Internet Appendix for "Bank Market Power and Monetary Policy Transmission: Evidence from a Structural Estimation"

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Abstract

This Internet Appendix provides additional information regarding the model solution and estimation results that supplements the main text. The content of the appendix is arranged as follows: Section I discusses the numerical solution. Section II provides proof to the properties of the static model which we present in Section F in the main text. Section III contains details of the demand estimation. Section IV reports results form the demand estimation using local market shares as the dependent variable. Section V describes how we measure banks' response to monetary policy shocks. Section VI and VII report additional estimation results on households' deposit and firms' loan demand using alternative instrumental variables. Section VIII presents additional analysis on monetary policy shocks and banks' equity returns. Section IX contains robustness check. Section X decomposes the monetary policy transmission following a different sequence from that in Section A, and finally, Section XI discusses the model implications by embedding the baseline model in a general equilibrium framework.

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I. Numerical Model Solution

In this appendix, we summarize the numerical methods used to solve the model. As a preliminary step, we discretize the state variable space. Our state space ($\mathbf{s}$) consists of four state variables: $\mathbf{s} \equiv \{f, \delta, L, E\}$, where f is the federal funds rate, δ is the annual loan charge-off rate, L is the amount of outstanding loans, and E is bank equity. We set the federal funds rate to be in the range of 0.1% to 8%, that is, $\underline{f} = 0.1\%$ and $\bar{f} = 8\%$. We set the boundaries for the loan charge-off rate, $\underline{\delta}$ and $\bar{\delta}$, at 0.1% and 3%, respectively. We set the upper bound for outstanding loans, $\bar{L}$, at $\bar{B}/\eta$, where $\bar{B}$ is the level of lending determined by equations (8) and (9) in the main text when all banks in the economy are unconstrained and price their loans at marginal cost, which is the sum of the federal funds rate, the marginal cost of servicing loans, and the expected default rate:

$$r^l = \bar{f} + \phi^l + \bar{\delta}.$$

We set the upper bound for bank equity, $\bar{E}$, at 10% of $\bar{L}$. We set the lower bounds of L and E to be small positive numbers.

Bank optimal policies are characterized by the set of choice variables, $\mathbf{p} \equiv (B(r^l), D(r^d), G, N, R, C)$, where $B(\cdot)$ is new loans issued, $D(\cdot)$ is deposits, G is government securities held, N is wholesale funding, R is reserves, and C is cash dividends. We first solve for $D(\cdot)$, taking $B(r^l)$ as given. Let D^* be the unconstrained optimal deposit intake in the static model that corresponds to the deposit rate

$$r^d = f - \phi^d - \frac{\partial r^d(D)}{\partial D}.$$

We then consider the following two cases. If $D^* \times (1-\theta) \geq L + B - E$, banks only hold deposits and government securities. Because external financing is costly, it is never profitable for them to issue nonreservables and hold government securities at the same time. We can verify that $D = D^*$ yields the highest possible profit for banks.

If $D^* \times (1-\theta) < L + B - E$, banks issue nonreservables subject to the linear-quadratic financing cost. At the same time, they also choose higher deposit intake to help close their funding shortage. Banks increase their deposits until the marginal cost of doing so (and thus deviating from the static optimum) equals the marginal cost of external financing. Banks' choice of deposits solves the equation

$$\frac{\partial D \times r^d(D)}{\partial D} - f + \phi^d = -\Phi^N \frac{N}{D}. \tag{IA.1}$$

After solving for $D(\cdot)$, we substitute it into equations (16), (17), (18), and (21) to obtain other firm policies: $\{G, N, R\}$. Our last step is to run a grid search over C and B to find the set of bank policies that yields the highest expected value. Finding the expected value for banks involves iterating on the value function, the details of which are as follows.

1. Because we have savers with heterogeneous sensitivities to deposit rates, α_i^d, we approximate savers' rate sensitivities using a truncated uniform distribution, with mean α^d and standard deviation σ_{α^d}. We then discretize the domain of α_i^d using 10 equally spaced grid points.

2. We conjecture the loan rate, $r_0^l(f)$, and the vector equilibrium deposit rates, $\boldsymbol{r_0^d}(f)$, as functions of the federal funds rate.

3. We conjecture bank value, $V_0(f, \delta, E, L)$, as a function of the state variables.

4. For each set of (f, δ, E, L), we search for the bank's optimal policy ($\mathbf{p}$) using the algorithm described above, and we update the bank's Bellman equation using equation (24) in the main text, which yields the updated value function for the bank, $V_1(f, \delta, E, L)$.

5. We repeat Steps 2 to 3 until the initial and the updated value functions, $V_0(f, \delta, E, L)$ and $V_1(f, \delta, E, L)$, converge.

6. Taking the policy calculated in Step 3, and using the law of motion for the aggregate and idiosyncratic shocks described in equation (22), we can simulate a panel of banks, denoting the simulated deposit and loan rates by $r_t^{d,j}$ and $r_t^{l,j}$, respectively, where j indexes the bank and t indexes time. We use simulated data to calculate the aggregate average deposit rates and loan rates, $\boldsymbol{r_1^d}(f)$ and $r_1^l(f)$, using equations (25) and (26) in the main text. Because we have heterogeneous savers, we need to forecast one average deposit rate for each of the 10 discretized α_i^d classes.

7. We repeat Steps 1 through 5 using the updated deposit and loan rates as the banks' conjectured equilibrium outcome. We keep iterating until the initial guess, $\boldsymbol{r_0^d}(f)$ and $r_0^l(f)$, is consistent with the actual equilibrium outcome, $\boldsymbol{r_1^d}(f)$ and $r_1^l(f)$, in the simulated data.

8. As the last step, we assess the goodness of fit of this algorithm. Using the simulated panel of banks constructed in Step 5, for each bank in each period we calculate the average deposit and loan rates offered by its competitors in the economy,

$$\exp(\alpha_i^d \bar{r}_{j,t}^{d,i} + \beta^d x^d + \xi^d) \equiv \frac{1}{\hat{J} - 1} \sum_{m \neq j} \Big[\exp(\alpha_i^d r_{m,t}^d + \beta^d x^d + \xi^d) \Big], \tag{IA.2}$$

and

$$\exp(\alpha^l \bar{r}^l_{j,t} + \beta^l x^l + \xi^l) \equiv \frac{1}{\hat{J}-1} \sum_{m \neq j} \Big[\exp(\alpha^l r^l_{m,t} + \beta^l x^l + \xi^l) \Big], \tag{IA.3}$$

where $\hat{J}$ is the number of banks we include in our simulation in a given period. Note that these rates, $\{\bar{r}^{d,i}_{j,t}, \bar{r}^l_{j,t}\}$ can differ across banks even within a given period because we exclude the bank's own rates when computing the averages. We then run a regression of $\{\bar{r}^{d,i}_{j,t}, \bar{r}^l_{j,t}\}$ on the banks' forecasted equilibrium rates, $\boldsymbol{r^d_1}(f)$ and $r^l_1(f)$, calculated in Step 6, and the R^2 for these regressions are reported in Section II.E of the main text.

II. Static Model Proofs

In this section, we prove the results presented in Section II.F.2 of the main text pertaining to the relations between the federal funds rate and loan and deposit spreads and quantities.

We start with the loan market, formalizing the relationship between the bank loan spread and the federal funds rate in equation (28). Taking partial derivatives of bank j's loan market share, s_j^l, as defined in equation (8), with respect to bank k's deposit rate, r_k^l (where $k \in 1, 2, ..., J$) and f, we obtain

$$\frac{\partial s_j^l}{\partial r_k^l} = \begin{cases} \alpha^l s_j^l (1 - s_j^l), & \text{if } j = k \\ -\alpha^l s_j^l s_k^l, & \text{if } j \neq k \end{cases} \tag{IA.4}$$

$$\frac{\partial s_j^l}{\partial f} = -\alpha^l s_j^l s_{J+1}^l, \tag{IA.5}$$

where s_{J+1}^l is the market share of borrowing from the bond market.

Taking the first-order condition of bank j's total profit in equation (27) with respect to its loan rate, r_j^l, we can characterize the bank's optimal loan rate as

$$r_j^l = f - \left(\frac{\partial \log B_j}{\partial r_j^l} \right)^{-1}. \tag{IA.6}$$

Bank j's loan demand (B_j) equals $K \times s_j^l$, where K is the number of firms in the economy. Using equation (IA.4), we can simplify equation (IA.6) to

$$r_j^l = f - \left(\frac{\partial \log s_j}{\partial r_j^l} \right)^{-1} = f - \frac{1}{\alpha^l \left(1 - s_j^l\right)}. \tag{IA.7}$$

Because all banks face identical problems, $s_j^l = S^l / J$. Thus, we can rearrange terms to give us equation (28). Next, we subtract f from both sides of equation (IA.7) and take the derivative with respect to the federal funds rate, f

$$\begin{aligned}\frac{d(r_j^l - f)}{df} &= -\frac{1}{\alpha^l \left(1 - s_j^l\right)^2} \times \frac{ds_j^l}{df} \\ &= -\frac{1}{\alpha^l \left(1 - s_j^l\right)^2} \times \left[\frac{\partial s_j^l}{\partial f} + \sum_{k=1}^{J} \frac{\partial s_j^l}{\partial r_k^l} \times \left(1 + \frac{d\left(r_k^l - f\right)}{df}\right)\right].\end{aligned} \tag{IA.8}$$

Substituting equations (IA.4) and (IA.5) into equation (IA.8), and with $\frac{d(r_j^l - f)}{df} = \frac{d(r_k^l - f)}{df}$, $\forall j, k = 1, 2, 3, \ldots, J$, we obtain

$$\frac{d(r_j^l - f)}{df} \times \left[(1 - s_j^l)^2 + s_j^l(1 - \sum_{k=1}^{J} s_k^l)\right] = -s_j^l(1 - \sum_{k=1}^{J} s_k^l - s_{J+1}^l). \tag{IA.9}$$

Rearranging terms and using $s_j^l = S^l/J$ gives us equation (30).

Next, in equation (IA.10), we turn to the relation between the quantity of loans and the federal funds rate. Using the results in equations (IA.8) and (IA.9), and using the fact that $B_j = s_j^l \times K$, we obtain

$$\frac{d \log B_j}{df} = \frac{d \log s_j^l}{df} = -\frac{\alpha^l \left(1 - s_j^l\right)^2}{s_j^l} \frac{d(r_j^l - f)}{df}. \tag{IA.10}$$

Rearranging terms and using $s_j^l = S^l/J$, we obtain equation (32).

Similar to the loan market, we next examine the relation between the deposit spread and the federal funds rate. We start by taking the partial derivative of bank j's deposit market share s_j^d, as defined in equation (3), with respect to bank k's deposit rate, r_k^l (where

$k \in 1, 2, \ldots, J$), and f to obtain

$$\frac{\partial s_j^d}{\partial r_j^d} = \begin{cases} \alpha^d s_j^d (1 - s_j^d), & \text{if } j = k \\ -\alpha^d s_j^d s_k^d, & \text{if } j \neq k \end{cases} \tag{IA.11}$$

$$\frac{\partial s_j^d}{\partial f} = -\alpha^d s_j^d s_{J+1}^d, \tag{IA.12}$$

where s_{J+1}^d is the market share of Treasury securities.

Taking the first-order condition of bank j's total profit in equation (27) with respect to its deposit rate, r_j^d, we can characterize the bank's optimal deposit rate as

$$r_j^d = f - \left(\frac{\partial \log D_j}{\partial r_j^d} \right)^{-1}. \tag{IA.13}$$

Note that the bank's deposit demand (D_j) equals $W \times s_j^d$, where W is the household wealth. Using equation (IA.11), we can simplify equation (IA.13) to

$$r_j^d = f - \left(\frac{\partial \log s_j}{\partial r_j^d} \right)^{-1} = f - \frac{1}{\alpha^d \left(1 - s_j^d\right)}. \tag{IA.14}$$

Rearranging terms and using $s_j^d = S^d/J$ gives us equation (29). Next, we subtract r_j^d on both sides of equation and take the derivative of equation (IA.14) with respect to the federal funds rate, f, to obtain

$$\begin{aligned} \frac{d(f - r_j^d)}{df} &= \frac{1}{\alpha^d \left(1 - s_j^d\right)^2} \times \frac{ds_j^d}{df} \\ &= \frac{1}{\alpha^d \left(1 - s_j^d\right)^2} \times \left[\frac{\partial s_j^d}{\partial f} + \sum_{k=1}^{J} \frac{\partial s_j^d}{\partial r_k^d} \times \left(1 - \frac{d\left(f - r_k^d\right)}{df} \right) \right]. \end{aligned} \tag{IA.15}$$

Substituting equations (IA.11) and (IA.12) into equation (IA.15), and with $\frac{d(f-s_j^d)}{df} = \frac{d(f-s_k^d)}{df}$, $\forall j, k = 1, 2, 3...J$, we can obtain

$$\frac{d(f - r_j^d)}{df} \times \left[(1 - s_j^d)^2 + s_j^d(1 - \sum_{k=1}^{J} s_k^d)\right] = s_j^d(1 - \sum_{k=1}^{J} s_k^d - s_{J+1}^d). \tag{IA.16}$$

Rearranging terms and using $s_j^d = S^d/J$ gives us equation (31), which describes how banks' deposit rates vary with the federal funds rate.

Finally, we examine the relationship between the quantity of deposits and the federal funds rate. Using the results in equations (IA.15) and (IA.16), we can obtain

$$\frac{d \log D_j}{df} = \frac{d \log s_j^d}{df} = \frac{\alpha^d \left(1 - s_j^d\right)^2}{s_j^d} \frac{d(f - r_j^d)}{df} > 0, \tag{IA.17}$$

which implies that the quantity of deposits rises with the federal funds rate, as depositors substitute out of cash and move proportionally into both deposits and treasuries.

III. Demand Estimation Details

In this appendix, we describe our demand estimation in detail. We start with a data definition. We combine the data from tiny local banks, which we define as banks with fewer than 10 domestic branches or with market shares less than 0.001%. This aggregation is useful because disaggregated data substantially slows down our demand estimation. It is also innocuous because these tiny banks have limited influence on the equilibrium. After combining tiny local banks, we have 753 banks on average in each year in our final sample.

Next, we describe deposit demand, which is characterized by the following preference parameters, $\Theta^d = \left(\alpha^d, \sigma^d_\alpha, \beta^d\right)$, where α^d and σ^d_α are the mean and standard deviation of the sensitivity to deposit rates, and the vector β^d contains the sensitivities to nonrate characteristics.

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

$$\hat{\Theta^d} = \arg\min_{\Theta^d} \xi\left(\Theta^d\right)' Z' W^{-1} Z \xi\left(\Theta^d\right), \tag{IA.18}$$

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

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 for the shocks, ξ^d, as

$$\xi^d\left(\Theta^d\right) = s^{-1}\left(s_0 | \sigma_{\alpha^d}\right) - \left(\alpha^d r^d_j + \beta^d x^d_j\right), \tag{IA.19}$$

where $s^{-1}(\cdot)$ is the inverse of the demand function specified by equation (3) in the main text.

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. For example, banks might lower deposit rates if they observe a positive demand shock. To identify the associated yield sensitivity, we use a set of supply shifters, c_j, as instrumental variables. Our particular supply shifters are salaries and noninterest expenses related to the use of fixed assets. These shifters have been used in previous studies, such as Dick (2008) and Ho and Ishii (2011). Our identifying assumption is that customers do not care about these costs, holding product characteristics constant. 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

$$Z = [x, c], \tag{IA.20}$$

where c is a vector of supply shifters including salaries and noninterest expenses related to the use of fixed assets, and x is a vector of nonrate bank characteristics including the number of branches, the number of employees per branch, bank fixed effects, and time fixed effects.

Using the demand parameters 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 SMD 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 a small number, $\hat{J}$, of ex ante symmetric representative banks. We calibrate the number of representative banks, $\hat{J}$, to match the average local banking concentration in the data, as measured by the HHI. 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 in the model close to what we observe in the data.

Because $\hat{J}$ is much smaller than the sample size of 753 banks, we need to adjust the quality value of the nonrate product characteristics for each of the $\hat{J}$ representative banks. We let q generically denote the utility from the nonrate product characteristics. These nonrate product characteristics include the number of branches, the number of employees per branch, bank fixed effects, and time fixed effects. We then choose a quality value, q, such that the sum of the exponential utility of the $\hat{J}$ symmetric banks is the same as that of $J = 753$ banks in the sample,

$$\hat{J}\exp(q) = \sum_{j=1}^{J} \exp\left(\hat{\beta}x_j + \hat{\xi}_j\right). \tag{IA.21}$$

Equation (IA.21) transforms the heterogeneous non-rate characteristics into symmetric quality values while preserving market concentration and the sum of exponential utility. We use (IA.21) to obtain the quality values for cash and the deposits at bank m, which are given by q_c^d and q_m^d, respectively. We normalize the quality value of Treasury bills to zero.

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

$$D_j(r_j^d|f) = \sum_{i=1}^{I} \mu_i^d \frac{\exp\left(\hat{\alpha}_i^d r_j^d + q_j^d\right)}{\exp\left(\hat{\alpha}_i^d f\right) + \exp\left(q_c^d\right) + \sum_{m=1}^{\hat{J}} \exp\left(\hat{\alpha}_i^d r_m^d + q_m^d\right)} W, \tag{IA.22}$$

where μ_i^d represents the fraction of each type, i, of depositors. Finally, we draw $\hat{\alpha}_i^d$ from a discretized uniform distribution with a mean of $\hat{\alpha}$ and a standard deviation of $\hat{\sigma}_\alpha$.

We estimate the loan demand function in a procedure that is similar to that used to estimate deposit demand except that we assume homogeneous sensitivity to loan rates, as we find that introducing heterogeneity in loan-rate sensitivity considerably slows down the estimation but has a limited impact on banks' rate-setting decisions. We include the same set of supply shifters and nonrate characteristics as in the deposit market but allow the sensitivities to these characteristics to differ from those in the deposit market.

As in the case of deposit demand, we can use equation (IA.21) to construct quality values for the absence of borrowing and for loans from bank m, which are given by q_n^l and q_m^l, respectively. We normalize the quality value of borrowing from the bond market to zero.

With the quality values in hand, we parameterize the loan demand functions as

$$B_j\left(r_j^l \middle| f\right) = \frac{\exp\left(\hat{\alpha}^l r_j^l + q_{lj}^l\right)}{\exp\left(\hat{\alpha}^l(\overline{f} + \overline{\delta})\right) + \exp\left(q_n^l\right) + \sum_{m=1}^{J} \exp\left(\hat{\alpha}^l r_m^l + q_m^l\right)} K, \tag{IA.23}$$

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. While this data limitation does not bias the demand parameters, as this term is absorbed by fixed effects, it poses an issue for the SMD part of our estimation because we need to plug the totality of equation (IA.23) into our dynamic model. Therefore, we relegate this parameter to our second-stage estimation.

IV. Demand Estimation Using Local Market Shares

In this Appendix, we check the robustness of the deposit demand estimation using a different level of aggregation. For the estimation of the demand parameters in Table 3 in the main text, market shares are defined at the U.S. national level. We now examine whether the assumption of a national market affects the estimated demand parameters. We discuss an alternative approach of using local deposit market shares and show that, both conceptually and practically, using local market shares should lead to similar results.

For illustration, we consider the simplest case of logit demand. In the context of logit demand, the demand estimation in the main text is equivalent to the regression

$$\ln s_{j,t} = \alpha r_{j,t} + \beta x_{j,t} + \xi_{j,t}, \tag{IA.24}$$

where $s_{j,t}$ is the market share of bank j in year t, $r_{j,t}$ is the deposit rate, $x_{j,t}$ represents other nonrate characteristics and α is the yield sensitivity for the average depositor in the national market.

Alternatively, we can estimate demand using a more disaggregate market definition. This is feasible for the deposit market because branch-level deposit data are available from the FDIC Summary of Deposits data. For instance, we can define the market as a county-year combination and estimate the regression

$$\ln s_{j,m,t} = \alpha r_{j,m,t} + \beta x_{j,m,t} + \xi_{j,m,t}, \tag{IA.25}$$

where $s_{j,m,t}$ is the market share of bank j in county m in year t, $r_{j,m,t}$ is the deposit rate, $x_{j,m,t}$ represents other nonrate characteristics, and α is the yield sensitivity of depositors.

Note that the yield sensitivity, α, estimated using disaggregate market shares has the same economic interpretation as that estimated using aggregate market shares. Both parameters measure the average yield sensitivities of depositors across all the local markets. Therefore, conceptually, these two methods should produce similar results.

Another way to understand the relation between these two levels of aggregation is to think about the estimation in two steps. First, we estimate yield sensitivity county by county. Second, we take a weighted average of the county-specific yield sensitivity to calculate the average yield sensitivity across all local markets. Again, this method is equivalent to imposing the restriction that α is the same across markets in a pooled regression.

Although the estimates from these two levels of aggregation are conceptually similar, it is nonetheless possible that these two methods could lead to quite different outcomes. To alleviate this concern, we re estimate the banks' deposit demand using market shares defined at the county level. The estimation results reported in Table IA.I are quantitatively similar to those in Table 3 in the main text. For instance, the estimated yield sensitivity is 0.903 with local market shares and 0.968 with national market shares.

Table IA.I
Demand Estimation: Local Deposit Market

This table reports the estimated deposit demand parameters using county-level market shares. Yield sensitivity refers to the average sensitivity of depositors to deposit rates. Log number of branches refers to the sensitivity of depositors to the log number of each bank's branches. Log number of employees refers the sensitivity of depositors to the log number of employees per branch. The sample includes all U.S. commercial banks from 1994 to 2017. The data are from the Call Reports and the Summary of Deposits.

	Deposit
Yield sensitivity	0.903***
	[0.199]
Log number of branches	0.509***
	[0.048]
Log number of employees	0.322***
	[0.021]
Bank F.E.	Yes
Year-Sector F.E.	Yes
Year-County F.E.	Yes
Observations	377,309
Adj. R^2	0.399

V. Impulse Responses to Monetary Policy Shocks

In this appendix, we describe the two types of impulse responses that we compute.

A. *Simple VARs*

First, we describe the impulse responses that we use as targeted moments in our simulated minimum distance estimation. Following Bernanke and Blinder (1992), we estimate the VAR

$$Y_t = \sum_{j=1}^{p} B_j Y_{t-j} + u_t, \tag{IA.26}$$

where Y_t is a vector of macroeconomic and bank variables—including the federal funds rate, the unemployment rate, log CPI, log bank loans, and log total credit—B_j is an autoregressive coefficient matrix, p is the number of lags, and u_t is a vector of reduced-form residuals with a covariance matrix $\Sigma_u = \mathbb{E}[u_t u_t']$. We define ϵ_t to be a vector of i.i.d. structural shocks with an identity covariance matrix. We can write u_t as a following function of structural shocks, $u_t = S\epsilon_t$. Under the assumption that the innovation in the federal funds rate affects real variables with lags, we can identify the coefficient matrix S via a Cholesky decomposition of the covariance matrix of the reduced-form residuals: $SS' = \Sigma_u$.

B. *VARs with high-frequency shocks*

Next, we describe the impulse responses that we use as external validity checks of the model. We use the local projections method of Jordà (2005) and high-frequency monetary shocks as external instruments from Gertler and Karadi (2015) to estimate the impulse response functions for both prices and quantities of bank loans and deposits. Formally, we estimate the panel specification

$$y_{i,t+h} = \beta_h \Delta f_t + \gamma_h' x_{i,t} + \eta_{i,h} + \epsilon_{i,t+h}, \tag{IA.27}$$

where $y_{i,t+h}$ is the dependent variable in quarter $t+h$, Δf_t is the change in the federal funds rate from the end of quarter $t-1$ to the end of quarter t, $\eta_{i,h}$ is horizon-specific bank fixed effects, and $x_{i,t}$ is a vector of control variables, which includes log assets, loans, securities, deposits, equity, borrowing, deposit spreads, loan spreads, the net interest margin, noninterest income, and noninterest expense as of the end of quarter t. As dependent variables, we consider deposit spreads, loan spreads, deposits, net non-interest expense, government securities, nonreservable borrowing, and assets.

We use the within-quarter unexpected monetary policy shocks constructed from changes in the federal funds futures price on FOMC announcement dates as instruments, following Gertler and Karadi (2015). We estimate the above specification for each forecast horizon $h = 1, 2, \ldots, H$ and cluster standard errors across banks and over time. The estimated coefficients $\hat{\beta}_h$, $h = 1, 2, \ldots, H$, trace out the response of the dependent variable over time.

VI. Demand Estimate Results Details

Table IA.II
Demand Estimation

In this table, we report the estimated deposit and loan demand parameters. The first column corresponds to the deposit demand parameter estimates. The second column contains the loan demand parameter estimates. Yield sensitivity (α) refers to the average sensitivity of depositors (borrowers) to deposit rates (loan rates). Log number of Branches (β_1) refers to the sensitivity of depositors (borrowers) to the log number of branches that each bank operates. Log number of Employees (β_1) refers to the sensitivity of depositors (borrowers) to the log number of employees per branch. Yield sensitivity (σ_α) refers to the dispersion in the sensitivity of depositors to deposit rates, with the dispersion set at zero for firms. The sample includes all U.S. commercial banks from 1994 to 2017. The data sources are the Call Reports and the FDIC Summary of Deposits.

	Deposit	Loan
Yield Sensitivity (α)	0.967***	-1.462***
	[0.140]	[0.332]
Log No. of Branches (β_1)	0.804***	0.948***
	[0.012]	[0.000]
Log No. of Employees (β_2)	0.714***	0.631***
	[0.015]	[0.028]
Yield Sensitivity Dispersion (σ_α)	0.553***	
	[0.116]	
Sector F.E.	Y	Y
Time F.E.	Y	Y
Observations	18062	18062
Adj. R^2	0.966	0.550

VII. Demand Estimation with Alternative Instruments

Table IA.III
Yield Sensitivity in the Deposit Market: Robustness

This table reports the estimated deposit demand parameters using alternative instruments. Column (1) uses local bank-teller wage data from the Bureau of Labor Statistics as an instrument, following Dick (2008). The instrument is the weighted average of the local bank teller wages over the markets in which the bank operates, where the weight is the bank's deposit share in each market relative to its total deposits. Column (2) uses bank salary expenses and bank fixed assets expenses as instruments. Column (3) uses all three instruments at the same time. The sample period is from 1997 to 2017. The data are from the Call Reports, the Summary of Deposits, and the Bureau of Labor Statistics.

	Local wage (1)	Bank expenses (2)	All (3)
Yield sensitivity	0.668**	0.687***	0.687***
	(0.282)	(0.028)	(0.028)
Log number of branches	0.769***	0.769***	0.769***
	(0.008)	(0.008)	(0.008)
Log number of employees	0.674***	0.674***	0.674***
	(0.013)	(0.013)	(0.013)
Bank F.E.	Yes	Yes	Yes
Year-Sector F.E.	Yes	Yes	Yes
Observations	11,394	11,394	11,394
Adj. R^2	0.970	0.969	0.969

Table IA.IV
Yield Sensitivity in the Loan Market: Robustness

This table reports the estimated loan demand parameters using alternative instruments. Column (1) uses local wage data from the Bureau of Labor Statistics as an instrument, following Dick (2008). The instrument is the weighted average of the local bank teller wages over the markets in which the bank operates, where the weight is the bank's deposit share in each market relative to its total deposits. Column (2) uses bank salary expenses and bank fixed assets expenses as instruments. Column (3) uses all three instruments at the same time. The sample period is from 1997 to 2017. The data are from the Call Reports, the Summary of Deposits, and the Bureau of Labor Statistics.

	Local wage	Bank expenses	All
	(1)	(2)	(3)
Yield sensitivity	-0.950	-1.149***	-1.134***
	(2.208)	(0.311)	(0.304)
Log number of branches	0.913***	0.935***	0.933***
	(0.234)	(0.039)	(0.038)
Log number of employees	0.652***	0.637***	0.638***
	(0.175)	(0.045)	(0.044)
Bank F.E.	Yes	Yes	Yes
Year-Sector F.E.	Yes	Yes	Yes
Observations	11,394	11,394	11,394
Adj. R^2	0.840	0.772	0.777

VIII. Additional Analysis of Monetary Policy Shocks and Bank Equity Returns

In this appendix, we provide additional evidence on the relation between monetary policy shocks and stock returns. First, we replicate the results in Table 7 in the main text using one-day changes in the one-year Treasury yield on FOMC days instead of using two-year Treasury yields. The results reported in Table IA.V confirm that this alternative measure of monetary policy shocks leads to similar results. We still find a nonmonotonic relation between monetary policy shocks and the returns on bank equity, and the relation is more pronounced in markets with higher bank concentration.

We next examine the possibility that the positive announcement effects of bank stock returns in a low interest rate environment could be driven by the information channel proposed by Nakamura and Steinsson (2018). We perform two exercises to address this concern. First, in Figure IA.1, we examine returns for all 49 Fama-French industries. If positive announcement effects are mainly a consequence of the central bank's assessment of the economic outlook, then we should see similar effects in other industries as well. However, we find that the banking industry is the only industry exhibiting a switch from negative interest sensitivity to positive interest sensitivity in the low-rate environment. Second, we use the monetary policy shocks constructed by Jarocinski and Karadi (2020). Their measure purges out the central bank information shocks from the surprises in federal funds futures on FOMC days. Our results are robust to this alternative measure of a monetary policy shock. This last result mitigates the concern that our reversal rate result is driven by a central bank information effect.

Table IA.V
Monetary Policy Shocks and Bank Equity Returns on FOMC Days

This table reports the estimates of the relation between bank equity returns and monetary policy shocks on FOMC days. Monetary policy shocks are measured by the one-day changes 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. The sample for columns (1) and (3) comprises observations in which the starting level of the federal funds rate is above 2%. The sample for columns (2) and (4) comprises observations in which the starting level of the federal funds rate is below 2%. We exclude observations during the collapse of the dot-com bubble (2000 to 2001) and the financial crisis (2007 to 2009). The standard errors are clustered by time.

	High FFR (1)	Low FFR (2)	High FFR (3)	Low FFR (4)
Policy shock	-1.365**	1.290	-0.103	-2.623
	[0.597]	[1.326]	[1.019]	[2.108]
HHI*Policy shock			-0.303	0.740**
			[0.262]	[0.372]
Δ Term spread	-0.605	2.944***	-0.471	2.644**
	[0.688]	[1.103]	[0.696]	[1.070]
Market return	0.298***	0.727***	0.296***	0.730***
	[0.074]	[0.069]	[0.073]	[0.069]
Observations	27,257	33,805	27,257	33,805
Adj. R^2	0.015	0.124	0.016	0.125

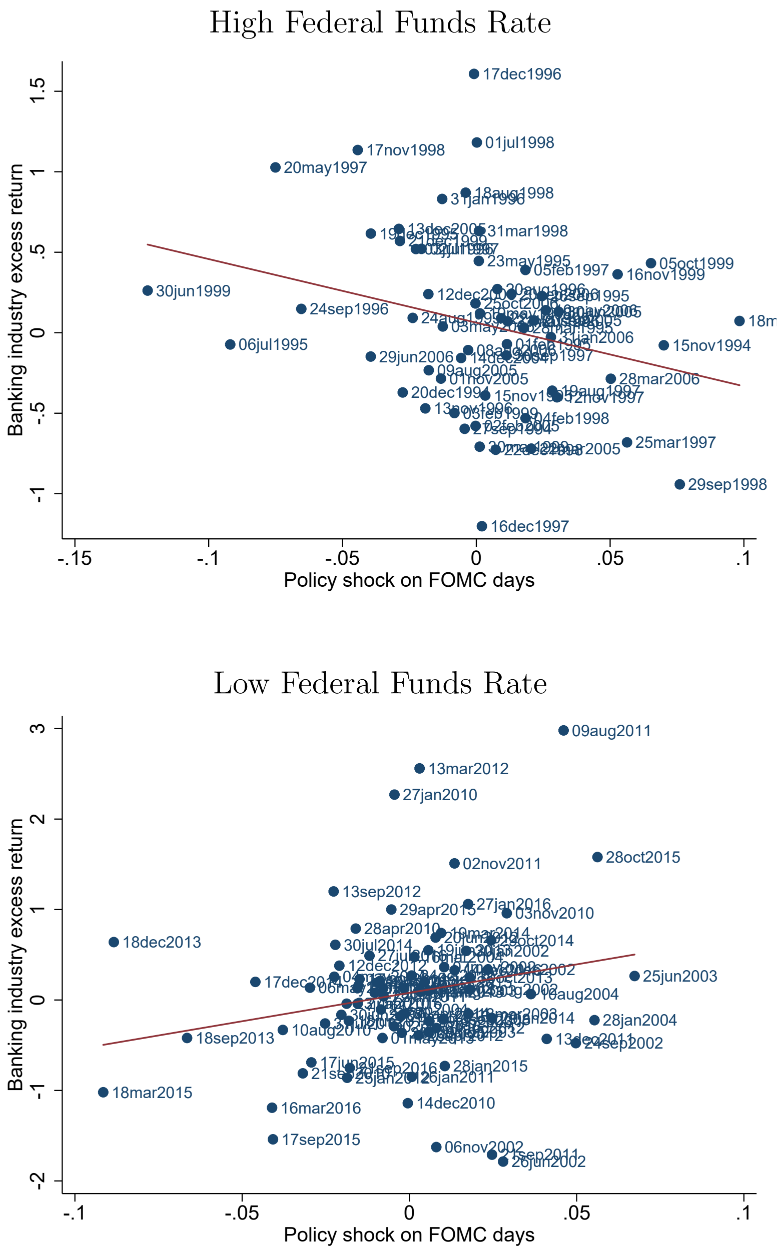

Figure IA.1. Monetary policy shocks and bank equity returns. This figure provides scatter plot of bank industry excess returns against monetary policy shocks on FOMC days from 1994 to 2017. The excess returns are defined as the difference between bank industry index returns and market returns. Monetary policy shocks are measured as the change in the three-month federal funds future subtracting central bank information shocks (Jarocinski and Karadi 2020). The sample for the upper panel constitutes observations in which the starting level of the federal funds rate is above 2%. The sample for the lower panel constitutes observations in which the starting level of the federal funds rate is below 2%. We exclude observations during the collapse of the dot-com bubble (2000 to 2001) and the financial crisis (2007 to 2009). Bank industry stock returns are from Kenneth French's website and monetary policy shocks are from the website of the *American Economic Journal: Macroeconomics*.

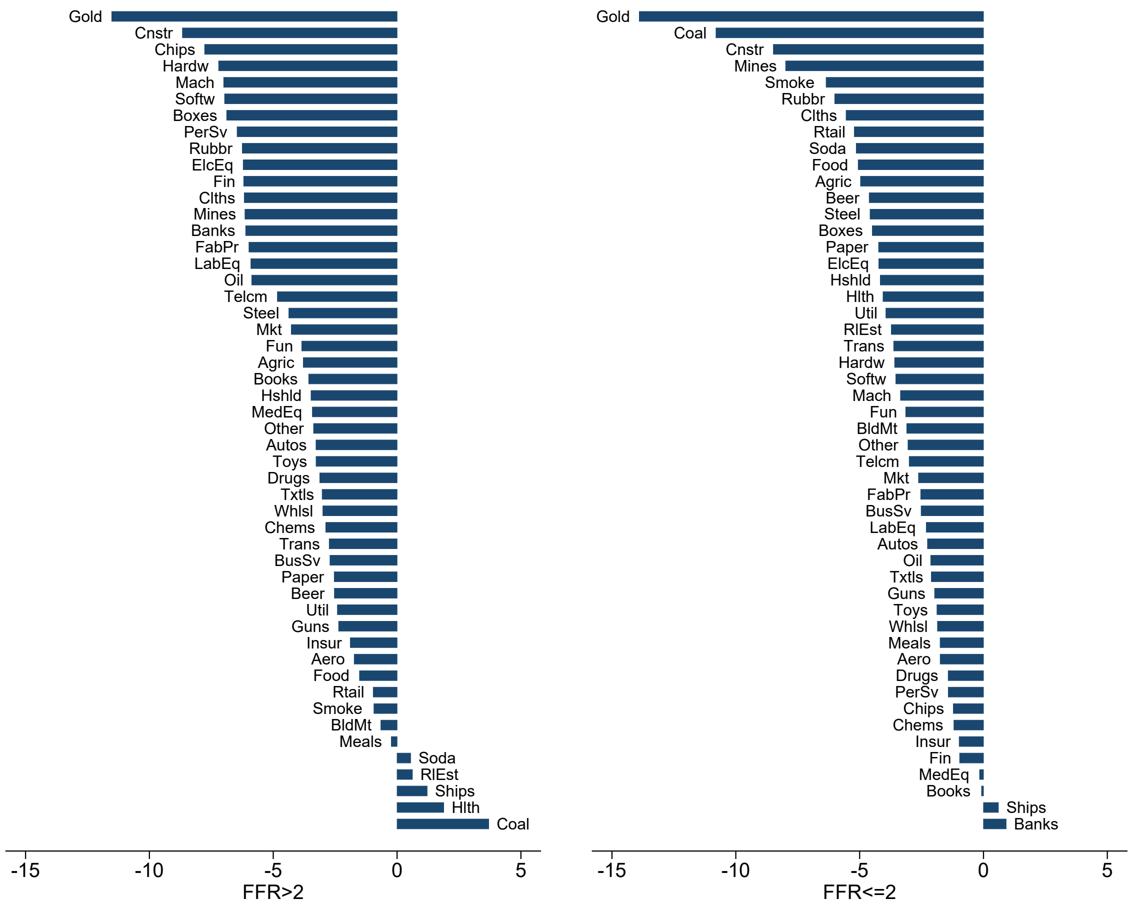

Figure IA.2. Monetary policy shocks and bank equity returns. The figure shows the sensitivity of bank and other industry stock portfolios to monetary policy shocks on FOMC days. The bars present the coefficients from regressions of Fama-French 49 industry returns on the change in the two-year Treasury rate over a two-day window around FOMC meetings, as in Hanson and Stein (2015). The sample includes all scheduled FOMC meetings from 1994 to 2017. The left panel uses a sample in which the federal funds rate (FFR) is above 2%. The right panel uses a sample in which the federal funds rate is below or equal to 2%. Industry returns are from Kenneth French's website. The two-year Treasury rate is obtained from the FRED database.

IX. Model Robustness

In this appendix, we consider several model extensions. The first is a major modification that changes the repayment schedule for loans and long-term bonds. In this case, we do not reestimate the model. The rest are minor extensions of the basic model in Section II. For these cases, we do reestimate the model.

A. *Average Interest Rate*

In this section, we modify the baseline model to introduce one additional state variable: the average contractual interest rate on outstanding loans. We follow Van den Heuvel (2002) and model the evolution of the average rate, $\{\rho_{j,t}\}$, as

$$\rho_{j,t} = \frac{\rho_{j,t-1} \times L_{j,t-1} + r^l_{j,t-1} \times B_{j,t-1}}{L_{j,t-1} + B_{j,t-1}}. \tag{IA.28}$$

Following this definition, the bank's cash inflow from interest payments can be written as

$$I_{j,t} = (L_{j,t} \times \rho_{j,t} + B_{j,t} \times r^l_{j,t})(1 - \delta_{j,t}). \tag{IA.29}$$

Note that the cash flow (IA.29) is multiplied by $(1 - \delta)$ because we allow both the principle and the interest payment to be subject to possible default. The rest of the model remains unchanged.

Table IA.VI
Moment Conditions: Alternative Model Specification

In this table, we report the simulated versus the actual moments. The dividend yield is defined as dividends over bank equity value, the nonreservable borrowing share is defined as the ratio of non-reservable borrowing to total assets, and the sensitivites of total credit and bank loans to the federal funds rate (FFR) is estimated via a vector autoregression. The solution is computed under an alternative model specification where we follow Van den Heuvel (2002) and track the evolution of the average rate on a bank's loan portfolio as a separate state variable.

	Actual Moment	Simulated Moment
Dividend yield	3.38%	2.78%
Nonreservable borrowing share	-29.90%	-16.82%
Std of nonreservable borrowing	12.60%	11.71%
Deposit spread	1.29%	1.37%
Loan spread	2.01%	2.13%
Deposit-to-asset ratio	0.699	0.782
Net noninterest expenses	1.20%	1.06%
Leverage	11.20	10.53
Market-to-book ratio	2.061	1.704
Credit-FFR sensitivity	-0.995	-0.896
Bank loan-FFR sensitivity	-1.592	-1.553

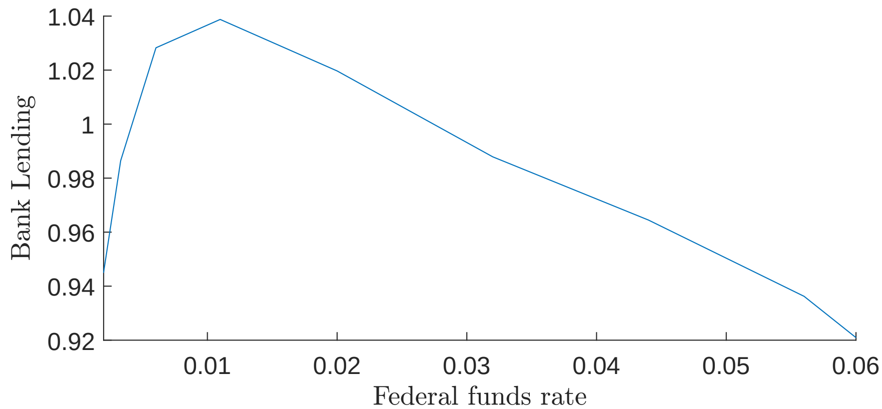

Figure IA.3. Optimal bank lending: Alternative model specification. This figure illustrates how bank optimal lending varies with the federal funds rate, which is on the x-axis. Bank lending, scaled by its unconditional average, is on the y-axis. The solution is computed under an alternative model specification where we follow Van den Heuvel (2002) and track the evolution of the average rate on a bank's loan portfolio as a separate state variable.

B. Minor model modifications

Table IA.VII
Parameter Estimates: Minor Model Modifications

In this table we report the model parameter estimates. The sample period is from 1994 to 2017. Parameters are estimated via SMD. Standard errors for the estimated parameters are clustered at the bank level and reported in brackets. "Equity issuance" corresponds to a model with an equity issuance cost. "Time-varying discount rate" corresponds to a model in which the banks' discount rate equals $f_t + \omega$. "Risk premia" corresponds to a case in which we subtract banks' risk premia in loan spreads before running the estimation. "Power cost" corresponds to a model in which banks face a cost for nonreservable borrowing that takes the following form $\phi^c(\frac{N_t}{D_t})^{\phi^p} D_t$, where ϕ^c and ϕ^p are the multiplicative and power components of this cost.

		Equity issuance cost		Time-varying discount rate		Risk premium		Power financing cost	
γ	Banks' discount rate	0.032	(0.013)	/	/	0.048	(0.011)	0.046	(0.008)
W/K	Relative size of the deposit market	0.217	(0.015)	0.218	(0.013)	0.215	(0.017)	0.224	(0.011)
q_n^l	Value of firms' outside option	-9.621	(0.210)	-9.652	(0.263)	-9.453	(0.214)	-9.671	(0.289)
ϕ^N	Quadratic cost of nonreservable borrowing	0.010	(0.001)	0.010	(0.001)	0.010	(0.001)	/	/
ϕ^d	Bank's cost of taking deposits	0.009	(0.001)	0.009	(0.001)	0.010	(0.001)	0.009	(0.001)
ϕ^l	Bank's cost of servicing loans	0.007	(0.002)	0.006	(0.002)	0.002	(0.004)	0.010	(0.001)
ψ	Net fixed operating cost	0.026	(0.006)	0.027	(0.007)	0.027	(0.006)	0.023	(0.006)
ϕ^e	Equity Issuance cost	0.112	(0.081)	/	/	/	/	/	/
ω	Time-varying discount rate	/	/	0.015	(0.006)	/	/	/	/
ϕ^c	Multiplicative nonreservable cost	/	/	/	/	/	/	0.014	(0.009)
ϕ^p	Power nonreservable cost	/	/	/	/	/	/	2.177	(0.471)

X. Additional Counterfactuals

Table IA.VIII
Determinants of Monetary Policy Transmission in Reverse Order

This table presents the results of a series of counterfactual experiments in which we examine the effects of adding frictions to our model. The first column lists the frictions that are added from the model. The second column presents the sensitivity of loans to the federal funds rate (FFR) when the corresponding frictions are added. The third column presents percent change in the sensitivity relative to the baseline case in row (1). All model solutions are under the same set of parameters reported in Table 3 in the main text.

		Sensitivity of Loans to FFR $\left(\frac{\Delta \ln l}{\Delta f}\right)$	Change relative to baseline (%)
(1)	No frictions	-0.913	/
(2)	+ Loan Market Power	-0.928	-1.59 %
(3)	+ Reserve Regulation	-0.913	0.00 %
(4)	+ Deposit Market Power	-1.091	19.40 %
(5)	+ Capital Regulation	-1.062	16.23 %

XI. Extended General Equilibrium Model

In this section, we extend our model by embedding it in a general equilibrium framework, thus achieving three goals. First, instead of assuming an exogenous federal funds rate process, in this setting we let this rate be pinned down by a Taylor rule, which depends on the monetary authority's policy, as well as on aggregate economic variables such as output and the inflation rate. Second, this setting allows us to have a meaningful distinction between nominal and real interest rates. Third, we can endogenize the relations between the interest rate, household liquid wealth W, and corporate borrowing demand K.

Our model contains a standard New Keynesian block and a banking block. The New Keynesian block determines the effects of productivity and monetary policy shocks on the nominal short-term rate and the inflation rate. The banking block determines the effect of the nominal short-term rate on bank lending rates.

A. The New Keynesian Block

There is a representative household with time-separable preferences. The household chooses real consumption, C_t, and real money balances, M_t/P_t, to maximize its utility, given the aggregate interest rate and price level,[1]

$$\{C_t, M_t\} = \arg\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma} (C_t^{1-\sigma} + \mu \left(M_t/P_t\right)^{1-\sigma}), \tag{IA.30}$$

[1] Note that we recycle the symbol C to denote the household's consumption, and β to denote the household's discount rate.

subject to the following budget constraint

$$P_t C_t - \frac{1}{1+i_t^M} M_t - \frac{1}{1+i_t} S_t - \frac{1}{1+\bar{i}_t} O_t \leq T_t + M_{t-1} + S_{t-1} + O_{t-1}, \tag{IA.31}$$

where M_t is nominal money balances, P_t is the price of the consumption good, μ is the utility weight on real money balances, and i_t^M is the nominal interest return earned on M_t, the determination of which we discuss below in equations (IA.42) and (IA.43). We use T_t to denote the sum of government transfers and the dividend payments received from firms and banks. Besides money, the household also holds other short-term investment securities, such as nonreservables issued by banks, S_t, and long-term corporate bonds issued by firms, O_t. The return from holding short-term investment securities equals the nominal federal funds rate target chosen by the monetary authority, i_t. The return on long-term corporate bonds equals the expected weighted average of future federal funds rates, $\bar{i}_t$,

$$\bar{i}_t \equiv \eta i_t + \mathbb{E}_t \left[\sum_{n=1}^{\infty} \eta (1-\eta)^n i_{t+n} \right]. \tag{IA.32}$$

In the following discussion, we use the generic symbol i to denote nominal rates and r to denote real rates. The short-term real rate is given by the short-term nominal rate minus the short-term inflation rate,

$$r_t = i_t - \pi_t. \tag{IA.33}$$

The long-term real rate is given by the long-term nominal rate minus the long-term inflation rate,

$$\bar{r}_t = \bar{i}_t - \bar{\pi}_t, \tag{IA.34}$$

where the long-term inflation rate, $\bar{\pi}_t$, is defined as the expected weighted average of future short-term inflation rates in a way that is analogous to equation (IA.32).

Optimal household demand for money equates the marginal rate of substitution between consumption and money with the opportunity cost of holding money,

$$M_t = \nu^{\frac{1}{\sigma}} P_t C_t \left(\frac{1}{1+i_t^M} - \frac{1}{1+i_t} \right)^{-\frac{1}{\sigma}}. \tag{IA.35}$$

We define $W_t \equiv M_t/P_t$ as household liquid wealth, which is total real balances that the household invests in money in a given period.

The first-order condition for optimal consumption is given by

$$c_t = \mathbb{E}_t \left[c_{t+1} \right] - \frac{1}{\sigma} \left(i_t - \mathbb{E}_t \left[\pi_{t+1} \right] - \rho \right), \tag{IA.36}$$

where $c_t \equiv \ln(C_t)$ is log consumption, $\pi_{t+1} \equiv \ln(P_{t+1}/P_t)$ is the one-period inflation rate, and $\rho = \ln(\beta)$ is the log discount rate.

On the production side, there exist two types of firms: intermediate and final goods producers. The price of the intermediate good is flexible, while the price of the final consumption good is set as in Calvo (1983) with staggered pricing.

We assume that a representative intermediate good firm uses capital to produce an intermediate good with a decreasing-return-to-scale technology. The firm chooses its optimal capital stock by solving the following static optimization problem

$$U_t = \max_{K_t} Z_t A_t K_t^{\upsilon} - K_t(1 + r_t^l), \tag{IA.37}$$

where U_t is firm profits, which is distributed to the household at the end of each period as dividends. In addition, $Z_t = (1 + r_t^l)/(\upsilon A_t K_t^{\upsilon - 1})$ is the real price of the intermediate good,

υ is the curvature of the firm's production function, and A_t is aggregate productivity, which follows an AR(1) process in logs, given by

$$\ln(A_t) \equiv a_t = \rho_a a_{t-1} + \varepsilon_t^a.$$

Next, r_t^l is the real cost of capital, which equals the weighted average of the real interest rates on corporate bonds and bank loans. We discuss the determination of r_t^l in equation (IA.42) below. Corporate bonds and loans are long term. As we assume in Section II in the main text, firms have to pay back a fraction η of their outstanding principal plus interest in each period. Taking the first derivative of equation (IA.37), the firm's optimal demand for capital can be written as

$$K_t = \left(\frac{\upsilon Z_t A_t}{1 + r_t^l}\right)^{\frac{1}{1-\upsilon}}. \tag{IA.38}$$

The intermediate good is then sold to a unit continuum of final good producers indexed by $i \in [0, 1]$, each producing its own retail good variety by costlessly assembling the intermediate good into a final variety, $Y_t(i)$, which is heterogeneous across producers. Aggregate output, Y_t, is then given by

$$Y_t \equiv \left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{IA.39}$$

where ε is the elasticity of substitution between final varieties. On each date, only a fraction $1 - \zeta$ of the final good firms can reset their prices, and firms choose optimal pricing to maximize their expected profits, taking into account future price rigidity

$$P_t(i) = \arg\max \sum_{k=0}^{\infty} \zeta^k \mathbb{E}_t \left[Q_{t,t+k} \left((P_t(i) - \psi_{t+k}) \left(\frac{P_t(i)}{P_{t+k}}\right)^{-\varepsilon} Y_{t+k}\right)\right]. \tag{IA.40}$$

Here, $Q_{t,t+k} \equiv \beta^k \left(C_{t+k}/C_t\right)^{-\sigma} \left(P_t/P_{t+k}\right)$ is the stochastic discount factor for nominal payoffs, and ψ_{t+k} is the nominal marginal cost for retailers, which equals the nominal price of the intermediate good, $P_{t+k}Z_{t+k}$. The real price of the intermediate good, Z_{t+k}, is determined by the optimality condition for the intermediate good firm in equation (IA.38).

Following the textbook treatment in Chapter 3 of Galí (2015), we can derive the new Keynesian Phillips curve (NKPC) based on our specification of the consumption and production sides of the economy,

$$\pi_t = \beta \mathbb{E}_t \left[\pi_{t+1} \right] + \kappa \tilde{y}_t + \lambda \tilde{r}^l_t, \tag{IA.41}$$

where $\tilde{y}_t = \ln(Y_t) - \ln(Y^n_t)$ and $\tilde{r}^l_t = r^l_t - r^{ln}_t$ are the deviations of log output and the cost of capital from their flexible-price counterparts (indicated by the superscript n). The coefficients $\kappa \equiv \frac{(1-\zeta)(1-\beta\zeta)(1-\upsilon)}{\zeta\upsilon}$ and $\lambda \equiv \frac{(1-\zeta)(1-\beta\zeta)}{\zeta}$ embody price stickiness (ζ) and the curvature of the production function (υ). The flexible-price output and cost of capital can be found by setting the price stickiness parameter, ζ, to zero.

B. The Banking Sector

We model the banking sector as in our baseline partial equilibrium setting discussed in Section II. Specifically, given bank j's deposit rate, $r^d_{j,t}$, bank j's deposit market share is pinned down by equation (3). To derive the demand for deposits from bank j, $D_{j,t}$, we multiply the bank's deposit market share by aggregate liquid wealth, W_t, from equation (IA.35). Similarly, to derive the demand for loans from bank j, $B_{j,t}$, we multiply bank j's loan market share, (8), by firms' aggregate borrowing needs, K_t, from (IA.38).

Note that both K_t and W_t are time-varying in the general equilibrium setting and are determined endogenously along with other aggregate variables, such as consumption, price levels, and interest rates. When each bank sets its rates, it treats aggregate variables, including K_t and W_t, as fixed. The aggregate interest rate in the loan market is defined as the market-share weighted average of banks' lending rates and the corporate bond interest rate. Similarly, the aggregate interest rate in the deposit market is defined as the market-share weighted average of banks' deposit rates, the interest rate of Treasury bills, and the real return on cash,

$$\begin{aligned} r_t^l &= \sum_{j \in \mathcal{A}^l} s_{j,t}^l \cdot r_{j,t}^l, \\ r_t^d &= \sum_{j \in \mathcal{A}^d} s_{j,t}^d \cdot r_{j,t}^d, \end{aligned} \tag{IA.42}$$

where $\mathcal{A}^l$ and $\mathcal{A}^d$ are the choice sets for firms and the household, respectively. Note that we expand the definition of $s_{j,t}^l$ in equation (IA.42) to include not only bank j's market share in the loan market but also the share of firm borrowing done in the corporate bond market. Similarly, we expand the definition of $s_{j,t}^d$ to include not only bank j's market share in the deposit market, but also the fraction of wealth invested in government bonds and cash. Naturally, the definitions of $r_{j,t}^l$ and $r_{j,t}^d$ expand to include the corresponding interest rates on corporate bonds and deposit options. In equilibrium, the sum of the inflation rate and the aggregate real interest rate in the deposit market equals the nominal return on money:

$$i_t^M = r_t^d + \pi_t. \tag{IA.43}$$

C. *Monetary Policy and Equilibrium*

The monetary authority chooses the short-term nominal rate following a Taylor rule,

$$i_t = \phi_0 + \phi_\pi \pi_t + \phi_y \tilde{y}_t + v_t, \tag{IA.44}$$

where ϕ_π and ϕ_y are nonnegative coefficients determined by the central bank. They indicate the strength of the interest rate response to inflation and the output gap. The variable v_t is the Taylor rule residual, which follows an AR(1) process given by $v_t = \rho_v v_{t-1} + \varepsilon_t^v$.

If the banking system is frictionless, bank lending rates are the same as the bond market interest rate, and firms' cost of capital is given by $r_t^l = \bar{i}_t - \bar{\pi}_t + \bar{\delta}_t$, where $\bar{\delta}_t$ is the expected default cost. In this case, the economy is characterized by a standard three-equation system in the New Keynesian literature: the NKPC, the monetary policy Taylor rule, and the DIS curve, which is the first-order condition for optimal consumption, given by equation (IA.36). We reproduce these three equations below:

$$\begin{aligned}
\text{(DIS) } & c_t = \mathbb{E}_t\left[c_{t+1}\right] - \frac{1}{\sigma}(i_t - \mathbb{E}_t\left[\pi_{t+1}\right] - \rho) \\
\text{(NKPC) } & \pi_t = \beta \mathbb{E}_t\left[\pi_{t+1}\right] + \kappa \tilde{y}_t + \lambda \tilde{r}_t^l \\
\text{(MP) } & i_t = \phi_0 + \phi_\pi \pi_t + \phi_y \tilde{y}_t + v_t
\end{aligned} \tag{IA.45}$$

However, in the presence of financial frictions, bank lending rates deviate from bond market interest rates, and firms' costs of capital depends on frictions in the banking sector such as bank market power and regulatory constraints. Specifically, in each period, after observing aggregate productivity, a_t, the monetary policy shock, v_t, and the fraction of defaulted loans, δ_t, banks decide optimal policies to maximize the expected discounted value of cash dividends to shareholders:

$$V(a_t, v_t, \delta_t, L_t, E_t \big| \Gamma_t) = \max_{\{r_t^l, r_t^d, G_t, N_t, R_t, C_{t+1}\}} \frac{1}{1+\gamma} \left\{ C_{t+1} + \mathbb{E}V(a_{t+1}, v_{t+1}, \delta_{t+1}, L_{t+1}, E_{t+1} \big| \Gamma_{t+1}) \right\}, \tag{IA.46}$$

$$s.t. \qquad r_t^d + \pi_t \geq 0 \qquad (13),\ (14),\ (15),\ (16),\ (17),\ (23),$$

where Γ_t denotes the cross-sectional distribution of bank states. We use P^{Γ} to denote the probability law governing the evolution of Γ_t: $\Gamma_{t+1} = P^{\Gamma}(\Gamma_t)$.

We define the equilibrium in this economy as follows.

DEFINITION 1 *An equilibrium consists of i) banks' optimal deposit intake and loan supply, ii) the household's optimal consumption and savings allocations, iii) firms' optimal investment and pricing decisions, and iv) aggregate consumption, output, inflation, and interest rates, such that*

1. *The household optimizes its consumption and savings decisions as in equation* (IA.30)*, given aggregate variables.*
2. *All firms choose optimal investment and pricing as in equations* (IA.37) *and* (IA.40)*, given aggregate variables.*
3. *All banks solve the problem given by equation* (IA.46)*, taking as given the other banks' choices of loan and deposit rates and aggregate variables.*
4. *The probability law governing the evolution of the banking industry is consistent with banks' optimal choices.*
5. *Aggregate consumption, output, and inflation are consistent with the household's and firms' optimal decisions.*
6. *Aggregate interest rates are consistent with banks' pricing in the deposit and loan markets.*
7. *In each period, the household's and firms' demand for deposits and bank loans equal banks' supply.*
8. *In each period, the bond market clears so that the household's holdings of corporate bonds and nonreservable claims equal the issuance by firms and banks, respectively.*
9. *In each period, the goods market clears so that household consumption plus firm investment equals total output.*

D. *Calibration and results*

We divide our parameter calibration into two groups. We first set the parameters of the New Keynesian block to standard values in the literature. The banking block is novel, so we rely on our parameter estimates reported in Table 3. We calibrate firms' outside option q_n^l t0 -8.25 so that the model-predicted sensitivity of bank loan to the federal funds rate matches that in the data. Note that we do not reestimate the other parameters in the general equilibrium model because the additional aggregate state variables in this setup add model complexity, which makes reestimation infeasible.

We follow the calibration in Galí (2015), Chapter 3, to set the parameters pertaining to the nonbanking sectors. We set the household's intertemporal elasticity of substitution, $1/\sigma$, to one, and its discount rate, β, to 0.96. The curvature of the intermediate good firms' production function, υ, is 0.33. The price stickiness parameter, ζ, is set to 0.2. The Taylor-rule responses to the output gap and inflation, $\{\phi_y, \phi_\pi\}$, are set to $\{0.5, 1.5\}$, and the constant term, ϕ_0, is calibrated at -4.3 to match the average short-term interest rate in the sample period. The utility weight on real money balances, ν, is calibrated at 0.43 to match the ratio of aggregate consumption to money balances. The persistence of the log aggregate productivity shock, ρ_a, and its standard deviation, σ_a, are calibrated at 0.66 and 0.10, respectively. The persistence of the monetary policy shock, ρ_v, and its standard deviation, σ_v, are calibrated at 0.06 and 0.9, respectively. Finally, we set the elasticity of substitution between the differentiated final output goods, ε, to six, which implies a steady-state markup of 20%.

With the calibrated general equilibrium model, we examine the relation between aggregate bank loans and the monetary policy shock. The results, shown in Figure IA.4, confirm our findings from the partial equilibrium model that the effect of monetary policy is nonmonotonic and hump-shaped. We also repeat our decomposition of monetary policy transmission mechanisms using the general equilibrium framework, with the results reported in Table IA.IX. First, consistent with the results from the partial equilibrium model, we find that the quantitative effect of the reserve requirement remains limited. Second, the effect of bank deposit market power remains quantitatively highly significant. Intuitively, the deposit market power channel depends on the competition between bank deposits and a zero-return storage technology such as cash. This mechanism is nearly unaffected by endogenizing monetary policy. Third, the effect of capital regulation channel becomes quantitatively weaker. The underlying reason is that the calibrated persistence of the federal funds rate in the general equilibrium setting is smaller than the estimated persistence used in our partial equilibrium setting. Because the capital regulation channel operates through maturity mismatch, the degree of the mismatch (and hence the effect of the channel) becomes weaker when the persistence of the federal funds rate becomes smaller. However, in the end, despite these quantitative differences, our main conclusions remain valid, as we find that both the deposit and loan market power channels are quantitatively important. Moreover, the monetary transmission channels based on market power have effects that are comparable to, if not larger than, those based on regulatory mechanisms.

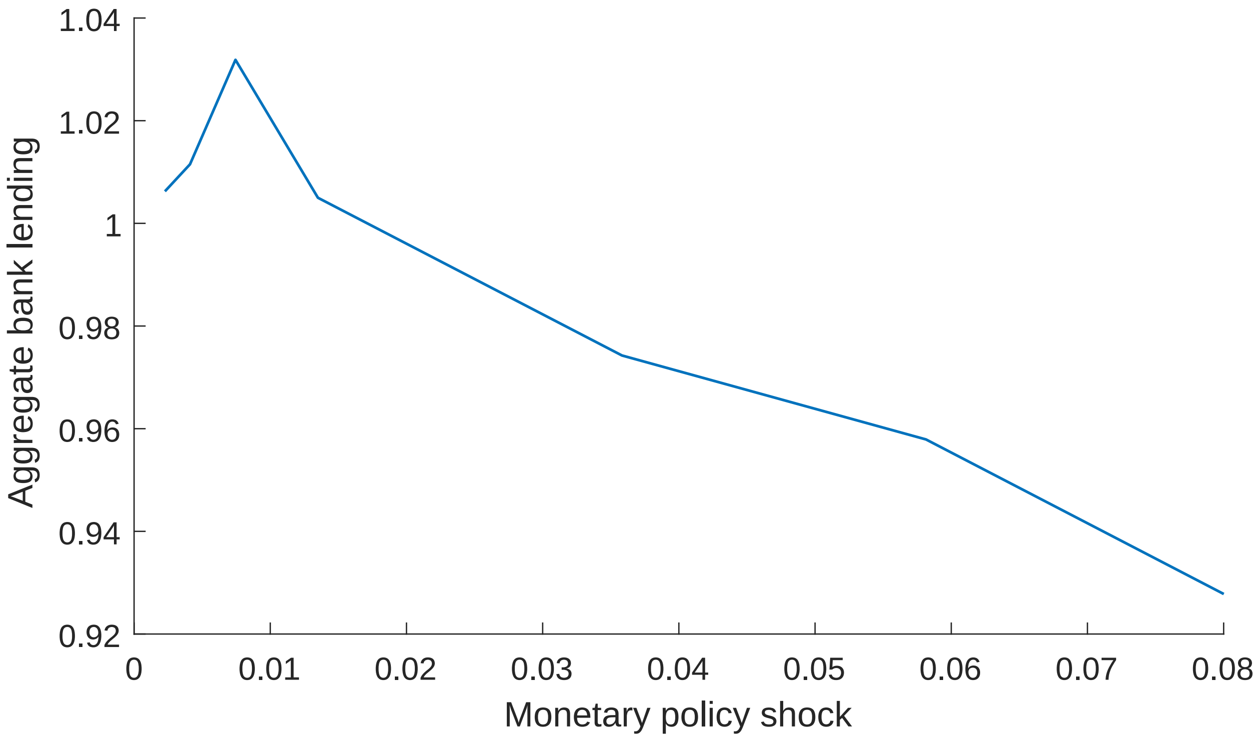

Figure IA.4. Aggregate bank lending and monetary policy shocks. This figure illustrates how aggregate bank lending responds to monetary policy shocks in the general equilibrium framework described in Section XI in the Internet Appendix. The monetary policy shock is on the x-axis. On the y-axis, the amount of aggregate bank lending is scaled by the unconditional average bank loan level.

Table IA.IX
Monetary Policy Transmission in a General Equilibrium Framework

This table presents the results of a series of counterfactual experiments conducted using the general equilibrium model described in Section XI in the Internet Appendix. The first column lists the frictions that are removed from the model. The second column presents the sensitivity of loans to the federal funds rate (FFR) when the corresponding frictions are removed. The third column presents the contributions of the corresponding frictions.

		Sensitivity of Loans to FFR $\left(\frac{\Delta \ln l}{\Delta f}\right)$	Change relative to baseline (%)
(1)	All frictions are present	-1.559%	/
(2)	− Reserve Regulation	-1.332%	14.56%
(3)	− Capital Regulation	-1.249%	19.86%
(4)	− Deposit Market Power	-0.771%	50.51%
(5)	− Loan Market Power	-2.024%	-29.88%

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