehicles of households and firms, which ultimately affects banks' market power in the deposit and loan markets.

We allow the Federal Funds rate to correlate with the process of loan charge-offs. Formally, the law of motion for the bank loan charge-offs and the Federal Funds rate is given by:

$$\begin{bmatrix} \ln \delta_{t+1} - \mathbb{E}(\ln \delta) \\ \ln f_{t+1} - \mathbb{E}(\ln f) \end{bmatrix} = \begin{bmatrix} \rho_\delta & \rho_{\delta f} \\ 0 & \rho_f \end{bmatrix} \cdot \begin{bmatrix} \ln \delta_t - \mathbb{E}(\ln \delta) \\ \ln f_t - \mathbb{E}(\ln f) \end{bmatrix} + \begin{bmatrix} \sigma_\delta & 0 \\ 0 & \sigma_f \end{bmatrix} \cdot \mathcal{N}_2, \tag{23}$$

where $\mathcal{N}_2$ stands for the density function of a standard bi-variant normal distribution.

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[8]Note that $f_t = f_t^1$ because the smallest increment of time is 1 year in the model. In practice, the Federal Funds rate is an overnight rate.

4.4 Bank's problem and equilibrium

Figure 8 summarizes the sequence of events in a typical time period. The bank enters the period and observes the Federal Funds rate, f_t, and the realization of the default fraction, δ_t. At that point, it takes the corresponding charge-offs. Next, banks interact with households and firms by setting the loan and deposit spreads, receiving the corresponding amount of deposits from households, and extending the corresponding amount of loans to firms. Depending on the extent of these activities, the banks adjust their reserves, holdings of government securities, and non-reservable borrowing. Finally, banks collect profits at the end of the period and distribute dividends to shareholders.

As discussed above, loan and deposit demand depend on the rates put forth by all banks in the economy. Accordingly, when each bank chooses its own deposit and loan rates (r_t^d and r_t^l), as well as its non-reservable borrowings (N_t), and investment in government securities (G_t), it rationally takes into account the choices made by other banks in both the current and future periods. As such, all of a bank's optimal choices depend on the composition of the banking sector, that is, the cross-sectional distribution of bank states, which we denote by Γ_t. Letting P^Γ denote the probability law governing the evolution of Γ_t, we can express the evolution of Γ_t as:

$$\Gamma_{t+1} = P^\Gamma(\Gamma_t). \tag{24}$$

Every period, after observing the Federal Funds rate (f_t) and the random fraction of defaulted loans (δ_t), the banks choose the optimal policy to maximize its discounted cash dividends to shareholders:

$$V(f_t, \delta_t, L_t, E_t | \Gamma_t) = \max_{\{r_t^l, r_t^d, G_t, N_t, R_t, C_{t+1}\}} \frac{1}{1+\gamma} \left\{ C_{t+1} + \mathbb{E}V(f_{t+1}, \delta_{t+1}, L_{t+1}, E_{t+1} | \Gamma_{t+1}) \right\} \tag{25}$$

$$s.t. \quad (10), (13), (14), (15), (16), (17), (24).$$

We define equilibrium in this economy as follows.

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Definition 1 *A stationary equilibrium occurs when:*

1. *All banks solve the problem given by (25), taking as given the other banks' choices of loan and deposit rates.*

2. *All households and firms maximize their utilities given the list of rates put forth by banks.*

3. *Each period, the deposit and loan markets clear.*

4. *The probability law governing the evolution of the industry, P^Γ, is consistent with banks' optimal choices.*

One of the state variables for bank's problem (Γ_t) is an object whose dimension depends on the number of banks in the economy. This dimensionality poses a challenge for numerically solving the banks' problem. To simplify the model solution, we follow Krusell and Smith (1998) by considering a low-dimensional approximation of Γ_t. Specifically, we postulate that all information about Γ_t relevant to banks' optimization can be summarized by the contemporaneous Federal Funds rate (f_t). Accordingly, we define the equilibrium "average" loan and deposit rates $\bar{r}_t^{l,i}(f_t)$ and $\bar{r}_t^{d,i}(f_t)$, respectively as,

$$\exp(\alpha_i^d \bar{r}_t^{d,i} + q_i^d) \equiv \mathbb{E}\left[\exp(\alpha_i^d r^d + q_i^d)\right], \tag{26}$$

and

$$\exp(\alpha_i^l \bar{r}_t^{l,i} + q_i^l) \equiv \mathbb{E}\left[\exp(\alpha_i^l r^l + q_i^l)\right]. \tag{27}$$

$\bar{r}_t^{l,i}(f_t)$ and $\bar{r}_t^{d,i}(f_t)$ summarize the choices of other banks, thereby allowing each bank to derive its choices of deposit and loan rate. In solving the model, we ensure that $\bar{r}_t^{l,i}(f_t)$ and $\bar{r}_t^{d,i}(f_t)$ are consistent with equilibrium bank choices by iterating over their values until convergence. We then regress the simulated evolution of the aggregates deposit and loan rates on the perceived law of motion based on the banks' belief. The R-squares for our approximation is 96% on the deposit market, and 99% on the loan market. Thus, although the banks do not take into account the full distribution, Γ_t, in the economy, the errors in forecasting rates that result from this omission are very small. This is mainly a result of two mechanisms in

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the model: 1) without any financial or regulatory constraint, banks have a static optimal deposit/loan rate. For example, on the lending market, the optimal level of loans serves to equalize the expected marginal interest income to the funding cost, which is a function of the current Federal Funds rate only. Therefore, the static optimal rate depends only on the Federal Funds rate, but not other aggregate moments; 2) for those constrained banks, they deviate from the static optimum by lowering the loan quantity and charging higher loan spreads. However, these banks cannot increase their spreads too much in order to avoid their market shares being stolen by other competing banks or borrowing opportunities. The competitive force on the market ensures that the banks who deviate from the static optimum introduce only modest distortions on the other banks' rate forecasts.

4.5 Monetary policy transmission

In this section, we use a simplified version of the model to illustrate the key transmission mechanisms.

4.5.1. Frictionless benchmark

First, we examine how the economy behaves in a frictionless benchmark model. By frictionless, we mean a simplified version of our model with the following six features: (1) the bank has no market power in either the deposit or the loan market, i.e., the deposit and loan demand elasticities are infinite; (2) there are no frictions related to non-reservable borrowing, $\phi^N = 0$; (3) the bank faces no capital requirement, $\kappa = 0$; (4) there is no reserve requirement, $\theta = 0$; (5) there is no maturity transformation, and (6) the operating costs, ϕ^d and ϕ^l, are zero. These features imply that the bank's problem can be viewed as a static problem.

In this static frictionless model, banks choose deposit rates, r^d, and loan rates, r^l, to maximize one-period profits

$$\Pi = \max_{\{r^l, r^d\}} r^l B - r^d D - f\left(B - D\right). \tag{28}$$

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When deposits fall short of loans, the bank can make up any funding shortfall, $B - D$, with non-reservable borrowing at a cost equal to the Federal Funds rate, f. There are no additional financing costs associated with non-reservable borrowing. When there are excess deposits, the bank can invest any this surplus, $D - B$, in government securities and earn the Federal Funds rate, f.[9] In the absence of a balance sheet friction, the bank can optimize its choices for deposit and loan amounts separately.

The optimal lending rates are given by the Federal Funds rate plus the marginal cost and the markup:
$$r^l = f + \left(-\frac{B'}{B}\right)^{-1},$$

and the optimal deposit rates are given by the Federal Funds rate minus the marginal cost and the markup:
$$r^d = f - \left(\frac{D'}{D}\right)^{-1}.$$

When there is perfect competition among banks, the demand elasticities, $-\frac{B'}{B}$ and $\frac{D'}{D}$, become infinite and the markups converge to zero. Deposit and lending rates converge to the Federal Funds rate:
$$r^d \to f, \ r^l \to f \tag{29}$$

Under the frictionless benchmark, banks function as the bond market, passing through the interest rate changes to the exact same degree.

4.5.2. Imperfect competition

When competition is imperfect, market power creates a wedge between the Federal Funds rate and the rates at which banks borrow and lend. Monetary policy can affect the market power of banks by influencing the attractiveness of bank deposits or loans relative to other outside options available to households or firms.

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[9]In reality, the Federal Funds rate is slightly higher than the risk-free Treasury yield because the Federal Funds rate contains a small risk premium while Treasury yield contains a small convenience yield. However, this difference is quite small.

In the model, bank deposits face competition from both bonds and cash. Investors get higher returns from investing in bonds but endure low liquidity. On the contrary, cash holdings offer high liquidity but zero return. Bank deposits are somewhere in between, offering investors both liquidity and a non-zero return. When the interest rate is high, the opportunity cost of holding cash increases, which allows banks to charge larger markup on deposits (e.g., Drechsler, Savov, and Schnabl 2017), so:

$$\frac{\partial \left(\frac{D'}{D}\right)^{-1}}{\partial f} > 0. \tag{30}$$

In the lending market, an increase in the Federal Funds rate makes bank loans less attractive to firms relative to the outside option of not borrowing to any investment. Therefore, total lending shrinks and banks optimally lower the markups they on loans to mitigate the effect of lower loan demand.[10]

$$\frac{\partial \left(-\frac{B'}{B}\right)^{-1}}{\partial f} < 0 \tag{31}$$

Figure 4 summarizes the effect of market power on monetary transmission. Bank market power creates an "intermediation wedge" between the rate paid by borrowers and the rate received by depositors. Furthermore, banks vary the "intermediation wedge" to maximize profits as monetary policy changes the attractiveness of the outside options for depositors and borrowers.

4.5.3. Balance sheet frictions

In the frictionless benchmark, the deposit market and loan market are entirely separable because the bank can costlessly use non-reservable borrowing and government securities as buffers. Now consider the case in which banks face balance sheet frictions, so they incur

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[10]Note that the transmission of Federal Funds rate to the lending rate is different from the standard cost pass-through problem in the industrial organization literature. The standard cost pass-through problem only concerns the pass-through of marginal costs to prices while the demand side is held constant (Bulow and Pfleiderer 1983). In contrast, in the setting of monetary transmission, the Federal Funds rate not only affects banks' marginal funding cost, it also affects borrowers by changing the attractiveness of outside option.

additional costs when using non-reservable borrowing. In this case, the banks' optimization problem becomes:

$$\Pi = \max_{\{r^l, r^d\}} r^l B - r^d D - f(B - D) - \Phi(N),$$

where $\Phi(N)$ is the cost of non-reservable borrowing or investing excess funding and $N = B - D$ is the funding imbalance. In the presence of balance sheet frictions, the bank cannot costlessly replace any lost deposits with wholesale borrowing. Therefore, shocks to deposits will be transmitted to loans.

4.5.4. Reserve requirement

Now consider the case in which banks face reserve regulation that requires that for every dollar of deposits, the bank needs to keep a fraction, θ, of these deposits as reserves. Assuming that the interest on reserves is zero, banks' optimization becomes

$$\Pi = \max_{\{r^l, r^d\}} r^l B - r^d D - f(B + R - D)$$

$$s.t. \ R \geq \theta D$$

Because the interest rate on reserves is zero, the reserve constraint is binding. We can solve for the optimal deposit rate as

$$r^d = f - \left(\frac{D'}{D}\right)^{-1} - \theta f. \tag{32}$$

Here we see that higher Federal Funds rates increase the opportunity cost of holding reserves, θf, which lowers deposit rates. Lower deposit rates, in turn, reduce the quantity of deposits and optimal supply of loans.

4.5.5. Capital regulation

Now consider the case in which banks face capital regulation that requires bank capital to exceed a certain fraction of bank assets. In this case, the banks' optimization problem becomes:

$$\Pi = \max_{\{r^l, r^d\}} r^l B - r^d D - f(B - D),$$

$$s.t. \ E_0 + (1 - \tau_c)\Pi \geq \kappa B.$$

In the presence of capital regulation, shocks to bank capital affect lending capacity. One way that monetary policy affects bank capital is through maturity mismatch. Because deposits are short-term, an increase in the Federal Funds rate raises the rate that the bank has to pay on all deposits. However, loans are long-term, so only a fraction of loans matures, with the remaining outstanding loans commanding a lower rate. Hence, an increase in the Federal Funds rate temporarily reduces bank capital and tightens the bank capital constraint in equation (20).

Another way that monetary policy affects bank capital is through market power. When the Federal Funds rate increases, bank profits from the deposit market increase, as the competition from cash lessens, but bank profits from the loan market decrease as borrowers are less willing to borrow at higher rates. The relative importance of the two forces vary under different Federal Funds rate environment, leading to variations in the tightness of banks' capital constraint.

5. Estimation

5.1 Estimation procedure

We divide the estimation procedure into two stages. In the first stage, we estimate the demand functions for deposits and loans following Berry, Levinsohn, and Pakes (1995). In

the second stage, we estimate the remaining parameters describing banks' balance sheet frictions using simulated method of moments (SMM).

We first estimate the deposit demand, and the loan demand follows analogously. The deposit demand is characterized by the following preference parameters, $\Theta^d = \left(\alpha^d, \sigma_\alpha^d, \beta^d\right)$, where α^d and σ_α^d are the mean and standard deviation of the sensitivity to deposit rates; and β^d are the sensitivities to non-rate characteristics.

Following Berry, Levinsohn, and Pakes (1995), we construct a nonlinear GMM estimator for the preference parameters exploiting a moment condition that is a product of instrumental variables, Z, and the unobservable demand shocks, ξ^d. Formally, the GMM estimator is

$$\hat{\Theta}^d = \arg \min_{\Theta^d} \xi \left(\Theta^d\right)' Z' W^{-1} Z \xi \left(\Theta^d\right),$$

where W is a consistent estimate of $\mathbb{E}\left[Z'\xi\xi'Z\right]$.

A key challenge in identifying the demand parameters is the natural correlation between deposit rates r_j^d and unobservable demand shocks ξ_j^d. Banks may lower deposit rates if they observe a positive demand shock. To identify the yield sensitivity, we use a set of supply shifters, c_j, as instrumental variables. Our particular supply shifters are salaries and non-interest expenses related to the use of fixed assets. These shifters are used in previous literature such as Dick (2007) and Ho and Ishii (2011). Our identifying assumption is that customers would not care about the cost per se once product characteristics are controlled for. Therefore, these supply shifters are orthogonal to unobservable demand shocks and thus shift the supply curve along the demand curve, allowing us to trace out the slope of the demand curve. Formally, the vector of instrumental variables Z is defined as follows:

$$Z = [x, c],\tag{33}$$

where x is a vector of non-rate bank characteristics including the number of branches, the number of employees per branch, bank fixed effects, and time fixed effects, and c is a vector of

supply shifters including salaries and non-interest expenses related to the use of fixed assets. Note that our identification of the demand curve does not use variations of monetary policy. In fact, any aggregate demand shocks are observed by time fixed effects. Therefore, our identification strategy avoids a common challenge for the studies on monetary transmission, namely, the endogeneity of monetary policy to aggregate bank credit supply.

We compute the unobservable demand shocks, ξ^d, using the nested fixed-point algorithm described in Nevo (2001). Specifically, for a given set of demand parameters Θ^d and the actual market shares in the data, s_0, we can solve

$$\xi^d \left(\Theta^d \right) = s^{-1} \left(s_0 | \sigma_{\alpha^d} \right) - \left(\alpha^d r_j^d + \beta^d x_j^d \right)$$

where $s^{-1}(.)$ is the inverse of the demand function specified by equations (3).

Using the demand parameter estimated in the first stage, we can construct the empirical demand system. Note that our data contain a large number of banks even after we combine tiny local banks into one option in the demand estimation. This feature of the data poses a challenge for the second stage SMM estimation because estimating a dynamic model with a large number of heterogeneous banks would be intractable. Therefore, we use the estimated demand parameters in the first stage to construct a demand system with $\hat{J}$ ex ante symmetric representative banks, where the number of representative banks $\hat{J}$ is calibrated to match the average local banking concentration in the data. Because the size distribution has a heavy left tail, this approach substantially reduces the number of banks in the model while keeping the market concentration similar to that in the data. Specifically, we calculate a quality value q for each of the $\hat{J}$ representative banks, which summarizes the utility from the non-rate product characteristics as follows:

$$q^d = \log \left(\frac{1}{\hat{J}} \sum_{j=1}^{J} \exp \left(\hat{\beta}^d x_j^d + \hat{\xi}_j^d \right) \right). \tag{34}$$

With the quality value in hand, we parameterize the deposit demand functions as:

$$D_j(r_j^d|f) \;=\; \sum_{i=1}^{I} \mu_i^d \frac{\exp\left(\hat{\alpha}_i^d r_j^d + q_j^d\right)}{\sum_{m\in\mathcal{A}} \exp\left(\hat{\alpha}_i^d r_m^d + q_m^d\right)} W \tag{35}$$

where $j = 1, 2, ..., \hat{J}$. $\hat{\alpha}_i^d$ is drawn from a discretized uniform distribution with a mean of $\hat{\alpha}$ and a standard deviation of $\hat{\sigma}_\alpha$ and μ_i are the fraction of each type of depositors. We normalize the quality value of bonds to zero, and we denote by q_d^d and q_c^d the quality values of bank deposits and cash, respectively.

We estimate the loan demand function in a similar procedure as the deposit demand except that we assume a homogeneous sensitivity to loan rate.[11] We include the same set of supply shifters and non-rate characteristics as the deposit market but allow the sensitivities to these characteristics to be different from those in the deposit market. Using the estimated demand parameters for the loan market, we can construct the quality value as

$$q^l = \log\left(\frac{1}{\hat{J}} \sum_{j=1}^{J} \exp\left(\hat{\beta}^l x_j^l + \hat{\xi}_j^l\right)\right). \tag{36}$$

Note that the quality value of not borrowing, q_n^l, cannot be estimated from the demand estimation because we do not observe its share. Therefore, we relegate this parameter to our second stage estimation. With the quality value in hand, we parameterize the loan demand functions as:

$$B_j(r_j^l|f) \;=\; \frac{\exp\left(\hat{\alpha}^l r_j^l + q_j^l\right)}{\sum_{m\in\mathcal{A}} \exp\left(\hat{\alpha}^l r_m^l + q_m^l\right)} K. \tag{37}$$

The final plug-in problem consists of inserting the estimated demand functions described in equations (35) and (37) into banks' dynamic problem (25). This plug-in problem operationalized the notion that banks set deposit and loan rates facing the above-specified demand curves for deposits and loans.

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[11]This is because we do not observe the market share of not borrowing.

In the second stage, we estimate seven additional parameters using simulated method of moments (SMM), which chooses parameter values that minimize the distance between the moments generated by the model and their analogs in the data. We use ten moments to identify the remaining seven model parameters. Parameter identification in SMM requires choosing moments whose predicted values are sensitive to the model's underlying parameters. Our identification strategy ensures that there is a unique parameter vector that makes the model fit the data as closely as possible.

First, we use banks' average non-reservable borrowing as a fraction of their deposits to identify the cost of holding non-reservables, ϕ^N. Intuitively, larger financing costs induce banks to finance loans mainly through deposits, and less via borrowing. Next, we use the average deposit and loan spreads to identify banks' marginal costs of generating deposits, ϕ^d, and servicing loans, ϕ^l. Higher marginal costs lead to higher spreads that banks charge in the deposit and lending markets.[12] In addition to marginal costs, banks also incur the net fixed operating cost, ψ, which is identified by two moments— the first moment is the total non-interest expenses minus the non-interest income. This moment directly measures the out of pocket cost that banks pay outside of their routine deposit-intaking and loan-servicing business; the second moment is banks' leverage ratio, which indirectly reflects the fixed operating costs that banks are facing. Higher fixed cost induces banks to operate at higher leverage. Next, we use banks' average dividend yield to identify the discount rate, γ. Intuitively, a high discount rate makes the banks impatient, so they pay out a larger fraction of their profit to shareholders instead of retaining it to finance future business. Finally, to identify the relative size of the deposit market, W/K, and the value of firms' outside option of not borrowing, q_n^l, we include banks' average deposit to asset ratio and the sensitivity of total borrowing to the Federal Funds rate which is estimated through a vector autoregression (VAR).[13] These two moments suit this purpose because keeping the

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[12]Deposit spreads are defined as the difference between the Federal Funds rate and deposit rates, while loan spreads are the difference between loan rates and Treasury yields matched by maturity.

[13]The details of the VAR is in the Online Appendix.

market shares of the banks constant, when W/K increases, it implies that the dollar amount of deposit intake will increases relative to the loan value, leading to a higher deposit asset ratio. When when the outside option becomes less valuable, its market share remains low regardless of the current Federal Funds rate. Thus, the sensitivity of the aggregate corporate borrowing to the Federal Funds rate should fall as q_n^l falls. In addition, a high loan-to-deposit ratio should be inversely related to q_n^l because when aggregate borrowing from the corporate sector is high, bank loans face proportionally higher demands. Last, we also include banks' market-book-ratio to ensure that our model predicts the right valuation for banks.

5.2 Baseline Estimation Results

Table 3 presents the point estimates for the 22 model parameters. In Panel A, we start with the parameters that we can directly quantify in the data. Specifically, we set the corporate tax rate to its statutory rate of 35%. Capital regulation stipulates that banks keep no less than 6% of their loans as book equity. Reserve regulation requires a 10% reserve ratio for transaction deposits, 1% for saving deposits, and 0% otherwise. In our model, we only have one type of deposit, so our estimate of the deposit ratio is a weighted average of these three requirements, where the weights are the shares of a particular type of deposit in total deposits. We model the Federal Funds rate and the bank-level loan default rate as log AR(1) processes, and we directly calculate their means, standard deviations, and autocorrelations from the data. Finally, we set the maturity of loans in our model to average loan maturity in the data, which is approximately 3.5 years. Specifically, we use repricing maturity, the time until the next interest reset, for floating rate loans. Furthermore, we use prepayment adjusted duration for mortgage loans and mortgage backed securities.[14]

Panel B in Table 3 presents the demand parameters from the first stage BLP estimation.[15] Not surprisingly, we find that depositors react favorably to high deposit rates while borrowers

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[14]Elenev, Landvoigt, and Van Nieuwerburgh (2016) shows that the average effective duration of mortgage loans is around four years.

[15]Detailed estimation results are presented in Table 5.

react negatively to high loan rates. Both yield sensitivities are precisely estimated, and the economic magnitudes are significant as well. A 1% increase in the deposit rate increases the market share of a bank by approximately 0.8%, while a 1% increase in the loan rates decreases bank market share by 0.9%. We also find that depositors exhibit significant dispersion in their rate sensitivity. Finally, we estimate depositors' and borrowers' sensitivities to non-rate bank characteristics such as the number of branches and the number of employees per branch. The estimates are also both statistically and economically significant. A 1% increase in the number of branches increases bank market share by 0.868% in the deposit market and 1.117% in the loan market. In comparison, the sensitivity to the number of employees per branch is smaller. A 1% increase in the number of employees per branch increases bank market share by 0.587% in the deposit market and 0.694% in the lending market. Using these estimates combined with bank and time fixed effects, we can calculate the implied quality parameter using (34), which we plug into the second-stage SMM estimation.

Panel C in Table 3 presents the balance sheet parameters from our second stage SMM estimation. We find that banks have a subjective discount rate of 4.6%, which is higher than the average Federal Funds rate observed in the data. Given the discount rate, banks pay out 3% of their equity value as dividends. We also find the cost of non-reservable borrowing both statistically and economically significant. At the average amount of non-reservable borrowing (30% of total deposit), a marginal dollar of non-reservable borrowing costs the bank 36 basis points above the cost implied by the prevailing Federal Funds rate.[16] Note that the average deposit spread is 1.3%. Because banks equate the marginal costs of their funding sources, these numbers imply the marginal cost of expanding deposit averages 1.7%, suggesting a large role for deposit market power. This result implies that banks cannot easily replace deposits with other funding sources. Therefore, shocks to bank deposits are likely to be transmitted to bank lending. Finally, we find that banks incur a 0.9% cost of maintaining deposits and a slightly lower 0.6% marginal cost of servicing their outstanding loans.

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[16]The marginal cost of non-reservable borrowing is $\frac{\partial \Phi}{\partial N} = 2\phi^N N = 2 \times 0.006 \times 0.3 = 0.0036$.

Table 4 compares the empirical and model-implied moments. The model is able to match closely the banks' balance sheet quantities, the spreads they charge, as well as their valuation. In both the data and the model, banks borrow non-reservable securities, which amount to 30% of deposit intake. The spread that banks charge in the deposit market is significantly lower than the spread they receive in the loan market. This result arises because as the Federal Funds rate approaches zero, bank deposits face increasing competition from cash. Thus, banks market power falls and deposit spreads become compressed.

As a external validation of the model, in Figure 8, we plot how banks' deposit and loan rates react to the Fed's monetary policy. Note that, in our moment matching exercise, we only target the average levels of these rates, but not their functional relationship with the underlying Federal Funds rate. First, our results in Figure 8 indicates that the pass-through of the Federal Funds rates on both the deposit and loan markets are less than one to one, as indicated by the slope of the plots. The result is consistent with the message in Table 5 and indicate that banks do have significant market power. In addition, our model predicted deposit and loan rates quite closely track the pattern that we see in the actual data, indicating that our model can capture quantitatively how banks price their products on both the deposit and loan markets.

We also examine how market value of bank equity will react to an unexpected Federal Funds rate shock in our model. In the data, a 25 basis point increase in the Federal Funds rate on average leads to a 2% drop in the bank equity value (English, Van den Heuvel, and Zakrajšek 2018). Models without market power tend to over predict this response. For example, if we model banks as a replicating portfolio with a long position on 4 year Treasuries and a short position on the Federal Funds rate with 10 times leverage, then 25 basis point increase in the Federal Funds rate would lead to a 10% drop in equity value.[17] Although our model is not geared to match asset pricing moments, it generates a 0.6% drop in equity value for a 25 basis point increase in the Federal Funds rate, which is broadly in

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[17]With a maturity mismatch of 4 years, the asset value drops by $1\% = 0.25\% \times 4$ for a 25 basis point increase increase in the Federal Funds rate. With 10 times of leverage, the equity value drops by 10%.

line with what the data suggests. The intuition is the same as in Drechsler, Savov, and Schnabl (2018)—bank market power allows banks to earn a deposit spread that is positively correlated with the Federal Funds Rate. The profit from the deposit market hedges against banks' interest rate exposure due to a maturity mismatch, thereby dampening the impact of rate hikes substantially. This result also highlights the importance of explicitly taking into account banks' market power when analyzing their reaction to monetary policy shocks.

6. Counterfactuals

6.1 Decomposing Monetary Policy Transmission

Now we examine the quantitative forces that shape the relation between monetary policy, as embodied in changes in the Federal Funds rate, and aggregate bank lending. To this end, we start with the baseline model in row (1) of Table 6, where we see that on average in our model, a one percent change in the Federal Funds rate translates into a 1.73% decrease in aggregate bank lending. In the data, if we run an impulse response of aggregate lending to monetary shocks, the coefficient that is roughly -1.6 over a three year horizon.[18] Though we do not explicitly target this moment in our estimation process, it turns out the degree of monetary transmission predicted by the model matches what we see in the data.

We proceed by eliminating the regulatory constraints and banks' local market power one by one to examine the effect of removing these frictions. As such, we analyze how the absence of each model ingredient influences the transmission of the Federal Reserve's monetary policy.

To this end, we first estimate the effects of the reserve requirement and the capital requirement by removing them from the baseline model in which all frictions are present. Row (2) presents the results from a version of the model without the reserve requirement. We find that the sensitivity of bank lending to the Federal Funds rate barely changes after we eliminate the reserve requirement. The small magnitude reflects the fact that the amount

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[18]The impulse response of aggregate lending to monetary shocks is shown in Online Appendix.

of non-interest bearing reserves held by banks is quite small in our sample period.[19] As a result, monetary policy has a limited effect on banks' marginal cost of lending through the reserve requirement. This result is interesting sheds light on a recent policy debate on interest on excess reserves. Since October 2008, the Federal Reserve started to pay interest on reserves and some worry that such a policy may render monetary policy ineffective in affecting bank lending.[20] However, our result shows that this concern is unwarranted as bank reserve channel has not been an important transmission channel since the 1990s. This result is also consistent with Xiao (2018), who shows that reserve requirement is not a quantitatively important feature which distinguishes commercial banks from shadow banks.

Row (3) presents the results from a version of the model without the capital requirement. It shows that the presence of capital requirement enhances monetary policy transmission by 28% ($\frac{1.727-1.240}{1.727} = 28.20\%$). This result connects two long-standing but somewhat separate sets of reduced-form evidence on bank capital channel. The first strand of literature shows that monetary policy has a significant effect on bank capital (Flannery and James 1984; English, Van den Heuvel, and Zakrajšek 2018). This literature often focuses on high-frequency responses of bank equity to interest rate changes, but it does not speak to low-frequency movement in bank lending. This is because capital requirements are based on book value of equity, which moves with a significant lag following the market value of equity. This slow movement makes it difficult to identify the impact of monetary policy on bank lending from high-frequency asset price data. The second strand of literature shows that bank capital has an economically significant impact on bank lending (Peek and Rosengren 2000; Mora and Logan 2012). This literature often exploits exogenous shocks to bank capital such as banks' exposure to oversea credit loss. It does not use monetary policy shocks because it is endoge-

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[19]After 2008, the amount of bank reserves has increased substantially. However, in this period, reserves started to bear interests, which effectively eliminate reserve channel.

[20]For instance, a January 2019 Wall Street Journal article titled "The Fed's Obama-Era Hangover" argues that "by paying banks not to lend, the central bank diminished its ability to control interest rates" (Gramm and Saving 2019). Another example is in an article in the *American Banker* on June 22, 2019 titled "Fed must stop rewarding banks for not lending," which argues: "It was thanks to interest on excess reserves that the Fed ended up stimulating so little in the economy, despite its efforts to ease so much" (Michel and Selgin 2017)

nous. Therefore, it only offers indirect evidence on the bank capital channel.[21] Compared to these two strands of literature, we are able to trace out the effects of monetary policy on bank lending through bank capital requirement by estimating a structural model, which sheds light on the quantitative magnitude of this long-established channel.

Does banks' market power play a more or less important role on monetary policy transmission, relative to the traditional regulatory-based transmission mechanisms? To answer this question, in row (4), we remove from the model banks' market power in the deposit market. In this case, banks receive a fixed lump-sum profit equal to their oligopolistic profit in the baseline case, and they use marginal cost pricing for deposit-intake decisions. Namely, they set the deposit rate equal to the Federal Funds rate minus the bank's marginal cost of servicing deposits, and they take as many deposits as depositors offer, given that deposit rate. If deposit market power is in place, when the Federal Funds rate increases, the opportunity cost for households to hold cash increases, making cash relatively less attractive than bank deposits. Banks react by charging higher deposit spreads and consequently lowering the amount of deposit intake. Banks' lending decisions partially echo this decline in deposit in-take because when the amount of lending exceeds deposits, banks need to use expensive non-reservable borrowing to finance their loans. Thus, the bank's market power, combined with the non-reservable borrowing cost, contribute to a negative relation between banks' lending and the Federal Funds rate. Our results confirm this intuition. Once we eliminate market power in the deposit market, bank lending becomes less sensitive to change in the Federal Funds rate. A 1% increase in the Federal Funds rate causes an almost one to one decrease in aggregate lending. This sensitivity is 35.78% ($\frac{1.727-1.109}{1.727} = 35.78\%$) smaller than the 1.73% sensitivity observed in the baseline case. Finally , this result is important in that it highlights the interconnectedness of banks' deposit taking and lending businesses. Banks' market power in the deposit market gets passed on to the loan market and contributes to

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[21]Note that there is a separate literature which examines heterogeneous responses to monetary policy across banks with different capital adequacy (Gambacorta and Mistrulli 2004). This literature does not answer the question of how large bank capital channel is.

the sensitivity of bank lending to the Federal Funds rate.

Then, we turn to banks' market power in the lending market. We remove the loan market power by setting the markup in loan spreads to zero. Note that by assuming marginal cost pricing for loans, we also eliminates the effects of other channels on loan supply. Therefore, to isolate the effect of loan market power, an appropriate benchmark should be row (5) in which the only friction present is the loan market power. By removing loan market from this benchmark, our results show that the presence of banks' loan market power makes the aggregate quantity of loans less sensitive to the Federal Funds rate, with the sensitivity goes down by -26.40% ($\frac{0.724-1.180}{1.727} = 26.40\%$). This result is consistent with Scharfstein and Sunderam (2016) and Corbae and Levine (2018), which show that loan market power allows banks to cushion the effects of monetary tightening on lending.

Finally, we compare the magnitude of regulatory based transmission channels with market power based channels. We find that market power based channels have comparable, if not larger, effects than the regulatory based channel. This has important implications for policy because the current policy discussions focus on regulatory transmission channels while often ignore the industrial organization of the banking system. Our result highlights the importance of accounting for the market structure of the banking system in assessing the monetary transmission mechanism.

6.2 Reversal Rate

In our previous analysis, we did not break down the effects of changes in the Federal Funds rate as a function of the rate level. We now turn to this question in Figure 6. In the top panel of Figure 6, we plot the amount of bank lending for different levels of the Federal Funds rate. We find that aggregate bank lending in the economy is inversely U-shaped. When the Federal Funds rate is above a threshold, an increase in the Federal Funds rate has the usual effect of tightening lending. However, when the Federal Funds rate falls below the threshold, an increase in the Federal Funds rate actually has the opposite effect of expanding lending.

In the top panel of Figure 6, we also present how aggregate bank lending react to monetary policy shocks conditional on the current Federal Funds rate level. Overall, and as expected, there is a negative relationship between the Federal Funds rate and the amount of lending. However, the negative relation is reversed in the region where the Federal Funds rate is below 1.1% . We call the region in which the Federal Funds rate is below 1.1% a "reversal rate" environment.

To understand why monetary policy, as embodied in changes in the Federal Funds rate, can have opposite effects on bank lending, we also plot in bottom panel of Figure 6 the level of bank capital and the optimal amount of bank lending in a world with no capital requirements. Note that optimal lending is the smaller of two quantities: desired lending and feasible lending. The former is the optimal amount of lending in the absence of a capital requirement, and the latter is maximal lending permitted by bank's equity capital. In equilibrium, desired lending is always decreasing in the Federal Funds rate, as high funding costs deter firms from borrowing. Hence, in high-rate regions, the capital requirement is slack, and the actual quantity of lending is the desired amount. On the other hand, when the Federal Funds rate is low, desired lending exceeds that allowed by the bank's equity. Thus, the capital requirement binds, and the actual lending tracks the bank's equity capital, which increases in the Federal Funds rate.

The excess of desired over capital-constrained lending makes sense given firms' equilibrium high demand for loans in a low interest rate environment. However, the question remains of the forces behind the positive relation between bank equity capital the Federal Funds rate when the latter is low. This result stems from the relative magnitudes of profits from lending and deposit taking. First, changes in the Federal Funds rate have opposite effects on bank profits in the deposit and lending markets. When the Federal Funds rate is high, holding cash is highly unattractive from the depositors' point of view, and banks face consistent weak competition from cash in the deposit market. Hence, bank profit from the deposit market increases in the Federal Funds rate. In contrast, bank profit from lending decreases in the

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Federal Funds rate, as higher funding costs makes the firms' outside option of not investing more appealing. Our parameter estimates imply that when the Federal Funds rate is low, the effect on profits from the deposit market dominates the effects from the lending market. Thus, an increase in the Federal Funds rate leads to higher bank profits, which in turn feed into the equity capital base, as banks find it optimal to shore up capital to deflect future financing costs by not paying out all of their profits to shareholders.

To understand more fully the dynamic response of bank lending to monetary policy shocks, in Figure 7, we simulate the response of bank lending to a shock to the Federal Funds rate. The economy starts at time zero in an initial steady state with the Federal Funds rate equal to the inflection point of 1.1%. At time one, the Federal Funds rate either increases to 2% or decreases to 0.2%, and it stays at that level afterwards until the economy reaches a new steady state. Each variable in the graph is scaled by its level in the old steady state, that is, when the Federal Funds rate is 1.1%.

The top panel depicts the response to an increase in the Federal Funds rate. In this case, banks faces less competition from households' demand for cash in the deposit market. Thus, they can behave more like monopolists by charging higher spreads and cutting the amount of deposits. Lower deposit intake increases the banks' marginal cost of lending because when their lending exceeds their capital plus deposit intake, they must turn to the market for non-reservable borrowing, in which they face increasing marginal external financing costs. A positive shock to the Federal Funds rate also increases the cost of capital in corporate sector, making firms more likely to switch to the outside option of not borrowing. Both effects shrink the amount of lending. Because deposits have shorter duration than loans, deposits drop sharply and converge almost instantaneously to the new steady state. Non-reservable borrowing increases to fill the gap between deposits and loans. In contrast, loan quantity converges slowly as the bank only replaces a fraction, μ, of its long-term loans each period. Note that there is only slight increase in banks' equity capital, which is the joint effect of two competing forces. On one hand, banks' equity takes a hit with a positive shock to the

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Federal Funds rate because of the maturity mismatch on their balance sheets; on the other hand, higher Federal Funds rate also enables banks to charge higher monopolistic profits on the deposit market; the two effects largely cancel out each other, leading to a relatively stable level of bank capital.

The bottom panel depicts the response to a decrease in the Federal Funds rate. As it approaches the zero lower bound, banks face increasingly intense competition from cash in the deposit market. As a result, the spread that banks can charge in the deposit market is squeezed, leading to a sharp drop in banks' profits. Given the high persistence in the Federal Funds rate, this lower profit translates into slower retained earnings accumulation over time and leads to decreased bank capital. In the new steady state, banks take large deposits in the deposit market, which can support increased lending. However, banks cannot lend more because their capital requirements tighten in the extremely low Federal Funds rate environment. Because total lending decreases, the banks face less of a need to seek external financing, and they use less non-reservable borrowing.

It is interesting to note that in the two graphs in Figure 7, the loan amount decreases when the Federal Funds rate changes in either direction. Although the loan amount moves in the same direction, the driving force is different in the two cases. When the Federal Funds rate increases, loans fall because higher spreads in the deposit market discourage households from making deposits. Banks turn to non-reservable borrowing to fund loans, and because of increasing costs in this market, the amount of lending is highly dependent on the quantity of deposits. Instead, when the Federal Funds rate decreases, the loan amount decreases because of the binding capital requirement, which in turn echoes changes in the banks' profit accumulation. The distinct driving forces underlying the above two plots are also reflected by the differential trends in banks' deposit quantity and non-reservable borrowing.

We obtain external validation of the reversal rate prediction from a reduced-form regression. Specifically, we examine the relation between bank equity returns and monetary policy news on Federal Open Market Committee (FOMC) meeting days. We use daily changes

in the one-year Treasury yield on FOMC meeting days to measure monetary policy news released by the FOMC meetings following Hanson and Stein (2015). The advantage of examining the one-year Treasury yield instead of the Federal Funds rate is that the former captures the effects of "forward guidance" in the FOMC announcement, which has become increasingly important in recent years (Hanson and Stein 2015).[22] The identifying assumption is that unexpected changes in interest rates in a one-day window surrounding scheduled Federal Reserve announcements largely arise from news about monetary policy because macroeconomic fundamentals would not change discretely within such a short window. While our sample period runs from 1994 to 2017, we exclude the burst of dot-com bubble (2000–2001) and the subprime financial crisis (2007–2009) because in these crisis times, monetary policy can be strongly influenced by the stock market rather than by inflation or economic growth (Cieslak and Vissing-Jorgensen 2017).

Table 7 reports the regression estimates. We split our sample into low and high interest environment based on Federal Funds rates using 1% as the cutoff. As shown in column 1, if the Federal Funds rate is above 1%, an increase in short-term interest rates reduces bank equity value. However, this conventional negative relation reverses sign when the starting level of the Federal Funds rate is below 1%. As shown in column 2, an increase in the short-term interest rate is associated with positive significant returns for bank equity. In other words, the market expects that an increase in interest rates leads to an increase in bank capital. This result is not driven by a steepening of the term structure, as we control for the change in the spread between five-year and the 1-year Treasury yield. In Columns 3 and 4 of Table 7, we interact the change in the interest rate with a reduced-form measure of deposit market power, the Herfindahl-Hirschman index (HHI) of the local deposit market in which the bank operates, where we define a local deposit market as a county. If a bank operates in several counties, the bank-level HHI is the weighted average of local HHIs, weighted by the deposits of the bank in each county. We find that when the Federal Funds rate is below 1%,

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[22]We also use two-year Treasury yield and the results are robust.

banks with greater market power in the deposit market experienced larger positive returns. In summary, we find that monetary policy has a nonmonotonic effect on bank capital. When the Federal Funds rate is high, the relation between the short-term rates and bank capital seems to be negative, but when the Federal Funds rate is low, this relation becomes positive. To the best of our knowledge, this paper is the first to document this empirical fact.

Our finding suggest that ultra-low interest rate policy may lower lending growth because it depresses banks' profitability and slows down bank capital accumulation. This result is related to Heider, Saidi, and Schepens (2018), which shows that the introduction of negative policy rates by the European Central Bank in mid-2014 leads to less lending by euro-area banks with greater reliance on deposit funding. Our result shows that such perverse effects can occur even when the rates are positive because banks' deposit spreads are compressed by the low rate environment.

Our result also sheds light on the sluggish bank lending recovery in the U.S. after the recent crisis. As shown in Figure 8, bank lending in the recent recovery has grown at a slower pace than in all previous recoveries since the 1960s. By the end of 2018, bank lending had increased only about 25% cumulatively from its level in August 2009, the month when the recovery started. Although many factors such as tightening banking regulation may contribute to this slow recovery, the ultra-low rate policy could be an important factor because it may unintentionally reduce bank profitability, which slows down bank capital accumulation and constrain banks' capacity to lend.

6.3 Heterogeneous Transmission across Banks

Next, we examine heterogeneity in monetary transmission across large and small banks, motivated by the finding in Kashyap and Stein (1995) that the impact of monetary policy on lending is stronger for small banks. They suggest that small banks cannot replace deposits with frictionless access to wholesale funding, so shocks to deposits from monetary tightening are more likely to be transmitted to the supply loans from small banks. However, one

limitation of the data used in Kashyap and Stein (1995) is the absence of a measure of the actual cost of external financing. While they proxy for this cost with the size of the bank, size is correlated with many other bank attributes, whose presence compromises the interpretation of their results. For instance, small banks tend to lend to small firms, whose credit demand is more cyclical. Therefore, the larger sensitivity of smaller bank lending is driven by the demand side rather than the financing friction in the supply side.

We can use our dynamic model to shed light on this issue via subsample estimation, where we split our sample at 10th percentile of bank size distribution, estimating a subset of the model parameters separately for the large and small banks. For these estimations, we fix the parameters that govern the preference of the household and the macroeconomic conditions. We also fix the discount rate for banks.[23] We re-estimate the remaining parameters that govern banks' operating efficiency and financing frictions.

The results are in Table 8. We find that besides a slight smaller cost to attract deposits, there are two notable difference between large and small banks—their external financing costs and the fixed operating cost. This result is particularly interesting because we do not use bank size in our vector of identifying moments. Instead, the external financing cost is identified from the fraction of assets financed by nonreservables; the fixed operating cost is identified from the banks' net non-interest expense and leverage ratio. These two differences jointly imply that loans issued by small banks are 35% more sensitive to the Federal Funds rate (the sensitivity is -2.10 among smaller banks and -1.36 among larger banks). Next, we decompose the two frictions, we find that the difference in external financing cost explain 76% of the heterogeneity in monetary transmission. Reducing the quadratic financing cost among small banks to 0.004 will decrease the loan-to-Federal Funds rate sensitivity to -1.535 among these banks. Because we allow only four parameters to differ for the large and small banks, we are effectively hold loan demand constant, thus isolating the effect of financial frictions.

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[23]This is because a relatively small fraction of the small banks have dividend records, which prevents us from identifying these banks' discount rate using their dividend yields. Because most small banks are not publicly listed, we also cannot calculate their market-to-book ratio.

This result is consistent with the hypothesis proposed by Kashyap and Stein (1995) that large and small banks differ significantly in the dimension of external financing costs, and that this difference leads to heterogeneous transmission of monetary policy to credit supply. In addition, the variation in fixed operating cost explains the remaining variation in monetary transmission. Small banks have relatively limited sources of earning non-interest incomes, which translates into a higher net operating cost and slower accumulation of equity buffer. As a result, when the Fed adjusts the interest rate, the shocks to bank net worth as a result of the maturity mismatch will influence the small banks more, which also leads to a stronger reaction in their ability to extend loans.

6.4 The Impact of Monetary Policy on Bank Lending over Time

In this section, we examine the impact of monetary policy on bank lending over time. Over the past few decades, we have witnessed substantial changes in both the macroeconomic environment and the banking industry structure over time. The average interest rate has declined substantially, which may affect banks' profitability. The banking industry itself has experienced a large volume of mergers, leading to increased concentration but a potentially higher operating efficiency.

To understand how the effect of monetary policy on bank lending has changed over time, we split our sample into two sub-periods—early (1994-2005) and late (2006-2017). We reestimate all models parameters using data in the two sub-periods following the same strategy described in Section 5.1. The estimation results are reported in Tables 9 and 10. With the estimated parameters, our model shows that the impact of aggregate bank lending to a 1% Federal Funds rate cut has declined from 2.17% in the early sample period to 1.44% in the late sample period. This result is consistent with the existing evidence in the literature that monetary policy seems to have more muted effect on real activity and inflation in recent decades (Boivin, Kiley, and Mishkin 2010).

What factors have been driving the declining impact of monetary policy on bank lending?

The first important factor is the changing macroeconomic environment. The average Federal Funds rate has decreased from 3.50% to 0.34% from the early sample period to late period. This means that in the late period the economy spends more time around the reversal rate region, where monetary policy has a weaker, or even opposite effect on bank lending decisions. Indeed, if we use the Federal Funds rate process from the early period, the gap between the monetary policy impact in early and late periods narrows by 58%.

The second important factor is bank market power. In our model, banks' market power is governed by the number of competing banks in the local market, $\hat{J}$, and the rate sensitivities that banks are facing in the deposit and loan markets, α^d and α^l. Overtime, the market concentration of banks has increased: the number of competing banks in the local market has decreased from 7 to 5, which increases banks' market power. However, at the same time depositors and borrowers also become more rate-sensitive, which decreases banks' market power. To We eliminate the difference in bank market power across the two subsamples by setting the late period values to be same as the early period. Doing so reduce the gap in monetary transmission by 18%.

The third important factor is banks' operating and external financing costs. As banks merge into bigger ones, their fixed operating cost has gone down substantially. This lowers their operating leverage, which consequently reduces their exposure to monetary policy. Furthermore, banks' costs to access the wholesale funding market has declined, which allows them to better cushion the loss of deposits. If we eliminate the difference in bank operating and financing costs, the gap in monetary policy further narrows by 24%.

7. Robustness

In this section, we examine the implications of several ingredients that we leave out in the baseline model but are nevertheless important for describing bank behaviors in reality.

First, instead of requiring dividends to be positive, we allow them to be negative, subject

to a linear equity issuance cost, ϕ^e. We re-estimate our model, with the parameter ϕ^e being identified by an additional moment—the ratio of bank equity issuance to total asset. In the data, this moment is 2%; in our model, we find that an equity issuance cost of 10% would yield a predicted equity issuance rate that matches what we observe in the data. The value is comparable to that among industrial firms (Hennessy and Whited 2007). Second, we introduce time varying discount rates. More specifically, we assume that banks apply a discount rate of $f + \omega$. In the absence of any intertemporal frictions, banks will discount using the Federal Funds rate, which implies that $\omega = 0$. In our estimation, we identify ω from banks' dividend yields, the same moment that we have previously used to identify the constant discount factor in our baseline model. Our results suggest that $\omega = 1.6\%$. Similar to the baseline estimates, this result indicates that banks do face substantial frictions in their maturity transformation activity. Our results concerning the decomposition of monetary transmission and reversal rate are robust to these alternative model specifications.

Another concern is that our model is set up in a risk-neutral world, while in reality, loan spread contains a risk premium component. To make the model and data moment comparable, we adjust the data moment by subtracting a risk premium. We calibrate the risk premium following Giesecke, Longstaff, Schaefer, and Strebulaev (2011), who show that credit risk premium in the bond market roughly equals to the expected default loss. After adjusting the data moment, we re-estimate the model. Our results suggest that the only notable difference lies in banks' estimated cost of serving loans, which becomes insignificantly different from zero. This result suggests that banks' perceived cost on the loan market is almost entirely driven by the default risk. Other than that, banks face zero marginal cost to extend one additional unit of credit. We verify that our main predictions stay robust under this re-estimation.

8. Conclusion

The U.S. banking sector has experienced an enormous amount of consolidation. The market share of the top five banks has increased from less than 15% in the 1990s to over 45% as of 2017. This consolidation begs the question of whether bank market power has a quantitatively important effect on the transmission of monetary policy. We study this question by formulating and estimating a dynamic banking model with regulatory constraints, financial frictions, and imperfect competition. This unified framework is useful because it allows us to gauge the relative importance of different monetary policy transmission channels.

In our counterfactuals, we show that the channel related to reserve requirements has minor quantitative importance. In contrast, we find that channels related to bank capital requirements and to market power are very important. We also find an interesting interaction between the market power channel and the bank capital channel. If the Federal Funds rate is low, depressing it further can actually contract bank lending, as the drop in bank profits in the deposit market has a negative impact on bank capital. Lastly, we show that accounting for bank market power and its interaction with regulatory constraints is key to understand the cross-sectional and time series variation in monetary transmission.

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Table 1: Summary Statistics

	mean	sd	p10	p25	p50	p75	p90
Deposit Share	0.086	0.535	0.004	0.005	0.010	0.024	0.088
Loan Share	0.028	0.160	0.001	0.001	0.002	0.006	0.027
Deposit Rates	1.774	1.275	0.117	0.562	1.667	2.883	3.546
Loan Rates	6.521	1.629	4.416	5.269	6.383	7.813	8.682
No. of Branches	80.963	342.600	12.000	14.000	20.000	40.000	115.000
No. of Employees per Branch	17.443	16.131	9.063	11.015	13.905	18.571	26.533
Expenses of Fixed Assets	0.458	0.153	0.271	0.342	0.437	0.564	0.729
Salary	1.683	0.451	1.065	1.343	1.634	1.990	2.493

This table reports summary statistics of the sample for BLP estimation. The sample period is from 1994 to 2017. The total size of the deposit market is defined as the sum of deposits, cash, and Treasury bills held by all the U.S. households. The total size of the loan market is defined as the sum of U.S. corporate and household debt. Deposit and loan rates are imputed using the interest expense and income from Call report. Expense of fixed assets and salary are scaled by total assets. Deposit share, loan share, deposit rates, loan rates, expense of fixed assets and salary are reported in percentage. The data is from Call report and FDIC Summary of Deposits.

Table 2: Bank Balance Sheet

Assets		Liabilities	
Existing loans	L_t	Deposits	D_t
New loans	B_t	Non-reservable borrowings	N_t
Reserves	R_t	Equity	E_t
Government securities	G_t		
Total Assets	$L_t + B_t + R_t + G_t$	*Total Liabilities and Equity*	$D_t + N_t + E_t$

This table illustrates the balance sheet of a typical bank at the beginning of the period.

Statutory Parameters			
τ_c	Corporate tax rate	0.350	
θ	The reserve ratio	0.024	
κ	The capital ratio	0.060	
Parameters Estimated Separately			
μ	Average loan maturity	3.429	
$\bar{f}$	Log Federal Funds rate mean	0.297	
σ_f	Log Federal Funds rate variance	1.633	
ρ_f	Log Federal Funds rate persistence	0.901	
$\bar{\delta}$	Log loan chargeoffs mean	-1.357	
σ_δ	Log loan chargeoffs variance	1.194	
ρ_δ	Log loan chargeoffs persistence	0.602	
$\hat{J}$	Number of representative banks	6	
Parameters Estimated via BLP			
α^d	Depositors' sensitivity to deposit rates	0.968	[0.16]
σ_{α^d}	The dispersion of depositors' sensitivity to deposit rates	1.916	[0.44]
α^l	Borrowers' sensitivity to loan rates	-1.462	[0.16]
q_d^d	Convenience of holding deposits	3.446	[0.19]
q_c^d	Convenience of holding cash	1.985	[0.16]
q_l^l	Convenience of borrowing through loans	1.151	[0.59]
Parameters Estimated via SMM			
γ	Banks' discount rate	0.045	[0.0219]
W/K	Relative size of the deposit market	0.217	[0.0461]
q_n^l	Value of firms' outside option	-9.641	[1.6006]
ϕ^N	Quadratic cost of non-reservable borrowing	0.006	[0.0004]
ϕ^d	Bank's cost of taking deposits	0.009	[0.0005]
ϕ^l	Bank's cost of servicing loans	0.007	[0.0007]
ψ	Net fixed operating cost	0.016	[0.0021]

This table reports the model parameter estimates. Panel A presents results for parameters that represent statutory rates. Panel B presents results from parameters that can be calculated as simple averages or by simple regression methods. Panel C presents results from parameters estimated via BLP. Panel D presents results from parameters estimated via SMM.

Table 4: Moment Conditions

	Actual Moment	Simulated Moment	T-stat
Dividend yield	3.38%	3.30%	-0.473
Non-reservable borrowing share	29.9%	26.2%	-0.177
Std of non-reservable borrowing	20.4%	16.3%	-1.175
Deposit spread	1.29%	1.28%	-0.184
Loan spread	2.81%	2.77%	-0.449
Deposit-to-asset ratio	0.699	0.751	1.401
Net noninterest expense	1.23%	1.21%	-0.203
Leverage	11.20	11.73	0.888
Market-to-book ratio	2.061	1.776	-1.511
Corporate borrowing-FFR sensitivity	-1.062	-1.044	0.028

This table reports the moment conditions in the simulated method of moment (SMM) estimation.

Table 5: Demand Estimation

	Deposit	Loan
Yield sensitivity (α)	0.800***	-0.904***
	[0.158]	[0.163]
Log number of branches (β_1)	0.868***	1.117***
	[0.009]	[0.000]
Log number of employees (β_2)	0.587***	0.694***
	[0.016]	[0.031]
Yield sensitivity dispersion (σ_α)	1.579***	
	[0.439]	
Sector F.E.	Y	Y
Time F.E.	Y	Y
Observations	15575	15575
Adj. Rsq	0.982	0.867

This table reports the estimated parameters of the deposit and loan demand. The first column reports parameters of deposit demand. The second column reports parameters of loan demand. Yield sensitivity (α) refers to the average sensitivity of the depositors (firms) to deposit rates (loan rates). Log No. of Branches (β_1) refers the sensitivity of the depositors (firms) to log number of branches that each bank has. Log No. of Employees (β_1) refers the sensitivity of the depositors (firms) to log number of employees per branch. Yield sensitivity (σ_α) refers to the dispersion in the sensitivity of the depositors to deposit rates (the dispersion is set to 0 for firms). The sample includes all the U.S. commercial banks from 1994 to 2017. The data sources are the Call report and the Summary of Deposits.

Table 6: Determinants of Monetary Policy Transmission

		Sensitivity of Loans to FFR ($\frac{\Delta \ln l}{\Delta f}$)	Contribution %
(1)	All frictions are present	-1.727%	/
(2)	− Reserve Regulation	-1.708%	1.1%
(3)	− Capital Regulation	-1.240%	28.20%
(4)	− Deposit Market Power	-1.109%	35.78%
(5)	− (2), (3), and (4)	-0.724%	58.08%
(6)	− Loan Market Power	-1.180%	-26.40%

This table depicts a series of counterfactual experiments in which we examine the effect of removing frictions from our model. The first column presents the friction which is removed from the model. The second column presents the sensitivity of loans to the Federal Funds rate (FFR) when the corresponding friction is removed. The third column presents the contribution of the corresponding friction.

Table 7: Monetary Policy Shocks and Bank Equity Returns on FOMC Days

	(1) High FFR	(2) Low FFR	(3) High FFR	(4) Low FFR
Policy Shock	-0.318	6.584**	-0.038	2.675
	[0.480]	[2.598]	[0.416]	[2.359]
HHI*Policy Shock			-0.058	0.509***
			[0.072]	[0.183]
Δ Term Spread	1.159	1.904*	1.194	1.854*
	[0.920]	[1.048]	[0.918]	[1.044]
Market Return	0.365***	0.866***	0.365***	0.862***
	[0.060]	[0.082]	[0.060]	[0.082]
Observations	36,454	24,608	36,454	24,608
Adj, R-squared	0.021	0.154	0.021	0.155

This table reports the estimates of the relation between bank equity returns and monetary policy shocks on FOMC Days. Monetary shocks are measured by the daily change in the one-year Treasury yield on FOMC days. HHI is the Herfindahl-Hirschman index of the local deposit market in which the bank operates. A local deposit market is defined as a county. If a bank operates in several counties, the bank-level HHI is the weighted average of local HHI, weighted by the deposits of the bank in each county. The sample includes all publicly traded U.S. banks from 1994 to 2017. We exclude observations during the burst of dot-com bubble (2000-2001) and the subprime financial crisis (2007-2009). The standard errors are clustered by time.

Table 8: Large versus Small Banks

Panel A: Moment conditions

	Large Banks			Small Banks		
	Actual	Simulated	t-stat	Actual	Simulated	t-stat
Dividends	3.30%	3.42%	-0.920	/	2.50%	/
Non-reservable borrowing share	35.4%	33.2%	-0.074	15.5%	13.1%	-0.114
Std of non-reservable borrowing	19.0%	15.2%	-0.770	17.2%	14.9%	-0.935
Deposit spread	1.32%	1.27%	-0.652	1.25%	1.24%	-0.184
Loan spread	2.81%	2.83%	0.159	2.67%	2.71%	0.449
Deposit-to-asset ratio	0.666	0.701	0.626	0.784	0.772	-0.303
Net noninterest expense	0.96%	1.01%	0.358	1.92%	1.64%	-2.835
Leverage	11.35	13.04	2.002	10.78	11.06	0.469
Market-to-book ratio	2.061	2.311	2.740	/	1.706	/
Corporate borrowing-FFR sensitivity	-1.062	-1.044	0.279	-1.062	-1.044	0.279

Panel B: Parameter Estimates

	ϕ^N	ϕ^d	ϕ^l	ψ	Sensitivity of Loans to FFR ($\frac{\Delta \ln l}{\Delta f}$)
Large Banks	0.004	0.009	0.005	0.002	-1.360
Small Banks	0.010	0.008	0.005	0.029	-2.102

This table presents the parameter estimates and the sensitivity of loans to the Federal Funds rate (FFR) in subsamples of large and small banks. ϕ^d and ϕ^l are banks' marginal costs of intaking deposits and servicing loans, respectively, and ϕ^N is the quadratic cost of borrowing non-reservables. The last column reports the sensitivity of loans to the Federal Funds rate, which is a measure of monetary policy transmission. Standard errors clustered at the firm level are in parentheses under the parameter estimates.

Table 9: Subsample Estimates: Early

	Statutory Parameters	
τ_c	Corporate tax rate	0.350
θ	The reserve ratio	0.028
κ	The capital ratio	0.060
	Parameters Estimated Separately	
μ	Average loan maturity	3.178
$\bar{f}$	Log Federal Funds rate mean	1.254
σ_f	Log Federal Funds rate variance	0.632
ρ_f	Log Federal Funds rate persistence	0.692
$\bar{\delta}$	Log loan chargeoffs mean	-1.427
σ_δ	Log loan chargeoffs variance	1.090
ρ_δ	Log loan chargeoffs persistence	0.574
$\hat{J}$	Number of representative banks	7
	Parameters Estimated via BLP	
α^d	Depositors' sensitivity to deposit rates	-0.743
σ_{α^d}	The dispersion of depositors' sensitivity to deposit rates	1.467
α^l	Borrowers' sensitivity to loan rates	-1.017
q_d^d	Convenience of holding deposits	3.465
q_c^d	Convenience of holding cash	2.763
q_l^l	Convenience of borrowing through loans	-0.016
	Parameters Estimated via SMM	
γ	Banks' discount rate	0.046
W/K	Relative size of the deposit market	0.217
q_n^l	Value of firms' outside option	-7.273
ϕ^N	Quadratic cost of non-reservable borrowing	0.006
ϕ^d	Bank's cost of taking deposits	0.009
ϕ^l	Bank's cost of servicing loans	0.005
ψ	Net fixed operating cost	0.030

This table reports the model parameter estimates for the early subsample (1994–2005). Panel A presents results for parameters that represent statutory rates. Panel B presents results from parameters that can be calculated as simple averages or by simple regression methods. Panel C presents results from parameters estimated via BLP. Panel D presents results from parameters estimated via SMM.

Table 10: Subsample Estimates: Late

	Statutory Parameters	
τ_c	Corporate tax rate	0.350
θ	The reserve ratio	0.022
κ	The capital ratio	0.060
	Parameters Estimated Separately	
μ	Average loan maturity	3.195
$\bar{f}$	Log Federal Funds rate mean	-1.080
σ_f	Log Federal Funds rate variance	1.486
ρ_f	Log Federal Funds rate persistence	0.623
$\bar{\delta}$	Log loan chargeoffs mean	-1.221
σ_δ	Log loan chargeoffs variance	1.352
ρ_δ	Log loan chargeoffs persistence	0.723
$\hat{J}$	Number of representative banks	5
	Parameters Estimated via BLP	
α^d	Depositors' sensitivity to deposit rates	-0.925
σ_{α^d}	The dispersion of depositors' sensitivity to deposit rates	1.830
α^l	Borrowers' sensitivity to loan rates	-1.454
q_d^d	Convenience of holding deposits	2.324
q_c^d	Convenience of holding cash	-0.446
q_l^l	Convenience of borrowing through loans	1.804
	Parameters Estimated via SMM	
γ	Banks' discount rate	0.045
W/K	Relative size of the deposit market	0.283
q_n^l	Value of firms' outside option	-7.829
ϕ^N	Quadratic cost of non-reservable borrowing	0.005
ϕ^d	Bank's cost of taking deposits	0.009
ϕ^l	Bank's cost of servicing loans	0.008
ψ	Net fixed operating cost	0.006

This table reports the model parameter estimates for the late subsample (2006–2017). Panel A presents results for parameters that represent statutory rates. Panel B presents results from parameters that can be calculated as simple averages or by simple regression methods. Panel C presents results from parameters estimated via BLP. Panel D presents results from parameters estimated via SMM.

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Panel A: Deposit Spread

kernel = epanechnikov, degree = 0, bandwidth = .66, pwidth = 1

Panel B: Loan Spread

kernel = epanechnikov, degree = 0, bandwidth = .61, pwidth = .92
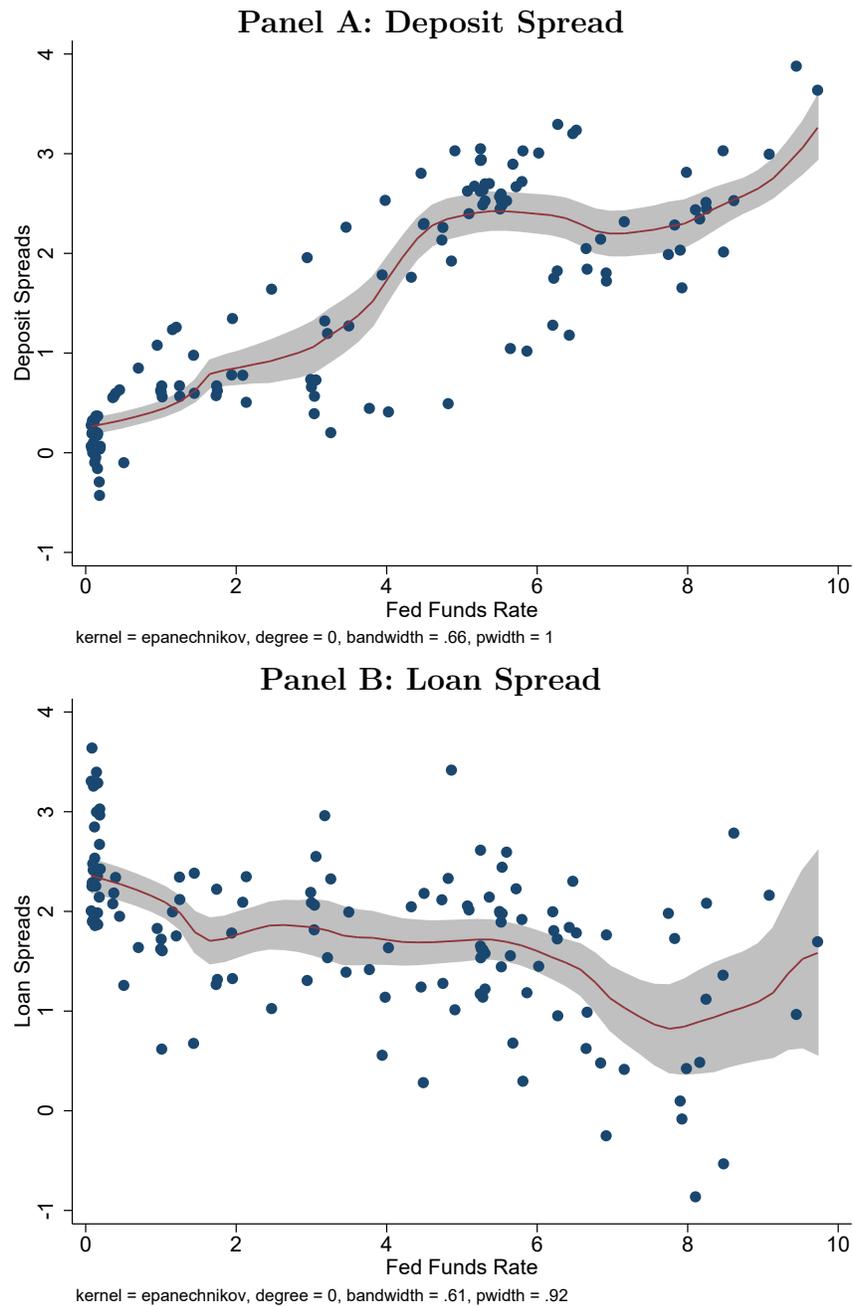
Figure 1: Deposit Spread, Loan Spread, and the Federal Funds Rate

This figure plots the non-parametric relationship between the Federal Funds rate and the average deposit spread and loan spread of U.S. banks. The sample is from 1985 to 2017. The data frequency is quarterly. The deposit spread and loan spread are constructed using the Call report and the Federal Funds rate is retrieved from FRED database of the Federal Reserve Bank of St. Louis.

Cash   Not Borrowing

Households —Deposits→ **Banks** —Loans→ **Firms**

Bond market
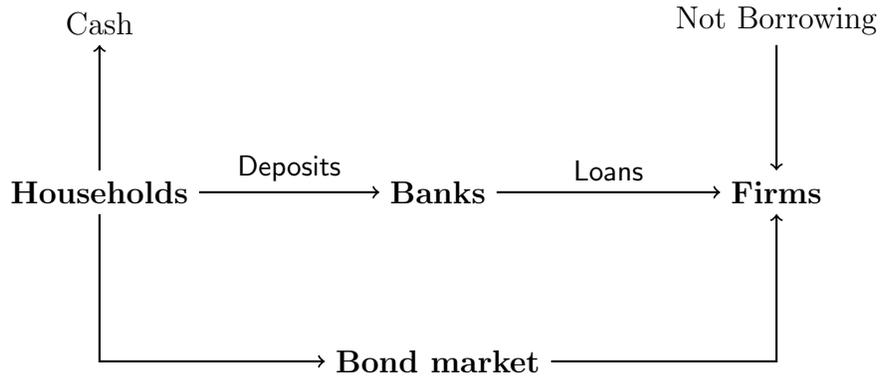
Figure 2: Flow of Funds in the Model

Fed Funds rate f_t Banks set deposit rates $r_{i,t}^d$

Charge-offs $\delta_{i,t}$ loan rates $r_{i,t}^l$ Households

μ fraction of loan matures

choose $D(r_{i,t}^d)$

Firms
choose $B(r_{i,t}^l)$

Banks collect profits
distribute dividends

Banks adjust reserve
government securities
non-reservables

...

t $t+1$
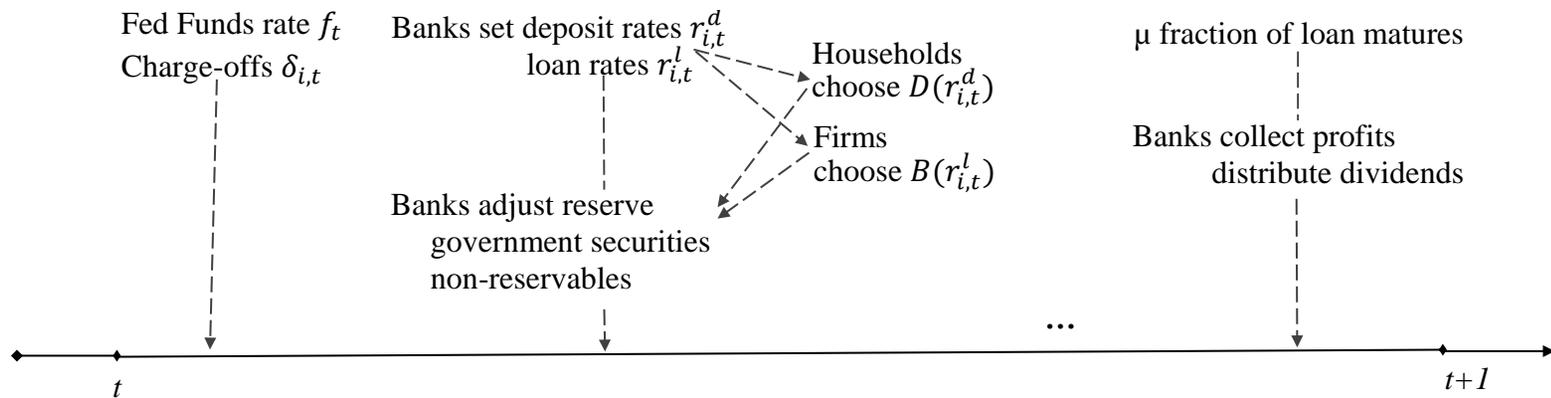
Figure 3: Timeline within a Period
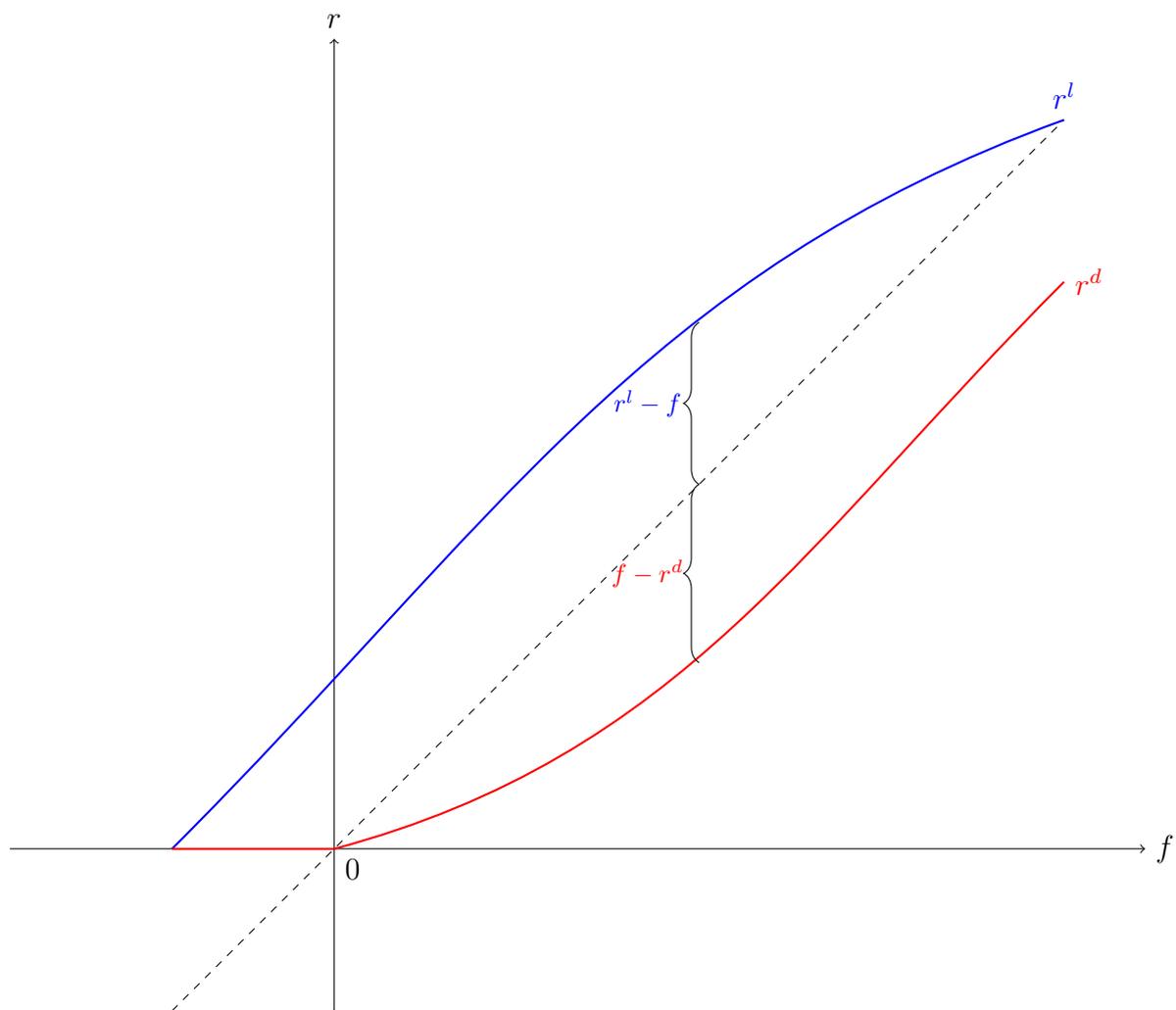
Figure 4: Relationship Between Deposit Rate, Loan Rate, and the Federal Funds Rate
This figure illustrates the relationship between deposit rate, loan rate, and the Federal Funds rate. The Federal Funds rate is on the x-axis; bank deposit rate and lending rate are on the y-axis.
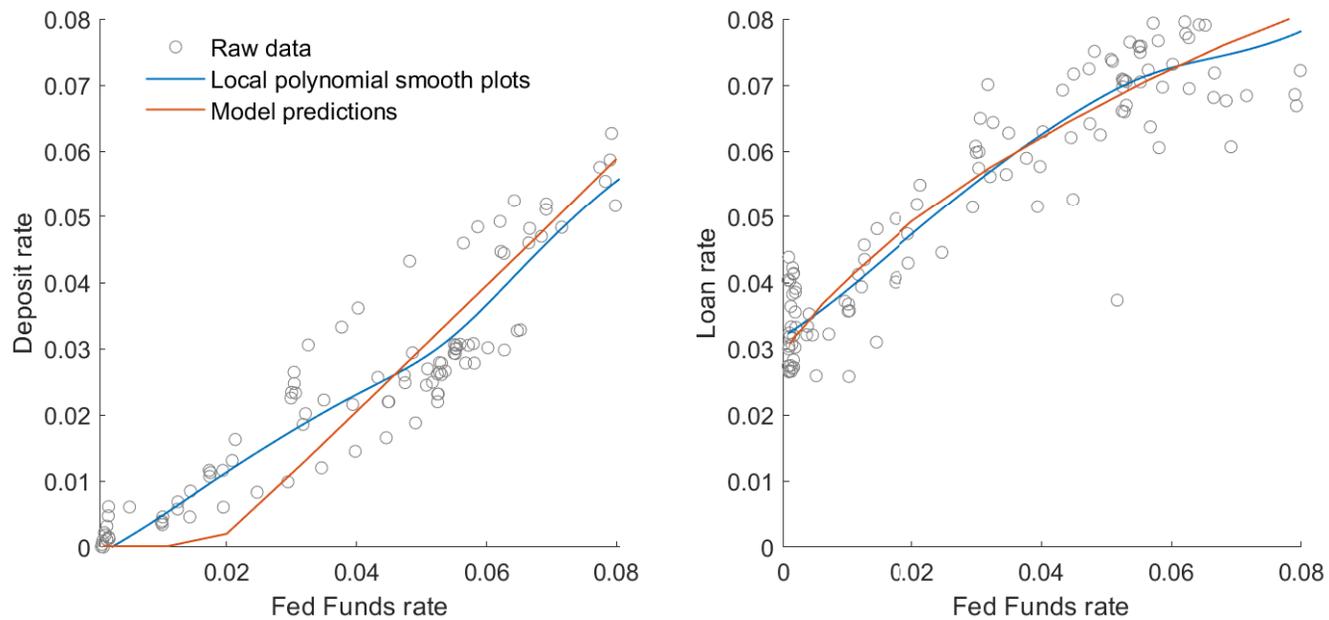
Figure 5: Model Predicted versus Actual Rates

This figure illustrates how banks' deposit and loan rates behave as functions of the Fed Funds rate. The grey circles represent the raw data from 1984 to 2017, aggregated at the quarterly frequency; the blue line is the local polynomial smooth plots based on the raw, and the red lines are the relationship predicted using the model.
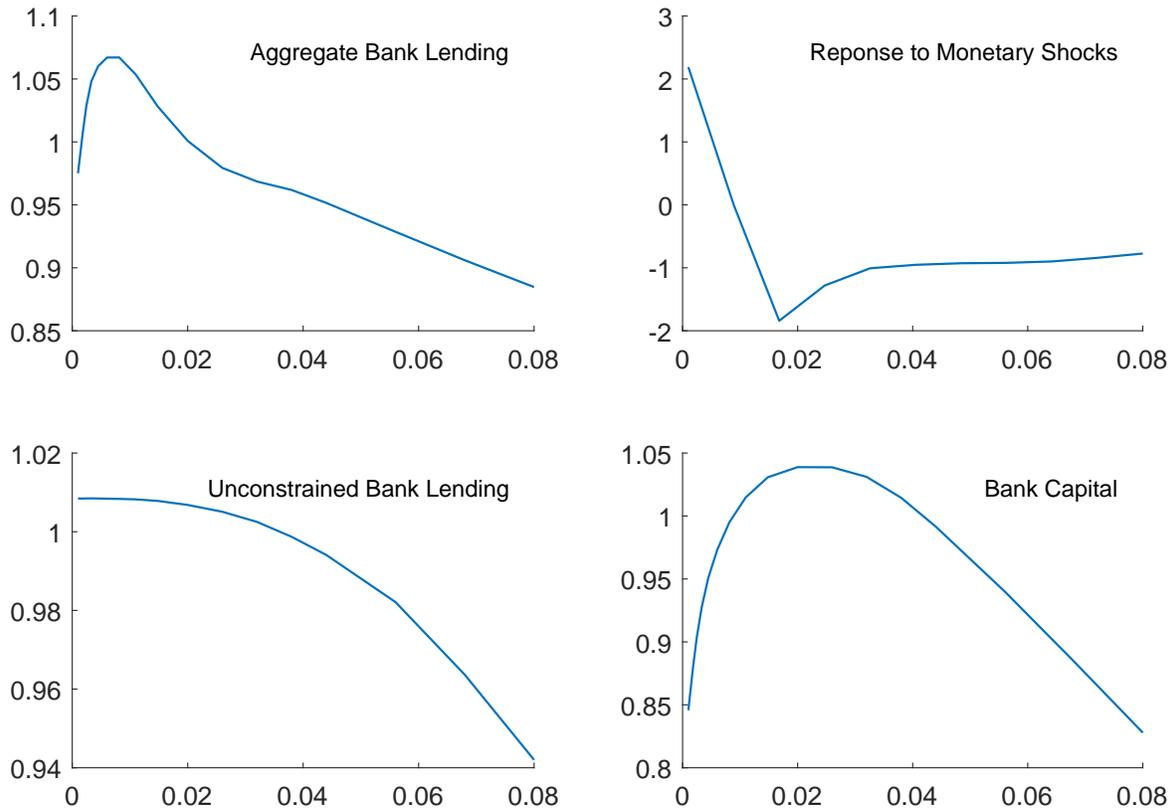
Figure 6: Bank Capital, Bank Lending, and Federal Funds Rate

This figure illustrates how bank capital and optimal lending vary with the Federal Funds rate. Banks' optimal lending is calculated under two alternative cases: the baseline line where banks are subject to the capital regulation and an alternative unconstrained case where the capital regulation is removed. The Federal Funds rate is on the x-axis; bank characteristics, scaled by their respective steady state values (when the Fed funds rate is 1.1%), is on the y-axis.
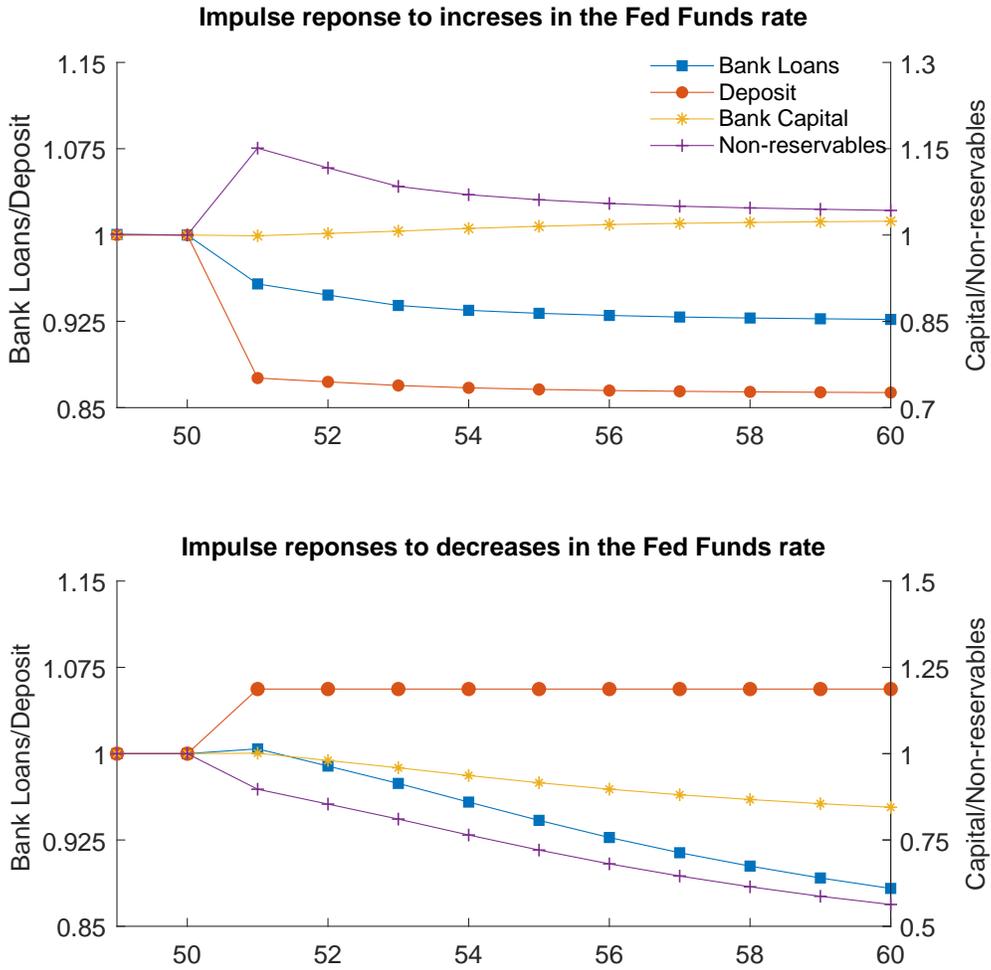
Figure 7: Impulse Response to Federal Funds Rate Shocks
This figure illustrates banks' impulse response to Fed fund rate shocks. The economy starts at Year 0 when it is in the old steady state with the FFR equal to 1.1%; In Year 1, the FFR either increases to 2% or decreases to 0.2%, and it stays at that level afterwards until the economy reaches the new steady state. Each variable in the graph is scaled by the level in the old steady state (when FFR = 1.1%).
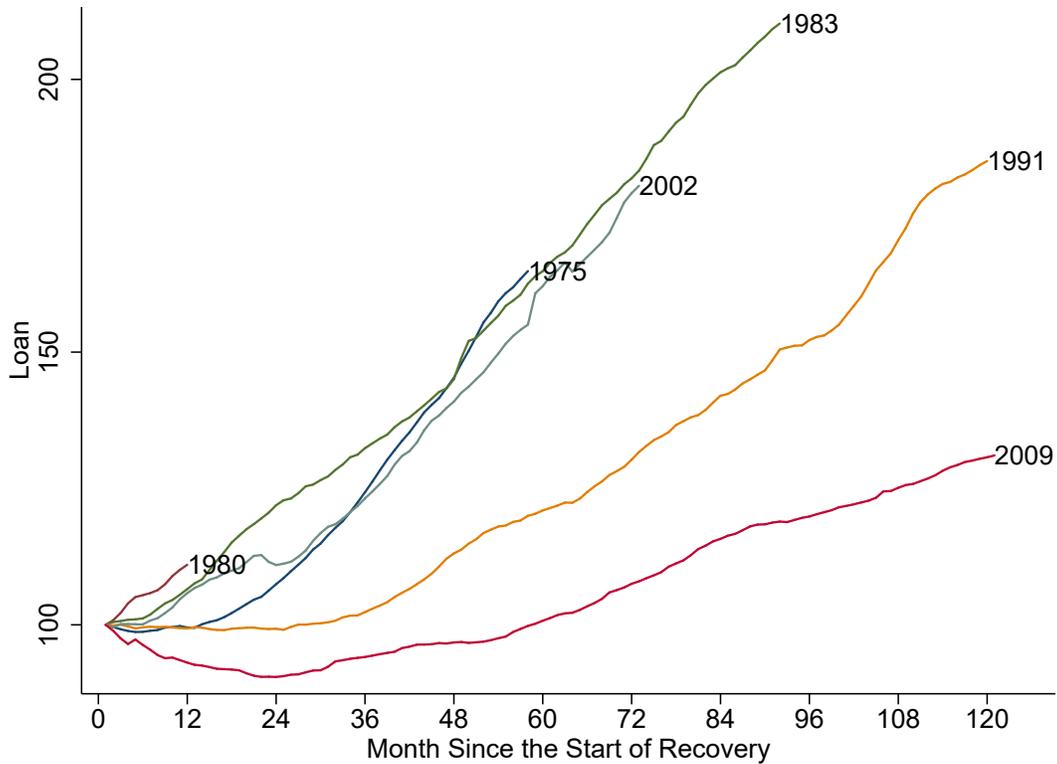
Figure 8: Bank Lending During Recoveries

This figure plots the amount of bank lending during recoveries since the 1960s. The horizontal axis is the month since the start of each recovery. The vertical axis is the amount of bank lending normalized by the level at the start of each recovery. The amount of bank lending and the recovery dates are retrieved from the FRED database of the Federal Reserve Bank of St. Louis.