The Effect of Monetary Policy on Bank Wholesale Funding

Online Appendices

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A Model for monetary policy and bank funding decisions

This section provides a simple static model to develop empirical hypotheses tested in the paper. Our particular focus is on the optimal funding decision of banks (i.e., retail deposits versus wholesale funding). We first present and solve the optimal bank portfolio problem, given the policy rate denoted by r. We then analyze how banks respond to a change in r.

Our model consists of two periods, $t = 0$ and $t = 1$. At $t = 0$, banks finance their assets from two sources of funding, retail deposits and wholesale funding. For simplicity, we only consider the cases when banks only invest in loans.[1] Loans are perfectly illiquid at $t = 0$ after their originations, and their payoffs realize at $t = 1$ with no default risk. Let L be the amount of loans issued; D and W be the amounts of retail deposits and wholesale funding raised. The demand for loans as well as the supplies of retail deposits and wholesale funding are all functions of the spread over the policy rate r. Specifically, let r_L, r_D, and r_W be the nominal loan, retail deposit, and wholesale funding rates set by the bank. The bank faces loan demand $L(\mu_L)$ that weakly decreases in the loan rate spread $\mu_L \equiv r_L - r$; retail deposit supply $D(\mu_D)$ that weakly increases in the deposit rate spread $\mu_D \equiv r_D - r$; and wholesale funding supply $W(\mu_W)$ that weakly increases in the wholesale funding rate spread $\mu_W \equiv r_W - r$. Let $\underline{\mu}_D$ (< 0) be the minimum spread to attract any positive deposit, such that $D(\mu_D) = 0$ for all $\mu_D < \underline{\mu}_D$. Note that this minimum spread is negative as deposit rates can be below the policy rate.

We denote the inverse loan demand as $r_L - r = \mu_L(L)$, where L is the amount of loans issued, and assume $\mu'_L(L) < 0$ and $\mu''_L(L) \leq 0$. The inverse retail deposit supply is denoted as $r_D - r = \mu_D(D)$, with $\mu'_D(D) > 0$ and $\mu''_D(D) \geq 0$. For simplicity, we assume perfectly elastic supply of wholesale funding at the policy rate r such that $r_W - r = \mu_W(W) = 0$. While the market rate of wholesale

[1] We implicitly assume that banks can also invest in securities with the rate of return equal to r. However, as we discuss later, banks using any positive amount of wholesale funding will never invest in securities, and we only focus on the cases in which banks use both retail deposits and wholesale funding.

funding is constant, its usage incurs additional cost that is quadratic in the volume of a bank's wholesale funding W, and given by $c(W) = c_0 + c_1 W^2$. We assume $c_0 = 0$ without loss of generality, and $c_1 > 0$. c_1 can be bank-specific, reflecting differential financial frictions due to, i.e., agency problems within bank.[2] Given these, banks choose the optimal (L^*, D^*, W^*) at $t = 0$ to maximize their net payoffs at $t = 1$.

Note that, as it is, the optimal choice is independent of the level of the policy rate r because only the spreads over the policy rate matter in this setup—when r changes by Δr, all nominal rates will also change by Δr to keep the spreads unchanged. We now introduce two features that make changes in r relevant for banks' optimization: (1) non-interest cost of (retail) deposit taking; and (2) changes in savers' demand for deposits. We begin by introducing the first.

A.1. Non-interest costs of retail deposit taking

We assume that retail deposit taking incurs opportunity costs for banks because not all of the raised deposits can be lent out immediately. With this feature, we show that the increase in r induces banks to decrease retail deposits and increase wholesale funding. We then show that this increase in wholesale funding is larger for banks facing fewer financial frictions. Finally, we extend our model to allow two types of depositors ("old" and "young") and argue that banks facing more young depositors have a larger decrease (increase) in retail deposits (wholesale funding) when r increases.

Suppose that funding from retail depositors incurs additional non-interest costs that need to be paid before $t = 1$. As loans are perfectly illiquid, this implies that not all of the retail deposits raised at $t = 0$ can be lent out immediately. Specifically, we assume that banks need to set aside a fixed fraction of total retail deposits raised at $t = 0$ to meet the "service" demand by these depositors—e.g., check clearing, settlement, or ATM services—that arises before the loans mature at $t = 1$. Let α be the portion of deposits that need to be held as non-interest bearing cash. This makes deposit funding costly as some funds cannot be lent out for the higher return. A similar cost arises when banks hold (non-interest bearing) reserves against deposit funding, so as to meet reserve requirements

[2] We hence assume a fixed interest spread and different non-interest costs for wholesale funding across banks. This setup is for simplicity and our main results still hold when we assume a strictly upward sloping supply for wholesale funding and different slopes across banks.

or withdrawal requests.[3] Importantly, this opportunity cost goes up when the policy rate r goes up, as can be seen below.

The bank chooses the optimal amount of loans as well as the funding mix to maximize its payoff π at $t = 1$:

$$\max_{L,W,D} \pi \equiv r_L \times L - r_D \times D - r_W \times W - c(W)$$

subject to $L = (1 - \alpha)D + W$. This can be written as

$$\begin{aligned}
\pi = (r_L - r) \times L - (r_D - r) \times D - (r_W - r) \times W - c(W) - r\alpha D \\
&= \mu_L(L) \times L - \mu_D(D) \times D - \mu_W(W) \times W - c(W) - r\alpha D \\
&= \mu_L\big((1-\alpha)D + W)\big) \times \big((1-\alpha)D + W)\big) - \mu_D(D) \times D - c_1 W^2 - r\alpha D, \quad \text{(A1)}
\end{aligned}$$

where the last term captures the opportunity cost of retail deposits that increases in r. We can derive the optimal (W^*, D^*) that maximizes the above, which also gives L^*.

For simplicity, we only focus on the case with the interior solutions of $W^*, D^* > 0$, also assuming that the second order conditions are met.[4] The optimal (W^*, D^*) can be solved from the first order conditions:

$$\begin{aligned}
\frac{\partial \pi}{\partial W} =& \mu'_L\big((1-\alpha)D + W\big) \times \big((1-\alpha)D + W\big) + \mu_L\big((1-\alpha)D + W\big) - 2c_1 W = 0, \\
\frac{\partial \pi}{\partial D} =& \big[\mu'_L\big((1-\alpha)D + W)\big) \times \big((1-\alpha)D + W\big) + \mu_L\big((1-\alpha)D + W\big)\big] \times \big(1-\alpha\big) \\
& - \big[\mu'_D(D) \times D + \mu_D(D) + \alpha r\big] = 0,
\end{aligned}$$

which accordingly provides the optimal loan and retail deposit rates set by the bank.

Financial frictions and wholesale funding reliance We now consider the effect of financial frictions, characterized by c_1 in our setup, on wholesale funding reliance. Based on the first order

[3] Hence, the mechanism under this setup is stronger if the spread between the target policy rate and the interest paid on reserves is larger.

[4] We briefly explain when the corner solution with $W^* = 0$ arises when discussing the extension of this baseline setup.

conditions, let

$$F_1 \equiv \mu_L'\big((1-\alpha)D^* + W^*\big) \times \big((1-\alpha)D^* + W^*\big) + \mu_L\big((1-\alpha)D^* + W^*\big) - 2c_1 W^*$$

and

$$\begin{aligned} F_2 \equiv & \big[\mu_L'\big((1-\alpha)D^* + W^*)\big) \times \big((1-\alpha)D^* + W^*\big) + \mu_L\big((1-\alpha)D^* + W^*\big)\big] \times \big(1-\alpha\big) \\ & - \big[\mu_D'(D^*) \times D^* + \mu_D(D^*) + \alpha r\big]. \end{aligned}$$

From the implicit function theorem,

$$\begin{bmatrix} \frac{\partial W^*}{\partial c_1} \\ \frac{\partial D^*}{\partial c_1} \end{bmatrix} = - \begin{bmatrix} \frac{\partial F_1}{\partial W^*} & \frac{\partial F_1}{\partial D^*} \\ \frac{\partial F_2}{\partial W^*} & \frac{\partial F_2}{\partial D^*} \end{bmatrix}^{-1} \times \begin{bmatrix} \frac{\partial F_1}{\partial c_1} \\ \frac{\partial F_2}{\partial c_1} \end{bmatrix},$$

it is straightforward to show that

$$\frac{\partial W^*}{\partial c_1} < 0, \qquad \frac{\partial D^*}{\partial c_1} > 0.$$

Result 1: A bank facing fewer financial frictions chooses to use more wholesale funding, and thus its wholesale funding reliance measured by the ratio of wholesale funding to retail deposits is higher.

Proof of Result 1

Note that

$$\begin{bmatrix} \frac{\partial W^*}{\partial c_1} \\ \frac{\partial D^*}{\partial c_1} \end{bmatrix} = - \begin{bmatrix} \frac{\partial F_1}{\partial W^*} & \frac{\partial F_1}{\partial D^*} \\ \frac{\partial F_2}{\partial W^*} & \frac{\partial F_2}{\partial D^*} \end{bmatrix}^{-1} \times \begin{bmatrix} \frac{\partial F_1}{\partial c_1} \\ \frac{\partial F_2}{\partial c_1} \end{bmatrix} = -F^{-1} \times \begin{bmatrix} -2c_1 \\ 0 \end{bmatrix},$$

where $F \equiv \begin{bmatrix} \frac{\partial F_1}{\partial W^*} & \frac{\partial F_1}{\partial D^*} \\ \frac{\partial F_2}{\partial W^*} & \frac{\partial F_2}{\partial D^*} \end{bmatrix}$.

We have $\frac{\partial F_1}{\partial W^*} = \mu_L''(L) \times L + 2\mu_L'(L) - 2c_1$ (< 0) and $\frac{\partial F_1}{\partial D^*} = \frac{\partial F_2}{\partial W^*} = [\mu_L''(L) \times L + 2\mu_L'(L)](1-\alpha)$, where both are negative by the assumptions on $\mu_L(L)$; and $\frac{\partial F_2}{\partial D^*} = [\mu_L''(L) \times L + 2\mu_L'(L)](1-\alpha)^2 - \mu_D''(D) \times D - 2\mu_D'(D)$, which is negative from the second order conditions.

Now, $F^{-1} = \frac{1}{det|F|}\begin{bmatrix} \frac{\partial F_2}{\partial D^*} & -\frac{\partial F_1}{\partial D^*} \\ -\frac{\partial F_2}{\partial W^*} & \frac{\partial F_1}{\partial W^*} \end{bmatrix}$, hence

$$\begin{bmatrix} \frac{\partial W^*}{\partial c_1} \\ \frac{\partial D^*}{\partial c_1} \end{bmatrix} = \frac{2c_1}{det|F|} \cdot \begin{bmatrix} \frac{\partial F_2}{\partial D^*} \\ -\frac{\partial F_2}{\partial W^*} \end{bmatrix}.$$

Note that

$$\begin{aligned} det|F| =& \{\mu_L''(L^*)L^* + 2\mu_L'(L^*) - 2c_1\}\{[\mu_L''(L^*)L^* + 2\mu_L'(L^*)](1-\alpha)^2 - [\mu_D''(D^*)D^* + 2\mu_D'(D^*)]\} \\ &- [\mu_L''(L^*)L^* + 2\mu_L'(L^*)]^2(1-\alpha)^2 = -[\mu_L''(L^*)L^* + 2\mu_L'(L^*)][\mu_D''(D^*)D^* + 2\mu_D'(D^*)] \\ &- 2c_1\{[\mu_L''(L^*)L^* + 2\mu_L'(L^*)](1-\alpha)^2 - \mu_D''(D^*)D^* - 2\mu_D'(D^*)\}, \end{aligned} \tag{A2}$$

which is positive from the assumptions on $\mu_L(L)$ and $\mu_D(D)$. Hence, $\frac{\partial W^*}{\partial c} < 0, \frac{\partial D^*}{\partial c} > 0$. $\square$

Policy rate change and funding composition We next analyze how banks react to changes in the policy rate. We begin by examining how a bank adjusts the amount of wholesale funding and retail deposits when the policy rate r changes. We then compare how this response varies when banks face different financial frictions.

Again, from the implicit function theorem,

$$\begin{bmatrix} \frac{\partial W^*}{\partial r} \\ \frac{\partial D^*}{\partial r} \end{bmatrix} = - \begin{bmatrix} \frac{\partial F_1}{\partial W^*} & \frac{\partial F_1}{\partial D^*} \\ \frac{\partial F_2}{\partial W^*} & \frac{\partial F_2}{\partial D^*} \end{bmatrix}^{-1} \times \begin{bmatrix} \frac{\partial F_1}{\partial r} \\ \frac{\partial F_2}{\partial r} \end{bmatrix}. \tag{A3}$$

Here, we have $\frac{\partial W^*}{\partial r} > 0, \frac{\partial D^*}{\partial r} < 0$. Intuitively, the increase in r makes deposit taking more costly, since the (opportunity) cost of retail deposits goes up. Hence, banks reduce the deposit rate spread to decrease retail deposits, and increase wholesale funding instead.

Result 2: When the policy rate goes up, banks decrease their retail deposits and increase wholesale funding.

Proof of Result 2

Similarly as in the previous proof, we have

$$\begin{bmatrix} \frac{\partial W^*}{\partial r} \\ \frac{\partial D^*}{\partial r} \end{bmatrix} = - \begin{bmatrix} \frac{\partial F_1}{\partial W^*} & \frac{\partial F_1}{\partial D^*} \\ \frac{\partial F_2}{\partial W^*} & \frac{\partial F_2}{\partial D^*} \end{bmatrix}^{-1} \times \begin{bmatrix} \frac{\partial F_1}{\partial r} \\ \frac{\partial F_2}{\partial r} \end{bmatrix} = - \frac{1}{det|F|} \cdot \begin{bmatrix} -\frac{\partial F_1}{\partial D^*} \cdot (-\alpha) \\ \frac{\partial F_1}{\partial W^*} \cdot (-\alpha) \end{bmatrix}, \tag{A4}$$

hence $\frac{\partial W^*}{\partial r} > 0$, $\frac{\partial D^*}{\partial r} < 0$ using the conditions derived in the previous proof. □

Differential financial frictions and funding responses We now compare how this response varies between banks facing differential financial frictions. Concretely, we argue that banks that face fewer frictions (i.e., lower c_1) add more wholesale funding than those that face more frictions. This is intuitive because the cost of additional wholesale funding is higher when c_1 is greater, preventing banks from adding more.

From (A4), we have

$$\frac{\partial W^*}{\partial r} = \frac{[\mu''_L(L^*)L^* + 2\mu'_L(L^*)](1-\alpha)}{[\mu''_L(L^*)L^* + 2\mu'_L(L^*)][\mu''_D(D^*)D^* + 2\mu'_D(D^*)] + 2c_1[[\mu''_L(L^*)L^* + 2\mu'_L(L^*)](1-\alpha)^2 - \mu''_D(D^*)D^* - 2\mu'_D(D^*)]}, \tag{A5}$$

where $L^* = W^* + (1-\alpha)D^*$. Hence, for fixed D^* and W^*, $\frac{\partial W^*}{\partial r}$ becomes smaller when c_1 becomes larger—banks add less wholesale funding when facing more frictions. Note, however, that different c_1 implies different choices of D^* and W^* to begin with. Nonetheless, under a linear setup where we assume $\mu_L(L) = -\ell_1 L + \ell_2$ with $\ell_1, \ell_2 > 0$, and $\mu_D(D) = d_1 D + d_2$ with $d_1 > 0,\ d_2 < 0$, $\partial W^*/\partial r$ becomes independent of the levels of D^* and W^* and decreasing in c_1, hence we have the following result.

Result 3: When $\mu_L(L)$ and $\mu_D(D)$ are linear, banks facing fewer frictions (i.e., lower c_1) always add more wholesale funding when the policy rate increases.

Proof of Result 3

Plugging $\mu_L(L) = \ell_1 L + \ell_2$, $\mu_D(D) = d_1 D + d_2$, and $L^* = W^* + (1-\alpha)D^*$ into (A5), we have

$$\frac{\partial W^*}{\partial r} = \frac{\ell_1(1-\alpha)}{2[\ell_1 d_1 + c_1\{\ell_1(1-\alpha)^2 + d_1\}]} \quad (> 0).$$

This is decreasing in c_1, hence a bank with smaller c_1 adds more wholesale funding when r increases. □

Extension: Differential deposit supply We finally extend the baseline setup to introduce differential deposit supply. Suppose that there are two types of depositors, "young" and "old". A young depositor's demand for retail deposits, denoted as $D_Y(\mu_D)$, has the same property as that in the baseline setup, with its inverse denoted as $\mu_D = \mu_{D,Y}(D_Y)$. An old depositor's demand, however, is neither a function of the deposit rate spread nor the policy rate; he constantly demands a fixed amount $\overline{D}$ as long as the offered spread is higher than $\underline{\mu}_D$. That is, the demand $D_O(\mu_D)$ equals to $\overline{D}$ for all $\mu_D \geq \underline{\mu}_D$, and equals 0 otherwise.

Consider a local market of depositors with measure 1, where y of them are young and $1-y$ of them are old. Then, the bank faces the combined deposit supply of $D(\mu_D)$ that equals $y \times D_Y(\mu_D) + (1-y)\overline{D}$ for any $\mu_D > \underline{\mu}_D$, and 0 if $\mu_D < \underline{\mu}_D$. This gives us the inverse deposit supply function $\mu_D(D; y)$ that is given by:

$$\mu_D(D; y) = \begin{cases} \mu_{D,Y}(D_Y) = \mu_{D,Y}\left(\frac{D-(1-y)\overline{D}}{y}\right) & \text{if } D > (1-y)\overline{D}, \\ \underline{\mu}_D & \text{if } D < (1-y)\overline{D}. \end{cases} \tag{A6}$$

We briefly discuss the corner solution case with no wholesale funding. When y is small and $\overline{D}$ is large, banks are in a "loan poor, deposit rich" market (Han et al. (2015)) where they choose to raise no wholesale funding ($W^* = 0$) and invest in both loans and securities.[5] In this region, banks do not substitute their retail deposits with wholesale funding when the policy rate goes up. Below, we focus on the regions with not too small y such that both D^* and W^* are strictly positive, and examine how $\partial D^*/\partial r$ and $\partial W^*/\partial r$ change when y changes.

[5] Note that in our setup where both securities' return and the minimum cost of wholesale funding are r, banks never invest in securities when $W^* > 0$, and they always invest in securities when $W^* = 0$.

Again, $\partial D^*/\partial r$ and $\partial W^*/\partial r$ can be derived from the implicit function theorem (equation (A3)), and are now also a function of y because $\mu_D(D;y)$ is a function of y. Here, $|\partial D^*/\partial r|$ increases in y when we fix W^* and D^*. However, as is the case with the discussion following equation (A3), different y implies different optimal choices of (W^*, D^*) to begin with, which complicates the cross-region comparison of $\partial D^*/\partial r$ with different y. Nonetheless, under the linear setup of $\mu_L(L) = -\ell_1 L + \ell_2$ with $\ell_1, \ell_2 > 0$, and $\mu_{D,Y}(D_Y) = d_1 D_Y + d_2$ with $d_1 > 0,\ d_2 = \underline{\mu}_D < 0$ as in the previous example, $|\partial D^*/\partial r|$ and $|\partial W^*/\partial r|$ increases in y and we have the following result:

Result 4: If $\mu_L(L)$ and $\mu_{D,Y}(D_Y)$ are linear, banks in the market with more young depositors decrease (increase) their retail deposits (wholesale funding) more when the policy rate increases.

Proof of Result 4

The first order conditions are:

$$\begin{aligned} F_1 \equiv& \mu_L'\big((1-\alpha)D^* + W^*\big) \times \big((1-\alpha)D^* + W^*\big) + \mu_L\big((1-\alpha)D^* + W^*\big) - 2c_1 W^*; \\ F_2 \equiv& \big[\mu_L'\big((1-\alpha)D^* + W^*)\big) \times \big((1-\alpha)D^* + W^*\big) + \mu_L\big((1-\alpha)D^* + W^*\big)\big] \times \big(1-\alpha\big) \\ & - \big[\mu_D'(D^*;y) \times D^* + \mu_D(D^*;y) + \alpha r\big], \end{aligned}$$

where $\mu_D(D;y) = \mu_{D,Y}(D_Y) = \mu_{D,Y}\Big(\frac{D-(1-y)\overline{D}}{y}\Big)$ from (A6) since $D_Y > 0$ when $W^* > 0$. Hence, $\mu_D'(D;y) = \mu_{D,Y}'(D_Y)/y$.

$\partial D^*/\partial r$ and $\partial W^*/\partial r$ can then be derived from the implicit function theorem, similar to (A4). Plugging in $\mu_L(L) = \ell_1 L + \ell_2$, $\mu_{D,Y}(D_Y) = d_1 D_Y + \underline{\mu}_D$, we have

$$\frac{\partial W^*}{\partial r} = \frac{1}{2} \cdot \frac{\ell_1(1-\alpha)\alpha}{(\ell_1 - c_1)d_1/y + c_1\ell_1(1-\alpha)^2}; \quad \frac{\partial D^*}{\partial r} = -\frac{1}{2} \cdot \frac{(\ell_1 - c_1)\alpha}{(\ell_1 - c_1)d_1/y + c_1\ell_1(1-\alpha)^2}.$$

Hence, both $|\partial D^*/\partial r|$ and $|\partial W^*/\partial r|$ are increasing in y. □

A.2. Rate dependent deposit elasticities

We now present the second channel that induces banks to decrease retail deposits and increase wholesale funding when the policy rate goes up. We only show the main result (i.e., Result 2 in Section A.1) under this setup, without repeating the additional cross-bank analysis.

As before, savers' demand for retail deposits (i.e., retail deposit supply for banks) increases in the deposit rate spread μ_D. We further assume that the price sensitivity decreases in the level of the policy rate r; for example, a 25 basis point increase in the deposit spread attracts more deposits when the policy rate is 1 percent, than when it is 5 percent.[6] Formally, for all policy rates with $r_H > r_L$, we assume that $\mu'_D(D; r_H) \geq \mu'_D(D; r_L)$ for all D, which also implies $\mu_D(D; r_H) \geq \mu_D(D; r_L)$ for all D. We assume $\alpha = 0$, which closes down the previous channel discussed in Section A.1, and $\mu'_D(D; r)$ is differentiable with respect to r.

Note that banks' objective function becomes

$$\begin{aligned} \pi =& \mu_L(L) \times L - \mu_D(D; r) \times D - \mu_W(W) \times W - c(W) \\ =& \mu_L\big(D + W\big) \times \big(D + W\big) - \mu_D(D; r) \times D - c_1 W^2, \end{aligned} \tag{A7}$$

with the first order conditions:

$$\begin{aligned} \frac{\partial \pi}{\partial W} &= \mu'_L\big(D + W\big) \times \big(D + W\big) + \mu_L\big(D + W\big) - 2c_1 W = 0, \\ \frac{\partial \pi}{\partial D} &= \big[\mu'_L\big(D + W\big) \times \big(D + W\big) + \mu_L\big(D + W\big)\big] - \big[\mu'_D(D; r) \times D + \mu_D(D; r)\big] = 0, \end{aligned}$$

as before, which gives the optimal (D^*, W^*) that also depend on r.

Now, suppose that the initial policy rate is r_0, and the optimal levels of retail deposits and wholesale funding are given as D^*_0, W^*_0. This implies $\mu'_L\big(D^*_0 + W^*_0\big) \times \big(D^*_0 + W^*_0\big) + \mu_L\big(D^*_0 + W^*_0\big) = \mu'_D(D^*_0; r_0) \times D^*_0 + \mu_D(D^*_0; r_0)$. If the policy rate increases to r_1, this condition becomes

$$\mu'_L\big(D^*_0 + W^*_0\big) \times \big(D^*_0 + W^*_0\big) + \mu_L\big(D^*_0 + W^*_0\big) < \mu'_D(D^*_0; r_1) \times D^*_0 + \mu_D(D^*_0; r_1)$$

because the deposit supply becomes more inelastic. As the LHS decreases in D and the RHS in-

[6] This type of demand arises when retail deposits and non-interest bearing currency are substitutes for the savers. See, for instance, Drechsler et al. (2017) for a model that results in deposit demand whose elasticity decreases in the policy rate when cash and deposits are substitutes.

creases in D, banks decrease the amount of retail deposits they raise, and increase wholesale funding instead. We hence have the following result.

Result 5: Banks reduce retail deposits and increase wholesale funding when the policy rate increases.

Proof of Result 5

This is straightforward from the implicit function theorem as in the proof of Result 2, and both $\mu'_D(D;r)$ and $\mu_D(D;r)$ increase in r. $\square$

B Robustness of Empirical Results

B.1 Deposit funding costs and wholesale funding reliance

Our model in Appendix A also suggests that banks with a very high cost of wholesale funding (which thus use less such funds) attempt to retain more retail deposits during monetary tightening than banks with easier access to wholesale funding markets; moreover, they pay higher interest to their retail depositors to attract more deposits (see also Williams (2016)). As an additional analysis, we examine whether banks offering a high retail deposit rate or high wholesale deposit rate have retail deposits whose quantities are less sensitive to changes in the policy rate. Note that there is an identification limitation in this analysis, and our results should thus be interpreted as suggestive. When sorting banks by their respective interest rates (i.e., prices) paid to a certain creditor class, different rates can reflect both demand and supply factors, and we cannot distinguish between the two without a proper instrument.

Table B.1 reports the results when we estimate the same specifications as in Table 4, with the only difference being that we replace *Large Bank* with *High Rate*. In Panel A, *High Rate* equals 1 if a bank's retail deposit rate belongs to the top quartile and 0 otherwise. As predicted, banks paying more to their retail depositors have a significantly smaller decrease in their retail deposits when the policy rate increases. On the other hand, there is no significant difference in the growth of wholesale funding for these banks. In Panel B, *High Rate* equals 1 if a bank's wholesale deposit rate belongs to the top quartile and 0 otherwise. Again, these banks retain more retail deposits when the policy rate increases, while the estimates are less significant than those in Panel A, both statistically and economically. Interestingly, these banks did not experience a greater increase in their wholesale funding even if they paid higher rates; instead, they had a smaller increase, albeit the difference is not statistically significant. This suggests that these banks faced greater financial frictions that led to higher funding costs, rather than demanding more such funds as in the case of Panel A.

Table B.1: Banks' Funding Composition and the Federal Funds Rate: By the level of Banks' Funding Cost

We report the panel regression estimates of the relationship between the change in banks' funding composition and the change in the federal funds rate, by the level of banks' funding cost. Panel A reports the results by banks' retail deposit rate. The dependent variables are the percentage change in the retail deposits of a bank (% Change in RD) in column (1), the percentage change in the wholesale funding of a bank (% Change in WSF) in column (2), the change in the wholesale funding to retail deposits ratio (Change in WSF to RD) in column (3), the change in RD from the previous quarter to the total liabilities of four quarters prior (Change in RD to TL(t-4)) in column (4), and the change in WSF from the previous quarter to the total liabilities of four quarters prior (Change in WSF to TL(t-4)) in column (5). We define High Rate dummy as 1 if a bank has retail deposit rate in top 25% among banks and 0 otherwise. Our main variable of interest is the interaction between the federal funds rate and the High Rate dummy. Other independent variables include bank-level controls (RE Loan to Total Loan Ratio, CI Loan to Total Loan Ratio, log Assets, Capital Ratio, Bank-level Total Loan Growth, Liquid Asset Ratio, Securitization) and macro controls (CP Spread, Term Premium, Aggregate-level Total Loan Growth). We use 4-quarters-lagged bank characteristics and macro variables in our analysis. For brevity, we do not report the controls in the table. We also include bank fixed effects and quarter-of-year fixed effects (for seasonality). Panel B reports the results by banks' wholesale deposit rate; we define High Rate dummy as 1 if a bank has wholesale deposit rate in top 25% among banks and 0 otherwise. We report the sums of the estimates of the lagged FFR and the interaction terms with the t-statistics of the sums. The table reports point estimates with t-statistics in parentheses. All standard errors are clustered at the year-quarter level. ***, **, * denote 1%, 5%, and 10% statistical significance.

Panel A: Retail Deposit Rate					
	(1)	(2)	(3)	(4)	(5)
Variables	% Change in RD	% Change in WSF	Change in WSF to RD	Change in RD to TL(t-4)	Change in WSF to TL(t-4)
Change in FFR (t-1 to t)	-0.852***	1.021	0.384***	-0.736***	0.159*
	(-4.03)	(1.54)	(3.09)	(-3.78)	(1.73)
Change in FFR (t-2 to t-1)	0.113	2.221***	0.207	0.069	0.246**
	(0.40)	(2.72)	(1.40)	(0.27)	(2.45)
Change in FFR (t-3 to t-2)	0.422	0.101	0.060	0.409	0.042
	(1.44)	(0.11)	(0.38)	(1.50)	(0.41)
Change in FFR (t-4 to t-3)	-0.479**	0.901	0.109	-0.433**	0.040
	(-2.07)	(1.34)	(0.96)	(-2.03)	(0.48)
Sum of Effects	-0.80***	4.24***	0.76***	-0.69***	0.49***
	(-5.03)	(7.39)	(7.82)	(-4.72)	(7.13)
High Rate	-0.505***	0.572***	0.169***	-0.426***	0.058**
	(-9.84)	(3.15)	(4.05)	(-9.88)	(2.35)
High Rate × Change in FFR (t-1 to t)	-0.035	0.959*	0.243**	-0.039	0.183***
	(-0.27)	(1.91)	(2.63)	(-0.34)	(3.01)
High Rate × Change in FFR (t-2 to t-1)	0.185	0.014	-0.039	0.175	-0.022
	(1.21)	(0.02)	(-0.38)	(1.27)	(-0.31)
High Rate × Change in FFR (t-3 to t-2)	-0.045	-1.267*	-0.170*	-0.028	-0.123*
	(-0.29)	(-1.81)	(-1.80)	(-0.20)	(-1.70)
High Rate × Change in FFR (t-4 to t-3)	0.279**	-0.536	-0.136*	0.207**	-0.055
	(2.55)	(-1.01)	(-1.74)	(2.07)	(-0.88)
Sum of Effects	0.38***	-0.83	-0.10	0.32***	-0.02
	(3.71)	(-1.63)	(-1.15)	(3.56)	(-0.30)

	(1)	(2)	(3)	(4)	(5)
Observations	129,453	129,453	129,453	129,453	129,453
R-squared	0.115	0.048	0.060	0.121	0.069
Bank FE and Quarter-of-year FE	Yes	Yes	Yes	Yes	Yes
Bank-level Controls	Yes	Yes	Yes	Yes	Yes
Macro Controls	Yes	Yes	Yes	Yes	Yes

Panel B: Wholesale Deposit Rate

Variables	(1) % Change in RD	(2) % Change in WSF	(3) Change in WSF to RD	(4) Change in RD to TL(t-4)	(5) Change in WSF to TL(t-4)
Change in FFR (t-1 to t)	-0.837***	1.116*	0.396***	-0.730***	0.175*
	(-4.04)	(1.79)	(3.19)	(-3.82)	(1.96)
Change in FFR (t-2 to t-1)	0.111	2.108***	0.223	0.073	0.248***
	(0.41)	(2.82)	(1.63)	(0.30)	(2.68)
Change in FFR (t-3 to t-2)	0.461*	-0.012	0.018	0.445*	0.021
	(1.70)	(-0.01)	(0.12)	(1.74)	(0.21)
Change in FFR (t-4 to t-3)	-0.473**	0.946	0.130	-0.428**	0.054
	(-2.13)	(1.54)	(1.18)	(-2.08)	(0.68)
Sum of Effects	-0.74***	4.16***	0.77***	-0.64***	0.50***
	(-4.69)	(7.88)	(7.52)	(-4.39)	(7.13)
High Rate	0.0273	-0.724***	-0.154***	0.026	-0.117***
	(0.89)	(-5.95)	(-6.15)	(0.97)	(-6.82)
High Rate × Change in FFR (t-1 to t)	-0.106	0.718**	0.210***	-0.071	0.126***
	(-1.01)	(2.33)	(2.81)	(-0.80)	(2.67)
High Rate × Change in FFR (t-2 to t-1)	0.191*	0.328	-0.102	0.156*	-0.037
	(1.99)	(0.92)	(-1.40)	(1.88)	(-0.71)
High Rate × Change in FFR (t-3 to t-2)	-0.198	-0.781*	0.002	-0.170	-0.034
	(-1.38)	(-1.86)	(0.02)	(-1.33)	(-0.63)
High Rate × Change in FFR (t-4 to t-3)	0.259***	-0.702**	-0.223***	0.191**	-0.113**
	(2.88)	(-2.05)	(-3.57)	(2.41)	(-2.61)
Sum of Effects	0.15*	-0.44	-0.11*	0.11	-0.06
	(1.72)	(-1.49)	(-1.65)	(1.42)	(-1.26)
Observations	129,340	129,340	129,340	129,340	129,340
R-squared	0.113	0.049	0.060	0.119	0.069
Bank FE and Quarter-of-year FE	Yes	Yes	Yes	Yes	Yes
Bank-level Controls	Yes	Yes	Yes	Yes	Yes
Macro Controls	Yes	Yes	Yes	Yes	Yes

B.2 Alternatively defined retail deposits

Recall that we defined retail deposits by subtracting wholesale deposits from total deposits, where wholesale deposits include large time deposits greater than $100,000, foreign deposits, and brokered deposits. Under this assumption, all checkable deposits are counted as retail deposits even though some of them are from non-retail savers. Here, we adopt a narrower definition of retail deposits ("*RD2*") excluding any non-interest bearing deposits, as the sum of interest-bearing demand deposits, MMDA and savings deposits, and small time deposits (less than $100,000), to confirm whether our findings are robust.

Table B.2 repeats the specifications for Tables 3, 4, 7, and 8 using this alternatively defined

RD2. In general, retail deposits fluctuate less (i.e., *Sum of Effects* is smaller) under this narrower definition than under our original definition. This may suggest that some non-interest bearing deposits decrease more than interest bearing deposits as the policy rate increases, since the spread between the policy rate and their return widens more. However, our estimates remain significant, both statistically and economically.

Table B.2: Alternative Definition of Retail Deposit

We report the robustness of our results using the alternative definition of retail deposit. Instead of our definition of RD in our main tables, we construct a new measure of retail deposits (RD2) excluding non interest bearing domestic deposits from RD. We report the sum of the estimates of the lagged FFR (*Sum of Effects*) in Tables 3, 4, 7, and 8.

Variables	(1) % Change in RD2	(2) Change in WSF to RD2	(3) Change in RD2 to TL(t-4)	
Table 3:				
Changes in FFR	-0.61***	0.89***	-0.44***	
	(-4.59)	(6.43)	(-4.39)	
Table 4:				
Changes in FFR	-0.61***	0.82***	-0.44***	
	(-4.52)	(6.35)	(-4.43)	
× *Large Bank*	-0.20	1.66***	0.10	
	(-0.92)	(3.46)	(0.87)	
Table 7:				
Changes in FFR	-0.62***	0.62***	-0.46***	
	(-3.96)	(4.01)	(-4.02)	
× *Young*	-0.25***	0.40***	-0.15**	
	(-2.87)	(3.89)	(-2.37)	
Table 8:	Old	Young	Old	Young
	(1)	(2)	(3)	(4)
Variables	Change in WSF to RD2		Change in RD2 to TL(t-4)	
Changes in FFR	0.67***	0.90***	-0.44***	-0.62***
	(3.92)	(7.15)	(-3.71)	(-5.06)
× *Large Bank*	0.38	2.58***	-0.23	-0.36**
	(0.41)	(4.94)	(-0.51)	(-2.05)

B.3 Decomposition of the policy rate change

We used changes in the FFR as the variable capturing the effect of monetary policy. Unlike asset prices, which are forward looking, savers' demand for retail deposits (i.e., bank money) would be a function of *current* interest rates, because they have fewer incentives to respond preemptively in anticipation of future rate changes (prior to the actual change in the offered rates). Hence, we predict that *expected* changes in the policy rate should still result in the bank funding responses that we predict.

Nonetheless, we can better control for macroeconomic news that coincides with a rate change by isolating the unexpected changes and focusing on the expected changes (Drechsler et al. (2017)). Following Kuttner (2001), we decompose *Change in FFR* into *Surprise Change* and *Expected Change*. We then repeat the specifications reported in Tables 3, 4, 7, and 8, replacing *Change in FFR* with *Surprise Change* and *Expected Change*. Table B.3 summarizes the estimation results, and our evidence of bank funding substitution is qualitatively unchanged, albeit slightly less significant.

B.4 Different sample selection

We verify the robustness of our results by constructing the sample differently. First, we rerun our analysis excluding deposits in banks' headquarters. Second, we limit our analysis to banks with assets in excess of $500 million. Third, we include all "single-branch" banks that we excluded previously.

In our analysis involving local banks or the deposit base of a bank, we use the FDIC Summary of Deposits data on banks' branch-level deposit distributions. As a robustness check, we rerun the analysis excluding deposits in banks' headquarters. We do this for two reasons. First, some banks tend to record all deposits under the headquarters even when they actually collect deposits from their branches. Second, the Summary of Deposits data include wholesale deposits in banks' branch-level deposits, but we ideally want to have data on retail deposits only. The noise in the data can be mitigated by excluding headquarters deposits because the wholesale deposits are more likely booked under the headquarters.

This will affect the sorting of local bank groups. The banks with a larger fraction of deposits in the headquarters are less likely to be a local bank, and the banks located in counties with a larger population of seniors are more likely to be sorted as a bank with a young deposit base. We rerun the tables that involve the definition of a local bank or the

Table B.3: Kuttner Measure of Surprise and Expected Changes

We report the robustness of our results using the surprise and the expected shock in the change in FFR using Kuttner (2001). We report the sum of the estimates of the lagged FFR (*Sum of Effects*) in Tables 3, 4, 7, and 8.

Variables	(1) % Change in RD	(2) % Change in WSF	(3) Change in WSF to RD	(4) Change in RD to TL(t-4)	(5) Change in WSF to TL(t-4)	
Table 3:						
Surprise (t-4 to t-1)	-0.022	0.206***	0.016*	-0.012	0.010**	
	(-0.75)	(3.23)	(1.65)	(-0.68)	(2.06)	
Expected (t-4 to t-1)	-0.014**	0.067***	0.023***	-0.018*	0.017***	
	(-1.99)	(3.66)	(4.21)	(-1.92)	(4.08)	
Table 4:						
Surprise (t-4 to t-1)	-0.022	0.068	0.015***	-0.012	0.016	
	(-0.80)	(0.35)	(4.05)	(-0.09)	(1.13)	
× *Large Bank*	0.013	0.204	0.022**	0.010*	0.010**	
	(0.40)	(-1.29)	(2.48)	(-1.95)	(1.99)	
Expected (t-4 to t-1)	-0.014**	-0.027***	0.021	-0.019	0.005	
	(-1.99)	(3.13)	(1.07)	(-0.71)	(1.09)	
× *Large Bank*	-0.008	0.026***	0.029	-0.001	0.016***	
	(-0.93)	(3.64)	(1.62)	(0.50)	(4.00)	
Table 7:						
Surprise (t-4 to t-1)	-0.022	0.149**	0.015	-0.018	0.009	
	(-0.78)	(2.04)	(1.16)	(-0.66)	(1.13)	
× *Young*	-0.009	0.037	0.016	-0.009	0.011	
	(-0.58)	(0.49)	(1.31)	(-0.64)	(1.40)	
Expected (t-4 to t-1)	-0.013**	0.060***	0.013***	-0.012**	0.008***	
	(-2.00)	(3.03)	(3.15)	(-2.07)	(2.89)	
× *Young*	-0.005	0.012	0.005	-0.004	0.002	
	(-1.18)	(0.80)	(1.53)	(-1.00)	(1.00)	
Table 8:	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Change in WSF to RD		Change in RD to TL(t-4)		Change in WSF to TL(t-4)	
Surprise (t-4 to t-1)	0.015	0.026	-0.017	-0.029	0.011	0.015
	(1.13)	(1.57)	(-0.66)	(-0.83)	(1.42)	(1.51)
× *Large Bank*	0.088	0.029	-0.010	0.026	0.016	0.029
	(1.18)	(0.73)	(-0.19)	(1.18)	(0.32)	(1.54)
Expected (t-4 to t-1)	0.014***	0.015***	-0.011*	-0.016**	0.008***	0.010***
	(3.51)	(3.36)	(-1.93)	(-1.96)	(3.36)	(3.28)
× *Large Bank*	-0.014	0.048***	0.006	-0.016**	-0.002	0.008
	(-0.71)	(3.47)	(0.43)	(-2.45)	(-0.17)	(1.17)

definition of a bank's deposit base. Table B.4 reports the results analogous to those in Tables 7 and 8. Our results are robust.

Next, we rerun our analysis using only large banks with an average asset size above $500 million. Although we are exploiting cross-sectional variation to identify the underlying channel, we attempt to confirm that the results are not driven solely by small banks. Note that the restriction drops a significant number of local banks from our sample. Consequently we re-estimate tables that do not use the definition of a local bank. Table B.5 reports results

Table B.4: Excluding Headquarters Deposits

We report the robustness of our results excluding headquarters deposits when we use the Summary of Deposits to define a local bank and the banks with a young deposit base. Panel A reports the sum of the estimates of the lagged FFR (*Sum of Effects*) in Table 7, and Panel B reports the sum of the estimates of the lagged FFR (*Sum of Effects*) in Table 8.

Panel A: Table 7	(1)	(2)	(3)	(4)	(5)	
	% Change in	% Change in	Change in	Change in RD	Change in WSF	
Variables	RD	WSF	WSF to RD	to TL(t-4)	to TL(t-4)	
Changes in FFR	-0.696***	2.966***	0.527***	-0.634***	0.315***	
	(-3.60)	(4.41)	(3.51)	(-3.53)	(3.01)	
× *Young*	-0.211***	0.955**	0.298***	-0.166**	0.186***	
	(-2.66)	(2.12)	(3.89)	(-2.39)	(3.51)	
Panel B: Table 8	Old	Young	Old	Young	Old	Young
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Change in WSF to RD		Change in RD to TL(t-4)		Change in WSF to TL(t-4)	
Changes in FFR	0.489***	0.767***	-0.539***	-0.865***	0.302***	0.476***
	(3.00)	(6.22)	(-3.00)	(-4.41)	(2.66)	(5.39)
× *Large*	0.286	1.683***	0.133	-0.393***	-0.108	0.426**
	(0.57)	(5.79)	(0.39)	(-3.03)	(-0.37)	(2.52)

analogous to those in Tables 3 and 4. Our results are robust.

Table B.5: Banks Size Above 500 Millions

We report the robustness of our results only with banks size above 500 million. Panel A reports the sum of the estimates of the lagged FFR (*Sum of Effects*) in Table 3 and Panel B reports the sum of the estimates of the lagged FFR (*Sum of Effects*) in Table 4.

Panel A: Table 3	(1)	(2)	(3)	(4)	(5)
	% Change in	% Change in	Change in	Change in RD	Change in WSF
Variables	RD	WSF	WSF to RD	to TL(t-4)	to TL(t-4)
Changes in FFR	-0.970***	2.884***	0.969***	-0.756***	0.439***
	(-4.36)	(4.42)	(4.68)	(-3.99)	(3.20)
Panel B: Table 4	(1)	(2)	(3)	(4)	(5)
	% Change in	% Change in	Change in	Change in RD	Change in WSF
Variables	RD	WSF	WSF to RD	to TL(t-4)	to TL(t-4)
Changes in FFR	-0.946***	2.817***	0.875***	-0.747***	0.405***
	(-4.32)	(4.29)	(4.26)	(-3.94)	(2.95)
× *Large*	-0.491	1.409**	2.138***	-0.177	0.793***
	(-1.14)	(2.04)	(3.06)	(-0.59)	(3.05)

Finally, note that we drop all "single-branch" banks from our main analysis to exclude very small banks that exclusively rely on retail deposits. We re-estimate all our tables to include all "single-branch" banks and find that our results are robust. The results are available from the authors upon request.

B.5 Extended sample analysis

As discussed in section 3.7., we extend our time series to include more recent years, ending in 2017:IV. We re-estimate our major regressions reported in Tables 3, 4, 7, and 8 using the extended time period. Our results are qualitatively similar although less significant. The only exception is the result for Table 7, where we compare banks with more senior depositors to those with fewer senior depositors.

Table B.6: Extended Sample Analysis

We report the robustness of our results using a sample period up to 2017. We report the sum of the estimates of the lagged FFR (*Sum of Effects*) in Tables 3, 4, 7, and 8.

Variables	(1) % Change in RD	(2) % Change in WSF	(3) Change in WSF to RD	(4) Change in RD to TL(t-4)	(5) Change in WSF to TL(t-4)	
Table 3:						
Changes in FFR	-0.39**	3.07***	0.40**	-0.35**	0.30***	
	(-2.08)	(5.21)	(2.23)	(-2.16)	(3.00)	
Table 4:						
Changes in FFR	-0.38**	3.10***	0.35**	-0.35**	0.29***	
	(-2.07)	(5.20)	(2.02)	(-2.19)	(2.86)	
× *Large Bank*	-0.19	-0.62	0.99***	0.01	0.35***	
	(-1.32)	(-1.20)	(3.81)	(0.11)	(2.90)	
Table 7:						
Changes in FFR	-0.35**	2.34***	0.11	-0.33**	0.11	
	(-2.07)	(4.08)	(0.73)	(-2.25)	(1.29)	
× *Young*	0.001	0.39	0.07	0.01	0.08	
	(0.00)	(0.97)	(0.50)	(0.05)	(1.32)	
Table 8:	Old	Young	Old	Young	Old	Young
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Change in WSF to RD		Change in RD to TL(t-4)		Change in WSF to TL(t-4)	
Changes in FFR	0.13	0.09	-0.23	-0.38*	0.14	0.15
	(0.87)	(0.39)	(-1.54)	(-1.77)	(1.64)	(1.27)
× *Large Bank*	0.87*	1.47***	-0.01	-0.36***	0.36	0.45***
	(1.66)	(2.90)	(-0.03)	(-2.85)	(1.22)	(2.58)

B.6 Other Supporting Tables and Figures

Table B.7: Summary Statistics of Bank and MSA Characteristics

We report the summary statistics of bank and MSA characteristics. Panel A reports the summary statistics of local banks and non-local banks. We report total assets, liquid asset ratio, capital ratio, RE loan to total loan ratio, CI loan to total loan ratio, total loan growth, wholesale funding to retail deposit ratio, retail deposit to total liabilities ratio, wholesale funding to total liabilities ratio, and securitization ratio, which is the bank-level measure of securitization activity using Loutskina (2011). All numbers are reported in percentage (%) except total assets which is in million dollars ($ mils). We report the t-statistics of the difference across two groups. Panel B reports the summary statistics of young and old MSA. We report population, income per capita, unemployment rate, housing supply elasticity, population density, the fraction of married population, the fraction of population with high education (bachelor and above), and bank competition in the market (Herfindahl index of bank deposits). We report both the fractions from American Community Survey (ACS) and Current Population Survey (CPS).

Panel A: Local Banks vs Non-Local Banks

	Total Assets ($ mils)	Liquid Asset Ratio	Capital Ratio	RE / Total Loan Ratio	CI /Total Loan Ratio	Total Loan Growth	WSF to RD	RD / Total Liabilities	WSF / Total Liabilities	Securitization
Local Banks	468.35	34.70	9.51	64.39	10.36	8.12	22.51	0.82	0.17	0.27
Non-Local Banks	12,212.30	30.70	9.09	61.38	17.02	8.65	30.07	0.77	0.21	0.25
Difference (t-stats)	*(-4.10)*	*(7.67)*	*(4.20)*	*(3.56)*	*(-10.32)*	*(-1.80)*	*(-7.93)*	*(9.07)*	*(-8.30)*	*(5.97)*

Panel B: Characteristics of Young MSA vs Old MSA

	Population	Income per Capita	Unemp Rate (%)	Housing Supply Elasticity	Population Density	ACS (%)		CPS (%)		Bank Herfindahl
						Married	> Bachelor	Married	> Bachelor	
Young MSA	789,382	28.32	5.73	2.46	231.55	39.04	18.26	41.38	18.91	0.21
Old MSA	508,309	28.02	5.97	2.58	231.77	41.66	16.77	43.13	16.74	0.20
Difference (t-stats)	*(1.90)*	*(0.58)*	*(-1.09)*	*(-0.73)*	*(-0.01)*	*(-8.08)*	*(2.31)*	*(-3.45)*	*(2.48)*	*(2.06)*

Table B.8: Banks' Funding Composition and the Federal Funds Rate: Local Bank Subsample with MSA Controls

We report the panel regression estimates in Table 3 only with local banks with MSA controls. We define local banks as banks with more than 70% of deposits on average from one MSA. The dependent variables are the percentage change in the retail deposits of a bank (% Change in RD) in column (1), the percentage change in the wholesale funding of a bank (% Change in WSF) in column (2), the change in the wholesale funding to retail deposits ratio (Change in WSF to RD) in column (3), the change in RD from the previous quarter to the total liabilities of four quarters prior (Change in RD to TL(t-4)) in column (4), and the change in WSF from the previous quarter to the total liabilities of four quarters prior (Change in WSF to TL(t-4)) in column (5). Independent variables include 4 lags of the change in the FFR, bank-level controls (RE Loan to Total Loan Ratio, CI Loan to Total Loan Ratio, log Assets, Capital Ratio, Bank-level Total Loan Growth, Liquid Asset Ratio, Securitization) and macro controls (CP Spread, Term Premium, Aggregate-level Total Loan Growth), and MSA-level controls (log Population, Income Per Capita, Unemployment Rate). We use 4-quarters-lagged bank characteristics, macro variables, and MSA-level controls in our analysis. We also include bank fixed effects and quarter-of-year fixed effects (for seasonality). We report the sum of the estimates of the lagged FFR and the *t*-statistic of the sum. The table reports point estimates with *t*-statistics in parentheses. All standard errors are clustered at the year-quarter level. ***, **, * denote 1%, 5%, and 10% statistical significance.

Variables	(1) % Change in RD	(2) % Change in WSF	(3) Change in WSF to RD	(4) Change in RD to TL(t-4)	(5) Change in WSF to TL(t-4)
Change in FFR (t-1 to t)	-0.930***	1.199*	0.460***	-0.812***	0.208**
	(-4.15)	(1.90)	(3.55)	(-3.95)	(2.27)
Change in FFR (t-2 to t-1)	0.186	2.042**	0.198	0.148	0.234**
	(0.68)	(2.58)	(1.37)	(0.58)	(2.48)
Change in FFR (t-3 to t-2)	0.421	-0.123	-0.010	0.402	-0.007
	(1.43)	(-0.14)	(-0.06)	(1.45)	(-0.06)
Change in FFR (t-4 to t-3)	-0.518**	0.662	0.065	-0.484**	-0.001
	(-2.27)	(1.02)	(0.55)	(-2.27)	(-0.01)
Sum of Effects	-0.84***	3.78***	0.71***	-0.75***	0.43***
	(-5.26)	(8.30)	(7.45)	(-5.04)	(7.01)
log Population (MSA)	2.902***	7.968***	0.082	2.850***	0.857**
	(3.84)	(3.23)	(0.17)	(4.43)	(2.45)
Income Per Capita (MSA)	0.034*	-0.189***	0.012	0.037**	0.010
	(1.86)	(-3.45)	(1.33)	(2.22)	(1.61)
Unemployment Rate (MSA)	-0.106**	-0.640***	-0.059*	-0.093**	-0.078***
	(-2.30)	(-4.70)	(-1.82)	(-2.31)	(-3.94)
Observations	86,060	86,060	86,060	86,060	86,060
R-squared	0.109	0.050	0.057	0.117	0.070
Bank FE and Quarter-of-year FE	Yes	Yes	Yes	Yes	Yes
Bank-level Controls	Yes	Yes	Yes	Yes	Yes
Macro Controls	Yes	Yes	Yes	Yes	Yes

Table B.9: All Banks

We report the panel regression estimates in Table 7 and Table 8 with all banks. Panel A reports the panel regression estimates of the relationship between the change in banks' funding composition and the change in the federal funds rate, by the deposit base of local banks. The dependent variables are the percentage change in the retail deposits of a bank (% Change in RD) in column (1), the percentage change in the wholesale funding of a bank (% Change in WSF) in column (2), the change in the wholesale funding to retail deposits ratio (Change in WSF to RD) in column (3), the change in RD from the previous quarter to the total liabilities of four quarters prior (Change in RD to TL(t-4)) in column (4), and the change in WSF from the previous quarter to the total liabilities of four quarters prior (Change in WSF to TL(t-4)) in column (5). Using the county-level fraction of seniors (whose age is above 65) from the Census, we construct the deposit-weighted fraction of seniors for each bank. Young dummy is 1 if the average deposit-weighted fraction of seniors of a bank is below the median and is 0 otherwise. Our main variable of interest is the interaction between the federal funds rate and the Young dummy. Other independent variables include bank-level controls (RE Loan to Total Loan Ratio, CI Loan to Total Loan Ratio, log Assets, Capital Ratio, Bank-level Total Loan Growth, Liquid Asset Ratio, Securitization), macro controls (CP Spread, Term Premium, Aggregate-level Total Loan Growth), and MSA-level controls (log Population, Income Per Capita, Unemployment Rate). We use 4-quarters-lagged bank characteristics, macro variables, and MSA-level controls in our analysis. For brevity, we do not report the controls in the table. We also include bank fixed effects and quarter-of-year fixed effects (for seasonality). Panel B reports the panel regression estimates of the relationship between the change in banks' funding composition and the change in the federal funds rate, by the deposit base of local banks and by bank size. The dependent variables are the change in wholesale funding to retail deposits ratio (Change in WSF to RD) in columns (1)–(2), the change in RD from the previous quarter to the total liabilities of four quarters prior (Change in RD to TL(t-4)) in columns (3)–(4), and the change in WSF from the previous quarter to the total liabilities of four quarters prior (Change in WSF to TL(t-4)) in columns (5)–(6). We report the sums of the estimates of the lagged FFR and the interaction terms with the t-statistic of the sums. The table reports point estimates with t-statistics in parentheses. All standard errors are clustered at the year-quarter level. ***, **, * denote 1%, 5%, and 10% statistical significance.

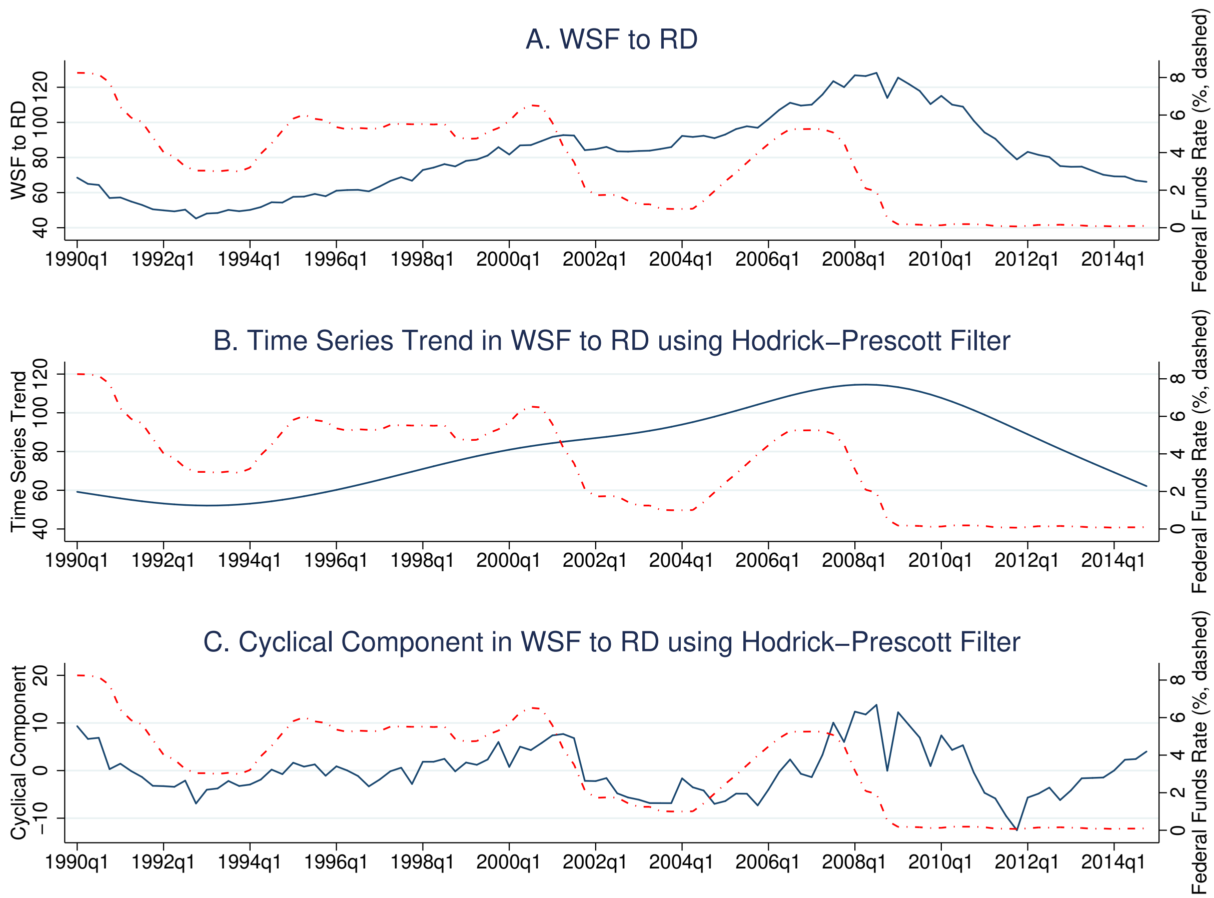
Panel A: Table 7 with All Banks	(1)	(2)	(3)	(4)	(5)
Variables	% Change in RD	% Change in WSF	Change in WSF to RD	Change in RD to TL(t-4)	Change in WSF to TL(t-4)
Change in FFR (t-1 to t)	-0.839***	1.650**	0.461***	-0.731***	0.235**
	(-3.75)	(2.08)	(3.47)	(-3.55)	(2.41)
Change in FFR (t-2 to t-1)	0.149	2.064**	0.102	0.099	0.165*
	(0.53)	(2.44)	(0.75)	(0.38)	(1.81)
Change in FFR (t-3 to t-2)	0.429*	-0.963	-0.057	0.430*	-0.064
	(1.73)	(-1.08)	(-0.39)	(1.83)	(-0.61)
Change in FFR (t-4 to t-3)	-0.344	0.921	0.076	-0.340	0.054
	(-1.58)	(1.42)	(0.66)	(-1.66)	(0.67)
Sum of Effects	-0.61***	3.67***	0.58***	-0.54***	0.39***
	(-4.22)	(6.25)	(5.34)	(-4.08)	(5.10)
Young	0.045	0.602***	0.080	0.050	0.085**
	(0.65)	(2.81)	(1.42)	(0.79)	(2.28)
Young × Change in FFR (t-1 to t)	-0.053	-0.845	-0.031	-0.035	-0.067
	(-0.42)	(-1.12)	(-0.34)	(-0.30)	(-0.92)
Young × Change in FFR (t-2 to t-1)	0.018	0.353	0.207*	0.027	0.161*
	(0.12)	(0.46)	(1.73)	(0.19)	(1.81)
Young × Change in FFR (t-3 to t-2)	-0.033	1.582**	0.154	-0.055	0.158*
	(-0.21)	(2.06)	(1.40)	(-0.38)	(1.88)
Young × Change in FFR (t-4 to t-3)	-0.136	-0.304	0.002	-0.086	-0.055
	(-1.14)	(-0.54)	(0.02)	(-0.80)	(-0.84)
Sum of Effects	-0.20*	0.79	0.33***	-0.15	0.20***
	(-1.71)	(1.37)	(3.85)	(-1.37)	(2.98)
Observations	129,480	129,480	129,480	129,480	129,480
R-squared	0.113	0.048	0.059	0.119	0.069
Bank FE and Quarter-of-year FE	Yes	Yes	Yes	Yes	Yes
Bank-level Controls	Yes	Yes	Yes	Yes	Yes
Macro Controls	Yes	Yes	Yes	Yes	Yes

Table B.9 continues

Panel B: Table 8 with All Banks						
	Old	Young	Old	Young	Old	Young
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Change in WSF to RD		Change in RD to TL(t-4)		Change in WSF to TL(t-4)	
Change in FFR (t-1 to t)	0.411***	0.393***	-0.629***	-0.895***	0.207**	0.170*
	(2.93)	(3.03)	(-3.33)	(-4.22)	(2.04)	(1.82)
Change in FFR (t-2 to t-1)	0.072	0.333**	0.069	0.138	0.141	0.317***
	(0.48)	(2.17)	(0.29)	(0.51)	(1.40)	(3.08)
Change in FFR (t-3 to t-2)	0.027	0.026	0.314	0.504*	-0.004	0.049
	(0.17)	(0.15)	(1.38)	(1.68)	(-0.04)	(0.43)
Change in FFR (t-4 to t-3)	0.058	0.082	-0.267	-0.482**	0.046	0.025
	(0.49)	(0.63)	(-1.44)	(-2.05)	(0.58)	(0.25)
Sum of Effects	0.57***	0.84***	-0.51***	-0.74***	0.39***	0.56***
	(4.95)	(8.82)	(-3.94)	(-4.62)	(4.83)	(8.72)
Large Bank	0.184	0.427*	0.139	-0.349	-0.023	0.063
	(0.65)	(1.76)	(0.69)	(-1.66)	(-0.12)	(0.47)
Large Bank × Change in FFR (t-1 to t)	0.163	1.019***	0.575***	-0.033	0.024	0.313**
	(0.43)	(3.00)	(2.84)	(-0.18)	(0.09)	(2.10)
Large Bank × Change in FFR (t-2 to t-1)	0.435	-0.028	-0.220	0.296	0.449	0.287
	(1.01)	(-0.05)	(-0.85)	(1.13)	(1.57)	(1.33)
Large Bank × Change in FFR (t-3 to t-2)	-0.808	-0.083	0.049	-0.041	-0.537	-0.132
	(-1.65)	(-0.21)	(0.20)	(-0.20)	(-1.48)	(-0.65)
Large Bank × Change in FFR (t-4 to t-3)	0.412	0.131	-0.202	-0.185	0.028	-0.193
	(1.04)	(0.42)	(-1.00)	(-1.28)	(0.10)	(-1.33)
Sum of Effects	0.20	1.04***	0.20	0.04	-0.04	0.28**
	(0.55)	(4.15)	(1.14)	(0.28)	(-0.16)	(2.29)
Observations	68,435	61,045	68,435	61,045	68,435	61,045
R-squared	0.058	0.071	0.123	0.123	0.064	0.086
Bank FE and Quarter-of-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Bank-level Controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes

Figure B.1: Wholesale Funding to Retail Deposits Ratio

The figure plots the time series of the wholesale funding to retail deposits ratio (WSF to RD). As in Figure 2, Panel A plots the aggregate WSF to RD, which we calculate by aggregating retail deposits and wholesale funding, by quarter, for all banks. The blue solid line plots the aggregate WSF to RD and the red dashed line plots the federal funds rate quarterly from 1990 to 2014. Panel B and Panel C plot the time series trend and cyclical component in WSF to RD using the Hodrick-Prescott filter.



C Construction of the Liquidity Ratio

In this section, we describe our construction of the *Liquidity Ratio* of a bank based on the publicly available data sources (FR Y-9C form). *Liquidity Ratio* is conceptually similar to, and tries to approximate, the LCR by calculating the potential liquidity stress of a bank during a liquidity stress scenario. We limit our analysis to the entities reporting the FR Y-9C, with total assets larger than $1 billion, after 1995Q1 for consistency in the variable definitions.

The *Liquidity Ratio* consists of two parts: The denominator is the sum of liabilities and off-balance-sheet exposures, weighted by liquidity adjustments reflecting the run-risk of each liability type or off-balance-sheet exposure; the numerator is the sum of assets, weighted by liquidity adjustments reflecting the market liquidity of each asset type. Adjusted liabilities grow when the expected funding outflow is higher during times of stress, while adjusted assets shrink when the expected price decline is greater in a market illiquidity event. Thus, a bank is more exposed to liquidity risks if its *Liquidity Ratio* is lower.[7]

$$\begin{aligned}\text{Liquidity Ratio} &= \frac{\text{potential liquidity inflow}}{\text{potential liquidity outflow}} \\ &= \frac{\text{liquidity adjusted assets}}{\text{liquidity adjusted liabilities and off balance sheet exposures}}\end{aligned}$$

Appendix C Table 1 summarizes liquidity adjustments used in the calculation of the *Liquidity Ratio*, which adopts some of the LCR assumptions when possible.

[7] This is thus similar to LCR which is the ratio of the stock of high quality liquid assets (HQLA) to potential net cash-flow over the next 30-calendar-day liquidity stress scenario. However, there are differences in the liquidity adjustments for certain assets and liability classes from those used in the LCR because we use publicly available data. We also exclude any derivative exposures due to data limitations.

Table C.1: Liquidity Adjustments for Liquidity Ratio Calculation

We report the liquidity adjustments for the balance sheet items based on the FR Y-9C. *Liquidity Ratio* is defined as the ratio between the liquidity-adjusted assets and the liquidity-adjusted liabilities. Liquidity-adjusted assets are the sum of the balance sheet assets weighted by respective liquidity adjustments. Liquidity-adjusted liabilities and off-balance-sheet exposures are calculated in a similar way. Stable deposits include money market deposit accounts and other savings accounts as well as the the time deposits of less than $100,000. All other deposits are considered to be non-stable.

Balance Sheet Items	Liquidity Adjustment
Assets	
Cash and balances due from depository institutions	1
Federal funds sold and securities purchased under agreements to resell	1
Treasury	1
Agency MBS	0.9
Non-agency MBS	0.75
Agency securities	0.85
Municipal securities	0.85
Other securities	0.5
Real Estate Loans	0.3
Commercial and Industrial Loans	0.1
Other Loans	0.2
Liability	
Federal funds purchased and securities sold under agreements to resell	1
Trading Liabilities	0.5
Commercial Paper	0.5
Other borrowed money, maturity less than 1 year	0.4
Deposit, non stable	0.15
Deposit, stable	0.1
Off Balance Sheet Items	
Unused Commitments	0.1
Standby letters of credit	0.1
Securities underwriting	0.3
Securities lent	0.1

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