Effects of Deposits on Banks' Choices of Balance-Sheet Composition*

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Abstract

This paper examines, theoretically and empirically, the impact of deposits on banks' balance-sheet composition. I propose a novel mechanism where a bank's wholesale borrowing constraint determines the effect of deposits on the bank. Unconstrained banks treat deposits and wholesale funding as substitutes. However, deposits relax the wholesale borrowing constraint because deposits are effectively subordinate to wholesale debt. Thus for constrained banks, deposits and wholesale funding can be complements. For such banks, an increase in deposits enables them to borrow more aggressively from wholesale creditors and hence issue more loans. Empirically, using the cross-sectional variation in deposit fluctuations driven by monetary policy rate changes, I estimate the causal effect of deposits on banks' balance-sheet composition. The empirical evidence supports the model predictions. In response to a 1% increase in deposit growth as a share of assets, unconstrained banks *reduce* wholesale funding growth by 0.2% of assets, while constrained banks *increase* their wholesale funding growth by 0.76% of assets. At the aggregate level of the banking sector, I find that deposit shocks account for a significant share of the variance of wholesale funding and loan growth. My findings also shed light on how monetary policy affects bank funding composition and vulnerability.

Keywords: Deposits, Wholesale Funding, Balance Sheet, Monetary Policy

JEL Codes: E43, E44, E52, G11, G21

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1 Introduction

Banks rely on both depositors and wholesale funding markets to finance the assets on their balance sheets. While there is extensive research on how fluctuations in wholesale funding could affect financial intermediaries' investment decisions, the existing literature largely ignores the effects of exogenous innovations to households' desire for bank deposits on banks' choices of balance-sheet composition. This paper studies, both theoretically and empirically, the relationship between deposits and banks' balance-sheet composition.

Since banks borrow from both depositors and wholesale funding creditors, their balance-sheet composition is heavily dictated by their ability to obtain funding from these two sources. This paper first examines the economic mechanism through which the supply of deposits from households affects banks' borrowing from the wholesale market. It then explores how we can empirically test a causal relation between deposits and wholesale funding. Lastly, the paper investigates how deposits affect the asset choices of banks.

I propose a novel channel for deposits to affect wholesale funding that is based on financial constraints imposed by wholesale creditors on banks. My model builds on the characteristics of the deposit franchise and household deposits. The deposit franchise allows banks to borrow cheaply from depositors. All else equal, cheap borrowing drives out expensive borrowing. This mechanism makes deposits and wholesale funding substitutes; an influx of cheaper deposits reduces the bank's need to borrow from the expensive wholesale market. However, owing to deposit insurance and the sluggish reactions of households, deposits are effectively functioning as a subordinated long-term debt from the perspective of a bank's creditors in the wholesale market. Therefore, more deposits provide additional protection to wholesale creditors, enabling constrained banks to borrow more aggressively in the wholesale market. As a result, contrary to the existing literature that posits a substitution between deposits and wholesale funding, this paper demonstrates that more deposits stimulate more wholesale borrowing when banks' borrowing constraint is binding.

I provide a model of this mechanism. The model builds on the framework presented in Drechsler et al. (2017), which features deposit supply variation induced by monetary policy changes. The model posits an economy consisting of two sectors—banks and households, with banks exercising significant market power over the deposit market. Banks generate profits by acquiring funds from depositors and wholesale funding creditors, and then investing in risky loans. Due to the high concentration of the banking sector, the deposit rate is set below the monetary policy rate, giving rise to a deposit spread that represents the cost of holding liquidity for households. Households maximize utility by investing in cash, deposits, and bonds, according to relative prices and liquidity services offered by the three types of assets. When policy rates change, the deposit spread varies due to a non-constant elasticity of deposits. The change influences the opportunity cost of holding deposits, prompting fluctuations in household deposit supplies.

The effective long maturity of deposits makes wholesale funding enjoy de facto seniority in practice. Adams et al. (2021) finds evidence for depositors' limited attention to information. Hence, as documented in Huang and Ratnovski (2011), in the event of a bank's bankruptcy, wholesale funding creditors run and are able to exit without significant losses. To limit the risk of default, wholesale creditors impose a borrowing constraint on their lending. I demonstrate that, when the borrowing constraint is not binding, more deposits reduce wholesale funding because the cost of wholesale funding is higher than that of deposits. However, when the constraint is binding, an increase in deposits eases the funding constraint, causing banks to borrow more aggressively from the wholesale funding market.

The model establishes a causal relationship between deposits and wholesale funding, contingent on banks' financial constraints. However, empirically estimating the causal effects of deposits is challenging. The challenge arises because changes in wholesale funding and in deposits are both correlated with changes in macroeconomic and bank-specific economic conditions. Consequently, regressing changes in wholesale funding on changes in deposits, where the regression coefficient is allowed to vary based on the magnitude of the bank's financial constraint, results in biased estimates. Motivated by Drechsler et al. (2017), I use the instrumental variable approach to address these challenges.

The model sheds light on how monetary policy, when interacted with bank market concentration, can be used to identify deposit shocks and to explore the effects of deposits on wholesale funding. The cross-sectional variation in bank market concentration facilitates identification. When the market is more concentrated, banks set the deposit rate lower and make smaller adjustments to the deposit rate when policy rates change. Consequently, banks operating in a more concentrated market increase their deposit spread by more when the policy rate rises and decrease the spread by more when the policy rate drops, in comparison to banks in a less concentrated market. This leads to variations in deposit inflows and outflows across banks, which can be used to identify the impact of deposits on wholesale funding and other balance-sheet components.

I estimate the causal effect of deposits on balance-sheet composition using this cross-sectional variation in bank market concentration. The instrumental variable for deposits is monetary policy rate changes interacted with bank market concentration. The underlying assumption is that the effects of monetary policy on other components of banks' balance sheets, other than deposits, are not correlated with bank market power. For instance, a surge in policy rate may reduce loan demand by increasing firms' cost of funding, but large-market-power banks should not experience a larger (or smaller) decline in loan demand than small-market-power ones. Data are drawn from call reports covering 1994 through 2019. I find that, on average, a 1% increase in deposit growth relative to assets leads to a 0.2% decrease in wholesale funding growth relative to assets. Importantly, the model implies that this negative relation will be weaker, or even reversed, for financially constrained banks. To gauge a bank's constraint, I compute the wholesale funding to deposit ratio as a proxy. A high ratio indicates that a bank has rich investment opportunities relative to its deposit base. Such banks are more likely to be financially constrained than are banks that borrow relatively little from the wholesale market. The empirical results confirm this view. Banks with the highest ratios of wholesale funding to deposits raise their wholesale funding growth relative to assets by 0.7% in response to a 1% increase in deposit growth relative to assets.

I next investigate the impact of deposits on banks' assets. The analysis reveals that when banks receive a positive deposit shock, they issue more loans and lend more in the federal funds and repo markets. Banks that face tighter constraints respond more significantly to deposit shocks compared to unconstrained banks. Such heterogeneity supports the idea that deposits can relax banks' financial constraint. This finding emphasizes the role of deposits in stimulating lending activities and shaping banks' asset composition, especially for those facing tighter financial constraints.

Finally, I explore aggregate implications of deposit shocks of the whole banking sector using my identified parameters. I construct aggregate deposit shocks, allocate them to individual banks, and apply identified parameters to individual banks based on their financial constraints. I find that a 1% increase in deposit growth leads to an increase in loans growth ranging from 0.58% to 0.88% and an increase in wholesale borrowing growth between 1.12% and 3.31%, according to the deposit share of constrained banks. My findings also indicate that deposit shocks account for 35% of the variance of wholesale funding growth and 49% of the variance of loan growth of the banking sector.

My results are important for four reasons. Firstly, I provide empirical evidence on the causal relation from deposits to bank balance-sheet behavior, demonstrating that banks adjust their wholesale funding borrowing and lending activities in response to fluctuations in deposits. Secondly, the impact of deposits is contingent on banks' financial constraints. The effects are more pronounced for banks facing tighter constraints compared to those that are unconstrained. Thirdly, I shed light on the indirect impact of monetary policy on wholesale funding through the deposit channel. Specifically, I demonstrate that when there is a monetary policy change, the relationship between deposits and wholesale funding depends on the constraint conditions of banks. If banks' borrowing constraints are binding, the effects of monetary policy are amplified through the deposit channel. Finally, the paper also suggests that as the banking sector becomes more concentrated, the impact of monetary policy on banks' balance-sheet composition via deposits will intensify. If more banks are financially constrained, in this more concentrated industry, the effect of monetary policy will become even stronger.

Related Literature. This paper builds upon several strands of literature. First, it contributes to the understanding of the relationship between deposits and wholesale funding. Choi and Choi (2021) explores the substitution between deposits and wholesale funding induced by tightening monetary policy. Acharya and Mora (2015) examines the substitution between core and non-core funding during bank stress when wholesale funding flows out. Hahm et al. (2013) studies the relationship between non-core funding reliance and financial stability. All these papers focus on the substitution between the two funding sources. By contrast, this paper proposes and investigates the potential complementary relationship between deposits and wholesale funding under the specific condition of banks' wholesale borrowing constraint being binding. By theoretically and empirically exploring this unique aspect, this research adds new insights to the existing literature on the dynamics of bank funding and balance-sheet composition.

Second, this paper contributes to the literature studying the causal effect of deposits. Since bank deposits are endogenous to the overall economic environment which may in turn affect bank lending, estimating the causal effect of deposits poses significant identification challenges. Existing studies are relatively scarce and mainly focus on finding quasi-natural experiments driving deposit shocks. A recent attempt is Carletti et al. (2021), which exploits a reform of investment income tax in Italy in 2011 that induced households to substitute bank bonds with deposits and finds that increases in deposits expand the supply of credit lines. Gilje et al. (2016) argues that the shale-boom discoveries in the U.S. resulted in wealth windfalls, which led to large increases in local bank deposits. They demonstrate that banks export these liquidity windfalls into non-boom markets and increase mortgage lending when such banks have branches in both markets. While these studies focus on the effect of deposits on bank lending, my paper complements these studies by emphasizing the causal effect of deposits on wholesale funding, while also considering banks' financial constraints.

Third, it relates to the burgeoning macro finance literature investigating the role of financial intermediaries. Adrian and Boyarchenko (2012), He and Krishnamurthy (2013) and Brunnermeier and Sannikov (2014) are theoretical attempts exploring the role of financial intermediaries in explaining fluctuations in asset prices. Empirical studies in this field include Du et al. (2018), which analyses the effect of capital shocks of banks on asset prices and Adrian et al. (2013), Adrian and Shin (2014) and He et al. (2017), which proxy intermediary stochastic discount factor and examine their pricing power. Banks' behaviors in these papers are basically driven by their internal forces, such as shocks to their net worth in He and Krishnamurthy (2013), variation in their effective risk aversion in Danielsson et al. (2011), and changes in haircuts in Geanakoplos (2010) and Gorton and Metrick (2012). However, deposits are not typically considered as a driving force behind banks' behaviors in these studies. Since bank deposits primarily originate from households as documented in Hirtle and Stiroh (2007), ignoring the role of deposits weakens the role of households in altering the behavior of financial intermediaries in these papers. My paper complements this strand of literature by emphasizing the significance of households in affecting balance-sheet composition of intermediaries through deposits.

My research also relates to the literature studying the effect of monetary policy on banks' behavior with considering banks' market power. Drechsler et al. (2017) is the first paper to propose the deposit channel of monetary policy, using market power as a source of variation. Supera (2021) further studies how shifts in the policy rate affect the flow of time deposits and, consequently, banks' business lending. Wang et al. (2022) examines the quantitative impact of bank market power on the transmission of monetary policy through the banking system, using a structural estimation. While these papers address banks' lending decisions, my research provides a comprehensive view of all balance-sheet components, with a focus on the liability side – wholesale funding. Additionally, I incorporate and investigate how a financial constraint influences the impacts of deposits.

In addition, this paper is closely related to the literature on the inelasticity of bank deposits. Flannery (1982) describes core deposits as quasi-fixed factors of production for banks, and Hutchison and Pennacchi (1996) finds that deposit flows are insensitive to interest rates. One possible reason for this inelasticity is high switching cost, as investigated in Sharpe (1997), Kiser (2002), and Kim et al. (2003). Additionally, a recent study by Adams et al. (2021) provides direct evidence for limited consumer attention to information about competitive alternatives as a reason for stickiness by conducting randomized controlled trials. Rather than focusing on underlying reasons for the inelasticity of deposits, my paper studies its implications for financial constraints and banks' exposure to deposit shocks.

Finally, my paper also contributes to the literature on external financial constraints. Kashyap and Stein (1995) argues that since external funding is costly, deposits as the primary source of funding play a crucial role in banks' investment decisions. My paper argues that deposits are significant for banks not only because they directly provide funding, but also because they alleviate external financial constraints faced by banks. My paper quantitatively studies the causal effect of deposits on wholesale funding.

The rest of this paper is organized as follows: Section (2) presents the model. Section (3) describes the data used in the empirical analysis, and presents the identification strategy and empirical results. Section (4) discusses aggregate implications for the whole banking sector. Finally, Section (5) concludes.

2 Model

In this section, I present a model to explain the relationship between deposits and wholesale funding for banks, and how monetary policy changes, combined with a measure for bank market power, could be used to identify deposit shocks. The model has two important elements: borrowing constraints and bank market power. First, in this model, the key component generating the relationship between deposits and wholesale funding is a borrowing constraint imposed by wholesale funding creditors on banks. The borrowing constraint is a result of the riskiness of bank lending. As bank lending is risky, banks may not have sufficient assets to make creditors full repayment. Therefore, wholesale lenders protect themselves ex ante by limiting the amount of their lending, based on a maximum probability of incurring a loss. This limit acts as a financial constraint on a bank, possibly preventing the bank from taking profitable investment activities. An important feature of the borrowing constraint is that it is affected by deposits. Wholesale lenders are de facto senior claimants on bank assets because they will run before sluggish depositors react in case of default. As a result, more deposits increase bank assets, making wholesale funding creditors willing to lend more to banks. This translates to an increase in wholesale borrowing as deposits rise, if the constraint is binding. Second, for the purpose of identification, banks in the model have market power in the deposit market, which follows the framework established in Drechsler et al. (2017). Details on how bank market power helps with identification will be discussed later.

The model assumes an economy with two sectors: banks and households, spanning a single period. There exist N banks indexed by i. At time zero, each bank raises funds and makes loans. At time one, banks receive loan payoffs and pay their lenders. Banks have two sources of funding: deposits and wholesale market. Distinctive characteristics set these two funding sources apart. Firstly, banks exercise market power over the deposit market, while the wholesale funding market is competitive. Banks' market power over deposits stems from households' inelastic demand for deposits, which enables banks to charge a premium on deposits. Secondly, wholesale funds are more susceptible to withdrawals than deposits. The inertness of household deposits documented in the banking literature, coupled with the presence of deposit insurance, effectively confers seniority to wholesale funding in practice, as attested by Huang and Ratnovski (2011). Wholesale funding creditors have the upper hand in withdrawing funds before depositors react when banks approach bankruptcy. Notably, in bank failures of Continental Illinois, Northern Rock, and IndyMac, wholesale financiers were able to exit before retail depositors without significant losses. Moreover, as documented by Shin (2008) and Goldsmith-Pinkham and Yorulmazer (2010), the highly publicized retail run on Northern Rock ensued after the bank had almost depleted its liquid assets to satisfy the exit of short-term wholesale funds.

Lastly, as aforementioned, with the awareness of the riskiness of associated with bank loans, wholesale funding creditors impose a borrowing constraint on their lending activities, which ensures that the likelihood of default remains smaller than p, where p is an exogenously determined small number. By contrast, households do not take into account the risk profile of bank loans due to the presence of deposit insurance and hence do not impose any limitations on their lending.

Wholesale funding. Bank i borrows H_i in the wholesale funding market for unsecured debt. Since there is a positive probability of wholesale creditor losing money, wholesale lenders charge $\bar{r} + \mu$ on lending to banks, where $\bar{r}$ is the federal funds rate and μ is a constant compensating them for the small probability of default. Owing to the common exogenous probability p and the competitive market for wholesale lending, I treat μ for the probability of default that is fixed and exogenous. Specifically, the payment that Bank i must remit to wholesale lenders at the subsequent period is given by:

$$(\text{commitments to wholesale lenders})_i = H_i(1 + \bar{r} + \mu) \tag{1}$$

Deposits. Bank i acquires D_i in the market for insured household deposits. By exercising its market power, the bank pays an interest rate of $\bar{r} - s_i$ to depositors, where s_i is determined endogenously by the bank's deposit levels via the equilibrium characteristics of the model. These features will be expounded upon subsequently in this section.

Loans. Bank i employs borrowed funds to grant a quantity of loans L_i. The marginal revenue is decreasing in the amount of total loans, reflecting the idea of limited investment opportunities. It is worth reemphasizing that loans entail a certain degree of risk, implying that the time-one payoff is uncertain at time zero. This uncertainty gives rise to the borrowing constraint imposed by wholesale funding creditors, which will be illustrated later in detail. The time-one payoff stemming from these loans can be expressed as:

$$(\text{loan revenues})_i = L_i(1 + \bar{r} + g - \frac{c}{2}L_i) \tag{2}$$

where g is a random variable capturing the uncertainty in the payoff. Since g represents the incremental rate earned by banks through lending activities, it follows that $g < 1$. For the sake of mathematical tractability, g is assumed to follow a uniform distribution bounded below and above by g^L and g^H, with an expectation of

$$E(g) = \frac{1}{2}(g^L + g^H) \tag{3}$$

Both the mean the uncertainty of g are determined outside of the model.

Unsecured lenders acknowledge that their claims possess de facto seniority over those of depositors, thereby having the first claim on the bank loan revenues. These unsecured lenders are exposed to losses in the amount of

$$(\text{wholesale lender loss})_i = \max(0, (\text{commitments to wholesale lenders})_i - (\text{loan revenues})_i) \tag{4}$$

This equation assumes that the bank has no income other than loans revenues. I return to this assumption below.

Wholesale lenders are willing to lend to the bank under the condition that the likelihood of incurring losses does not exceed a predetermined exogenous probability p, where p is a small value approaching zero. This assumption shares the similarity in spirit with Brunnermeier and Pedersen (2009), where creditors control their value-at-risk (VaR). Moreover, implicit in this equation is the idea that wholesale funders possess comprehension of the equilibrium and, hence, are aware that the bank determines its deposit and loan levels.

The bank is risk-neutral, maximizing its expected payoff to owners. With limited liability, owners receive payoffs as

$$\Pi_i \equiv \max\left(0, \underbrace{L_i(1 + \bar{r} + g - \frac{c}{2}L_i)}_{\text{Loans revenues}} \underbrace{-H_i(1 + \bar{r} + \mu) - D_i(1 + \bar{r} - s_i)}_{\text{Cost of funding}}\right) \tag{5}$$

The bank chooses its unsecured borrowing H_i, deposits D_i and loans investment L_i to maximize the expected owner payoff,

$$E(\Pi_i)^* = \max_{D_i, H_i, L_i} E(\Pi_i) \tag{6}$$

$$= \max_{D_i, H_i, L_i} \text{Prob}(\Pi_i > 0) \times E(\Pi_i | \Pi_i > 0) \tag{7}$$

subject to the bank's loan constraint:

$$
\begin{aligned}
L_i &= D_i + H_i \qquad (8)\\
D_i &\geq 0\\
H_i &\geq 0
\end{aligned}
$$

and the banks' wholesale borrowing constraint:

$$
\text{Prob}\left(1 + \bar{r} + g - \frac{c}{2}L_i - \frac{H_i}{L_i}(1 + \bar{r} + \mu) \leq 0\right) \leq p \qquad (9)
$$

Constraint (8) suggests that, given a sufficient number of lending opportunities, the bank allocates all of its borrowed funds towards issuing risky loans. This is why the bank has only loan revenues in Equation (2). Although it is possible for the bank to obtain funds from depositors, abstain from borrowing in the wholesale funding market, and invest all of its funds in risk-free instruments, or for banks to borrow from depositors and lend out in the wholesale funding market, I disregard these scenarios by imposing the limitations expressed in Equation (8). Furthermore, Inequality (9) represents a requirement that Equation (4) maintains a positive value with a likelihood not surpassing p.

Plugging in the loan constraints (8) into the bank's maximization problem, we have

$$
E(\Pi_i)^* = \max_{D_i, H_i} \text{Prob}(\Pi_i > 0) \times E(\Pi_i | \Pi_i > 0) \qquad (10)
$$

where the probability of not default is written as

$$
\text{Prob}(\Pi_i > 0) = \text{Prob}\left(g > \frac{c}{2}(H_i + D_i) - \frac{D_i}{H_i + D_i}s_i + \frac{H_i}{H_i + D_i}\mu\right) \qquad (11)
$$

That is to say, to prevent the bank from defaulting, the return must exceed a specific threshold. It is important to note that this threshold is an increasing function of H_i, implying that the bank is more susceptible to default when it relies more heavily on wholesale funding.

To better illustrate the intuition, we can express the conditional expected payoff given the absence of default as follows.

$$
\begin{aligned}
E(\Pi | \Pi_i > 0) &= E\left(\Pi_i | g > \frac{c}{2}(H_i + D_i) - \frac{D_i}{H_i + D_i}s_i + \frac{H_i}{H_i + D_i}\mu\right)\\
&= -\frac{c}{4}(H_i + D_i)^2 + \frac{1}{2}D_i s_i - \frac{1}{2}H_i\mu + \frac{1}{2}g^H(H_i + D_i) \qquad (12)
\end{aligned}
$$

The last three terms represent the conditional expected profits from wholesale funding and deposits together, while assuming that the revenue of loans is independent of the amount of total loan investments. The first term accounts for the changes in the marginal revenues.

Note that in Equation (12), the conditional expected payoff increases with H_i when $H_i + D_i < (g^H - \mu)/c$. In addition, it is pertinent to recall that, given a certain level of deposits, the likelihood of default increases with H_i. Thus, when borrowing more from wholesale funding, banks increase the conditional expected payoff but decrease the probability of no default.

Let's come back to the borrowing constraint. Relying on the assumption that g follows a uniform distribution, we can re-write the borrowing constraint (9) as

$$H_i \leq \overline{H_i} \tag{13}$$

where $\overline{H_i}$ makes the borrowing constraint (9) bind:

$$\text{Prob}\left(g < \frac{c}{2}(\overline{H_i} + D_i) - \frac{D_i}{\overline{H_i} + D_i}(1 + \bar{r}) + \frac{H_i}{H_i + D_i}\mu\right) = p \tag{14}$$

Therefore, $\overline{H_i}$ is a function of D_i,

$$\overline{H_i} = \frac{\bar{g} - \mu}{c} + \frac{\left((\bar{g} - \mu)^2 + 2c(1 + \bar{r} + \mu)D_i\right)^{1/2}}{c} - D_i \tag{15}$$

where $\bar{g} = pg^H + (1 - p)g^L$. With a higher level of deposits D_i, banks can finance a larger amount of loans. Due to the de facto seniority of wholesale funding creditors, they are more willing to lend higher amounts to the bank, as reflected by an elevated $\overline{H_i}$. On the other hand, a higher deposit level reduces the marginal revenue of loans, decreasing the borrowing limit. Later in this section, I will demonstrate that when the constraint is binding, $\frac{\partial \overline{H_i}}{\partial D_i} > 0$. In other words, a higher deposit level eases the borrowing constraint, driven by the seniority of wholesale funding in practice. With more deposits, banks can generate more revenues from the loans funded by additional deposits. Additional revenues add more protection to wholesale funding creditors, thereby alleviating the borrowing constraint of the bank. This is also in line with the notion that large banks have better access to wholesale funding market than small banks documented in the banking literature.

Households. The framework on the household side is borrowed from Drechsler et al. (2017), where households are modeled as representative agents. At time zero, each household has an initial endowment of W_0 and allocates its investments across bonds, deposits, and cash. The household maximizes the time-one utility of final wealth, W, and liquidity services,

l, according to a CES function.

$$u(W_0) = \max \left(W^{\frac{\rho-1}{\rho}} + \lambda l^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}} \tag{16}$$

where λ is a parameter capturing the household's preference over liquidity, and ρ is the elasticity of substitution between wealth liquidity services. Following Drechsler et al. (2017), I assume $\rho < 1$, which implies that wealth and liquidity are complements.

Liquidity services are provides by cash, M, and deposits, D, based on a CES aggregator:

$$l(M, D) = \left(M^{\frac{\epsilon-1}{\epsilon}} + \delta D^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}} \tag{17}$$

where δ measure the liquidity of deposits relative to cash and ϵ is the elasticity of substitution between cash and deposits. ϵ is assumed to be larger than 1 to capture that cash and deposits are substitutes as both offer liquidity services.

Deposits are themselves a composite good produced by a set of N banks.

$$D = \left(\frac{1}{N} \Sigma_{i=1}^{N} D_i^{\frac{\eta-1}{\eta}} \right)^{\frac{\eta}{\eta-1}} \tag{18}$$

where η is the elasticity of substitution across banks. Bank market power stems from deposits from different banks being imperfect substitutions, $\eta > 1$.

Other than deposits and cash, the representative household can also invest in bonds, which offers federal fund rate $\bar{r}$, a higher interest rate than the deposit rate of $\bar{r} - s_i$ and the rate of zero on cash. As a result, households face a choice between investing in bonds, which offers higher monetary interest rates but no liquidity services, and holding cash or deposits, which provide liquidity services at the cost of lower returns.

Denote the weighted average deposit spread as

$$s = \frac{1}{N} \Sigma_{i=1}^{N} \frac{D_i}{D} s_i \tag{19}$$

Then, the household's budget equation is written as

$$W = W_0(1 + \bar{r}) - M\bar{r} - Ds \tag{20}$$

where the household earns the rate $\bar{r}$ on their initial wealth and give up the federal fund rate and the deposit spread to access the liquidity services provided by cash M and deposits D, respectively.

To solve the model, we first need to know the household's demand for bank i's deposits.

This can be seen from households' indifference between banks at the margin:

$$\frac{D_i}{D} = \frac{s_i}{s}^{-\eta} \tag{21}$$

In a symmetric equilibrium, the deposit demand for bank i's deposits is given by

$$\frac{\partial D_i}{\partial s_i}\frac{s_i}{D_i} = \frac{1}{N}\left(\frac{\partial D}{\partial s}\frac{s}{D}\right) - \eta(1-\frac{1}{N}) \tag{22}$$

where the household's demand for aggregate deposits, $\frac{\partial D}{\partial s}\frac{s}{D}$, can be derive from other first-order conditions:

$$\frac{l}{W} = \lambda^{\rho}\left(\frac{M}{l}\bar{r} + \frac{D}{l}s\right)^{-\rho} \tag{23}$$

$$\frac{D}{M} = \delta^{\epsilon}\left(\frac{s}{r}\right)^{-\epsilon} \tag{24}$$

Households must be marginally indifferent between liquidity and bonds and between cash and deposits. It is worth noting that the substitution between cash and deposits is dependent on the relative price of two, with the price of cash being $\bar{r}$ and the price of deposits being s. Consequently, the federal funds rate plays a role in determining the deposit spread charged by banks in equilibrium, through affecting household's demand elasticity for deposits.

$$-\frac{\partial D}{\partial s}\frac{s}{D} = \underbrace{\left(\frac{1}{1+\delta^{\epsilon}\left(\frac{\bar{r}}{s}\right)^{\epsilon-1}}\right)\epsilon}_{\text{substitution to cash}} + \underbrace{\left(\frac{\delta^{\epsilon}\left(\frac{\bar{r}}{s}\right)^{\epsilon-1}}{1+\delta^{\epsilon}\left(\frac{\bar{r}}{s}\right)^{\epsilon-1}}\right)\left(\frac{1}{\lambda^{\rho}s_l^{1-\rho}+1}\rho + \frac{\lambda^{\rho}s_l^{1-\rho}}{\lambda^{\rho}s_l^{1-\rho}+1}\right)}_{\text{substitution to bonds}} \tag{25}$$

where $s_l = \frac{M}{l}\bar{r} + \frac{D}{l}s$ is the weighted average of the price of liquidity. Note that the first term represents the substitution between cash and deposits, while the second term represents the substitution between bonds and deposits. This equations tells us that the aggregate demand elasticity for deposits is a weighted average of the two. Clearly, the federal funds rate affects deposit elasticity by altering the relative price of cash and deposits, and thus changing the weight of substitution with cash and the weight of substitution with bonds. When the federal funds rate increases, cash becomes more expensive, which leads to less substitution between deposits and cash but more substitution between deposits and bonds. Since bonds do not provide liquidity like cash does, the elasticity of substitution from deposits to bonds is naturally smaller than the one from deposits to cash. Consequently, the deposit demand becomes more inelastic when the federal funds rate rises. In response to the reduction in elasticity, banks raise the deposit spread, s, in equilibrium. This equation also highlights the importance of cash in the model. Without it, the weight on the substitution to bonds becomes one, making the demand elasticity no longer dependent on the federal funds rate $\bar{r}$.

Equilibrium. To determine the equilibrium, we first need to solve bank's maximization problem. The optimality condition of H_i, if the borrowing constraint is not binding, is now

$$0 = \frac{\partial E(\Pi_i)}{\partial H_i} = \frac{\partial \text{Prob}(\Pi_i > 0)}{\partial H_i} E(\Pi_i | \Pi_i > 0) + \frac{\partial E(\Pi_i | \Pi_i > 0)}{\partial H_i} \text{Prob}(\Pi_i > 0) \tag{26}$$

The first term on the right stands for the marginal decrease in the probability of not default from rising another dollar of wholesale funding. The second term captures the marginal increase in expected profits, if not in default, from the bank's wholesale borrowing. This gives us a relationship between the optimal H_i^* and D_i^*.

Proposition 1. *If the bank's borrowing constraint is not binding in equilibrium, i.e. $H_i^* < \overline{H_i}$, then banks reduce wholesale funding in response to an increase in deposits. Mathematically, this can be expressed as $\frac{\partial H_i^*}{\partial D_i^*} < 0$ where H_i^* satisfies the first-order condition (26).*

Proof. In the appendix. ■

The intuition can be seen by considering the scenario in which a bank is on the first-order condition and suddenly obtain more deposits. Since deposits are less costly than wholesale funding, banks can slightly reduce H_i while keeping the conditional expected payoff $E(\Pi_i | \Pi_i > 0)$ in Equation (12) unchanged. A lower level of H_i also reduces the probability of default. As a result, a small reduction in H_i can lead to a higher level of expected profits. In other words, banks with more deposits D_i reduce their borrowing from the wholesale funding market.

Proposition 2. *If the bank's borrowing constraint binds in equilibrium, i.e. $H_i = \overline{H_i}$, an increase in deposits will result in an increase in wholesale borrowing. In other words, $\frac{\partial H_i}{\partial D_i} > 0$, where $H_i = \overline{H_i}$*

Proof. In the appendix. ■

The relationship is evident from $\overline{H_i}$ being an increasing function of D_i when the constraint is binding. When the constraint binds, the marginal benefit of raising an additional unit of wholesale funding is positive. A higher level of deposits reduces the probability of default, thereby creating more room for wholesale borrowing. Therefore, in response to an increase in deposits, banks borrow more from the wholesale funding market.

According to the model, the relationship between deposits and wholesale funding hinges on a bank's borrowing constraint. If the constraint is not binding, the bank decreases its wholesale funding when more deposits are received. In contrast, when the constraint is binding, a surge in deposit inflows relaxes the borrowing constraint, by providing wholesale creditors more protection. Thus, banks can obtain more funds from the wholesale funding market to finance profitable lending ventures.

Numerical solutions. I provide numerical solutions to the model, which aims to illustrate the relationship between deposits and wholesale funding. Parameters are presented in Table (1). I use the value of c to differentiate between the scenario where the borrowing constraint is binding and the one where it is not. When c is smaller, the marginal revenue of loans decreases at a slower rate, thus prompting banks to seek additional borrowing, leading to a binding constraint.

The results are shown in Figure (1) and Figure (2), where the federal funds rate ranges from 1 percent to 7 percent. In the case of $c_1 = 0.004$, the borrowing constraint does not bind. As shown in Figure (1), when the federal funds rate rises, banks charge a higher spread because of an increased inelasticity of household demand for deposits. This higher spread, in turn, prompts households to withdraw deposits from banks, leading to a decline in deposits. In the case where the borrowing constraint is not binding, banks can obtain additional wholesale funding as they lose deposits. Therefore, we observe an inverse relationship between deposits and wholesale funding. Due to the higher cost of funding, the increase in wholesale funding is typically smaller than the decrease in deposits.

In contrast, deposits and wholesale funding display a positive relationship in the case of $c_2 = 0.001$. With a smaller c, banks seek additional borrowing to finance lending opportunities, causing the constraint to become binding. Similar to the case of unconstrained banks, the deposit spread increases as the federal funds rate rises, and deposits decrease with respect to the federal funds rate. However, a lower level of deposits intensifies banks' borrowing constraint. When losing deposits, banks must reduce wholesale funding. As shown in the bottom panel of Figure (2), we observe a positive correlation between deposits and wholesale funding, with both decreasing in the federal funds rate.

3 Empirical Analysis

The model predicts heterogeneous impacts of deposits on balance-sheet composition based on a bank's financial constraint. In this section, I present the empirical evidence at both the aggregate level and the bank level supporting this argument. First, at the aggregate level, I show that the relation between deposit growth and wholesale funding growth of the whole banking sector is time-varying. Consistent with the model prediction, the relation is significantly positive when banks are likely to be financially constrained. Second, I also provide bank-level evidence. Although the model features homogeneous banks, it is useful to turn to the cross-section of banks to inspect the mechanism. At the bank level, to identify the causal effects of deposits, I use changes in the federal funds rate interacted with bank market power, suggested by the deposit channel of monetary policy, to instrument deposits. I further construct proxies for financial constraint levels and investigate whether banks with different constraint levels exhibit different behaviors.

3.1 Data

Branch-level deposit data. The data on deposit quantities by branch are obtained from the Federal Deposit Insurance Corporation (FDIC). The data are available at an annual frequency starting from 1994. The data contain information on branch characteristics such as the parent bank, deposits as of June 30 each year, and geographic address. To calculate the county-level Herfindahl-Hirschman Index (HHI), I sum up the squares of the deposit shares for each bank in each county. To calculate the bank-level HHI, I take the weighted average of the county-level HHI for each county where a bank operates branches, with the weights being the deposit share of the bank in each county. Details on computing bank-HHI will be demonstrated later.

Bank-level financial data. Financial data at the bank level are obtained from call reports provided by the Federal Reserve Bank of Chicago. These data contain quarterly bank-level information on banks' balance sheets and income statements for all commercial banks in the United States. I use data from 1994 to 2019. I match the bank identifier in this dataset with the bank-HHI computed using the FDIC branch-level deposit data.

Federal funds rate data. I collect the federal funds target rates from Federal Reserve Economic Data (FRED). Following Drechsler et al. (2017), I compute the average of the upper and lower federal funds rate target after the introduction of a target range corridor in 2008 as the policy target rate.

Aggregate data on commercial banks. The aggregate-level data on commercial banks are obtained from the Assets and Liabilities of Commercial Banks in the United States - H.8 dataset. This dataset contains information on selected items of assets and liabilities for domestically chartered commercial banks in the United States, covering the period from January 1973 to the present. I use data from 1973 to 2019. Additionally, I collect data from the FDIC Banking Profile, which provides data on the net income of FDIC-insured commercial banks and savings institutions at the aggregate level, covering the period from 1984 to the present.

3.2 Time-series Analysis

I start by showing the aggregate-level evidence supporting for the model prediction that the effect of deposits depends on financial constraints. I use the aggregate-level data on the balance sheet of the whole commercial banking system from the Federal Reserve's H8 Dataset on Assets and Liabilities of Commercial Banks in the United States. To examine the relationship between deposit growth and wholesale funding growth, I define the growth of two variables as the monthly change normalized by the amount of assets at the last month. In contrast to defining log differences as growth rates, using monthly changes normalized by last-month assets makes the two growth rates more comparable as both can be interpreted as the monthly change as a share of assets.

To investigate whether the relationship between deposit and wholesale funding growth evolved over time as financial constraints changed, I split the whole sample period 1973 to 2019 into three sub-periods: 1973-1994, 1995-2007, and 2010-2019. To avoid the impacts of global financial crisis, I exclude 2008 and 2009 from the sample. The motivation for breaking out sample in this way is the possible changes in bank financial constraints. During the second sub-period, i.e. from mid-1990s leading up to the 2008-2009 Global Financial Crisis, banks likely faced financial constraints. Two changes during this period encouraged bank investment. First, restrictions on the opening of bank branches in different states that had been in place since the McFadden Act of 1927 were removed under the Riegle-Neal Interstate Banking and Branching Efficiency Act (IBBEA) of 1994. The passage of the IBBEA opened doors to nationwide branching in mid-1990s, resulting in an increase in business opportunities. This expansion may have led to banks becoming constrained as they may not have sufficient funding to finance all profitable investments. Second, US housing prices had been rising strongly since the mid-1990s. This surge in housing prices presented enhanced mortgage lending opportunities for banks, making banks financially constrained. Chakraborty et al. (2018) studies this housing price surge on bank lending and finds that lending opportunities in the real estate market led banks to reduce commercial lending, suggesting that banks were constrained during the housing price boom[1]. The other cutoff, 2010, is chosen to separate periods before and after the global financial crisis. Banks were unlikely to be constrained after the crisis. As documented in Sims and Wu (2020), the implementation of the Fed's quantitative easing to combat financial crisis boosted bank reserves and relaxed financial constraints.

I find that the correlation between deposit growth and wholesale funding growth was weak before 1995 (correlation of 0.04), significantly positive for the period 1995 to 2007

[1]More information about bank investment opportunities since mid-1990s to global financial crisis can be find in Appendix (5)

(correlation of 0.24), and significantly negative for the post-crisis period (correlation of -0.20). To statistically study the relationship between deposits and wholesale funding, I also run the following regression for the three sub-periods respectively.

$$\frac{\Delta Wholesale_t}{Assets_{t-1}} = \beta \frac{\Delta Deposits_t}{Assets_{t-1}} + \alpha_m + \epsilon_t \tag{27}$$

where $\Delta Wholesale_t/Assets_{t-1}$ and $\Delta Deposits_t/Assets_{t-1}$ are monthly growth of wholesale funding and that of deposits of the banking sector, normalized by assets, and α_m represents seasonal month dummies. Standard errors are Newey-West standard errors with the choice of truncation parameters following Lazarus et al. (2018).

Table (2) presents the results. The coefficient on deposit growth is statistically significantly positive for the period 1995 to 2007, whereas it is statistically insignificant for the other two sub-periods. I also do Chow test to verify that the coefficient for the period 1995-2007 is statistically different from the other two coefficients.

The varying coefficients on deposit growth demonstrate the evolving relationship between deposits and wholesale funding over time. Specifically, from mid-1990s to 2007, a period when banks were likely to be constrained, the coefficient is statistically significantly positive, implying that higher deposit growth is associated with higher wholesale funding growth. This observation aligns with the model's prediction that, in times of financial constraints, an increase in deposits can alleviate borrowing constraints and lead to more wholesale funding. However, there could be other confounding factors that may influence both deposits and wholesale funding in this period, contributing to the positive relationship. To achieve a rigorous identification, I will turn to cross-sectional analysis in the following subsection.

3.3 Identification Strategy

The aggregate-level evidence shown in Section (3.2) does not establish a causal effect of deposits. In practice, identifying a causal relationship between deposits and a banks' balance-sheet composition presents considerable challenges owing to omitted variable bias. First, the presence of confounding factors that influence both deposits and wholesale funding poses a major obstacle. For example, a weak economic condition could result in slow income growth for households and thus a low level of deposits. At the same time, a weak economic condition is usually associated with a dearth of profitable investment opportunities, reducing banks' desire to borrow from the wholesale funding market. As a result, both bank deposits and wholesale funding are directly affected by overarching economic conditions, making the identification of the effect of deposits impossible.

Second, shocks to deposit demand and deposit supply often occur simultaneously and are hard to disentangle. For instance, policy measures aimed at stimulating the economy, such as tax rebates, could increase households' deposit supply to banks. These measures, however, may also be accompanied by other economic policies that can affect banks' lending activities and therefore influence their demand for deposits. Consequently, disentangling the impacts of shocks to deposit supply and deposit demand on banks' balance sheets is a challenge in empirical studies.

As aforementioned, to address the identification challenge, I take advantage of the deposit channel of monetary policy proposed by Drechsler et al. (2017) and exploit the cross-bank variation to identify the effects of deposits. The deposit channel of monetary policy emphasizes the role of bank market power in deposit markets in monetary policy transmission. The market power in deposit markets allows banks to pay deposit rates that are lower than the federal funds rate and relatively insensitive to changes in the federal funds rate. Banks in more concentrated markets charge a larger deposit spread, which refers to the difference between the federal funds rate and deposit rates, than those in less concentrated markets. Consequently, following an increase in monetary policy rate, banks raise deposit rates incompletely and thus experience deposit outflows. The deposit channel demonstrates that when the federal funds rate rises, banks in more concentrated regions increase deposit spreads by more and experience a larger deposit outflow than banks in less concentrated areas. I exploit the cross-sectional variation in deposit inflows and outflows following changes in the federal funds rate to identify the effects of deposits on banks' wholesale funding and other balance-sheet components.

The variation in deposit growth across banks following a decrease or an increase in the federal funds rate comes from different branch networks of banks. Banks operate their deposit franchise through branches. These branches are located in areas with varying degrees of deposit market concentration. Banks with more deposits in branches located in highly concentrated markets are expected to experience larger fluctuations in deposit growth following a change in the federal funds rate, relative to banks with deposits collected from less concentrated markets. The geographic variation in branch networks thus gives rise to cross-sectional variation in bank market power and thus in deposit fluctuations.

The model also predicts that the relationship between deposits and wholesale funding depends on a bank's borrowing constraint. When monetary policy tightening reduces deposit supply, financially unconstrained banks substitute deposit outflows with wholesale funding to smooth their lending. On the contrary, for a bank whose lending is already limited by the borrowing constraint, a reduction in deposit supply tightens the financial constraint, resulting in a further decline in wholesale funding. To empirically investigate the impacts of constraints, I construct a proxy for financial constraints using wholesale-to-deposit ratios and assign constraint levels from 0 to 4 to banks at a quarterly basis. I will elaborate on the proxy for constraints later in this section.

3.3.1 Bank Market Power

As mentioned previously, I exploit the cross-sectional variation in bank market concentration to estimate the causal effect of deposits on wholesale funding and other balance-sheet components. I start by constructing a proxy for bank-level market concentration. Specifically, I measure bank market concentration in deposit markets with Herfinsahl-Hirschman Index (HHI). First, using branch-level data on deposits and branch-level geographic information from FDIC, I compute county HHI by summing up the squares of deposit shares of all banks operating in a given country in a given year. Branch HHI is the same as the county HHI where the branch is located.

$$BranchHHI_{b(c)t} = CountyHHI_{ct} = \sum_{i=1}^{N_{ct}} \left(\frac{D_{ict}}{D_{ct}} \right)^2 \tag{28}$$

where b and c represent branch b in county c. t is at the year level. i stands for individual banks operating branches in county c. N_{ct} is the total number of banks in county c at year t. Herfindahl-Hirschman index (HHI) is compute as the sum of squares of deposit shares by banks, where each bank i has the deposit share in county c as D_{ict}/D_{ct}.

Second, I measure Bank HHI as the weighted average of branch HHI over all branches of a given bank, where the weight is the deposit shares of branches. Specifically,

$$BankHHI_{it} = \sum_{b=1}^{N_{it}} BranchHHI_{b(i)t} \times \frac{D_{b(i)t}}{D_{it}} \tag{29}$$

where N_{it} is the number of branches of bank i in year t. $D_{b(i)t}$ is the amount of deposits of branch b in year t. D_{it} denotes total deposits of bank i in year t. $D_{b(i)t}/D_{it}$ stands for the deposit share of branch b of bank i in total deposits of bank i.

The measure of bank market power is under the assumption that banks that rely more heavily on deposits from highly concentrated deposit markets possess greater market power than those operating in less concentrated markets.

3.3.2 The Deposit Channel

The identification strategy is motivated by the deposit channel of monetary policy. I begin with a cross-sectional analysis of the impact of bank market power on deposits following changes in monetary policy rates, as suggested by the deposit channel. As discussed in

Section (2) and in Drechsler et al. (2017), the deposit channel implies that banks with greater market power exhibit larger deposit fluctuations in response to changes in monetary policy. I investigate the role of bank market power on deposit quantity response to monetary policy by estimating the following regression.

$$\frac{\Delta Deposits_{it}}{Assets_{it-1}} = \beta_1 \Delta FF_t \times BankHHI_{it-1} + \beta_2 BankHHI_{it-1} + X_{it-1}\gamma + \alpha_t + \alpha_i + \epsilon_{it} \quad (30)$$

The regression model is estimated at the bank-quarter level. $\Delta Deposits_{it}/Assets_{it-1}$ represents the deposit growth of bank i at quarter t as a share of assets, measured as the quarterly change of deposits between quarter t and $t-1$, normalized by assets at quarter $t-1$. ΔFF_t is the contemporaneous change in the federal funds target rate at quarter t. The target rate is computed as the average of the upper and lower federal funds rate targets after the introduction of a target rate corridor in 2008. $BankHHI_{it-1}$ is the bank-level deposit concentration of bank i at $t-1$. α_i are bank fixed effects, controlling for time-invariant bank characteristics. For example, if a bank with greater market power always has higher deposit growth than another bank with smaller market power, bank fixed effects help control this, and thus the difference in deposit growth will not be explained by variation in market power. α_t are time fixed effects, controlling for time-series variation in deposit growth. For instance, if deposit growth fluctuates with time-varying economic conditions for all banks, time fixed effects control for the time-series variation, mitigating the concern that variation in deposit growth could come from the overall economic conditions. Control variables, X_{it-1}, include lagged terms of log of assets, deposit-to-assets ratios, wholesale-to-deposit ratio, and the tier-1 capital ratio. I cluster standard errors at the bank level.

The explanatory variable of interest is the interaction term between changes in the federal funds rate and bank market power, i.e. $\Delta FF_t \times BankHHI_{it-1}$. Given that most banks' market power remains relatively stable over time, the coefficient on this interaction term, β_1, primarily captures the cross-sectional variation in deposit growth across banks with varying bank HHI, following a change in the policy rate. The deposit channel of monetary policy suggests that banks with greater market power increase their deposit rates by less when the federal funds rate rises, leading to larger deposit outflows than banks with less market power. Hence, we expect $\widehat{\beta_1}$ to be negative.

Table (3) presents the results for deposit fluctuations driven by monetary policy changes. The statistically significantly negative coefficient on the interaction $\Delta FF_t \times BankHHI_{it-1}$ confirms that a rise in the federal funds rate leads to larger deposit outflows for large-market-power banks. Column (1) excludes time fixed effects and adds ΔFF_t as an independent variable. The negative coefficient on ΔFF_t shows a decrease in deposit growth following an increase in the federal funds rate. The highly significantly negative $\widehat{\beta}_1$ suggests banks with greater market power experience larger fluctuations in deposit growth when the federal funds rate alters, consistent with the deposit channel of monetary policy. The effect is slightly smaller when I include time fixed effects in Column (2), or add control variables in Column (3), or include both time fixed effects and controls in Column (4).

The result in Table (3) offers compelling evidence of the cross-sectional variation in bank deposit growth in response to shifts in the monetary policy rate, due to the presence of bank market power in the deposit market. This provides support for the deposit channel of monetary policy. It, therefore, implies the validity of using policy rate changes interacted with bank market power to instrument deposit changes, for the purpose of identifying the effects of deposits, as discussed in the following subsection.

3.3.3 Effects of Deposits on Banks' Balance-Sheet Composition

Recall that the objectives of this paper are to examine the causal effects of deposits on banks' balance-sheet composition, and to test whether this effect is influenced by banks' financial constraints as proposed by the model. To address the identification issue, I leverage the deposit channel of monetary policy, using policy rate changes to generate variation in deposit growth across banks with different levels of bank HHI. The evidence supporting the deposit channel is presented in the preceding subsection. In this subsection, I start by analysing the impact of deposits on wholesale funding. I then examine whether the effect differs based on banks' constraints, using a proxy for constraint levels. Lastly, I explore the effects of deposits on components of bank assets.

3.3.3.1 Impact of Deposits on Wholesale Funding.

With the confirmed deposit channel of monetary policy, evidenced by the first-stage regression in the preceding subsection, I run the following regression to estimate the causal effect of deposits on wholesale funding, where the unit of observation is a bank-quarter:

$$\frac{\Delta Wholesale_{it}}{Assets_{it-1}} = \beta_1 \frac{\Delta Deposits_{it}}{Assets_{it-1}} + \beta_2 BankHHI_{it-1} + X_{it-1}\gamma + \alpha_t + \alpha_i + \epsilon_{it} \tag{31}$$

where the deposit growth as a share of assets, $\Delta Deposits_{it}/Assets_{it-1}$, is instrumented by $\Delta FF_t \times BankHHI_{it-1}$. The dependent variable, $\Delta Wholesale_{it}/Assets_{it-1}$, is the growth of wholesale funding, measured as the quarterly change in wholesale funding of bank i at quarter t, normalized by the assets at $t-1$. Other variables are defined in the same way as the first-stage regression (30). Again, I cluster standard errors at the bank level to allow for serial correlation and heteroskedasticity.

The coefficient of interest is β_1 in Equation (31). A negative $\widehat{\beta_1}$ suggests a substitution relationship between deposits and wholesale funding. On the contrary, a positive $\widehat{\beta_1}$ implies a complementary relationship between the two. As predicted in Section (2), a substitution suggests that banks, on average, are operating without constraints. In contrast, a complementarity indicates the presence of constraints on banks.

Table (4) presents the result. Column (1) shows a statistically significantly negative estimate on β_1, suggesting that a 1% increase in deposit growth as a share of assets leads to a decline in wholesale funding growth by 0.11% of assets. The effect becomes larger when control variables are included (shown in Column (2) of Table (4)), implying that a 1% increase in deposit growth causes a 0.20% reduction in wholesale funding growth. In both specifications, the coefficients on deposit growth are statistically significant and negative, meaning that banks, on average, are not financially constrained, according to the model. Specifically, when unconstrained banks experience deposit inflows driven by expansionary monetary policy, they substitute wholesale funding with deposits due to lower cost of funding of deposits. Similarly, when unconstrained banks experience deposit outflows, they become more reliant on wholesale funding to respond to the decline in deposits. Because wholesale funding is more costly than deposits, the substitution is less than one-to-one. This result is also suggested in Choi and Choi (2021), which argues that when monetary tightening reduces deposit supply, banks try to replace deposit outflows with wholesale funding to smooth lending. In addition, Columns (3) and (4) in Table (4) present the OLS estimates for the relationship between deposit growth and wholesale funding growth. As discussed earlier, OLS estimates can be biased due to the presence of omitted variables. The results from Columns (3) and (4) suggest that OLS underestimates the negative effect of deposits on wholesale funding.

To test whether the instrumental variables regression suffers from the problem of weak instrument, I follow Olea and Pflueger (2013) to compute effective F statistics. This test proposed by Olea and Pflueger (2013) is robust to heteroskedasticity, autocorrelation, and clustering. Table (4) reports the effective F statistics of the first-stage regression. The null hypothesis of weak instrument is rejected[2].

In summary, Table (4) illustrates the average causal effect of bank deposits on wholesale funding across all banks. Crucially, as the model highlights, the status of a bank's borrowing constraint can influence this causal effect of deposits. In the subsequent subsection, I address the following question: In response to deposit shocks, do banks with different levels of

[2]The null hypothesis is that the Nagar bias exceeds 10% of a "worst-case" bias with a size of 5%.

borrowing constraints demonstrate different behaviors?

3.3.3.2 Proxy for Financial Constraints.

To investigate the effects of financial constraints, I need a measure to gauge the constraint conditions of banks. I use the ratio of wholesale borrowing to deposits to proxy for the tightness of a bank's financial constraint. I do this for a few reasons. First, my model implies that constrained banks are more likely to borrow from wholesale markets due to the insufficiency of deposits to fund all profitable investment opportunities. Second, wholesale-to-deposit ratio indicates the relative importance of external and internal funds of banks, which is analogous to the idea of using debt-to-cash flow ratio to measure non-financial firms' constraint conditions in corporate finance literature. In this subsection, I will discuss motivations for this proxy in detail, and then explore the effect of constraints on the impact of deposits using this proxy for the tightness of constraints.

A. Description

Let me first describe why wholesale-to-deposit ratio plausibly measures the tightness of financial constraints. According to the model, when a bank is not financially constrained, its optimal level of wholesale borrowing is determined by a set of first-order conditions and can be written as the following[3].

$$H = H^* = \frac{g^H + \sqrt{(g^H)^2 - 6Dsc}}{3c} - D \tag{32}$$

where the subscript i for an individual bank is omitted for simplification. Recall that c controls the marginal benefit of issuing an additional unit of loans. The case $c > 0$ captures the idea that the bank has a limited profitable lending opportunities. The magnitude of c governs the rate at which the marginal revenue of issuing additional loans declines. Intuitively, a larger c indicates a smaller pool of loans.

For a financially constrained bank, its wholesale borrowing equals the upper limit of its borrowing capacity, which is given as

[3]For mathematical simplicity, I set $\mu = 0$ in the subsequent derivations. Given the assumption that wholesale funding market is competitive, μ is a constant and does not change across banks. Thus, assuming $\mu = 0$ does not affect model's implications on the cross-sectional variation in financial constraints of banks. Full solutions for the case where $\mu > 0$ are shown in Appendix (5).

$$H = \overline{H} = \frac{\bar{g} + \sqrt{\bar{g}^2 + 2c(1+\bar{r})D}}{c} - D \tag{33}$$

I quantify banks' constraint level by comparing the difference in banks' borrowing capacity and its optimal wholesale funding when they are not constrained. Mathematically,

$$\begin{aligned} \overline{H} - H^* &= \frac{\bar{g} + \sqrt{\bar{g}^2 + 2c(1+\bar{r})D}}{c} - \frac{g^H + \sqrt{(g^H)^2 - 6Dsc}}{3c} \\ &= \frac{1}{c}\left(\sqrt{\bar{g}^2 + 2c(1+\bar{r})D} - \sqrt{(\frac{g^H}{3})^2 - \frac{2}{3}Dsc} + \bar{g} - \frac{g^H}{3}\right) \end{aligned} \tag{34}$$

In the equation, $\bar{g} = pg^H + (1-p)g^L$, the parameter p represents the maximum probability set by wholesale creditors to avoid losses. A positive difference between $\overline{H}$ and H^*, i.e. $\overline{H} - H^* > 0$, suggests that the borrowing constraint does not bind. The sign of this difference is determined by the expression in the parenthesis of Equation (34), which depends on several factors. First, it is evident that a smaller value of c reduces the first two terms in the parenthesis, which can make the difference between $\overline{H}$ and H^* negative. As a consequence, banks with a smaller c are more likely to be constrained. As mentioned earlier, c governs the rate at which the marginal revenue of issuing additional loans declines. A small c indicates more profitable investment opportunities, encouraging banks to issue more loans compared with banks with a large value of c.

Second, Equation (34) also reveals that deposits, denoted by the parameter D, could amplify the disparity between $\overline{H}$ and H^*. When D achieves a sufficiently large value, banks' demand for wholesale funding decreases, assuming that all other parameters remain constant. In such a scenario, banks do not need additional funding to finance investments as they already possess substantial and inexpensive funding from deposits. Hence, banks with a large amount of deposits are less likely to have a binding constraint. As a result, financially constrained banks rely more heavily on the wholesale funding market compared to unconstrained ones. This is driven by the abundance of lending opportunities they aim to finance and the inadequate levels of deposits they have on hand. Put differently, constrained banks are expected to demonstrate a higher dependency on wholesale funding relative to deposits.

Additionally, other parameters such as p, g^H, and g^L also contribute to the sign of the expression in Equation (34) and consequently affect the constraint conditions of banks. However, it is plausible to assume that these parameters are not as influential as c and D in driving the cross-sectional variation in financial constraints, and thus are less important for my purpose of comparing constrained and less constrained banks. For instance, a larger p is more likely to result in a positive difference between $\overline{H}$ and H^*. This suggests that banks are less constrained when wholesale creditors are willing to tolerate a higher probability of loss and provide larger funding amounts. Since the wholesale funding market is centralized, it is reasonable to assume that wholesale creditors' risk preferences do not significantly vary across banks. Therefore, p should not be a major driver of the cross-sectional variation in financial constraints. Furthermore, the sign of $\overline{H} - H^*$ is more likely to be positive when the riskiness of assets is low. Suppose two banks have the same expected rate of return, but one has riskier assets, reflected in higher g^H and lower g^L. In this case, the riskier bank would have a smaller $\bar{g}$ due to a close-to-zero p, leading to a lower limit for wholesale borrowing, $\overline{H}$. As a result, the riskier bank is more likely to be constrained compared to the less risky one. Intuitively, the borrowing constraint is influenced by the riskiness of bank assets. A plausible measure of asset riskiness is represented by risky-weighted assets, which is also reflected in the regulatory indicator known as the tier-1 capital ratio. Tier-1 capital ratio assesses a bank's capital adequacy by taking into account the level of risky-weighted assets it holds. It is documented that U.S. banks typically hold significantly more equity capital than required by regulators based on this measure (Berger et al. (2008)). In other words, given banks' capital levels, the riskiness of their assets generally are below regulatory requirements across the banking industry. Thus, it is reasonable to conjecture that asset riskiness is not the primary factor driving the cross-sectional variation in financial constraints.

A similar idea is exploited in corporate finance literature investigating financial constraints of non-financial companies. Since most of deposits are federally insured and the funding cost of deposits is much smaller than that of wholesale funding, deposits are equivalent to cash flow as a form of "internal funds" for non-bank firms (Jayaratne and Morgan (2000)). In contrast to deposits, wholesale funding is unsecured and thus requires a higher cost of funding due to information frictions, acting as a form of "external debt" of non-financial firms. In corporate finance literature, it is found that firms borrowing more external debt tend to be more constrained. For example, Kaplan and Zingales (1997) study non-financial firms and rank the degree to which firms are financially constrained[4]. They find that the likelihood of being classified as financially constrained is significantly greater in firms with more debt and significantly lower in firms with more cash flow, which indicates that more constrained firms have a higher debt-to-cash flow ratio than unconstrained ones. This debt-to-cash flow ratio for non-bank firms is analogous to wholesale-to-deposit

[4] Kaplan and Zingales (1997) integrate information from firms' annual reports or 10-K, management's discussion of liquidity that describe the firm's future needs, with quantitative data and public news to rank the degree of financial constraints.

ratio for banks, with both indicating the relative importance of external and internal funds. This suggests the potential of wholesale ratio to proxy banks' financial constraints. Another financial constraint index in this field is constructed by Whited and Wu (2006) via GMM estimation of an investment Euler equation. They also obtain a positive coefficient on the debt to asset ratio in determining the financial constraint index, which indicates a more highly leveraged firm will have a higher shadow cost of external funds, in other words, it will be more financially constrained. In sum, using wholesale ratio of banks to measure the degree of financial constraint is analogous to the idea that firms with more external borrowing are more likely to be constrained in the corporate finance literature studying non-bank firms. It captures the idea that given higher cost of wholesale funding induced by information friction and uninsurance, banks borrow more from external funding sources and thus having a high wholesale ratio, only if they have profitable investment opportunities that they desire to fulfill.

Although the model features either binding or nonbinding financial constraints, more realistically, the spirit of the model is that the closer a bank is to the constrained optimum, the tighter is the constraint. Consequently, I quantify banks' constraint level based on their wholesale ratio. The wholesale ratio is calculated by dividing the amount of wholesale funding by the amount of deposits. A high wholesale ratio indicates that the bank relies more on wholesale funding to finance its investments relative to the amount of deposits it holds, suggesting that the bank is potentially constrained. By contrast, a low wholesale funding ratio means that the bank does not have a significant need for additional funding beyond its existing deposits, implying a potential scarcity of profitable lending opportunities or an abundance of deposits that adequately meet the banks' funding needs. Specifically, the wholesale funding ratio is calculated as the rolling average from quarter $t-2$ to $t+2$. The wholesale ratio for bank i at quarter t is thus written as:

$$\text{Wholesale Ratio}_{it} = \frac{1}{5}\sum_{t=t-2}^{t+2}\frac{H_{it}}{D_{it}} \tag{35}$$

Before proceeding with the construction of a constraint proxy using wholesale ratio, I first discuss whether wholesale ratio can be used for the identification purpose in practice. From an empirical standpoint, an effective proxy for constraint should meet the following two criteria. First, it is important that the proxy should be uncorrelated with bank market power, measured by Bank HHI. Any correlation between the proxy and bank market power could introduce bias into estimates on the impact of constraints, thus compromising the validity of findings. This implies that the variation observed in the proxy and in bank market power should be orthogonal to each other. Second, the proxy should exhibit considerable variation. The presence of significant variation helps accurately identify the effect of binding constraints.

Regarding the first criterion, it is reassuring to find that the wholesale ratio is almost unrelated with bank market power. The correlation between wholesale ratio and bank HHI is close to zero (a correlation of -0.05). This indicates that wholesale ratio and bank market power are largely independent of each other, fulfilling the requirement for an uncorrelated proxy. Furthermore, the wholesale ratio exhibits sufficient variation. With a maximum value exceeding 44 percent and a standard deviation of 8.3 percent, the wholesale ratio demonstrated a wide range of values. This variation allows for the identification of effects of binding constraints on banks' behavior. Taken together, the wholesale ratio satisfy the discussed criteria, making it a reasonable proxy for measuring banks' constraint conditions in empirical analysis.

To assign banks constraint levels, I discretize banks' wholesale ratio for each quarter. Banks with the highest wholesale ratio are mostly constrained in a given quarter, while banks with the lowest wholesale ratio are least constrained. As previously noted, there are significant differences in the wholesale ratio among banks. Take 2007Q2 as an example. Figure (3) depicts the distribution of the wholesale ratios across banks as of 2007Q2. The distribution is right skewed: there is very few variations of wholesale ratio among the bottom percentiles of the distribution, yet very large variation among the top percentiles. Specifically, the average wholesale ratio is under 1% for the bottom 30% of banks. However, some banks have notably high wholesale ratios. The average ratio for top 10% banks is 28%, far surpassing other banks. Thus, an informative grouping strategy is to have finer division at the top and coarser division at the bottom percentiles. As banks in the bottom 30%, with their particularly low wholesale ratios (<1%), are considered unconstrained and assigned a constraint level of 0. The top 10% banks exhibit much larger wholesale ratios than others, they are assigned a constraint level of 4. Banks in the middle are divided into three groups with constraint levels of 1, 2, and 3, with each group consisting of 20% of banks.

This classification scheme is designed to distinguish the relative differences in the degree to which banks are financially constrained within a quarter. Since banks can switch among constraint levels quarter by quarter, I exploit both cross-sectional and time-series variation for identification. Another way of constructing a proxy for constraint levels using wholesale ratios is to compute the average wholesale ratio for each bank over all periods, and then to sort out banks according to their average wholesale ratio. However, only cross-sectional variation is used for identification by this approach.

B. Classification Results

Table (5) summarizes the classification of banks. Panel A, B, and C provide median values of a variety of bank characteristics for groups of banks sorted by constraint levels at 1994Q3, 2007Q2 and 2019Q2, which are the first, the last and a mid-point quarter of the whole sample periods, respectively. A few notable observations are demonstrated below.

First, the mostly constrained banks have less liquid assets than others, such as cash and securities. This has the economic interpretation that, instead of holding more liquid assets, banks that are more constrained are those with better lending opportunities than less constrained ones. In addition, this relationship between financial constraints and liquid asset ratio is consistent with implications of Kashyap and Stein (2000) and my model. Kashyap and Stein (2000) find that the impact of monetary policy on bank lending behavior is stronger for banks with lower security-to-asset ratios[5], while my model predicts the same pattern for banks that are more constrained. Since more financially constrained banks are also those with less liquid assets, as shown in Table (5), my proxy for financial constraints aligns with their empirical finding[6].

Second, banks that are more constrained have higher returns on equity. Return on equity is measured as net income divided by book value of equity and reflects banks' profitability and performance. I expect banks having high profitability as operating profitable businesses and facing good lending opportunities. The positive relationship between the level of financial constraints and return on equity captures the intuition that only banks with good investment opportunities are likely to want to invest enough to be constrained. In addition, constrained banks having better lending opportunities are also demonstrated by the lower tier-1 capital ratio of these banks. Tier-1 capital ratio measures the risk-based capital adequacy of banks. A lower capital ratio means more risk-taking behaviors of a bank, for example issuing loans, relative to its capital.

Third, banks that are more constrained have a larger wedge between wholesale funding rate and deposit rate. Both rates are measured as the interest expenses on that type of liability divided by the amount of the corresponding liability[7]. This positive relationship between the level of constraints and the rate wedge is driven by wholesale funding rates.

[5]The key finding in Kashyap and Stein (2000) is that the impact of monetary policy on bank lending behavior is stronger for banks with lower ratios of securities to assets, as the more liquid bank can relatively easily protect its loan portfolio by simply drawing down its large buffer stock of securities in response to a Fed-induced shortfall in deposits.

[6]However, my model differs from Kashyap and Stein (2000) by proposing that the dissimilar behaviors of banks in response to monetary policy are due to borrowing constraints imposed by wholesale creditors, but not due to ratios of liquid assets.

[7]Deposit rate is measured as interest expenses on domestic deposits divided by interest-bearing domestic deposits. Wholesale funding rate is computed as the interest expenses on Federal funds and repo liabilities, trading liabilities, and other borrowed money, divided by the sum of the three types of liabilities.

Take 2007Q2 as an example. The rate wedge was 0.91 percent for the mostly constrained banks, higher than 0.19 percent for the least constrained banks, while deposit rates were about the same across groups of banks. This pattern adds credence to my proxy. The wedge between the cost of internal and external funds is likely caused by hidden information problems (Myers and Majluf (1984) and Greenwald et al. (1984)) or agency problems (Hart and Moore (1994), Jensen and Meckling (1976) and Jensen (1986)). It reflects the market imperfection and should suggest how difficult it is for a bank to raise external funds. Hence, the observed positive relationship between the level of constraints and the level of rate wedges is consistent with the notion that a firm is considered more financially constrained as the wedge between its internal and external cost of funds increases (Kaplan and Zingales (1997)).

Fourth, as mentioned previously, the constraint proxy is not correlated with bank market power. There is little variation in median values of bank HHI across groups of banks with different constraint levels. This confirms the validity of my proxy for identification purpose since any correlation with bank market power would contaminate the estimate on the effect of financial constraints.

Finally, Table (5) shows that banks that are more constrained are larger than those that are less constrained. This pattern stands in contrast to literature that studies the effect of constraints on non-financial firms. For example, both Whited and Wu (2006) and Kaplan and Zingales (1997) find that smaller firms are more likely to be financial constrained. Supporting this result is the idea that commercial banks are much more regulated than non-bank firms. Smaller non-bank firms may experience more severe asymmetric information issues, which can restrict their access to external funding compared to larger firms. In contrast, banks, regardless of their size, are obligated to regularly disclose their balance-sheet and income-statement information. As a result, the degree of asymmetric information problems in the banking sector may not vary significantly based on bank size. In addition, small banks typically operate within local markets, while large banks have a broader geographic reach for lending. This implies that small banks may have fewer investment opportunities, making them less financially constrained compared to larger banks.

C. Large Banks

As demonstrated above, there is a positive relationship between constraint levels and bank size. The correlation coefficient between constraint levels and log of bank assets is 0.38 and statistically significant. As of 2019Q2, among the banks classified as mostly constrained (i.e., banks with a constraint level of 4), 10% of them are ranked within the top 200 banks based on size. For instance, JP Morgan Chase, which is one of the largest banks in the US, consistently falls within the mostly constrained group across all quarters, with an average wholesale ratio exceeding 35% over the years. Citibank shares a similar pattern, being part of the mostly constrained banks group for all quarters. Bank of America's constraint levels vary, with some quarters at a level of 4 and others at a level of 3.

Nevertheless, it is worth noting that not all large banks borrow extensively from wholesale funding markets. For example, TD Bank, which ranked among the top 10 banks in terms of size in 2019, is considered unconstrained in 2019. Another notable case is Silicon Valley Bank (SVB). Despite being the 30th largest bank by size at the end of 2019, SVB borrowed little from wholesale markets and thus had a low constraint level of 0 or 1 following the financial crisis. Its wholesale ratio in 2019 stood at approximately 1%. This indicates that SVB had abundant deposits and limited profitable investment opportunities to finance. This observation aligns with its actions during the pandemic, as SVB responded to a surge in deposits in 2021 by investing a significant portion of its funding into government-backed securities, indicating a scarcity of lucrative lending opportunities.

Additionally, there are also smaller banks that rely heavily on wholesale funding. The Union Bank Company, for instance, operates with only one main office and one branch located in Ohio, employing a total of 10 individuals. However, it has a wholesale ratio of 33 percent, surpassing many large banks. In summary, while using the wholesale ratio as an indicator for being constrained does capture large banks, there is still notable variation observed among banks of different sizes.

D. Regression Results

Using the constraint level proxy, I run the following regression to estimate the effect of financial constraints:

$$\frac{\Delta Wholesale_{it}}{Assets_{it-1}} = \beta_0 \frac{\Delta Deposits_{it}}{Assets_{it-1}} + \sum_{j=1}^{4} \beta_j \frac{\Delta Deposits_{it}}{Assets_{it-1}} \times Cons_{ijt} + X_{it-1}\gamma + \alpha_i + \alpha_t + \epsilon_{it} \tag{36}$$

where $Cons_{ijt}$ is a dummy variable which equals one if the constraint level of bank i at quarter t is j and zero otherwise, and $j \in \{1, 2, 3, 4\}$. I leave $j = 0$ as the baseline case, i.e. banks being unconstrained. $\Delta Deposits_{it}/Assets_{it-1}$ and $\Delta Deposits_{it}/Assets_{it-1} \times Cons_{ijt}$ are instrumented by $\Delta FF_t \times BankHHI_{it-1}$ and $\Delta FF_t \times BankHI_{it-1} \times Cons_{ijt}$, $j = 1, 2, 3, \text{and } 4$. Control variables X_{it-1} include lagged Bank HHI, lagged log of assets, lagged deposit ratio, lagged Tier 1 capital ratio and lagged wholesale ratio. I also include $Cons_{ijt}$ as controls. These dummies help to rule out other characteristics of constrained banks that may affect wholesale borrowing. Other variables are defined in the same manner as the previous regression specifications.

The estimates of β_j for $j \in \{1, 2, 3, 4\}$ are of my interest. A statistically significant estimate of β_j would demonstrate that the impact of deposits on wholesale funding is influenced by the presence of constraints. According to my model, $\widehat{\beta_j}$ should be positive, suggesting that deposits can alleviate financial constraints and consequently result in increased borrowing from the wholesale market.

Table (6) presents the results with different combinations of control variables. Column (1) includes control variables as previous baseline regressions. The coefficients on the interaction terms between deposit growth as a share of assets and the dummies for constraint levels 3 and 4 are positive and highly significant. However, the coefficients on the interactions with the dummies for constraint levels 1 and 2 are statistically insignificant and close to zero. Specifically, in cases where banks have low or zero constraint levels, a 1% increase in deposit growth as a share of assets leads to a 0.23% decrease in wholesale funding growth as a share of assets. However, when their constraint level reaches 3, banks respond to a 1% increase in deposit growth as a share of assets by increasing wholesale funding growth by 0.29% of assets. In situations where the constraint level reaches 4, banks experience a significant increase in wholesale funding growth by 0.76% of assets in response to a 1% increase in deposit growth as a share of assets.

Column (2) adds security-to-asset ratio as an additional control variable. The inclusion of securities aims to capture the idea that banks may use their security holdings as a buffer against deposit shocks (Jayaratne and Morgan (2000)). If the supply of deposits contracts, banks could maintain their lending activities by selling securities (Kashyap and Stein (2000)), which may affect the constraint conditions for banks. The coefficient estimates on interaction terms remain unchanged. This suggests that the effect of constraints on the wholesale-deposit relationship is not driven by security holdings.

Column (3) adds in characteristics that control for loan demand, which could potentially be correlated with financial constraints. These variables include lagged loan-to-asset ratio, lagged loan growth, lagged loan loss provisions as a share of total loans, and lagged growth of loan loss provisions. The inclusion of these variables allows us to account for loan demand factors and banks' expectations of future loan losses (see Jayaratne and Morgan (2000)). The coefficients on β_j, $j \in \{3, 4\}$, become slightly larger while remaining statistically significant. Column (3) indicates that the effects of financial constraints on wholesale-deposit relation is not driven by loan demand of banks.

To test whether the instrumental variables regression suffers from the problem of weak instrument, I follow Lewis and Mertens (2022) to compute general test statistics. Lewis and Mertens (2022) extends the robust test of Olea and Pflueger (2013) for one endogenous regressor to the general case with multiple endogenous regressors. Table (6) reports the general test statistics of the first-stage regression. The null hypothesis of weak instrument is rejected.

Overall, these results show in Table (6) align with the model prediction that a higher deposit growth can alleviate the borrowing constraint when banks' constraints are binding. The consistency among results across different combinations of controls support the model implication that the impact of the deposit growth on wholesale funding is contingent upon the level of constraint faced by banks.

3.3.3.3 Other Components of Balance Sheets

In this section, I examine the effects of deposits on the components of bank assets. Since banks imperfectly substitute wholesale funding with deposits, more deposits lead to an increase in total assets. Studying the effects of deposits on bank assets provides details on how banks absorb the additional funding induced by more deposits. It also allows me to verify the robustness of the earlier results on the impact of financial constraints on bank behaviors: a financially constrained bank should pursue more lending than the unconstrained one since it has better lending opportunities. Moreover, this investigation can shed light on the recent failure of Silicon Valley Bank (SVB), which could be attributed to its excessive holdings of government backed securities following a sudden deposit influx during the COVID-19 pandemic. It remains unclear whether this is a common practice for banks to invest in more securities rather than more loans following deposit inflows. I estimate the effect of deposits on the components of bank assets by running the following regression.

$$\frac{\Delta Y_{it}}{Assets_{it-1}} = \beta_1 \frac{\Delta Deposits_{it}}{Assets_{it-1}} + \beta_2 BankHHI_{it-1} + X_{it-1}\gamma + \alpha_i + \alpha_t + \epsilon_{it} \tag{37}$$

where $\Delta Deposits_{it}/Assets_{it-1}$ is instrumented by $\Delta FF_t \times BankHHI_{it-1}$, same as Equation (31). $\Delta Y_{it}/Assets_{it-1}$ denotes the growth rate of total assets, loans[8], securities, cash, and federal fund sold and securities purchased under agreement to resell, as a share of assets. Growth rates as a share of assets are calculated as quarterly changes between time t and $t-1$, divided by the total assets at time $t-1$. X_{it} are the same controls used in regression

[8] Agricultural loans are excluded from the analysis due to the main driver of agricultural loans being loan demand (Scott et al. (2022)) and the tendency of banks with larger market power to have a greater share of agricultural loans, as evidenced by the data. The exclusion of agricultural loans mitigates the issues of the potential correlation between loan demand and bank HHI that could compromise the instrumental variable's validity. It is worth mentioning that the exclusion of agricultural loans does not significantly impact the implications regarding bank loans since agricultural loans represent only a small fraction of total loans for most banks, with a median share of just 1.8 percent.

(31).

Table (7) shows the results for various outcome variables. From the Column (1), the coefficient on asset growth is significantly positive and smaller than one, providing support for the imperfect substitution between wholesale funding and deposits when banks have more deposits: the coefficient estimate should be zero if banks perfectly substitute between the two funding sources, and one if the two types of funding are not substitutable at all. Column (2) shows a positive coefficient on the growth of loans. The point estimate is 0.34 and highly statistically significant. Thus, an increase of 1% of assets in deposit growth leads to an increase of 0.34% of assets in loan growth. The significantly positive coefficients in Column (4) and (5) imply that, in additional to making more loans, banks also increase their cash holdings and lend more in the federal funds and the repo market to respond to additional deposit funding. Note that the coefficient on the growth of securities, shown in Column (3), is insignificant and near zero. This result suggests that, in contrast to SVB which almost invested all of its deposit inflows in securities, banks typically do not engage in additional investments in securities when they experience positive deposit shocks.

It is worth noting that all these estimated causal relationships above are based on a contemporaneous manner. Banks are likely to gradually adjust their exposures to multiple types of assets over time instead of contemporaneously. For example, it may take some time for banks to evaluate borrowers' default risk before issuing new loans. The regression (31) only estimates the contemporaneous effects of deposits, so my results in Table (7) do not speak to long-term effects. Notably, estimating changes over a shorter time span is preferred from an identification standpoint as it helps control for other factors that may vary with monetary policy over a more extended period.

Next, I test whether financial constraints affect the relationship between deposit and loan growth. As suggested by the model, a bank is considered financially constrained if its lending activities are limited by the availability of funding. In other words, if the bank had access to more funding, it would be able to invest more in loans. This implies heterogeneous effects of deposits on bank lending according to banks' financial constraints. The impact of deposits on bank loans should be more pronounced for constrained banks compared to unconstrained ones. The financial constraint thus reinforces the link between deposit and loan growth.

Using the constraint proxy, I estimate the effect of financial constraints by interacting the measure of constraint levels and deposit growth.

$$\frac{\Delta Loans_{it}}{Assets_{it-1}} = \beta_0 \frac{\Delta Deposits_{it}}{Assets_{it-1}} + \Sigma_{j=1}^{4} \beta_j \frac{\Delta Deposits_{it}}{Assets_{it-1}} \times Cons_{ijt} + X_{it-1}\gamma + \alpha_i + \alpha_t + \epsilon_{it} \tag{38}$$

where the dependent variable is the growth of bank loans as a share of assets. The key variables of interest are the interactions between deposit growth as a share of assets and constraint levels, instrumented by $\Delta FF_t \times bankHHI_{it-1}$ and $\Delta FF_t \times bankHHI_{it-1}$ interacted with $Cons_{ijt}$. $Cons_{ijt}$ are dummy variables which equals one if the constraint level of bank i in quarter t is j, where $j \in \{1, 2, 3, 4\}$, and zero otherwise. Control variables and fixed effects are the same as regression (36).

Table (8) reports the results. Column (1) in Table (8) show that a 1% increase in deposit growth as a share of assets leads to a 0.3% increase in loan growth as a share of assets for unconstrained banks, whose constraint levels are zero. This table also reports positive and significant coefficients on interactions with dummies for constraint levels 2, 3, and 4. However, the coefficient on the interaction term with the dummy for the constraint level being 1 is insignificant. This implies that, for banks with low constraint levels, the effect of deposits on loans is similar to that of unconstrained banks. As the constraint level rises, the influence of deposits on loans becomes stronger.

In terms of magnitudes, the coefficients on interactions in Table (8) implies that a 1% increase in deposit growth leads banks with a constraint level of 4 to raise its loan growth by 0.6% of assets compared to banks with a constraint level of 0. This figure decreases to 0.4% and 0.2% if the constraint level turns to 3 and 2, respectively. These economically large effects indicate a high pass-through of bank deposits to loans if the bank is highly financially constrained.

Positive coefficients on interactions in Table (8) also verify the effectiveness of proxies for constraint levels of banks. A financially constrained bank, given its plethora of promising lending opportunities by definition, should increase its lending more substantially once it obtains additional funding, relative to unconstrained ones. This is evidenced by the positive coefficients on interactions between deposit growth and the dummy variables for constraint levels 2, 3, and 4. These coefficients suggest that the rise in loan growth, stimulated by a rise in deposit growth, is more pronounced for banks with high levels of constraints compared to less constrained banks.

Table (8) demonstrates that financial constraints can amplify the transmission from deposits to bank lending. This result provides further support for the hypothesis that deposits can relax financial constraints on wholesale borrowing. Combined with the results for wholesale funding, an increase in deposits, driven by an expansionary monetary policy, alleviates banks' financial constraint, enabling them to secure additional funding from wholesale funding markets and to extend their provision of loans. These findings highlight that a bank's lending response to deposit influxes is significantly contingent on its financial constraint. The tighter the financial constraint a bank faces, the more it increases its lending when it obtains additional deposit funding.

To sum up, this section estimates how a bank adjusts its wholesale funding and a variety of assets in response to an increase in deposits. The data reveal that the sensitivity depends on the tightness of financial constraints, proxied by wholesale-to-deposit ratio. Point estimates imply that banks that are unconstrained or nearly unconstrained cut their wholesale funding growth by 0.2% of assets in response to an increase in deposit growth of 1% of assets. By contrast, banks that are highly constrained increase wholesale funding growth by about 0.7% of assets. Similarly, unconstrained banks increase loan growth by 0.3% of assets in response to a 1% increase in deposit growth as a share of assets, whereas highly constrained banks increase loan growth by 0.9% of assets.

4 Aggregate Implications

This section explores aggregate implications of the previous section's evidence by asking the question of how the entire banking sector responds to aggregate deposit shocks. For concreteness, let's consider a scenario where an unanticipated surge in overall economic activity. This economic surge creates an increase in bank deposits as household income rises, and simultaneously increase demand for loans. In reaction to this economic growth, banks change their balance sheets. These changes arise both directly from the influx of deposits and indirectly from the ripple effects of the economic boom, such as the surge in loan demands. Solely examining the shifts in bank balance sheets does not allow us to separate the balance-sheet effects of the increase in deposits from the balance-sheet effects of the surge in loan demand. The instrumental variable estimation, as discussed in the previous section, provides us with the causal effect of deposits, which can help us identify this direct impact of aggregate deposits.

Since the effects of deposits are heterogeneous across banks based on their individual financial constraints, the aggregate implication depends on both the volatility of shocks to total deposits, and how these shocks are distributed among banks with different constraints. Once we have aggregate deposit shocks allocated to individual banks, we can get the aggregate implication by multiplying the deposit shocks with the corresponding parameters estimated in the previous section and then summing the results across all banks. Subsection

(4.1) estimates the properties of aggregate deposits. Subsection (4.2) uses parameter estimates from the previous section to infer the direct effects of these aggregate deposit shocks on aggregate wholesale funding and loans.

4.1 Aggregate Deposit Shocks

This subsection constructs aggregate deposit shocks and allocates aggregate shocks to individual banks. This exercise will provide me with 1). the magnitude of the volatility of aggregate deposit shocks, 2). inputs to estimate the effect of deposit shocks on wholesale funding and loans at the industry level for the next subsection (4.2).

Aggregate deposits can be viewed as a function of a few macroeconomic variables. As documented in Harvey and Spong (2001), factors such as households' access to novel financial products due to technological development and changing demographics in the markets can shape deposits. Bomberger (1993) studies household income and wealth as determinants of deposits. Van Roosebeke and Defina (2022) argues that inflation may affect deposits through its impact on household saving rate. In my model, households' allocation among cash, deposits, bonds also depends on the federal funds rate and the deposit spread defined as the difference between the federal funds rate and the deposit rate. We thus can summarize the size of aggregate deposits as a function of a few variables.

$$D = D(\text{wealth, income, demographics, inflation, fed funds rate, deposit spread}) \tag{39}$$

Recall that the goal of this section is to examine the effect of aggregate deposit supply shocks on wholesale borrowing and loans. To do so, I need to construct deposit shocks not driven by banks. This is challenging because, theoretically, if banks demand more deposits, they can cause changes in deposits by changing the deposit spread, according to Equation (39). For example, an increase in banks' risk tolerance will increase their desire to make loans, so banks can raise deposits by raising deposit rates. Simultaneously, to respond to the desire of making more loans, banks may also borrow more from wholesale funding market. As a result, we may observe a positive relationship between deposits and wholesale funding that is not an effect of exogenous deposit supply shocks but driven by banks themselves.

However, the literature indicate that this channel of banks driving aggregate deposits is empirically weak, because the elasticity of aggregate deposits is very low. For example, Acharya and Mora (2015) note that during the financial crisis, banks even hiked deposit rates in an attempt to attract depositors when faced with a liquidity insufficiency, yet, they still could not boost deposit inflows. Chiu and Hill (2018) quantitatively study the behavior of household deposit funding. They examine the rate elasticity of household deposits and find that household deposits are rate inelastic. Based on this inelasticity of household deposits documented in the literature, I adopt as a maintained assumption that changes in aggregate deposits occur because of changes in the household sector, such as wealth and income, and other macroeconomic determinants that affect households, but not because of changes in deposit spreads induced by banks. Given this maintained assumption, I can define aggregate deposit shock as the difference between actual deposits and the conditional expectation of deposits and interpret the difference as the shock driven by household supply but not by banks themselves. Specifically, I run the autoregressive models using quarterly time-series data on the aggregate banking sector from 1994 to 2019[9].

$$\Delta \log(Deposits_t) = \alpha + \sum_{j=1}^{j=6} \beta_j \Delta \log(Deposits_{t-j}) + \epsilon_t \tag{40}$$

where $\Delta \log(Deposits_t)$ is the aggregate deposit growth at quarter t, calculated as the log difference of the whole commercial banking sector between quarter t and $t-1$. Aggregate deposits are deposits of all commercial banks in the United States. According to Akaike's information criterion, I include six lags of deposit growth in the model. The error terms ϵ_t symbolizes the unanticipated fluctuations in aggregate deposit growth. As a result, the mean of innovations in deposit growth, i.e. ϵ_t, is close to zero. The standard deviation is 1.1%, and minimum and maximum are -2.0% and 4.0% respectively.

Then, since the effects of deposits on wholesale and loans depends on a bank's financial constraint, I need to distribute the aggregate deposit shocks to individual banks. I assume that each bank experiences the same deposit growth shock as the shock to aggregate deposit growth. Then, I convert shocks to deposit growth to shocks to level changes. Specifically, deposit shocks at quarter t for bank i can be expressed as follows:

$$DepositShock_{i,t} = Deposits_{i,t-1} \times \epsilon_t \tag{41}$$

The constructed deposit shocks at the bank level will be used as inputs to estimate the aggregate impact of deposit shocks in subsection (4.2).

[9] It is worth noting that without the maintained assumption that changes in aggregate deposits are not driven by banks, I can not construct aggregate deposit shocks using autoregressive approach to identify the effect of deposit shocks on balance-sheet behavior, because the relationship between the two could be driven by banks but not households. In addition, It would be better to do the same exercise for banks sharing the same degree of constraint level, because the deposit shocks may be different across banks with different constraint statuses. However, since I assign banks constraint levels quarter by quarter, the composition of banks in each group varies over time. Therefore, I construct the aggregate deposit shocks of the entire banking sector without considering the potential heterogeneity of banks with different constraints.

Since the proportion of constrained banks significantly influences the aggregate effect, I explore the size of constrained banks in the whole banking system before quantifying the aggregate implication. Figure (4) plots the deposit share of mostly constrained banks (those whose constraint level is 4) within the banking sector from 1994 to 2019. The figure shows that the share of mostly constrained banks is time varying. It should be noted that, despite these mostly constrained banks being classified as those with wholesale ratios falling within the uppermost decile in terms of the number of banks, the deposit share of such heavily constrained banks surpasses 10 percent. This is due to the propensity of larger banks to maintain more substantial wholesale-to-deposit ratios, thus their contribution to aggregate deposits is disproportionately large compared to their number.

As demonstrated in the figure, the deposit share of mostly constrained banks experienced notable fluctuations following the Global Financial Crisis. Prior to this financial upheaval, in the 1990s and early 2000s, the deposit share of constrained banks hovered around 50 percent. It exceeded 60 percent in 2008. This is consistent with Acharya and Mora (2015), which argues that during this period of financial crisis, US banks faced severe wholesale funding constraints. The share subsequently declined after the financial crisis. The implementation of the Fed's quantitative easing to combat financial crisis boosted bank reserves and relaxed financial constraints, as documented in Sims and Wu (2020). As a result, the deposit share of constrained banks stabilized at around 30 percent in the post-crisis period, with a temporary surge in 2016.

4.2 Aggregate Effects on Wholesale Funding and Loans

In this subsection, I use both coefficient estimates in Section (3) and the constructed deposit shocks from subsection (4.1) to establish aggregate effect of deposits on wholesale funding and loans of the banking sector. As indicated by the coefficient estimates from Section (3), unconstrained banks, specifically those at the constraint level of zero, experience a reduction in wholesale funding growth by 0.23% of assets when deposit growth ascends by 1% of assets. The coefficients for banks with constraint levels of 1 and 2 do not significantly deviate from those of unconstrained banks. In contrast, the coefficients for banks with constraint levels of 3 and 4 are statistically significant and positive. According to the estimated coefficients, banks with constraint levels 4 and 3 witness increases in wholesale funding growth by 0.75% and 0.29% of assets, respectively, when deposit growth goes up by 1% of assets. These results suggest that the impact of deposit shocks on wholesale funding is contingent upon banks' constraints.

Note that the identification of the effect of deposit shocks on wholesale funding in Section

(3) is based on deposit and wholesale growth *normalized* by assets. Consequently, I first scale individual deposit shocks in level changes by the previous quarter's assets. Subsequently, for each bank, I compute the effect on wholesale growth by multiplying individual bank deposit shocks by their corresponding coefficient, contingent on the bank's constraint level. Finally, I sum up the level-changes in wholesale funding of all banks to derive an aggregate effect on wholesale funding. Specifically,

$$WholesaleShock_t^{IV} = \sum_{i=1}^{N} Assets_{it-1} \times \left(\sum_{k=0}^{k=4} \beta_k \cdot \mathbb{1}(ConsLevel_{it} = k) \cdot \frac{DepositShock_{it}}{Assets_{it-1}} \right) \tag{42}$$

where N is the total number of banks. The coefficient β_k is multiplied to deposit shocks of bank i at quarter t if the bank's constraint level is k, $k \in \{0, 1, 2, 3, 4\}$.

To compare the effects of deposit shocks using the IV approach with those obtained using OLS, I run the following OLS regression and compute the effects on wholesale funding.

$$\Delta log(Wholesale_t) = \gamma_1 \Delta log(Deposits_t) + \gamma_q + \nu_t \tag{43}$$

where γ_q, $q \in \{1, 2, 3, 4\}$, represent seasonal quarterly dummies. Then the effects on wholesale funding induced by aggregate deposit shocks in Equation (40) can be computed as

$$WholesaleShock_t^{OLS} = \widehat{\gamma_1} \epsilon_t \cdot Wholesale_{t-1} \tag{44}$$

I conduct the same exercise on effects of deposit shocks on bank loans. Figure (5) and Figure (6) show time series of aggregate wholesale funding changes and aggregate loan changes induced by aggregate deposit shocks, comparing the IV approach and the OLS approach.

As shown in these figures, positive deposit shocks led to more wholesale funding at the aggregate level, but the magnitude varies over time. As expected, the magnitude was larger prior to the Global Financial Crisis, a period when mostly constrained banks constituted a substantial portion of the deposit market. The magnitude diminished after the crisis, a time when many larger banks transitioned to a state of lesser constraint, resulting in a reduced deposit share for the primarily constrained banks[10]. In addition, the OLS approach

[10] Note that the measurement of the constraint level is a relative assessment within a given quarter. Regardless of the overall economic climate, 10 percent of banks are invariably classified as the most heavily constrained within each quarter. However, the overall constraint level post-crisis is lower than that observed pre-crisis according to wholesale-to-deposit ratios. As such, the magnitude of the effect in the post-crisis period could be overstated, since some banks classified as constrained during this period may be considered unconstrained by pre-crisis standards.

underestimates the effect of deposits, suggested by both figures. Specifically, a 1% increase in deposit growth leads to an increase in loans growth ranging from 0.58% to 0.88% and an increase in wholesale borrowing growth between 1.12% and 3.31%, according to the deposit share of constrained banks. OLS estimates suggest a 1% increase in deposit growth results in an increase of 0.45% in loan growth and of 0.93% in wholesale borrowing growth. This is consistent with Khwaja and Mian (2008), which also find that OLS gives an underestimate of the true effect of deposits on loans.

Variance. Finally, I investigate the proportion of variance of the aggregate wholesale and loan shocks attributable to deposit shocks. To do this, I first construct aggregate wholesale and loan shocks using autoregressive models.

$$\Delta \log Y_t = \gamma + \sum_{j=1}^{j=q} \Delta \log Y_{t-j} + e_t \tag{45}$$

where Y is the aggregate level of wholesale borrowing or loans of all commercial banks, so the dependent variables are quarterly growth rates of wholesale borrowing or loans of the whole banking system, measured as log differences. According to AIC, I include seven lags for wholesale growth, i.e. $q = 7$, and four lags for loan growth, i.e. $q = 4$. The residual e_t represents shocks to wholesale or loan growth.

Now I can compute the fraction of variance of wholesale that are due to deposit shocks as the following.

$$\frac{\text{Variance driven by deposit shocks}}{\text{Total variance}} = \frac{var(\widehat{e_t})}{var(e_t)} \tag{46}$$

where e_t is shock to aggregate wholesale growth in Equation (45), and $\widehat{e_t}$ is the change to wholesale growth driven by deposit shocks, indicated by Equation (42). The fraction of the variance of loan growth driven by deposit shocks is computed in the same way. As a result, I find that deposit shocks account for 35% of the variance of wholesale funding growth and 49% of the variance of loan growth.

5 Conclusion

I propose a novel mechanism through which banks' deposits influence their balance-sheet composition, contingent on the borrowing constraint imposed by wholesale funding creditors. Unconstrained banks substitute wholesale funding with deposits, whereas constrained banks have their constraints eased with more deposits, which enables them to borrow more aggressively from wholesale creditors. This is due to the de facto seniority of wholesale funding, driven by the inelasticity of household deposits and the presence of deposit insurance.

I provide the evidence for this economic mechanism by estimating the causal relationship between deposits and banks' balance-sheet components. The findings support the model's predictions, revealing different effects of deposits on wholesale borrowing for constrained and unconstrained banks. Furthermore, the positive impact of deposits on loans is more pronounced for financially constrained banks. In addition, using the identified parameters, I investigate the aggregate implications of deposit shocks. My results suggest that, at the aggregate level of the banking sector, OLS underestimates the true effect of deposits on loans and wholesale borrowings. I find that deposit shocks account for 35% of the variance of wholesale funding growth and 49% of the variance of loan growth.

My findings suggest the indirect impact of monetary policy on wholesale funding and thus banks' funding composition and vulnerability, contingent on financial constraints. This paper also implies that both bank market power in the deposit market and financial constraints could bolster monetary policy transmission.

Deposits serve as both the primary source of safe assets for households and the major funding source for banks. Thus, comprehending the impact of deposits on banks' assets and liabilities is crucial for regulation and policy. This research emphasizes the role of financial constraints in transmitting deposit shocks to banks' balance-sheet composition.

TABLES

Table 1: PARAMETERS USED IN SOLVING NUMERICAL SOLUTIONS

Parameters	Values	Description
N	5	The number of banks
η	1.1	Elasticity of substitution across deposits at different banks
ϵ	2	Elasticity of substitution between deposits and cash
ρ	0.2	Elasticity of substitution between wealth and liquidity services
λ	0.00125	Share parameter for liquidity services
δ	0.8	Share parameter for deposits
g^H	0.1	Upper bound of g
g^L	-0.1	Lower bound of g
p	0.1	Probability of default for borrowing constraint
c_1	0.004	Parameter for marginal revenue of loans when constraint does not bind
c_2	0.001	Parameter for marginal revenue of loans when constraint does bind
W_0	10	Initial wealth

Notes. This table shows parameters used in numerically solving the model. Values of λ, ρ, δ, ϵ, N and η follow Sa and Jorge (2019).

Table 2: DEPOSIT AND WHOLESALE FUNDING GROWTH

	(1)	(2)	(3)
Period	1973 Jan - 1994 Dec	1995 Jan - 2007 Jun	2010 Jan - 2019 Dec
Variables		Wholesale funding growth	
Deposit Growth	0.04	0.29***	-0.08
	(0.05)	(0.06)	(0.06)
Observations	(263)	(150)	(120)
Month dummy	yes	yes	yes

Notes. This table shows the relationship between deposit growth and wholesale growth of the whole banking industry. Each column of this table presents estimated coefficients from a specification of the form: $\Delta Wholesale_t/Assets_{t-1} = \beta\Delta Deposits_t/Assets_{t-1} + \alpha_m + \epsilon_t$, where $\Delta Wholesale_t/Assets_{t-1}$ and $\Delta Deposits_t/Assets_{t-1}$ are monthly growth of wholesale funding and that of deposits of the banking sector normalized by assets at month $t-1$, and α_m represents month dummies. In Column (1), the sample covers 1973 January - 1994 December. In Column (2), the sample consists of months from 1995 January to 2007 June. In Column (3), the sample covers the period from 2010 January to 2019 December, which is the time after the crisis but before COVID pandemic. Standard errors are Newey-West standard errors. *, **, *** indicates significance at the 0.1, 0.05, and 0.01 levels, respectively. The choice of truncation parameters for Newey-West standard errors follows Lazarus et al. (2018).

Table 3: DEPOSIT CHANNEL OF MONETARY POLICY

	Deposit Growth			
VARIABLES	(1)	(2)	(3)	(4)
ΔFF	-0.15***		-0.06*	
	(0.04)		(0.03)	
$\Delta FF \times BankHHI$	-1.01***	-0.91***	-0.99***	-0.86***
	(0.12)	(0.12)	(0.11)	(0.11)
BankHHI	1.70***	0.45**	-0.81***	-0.76***
	(0.24)	(0.23)	(0.28)	(0.29)
Deposit Ratio			-40.82***	-38.96***
			(1.64)	(1.64)
Log of Assets			-1.83***	-2.41***
			(0.04)	(0.07)
Wholesale Ratio			-18.39***	-16.57***
			(1.12)	(1.11)
Tier 1 Capital Ratio			-5.56***	-6.27***
			(0.71)	(0.72)
Observations	676,026	676,026	673,736	673,736
R-squared	0.11	0.14	0.17	0.19
Bank×ZLB FE	Yes	Yes	Yes	Yes
Time FE	No	Yes	No	Yes

Notes. This table estimates the effect of Fed fund rate changes on deposit growth. The data are at the bank-quarter level from 1994 to 2019. $\Delta Deposits_{it}$ represents deposit growth of bank i at quarter t, measured as quarterly change of deposits between quarter t and $t-1$, normalized by assets at quarter $t-1$. ΔFF_t is the contemporaneous change in the Fed fund target rate at quarter t. The target rate is measured as the average of the upper and lower Fed funds rate target after the introduction of a target rate corridor in 2008. $BankHHI_{it-1}$ is the bank-level deposit concentration of bank i at $t-1$. Column (1) and (2) only include $BankHHI$ as a control variables. Column (3) and (4) add more controls including lagged terms of log of assets, deposit-to-assets ratios, wholesale-to-deposit ratio, and the tier-1 capital ratio. Fixed effects are denoted at the bottom. Standard errors are clustered by bank. *, **, *** indicates significance at the 0.1, 0.05, and 0.01 levels, respectively.

Table 4: EFFECTS OF DEPOSITS ON WHOLESALE FUNDING

	Wholesale Growth			
	IV		OLS	
VARIABLES	(1)	(2)	(3)	(4)
Deposit Growth	-0.11**	-0.20***	-0.08***	-0.08***
	(0.04)	(0.05)	(0.00)	(0.00)
BankHHI	-0.01	-0.20**		-0.11**
	(0.06)	(0.10)		(0.08)
Deposit Ratio		-7.09***		-2.17***
		(2.02)		(0.29)
Log of Assets		-0.37***		-0.07***
		(0.12)		(0.02)
Wholesale Ratio		-12.95***		-10.85***
		(0.91)		(0.27)
Tier-1 Capital Ratio		-0.73**		0.07
		(0.37)		(0.15)
Observations	676,026	673,736	697,493	673,736
Bank×ZLB FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Effective F stats	56.77	57.76	N.A.	N.A.

Notes. This table estimates the causal effect of deposits on wholesale funding. Deposit growth and wholesale funding growth are computed as the quarterly change in deposits and wholesale funding normalized by the assets at quarter $t-1$. Column (1)-(2) use the instrumental variable approach and Column (3)-(4) use OLS estimates. Column (1) only includes BankHHI as a control variable. Column (2) adds lagged terms of log of assets, deposit-to-assets ratios, wholesale-to-deposit ratio, and the tier-1 capital ratio, as additional control variables. Deposit growth is instrumented by $\Delta\text{FF} \times BankHHI$. Column (3) does not include control variables other than fixed effects. Column (4) include the same controls as Column (2). Data are from Call Reports. Fixed effects are denoted. Effective F statistics following Olea and Pflueger (2013) are reported at the bottom for Column (1) and (2). The null hypothesis of weak instrument is rejected. Standard errors are clustered by bank. *, **, *** indicates significance at the 0.1, 0.05, and 0.01 levels, respectively.

Table 5: SUMMARY STATISTICS BY CONSTRAINT LEVEL, MEDIAN, 1994, 2007, 2019

Panel A: 1994

	Least constrained 0	1	2	3	Most constrained 4
Cash/Assets	4.87	4.49	4.16	4.09	4.24
Securities/Assets	32.40	31.28	31.14	29.60	27.76
Deposits/Assets	89.64	89.45	88.12	85.07	76.92
Return on Equity	12.08	12.71	13.45	13.94	14.56
Tier 1 Capital Ratio	17.19	15.24	14.71	13.65	12.34
Deposit Rate	3.45	3.52	3.56	3.56	3.51
Rate Wedge	-1.51	-1.02	0.15	0.62	0.88
Log(Assets)	10.66	10.81	10.96	11.34	12.36
Bank HHI	0.23	0.22	0.23	0.22	0.22

Panel B: 2007

	Least constrained 0	1	2	3	Most constrained 4
Cash/Assets	3.62	3.15	2.75	2.55	2.39
Securities/Assets	22.34	18.39	16.25	16.51	19.32
Deposits/Assets	88.22	86.97	84.00	79.52	70.82
Return on Equity	9.78	10.87	10.89	10.62	11.11
Tier 1 Capital Ratio	16.13	13.01	12.07	11.44	11.29
Deposit Rate	3.53	3.69	3.82	3.85	3.82
Rate Wedge	0.19	0.80	0.83	0.77	0.91
Log(Assets)	11.23	11.71	11.96	12.23	12.71
Bank HHI	0.21	0.20	0.20	0.20	0.20

Panel C: 2019

	Least constrained 0	1	2	3	Most constrained 4
Cash/Assets	9.29	6.19	5.10	4.34	4.23
Securities/Assets	21.26	17.39	15.33	14.88	16.75
Deposits/Assets	87.68	87.21	85.11	81.45	75.41
Return on Equity	9.60	10.41	10.20	10.31	9.96
Tier 1 Capital Ratio	17.83	14.76	13.91	13.42	13.49
Deposit Rate	0.41	0.44	0.48	0.53	0.53
Rate Wedge	0.05	0.48	0.49	0.52	0.61
Log(Assets)	11.82	12.38	12.59	12.72	12.79
Bank HHI	0.23	0.21	0.21	0.21	0.20

Notes. This table provides median values of a variety of bank characteristics for groups of banks sorted by constraint levels. Panel A, B, and C are for 1994Q3, 2007Q2, and 2019Q2, which are the first, the last, and a mid-point quarter of the whole sample periods, respectively.

Table 6: FINANCIAL CONSTRAINTS AND DEPOSIT-WHOLESALE RELATIONSHIP

	Wholesale Funding Growth		
	(1)	(2)	(3)
Deposit Growth	-0.23***	-0.23***	-0.23***
	(0.04)	(0.04)	(0.04)
Deposit Growth × ConsLevel=4	0.99***	0.99***	1.01***
	(0.30)	(0.30)	(0.30)
Deposit Growth × ConsLevel=3	0.52***	0.52***	0.53***
	(0.13)	(0.13)	(0.12)
Deposit Growth × ConsLevel=2	0.07	0.07	0.08
	(0.06)	(0.06)	(0.06)
Deposit Growth × ConsLevel=1	-0.04	-0.04	-0.04
	(0.03)	(0.03)	(0.02)
ConsLevel=4	4.66***	4.66***	4.67***
	(0.30)	(0.30)	(0.30)
ConsLevel=3	2.04***	2.04***	2.00***
	(0.12)	(0.12)	(0.14)
ConsLevel=2	1.22***	1.21***	1.18***
	(0.07)	(0.07)	(0.08)
ConsLevel=1	0.50***	0.49***	0.46***
	(0.04)	(0.04)	(0.05)
Lagged Security Ratio		0.42	1.83***
		(0.32)	(0.68)
Lagged Loan Ratio			1.88
			(1.30)
Lagged Loan Growth			0.02
			(0.01)
Lagged Loan Loss Provision Ratio			-0.88
			(2.68)
Lagged Loan Loss Provision Growth			2.56
			(2.60)
Observations	644,841	644,841	644,825
Baseline Controls	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Bank×ZLB FE	Yes	Yes	Yes
Generalized test stats	31.10	31.06	35.86

Notes. This table estimates the effect of financial constraints on deposit-wholesale relationship. $ConsLevel = j$ is a dummy variable which equals one if the constraint level of bank i at quarter t is j and zero otherwise, and $j \in \{1, 2, 3, 4\}$. $j = 0$ is the baseline case, i.e. banks being unconstrained. Baseline control variables include lagged terms of log of assets, deposit-to-assets ratios, wholesale-to-deposit ratio, and the tier-1 capital ratio. Column (1) only include baseline controls. Column (2) add lagged security ratio as an additional control. Column (3) further include more variables to control for loan demand. Fixed effects are denoted. Generalized test statistics following Lewis and Mertens (2022) are reported at the bottom. The null hypothesis of weak instruments is rejected. Standard errors are clustered by bank. *, **, *** indicates significance at the 0.1, 0.05, and 0.01 levels, respectively.

Table 7: EFFECTS OF DEPOSITS ON BANK ASSETS

	Growth of				
	Assets	Loans	Securities	Cash	Fed Fund Sold and Securities Purchased under Aggreement to Resell
VARIABLES	(1)	(2)	(3)	(4)	(5)
Deposit Growth	0.91***	0.34***	0.09	0.12**	0.61***
	(0.06)	(0.08)	(0.08)	(0.05)	(0.09)
BankHHI	-0.18	-0.08	-0.38***	-0.01	0.49***
	(0.12)	(0.15)	(0.10)	(0.06)	(0.18)
Deposit Ratio	1.80	1.96	1.90	-3.03*	13.30***
	(2.41)	(3.02)	(3.11)	(1.84)	(3.74)
Log of Assets	-0.24	-0.20	-0.02	-0.10	0.96***
	(0.15)	(0.19)	(0.19)	(0.11)	(0.23)
Wholesale Ratio	-9.25***	-2.63**	-2.95**	-2.47***	5.54***
	(1.08)	(1.31)	(1.34)	(0.80)	(1.64)
Tier-1 Capital Ratio	0.52	4.63***	0.40	-2.96***	-2.94***
	(0.44)	(0.54)	(0.52)	(0.32)	(0.68)
Observations	673,736	673,736	673,736	673,736	673,736
Bank×ZLB FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Effective F stats	57.76	57.76	57.76	57.76	57.76

Notes. This table estimates the causal effect of deposits on bank assets. Deposit growth and asset growth are computed as the quarterly change in deposits and wholesale funding normalized by the assets at quarter $t-1$. In Column (1)-(5), the dependent variables are growth of total assets, loans, securities, cash, and fed fund sold and securities purchased under agreement to resell, respectively. Control variables include Bank HHI, lagged terms of log of assets, deposit-to-assets ratios, wholesale-to-deposit ratio, and the tier-1 capital ratio. Deposit growth is instrumented by $\Delta \text{FF} \times BankHHI$. Data are from Call Reports. Fixed effects are denoted. Effective F statistics following Olea and Pflueger (2013) are reported at the bottom. The null hypothesis of weak instrument is rejected. Standard errors are clustered by bank. *, **, *** indicates significance at the 0.1, 0.05, and 0.01 levels, respectively.

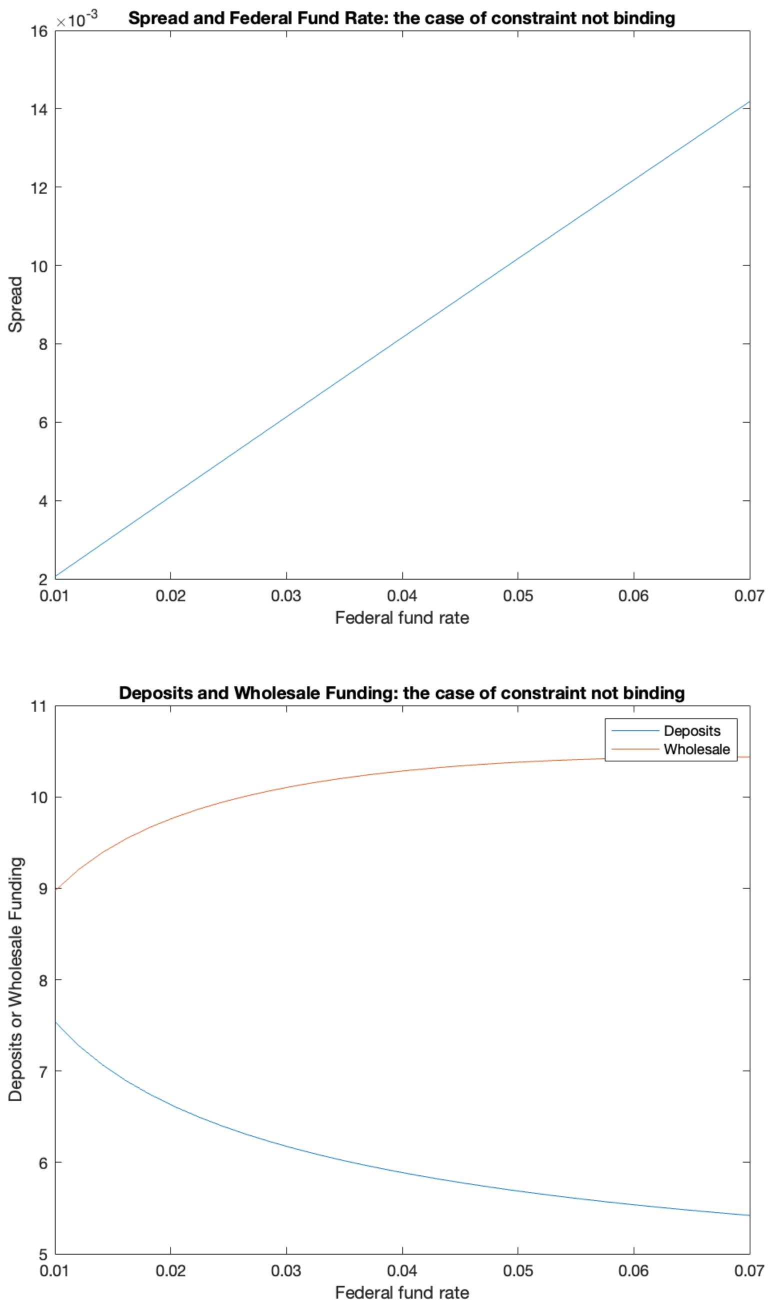
Table 8: THE EFFECTS OF FINANCIAL CONSTRAINTS ON LOANS

	Loan Growth		
	(1)	(2)	(3)
Deposit Growth	0.30***	0.31***	0.21***
	(0.06)	(0.06)	(0.06)
Deposit Growth × ConsLevel=4	0.62**	0.62**	0.54**
	(0.31)	(0.31)	(0.27)
Deposit Growth × ConsLevel=3	0.39**	0.39**	0.34**
	(0.17)	(0.17)	(0.14)
Deposit Growth × ConsLevel=2	0.16*	0.16*	0.14*
	(0.09)	(0.09)	(0.08)
Deposit Growth × ConsLevel=1	0.04	0.04	0.04
	(0.04)	(0.04)	(0.04)
ConsLevel=4	3.08***	3.08***	2.98***
	(0.41)	(0.40)	(0.37)
ConsLevel=3	1.44***	1.43***	1.54***
	(0.14)	(0.14)	(0.15)
ConsLevel=2	0.86***	0.85***	0.99***
	(0.10)	(0.10)	(0.10)
ConsLevel=1	0.43***	0.43***	0.55***
	(0.07)	(0.07)	(0.08)
Lagged Security Ratio		1.06**	-6.92***
		(0.43)	(0.88)
Lagged Loan Ratio			-11.03***
			(1.66)
Lagged Loan Growth			0.13***
			(0.02)
Lagged Loan Loss Provision Ratio			-31.08***
			(4.23)
Lagged Loan Loss Provision Growth			23.84***
			(3.74)
Observations	644,841	644,841	644,825
Baseline Controls	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Bank-ZLB FE	Yes	Yes	Yes
Generalized test stats	31.10	31.06	35.86

Notes. This table estimates the effect of financial constraints on deposit-loan relationship. $ConsLevel = j$ is a dummy variable which equals one if the constraint level of bank i at quarter t is j and zero otherwise, and $j \in \{1, 2, 3, 4\}$. $j = 0$ is the baseline case, i.e. banks being unconstrained. Baseline control variables include lagged terms of log of assets, deposit-to-assets ratios, wholesale-to-deposit ratio, and the tier-1 capital ratio. Column (1) only include baseline controls. Column (2) add lagged security ratio as an additional control. Column (3) further include more variables to control for loan demand. Fixed effects are denoted. Generalized test statistics following Lewis and Mertens (2022) are reported at the bottom. The null hypothesis of weak instruments is rejected. Standard errors are clustered by bank. *, **, *** indicates significance at the 0.1, 0.05, and 0.01 levels, respectively.

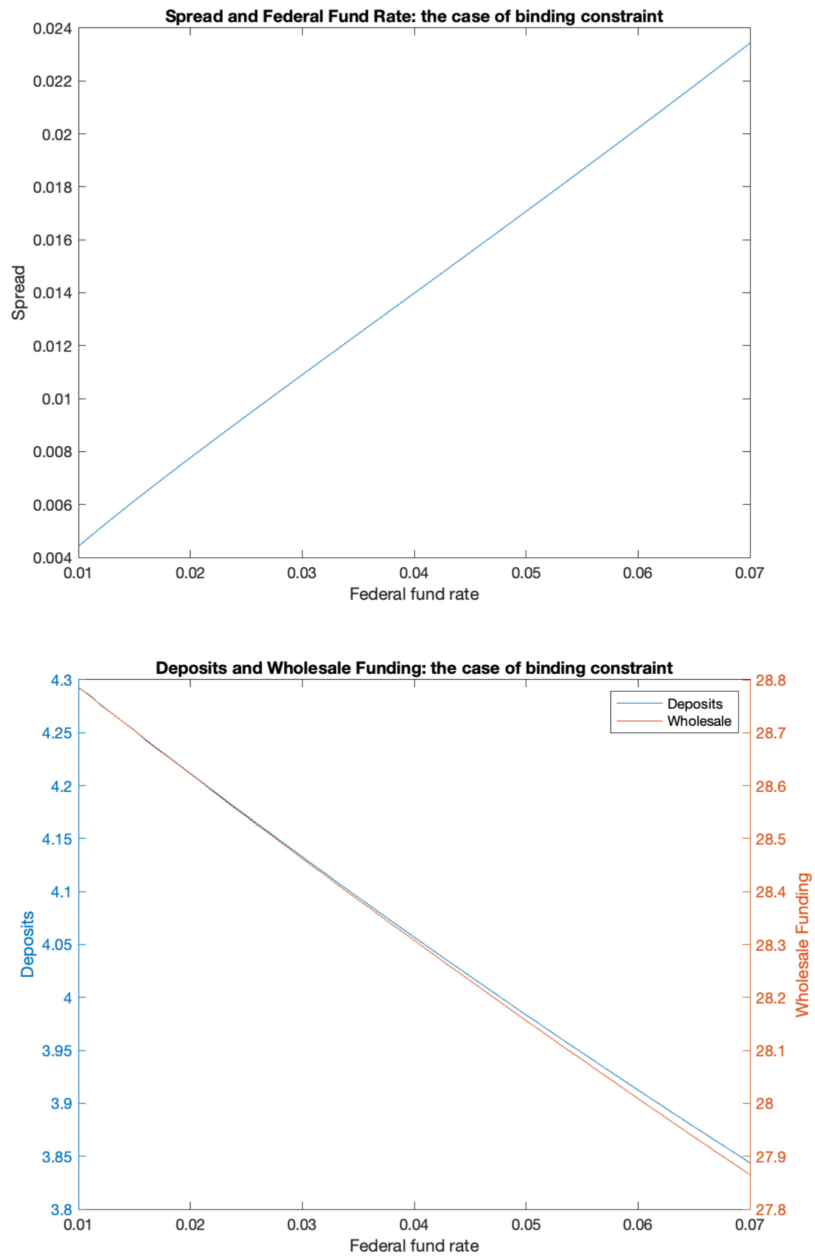
FIGURES

Figure 1: UNBINDING CONSTRAINTS: EFFECTS OF MONETARY POLICY



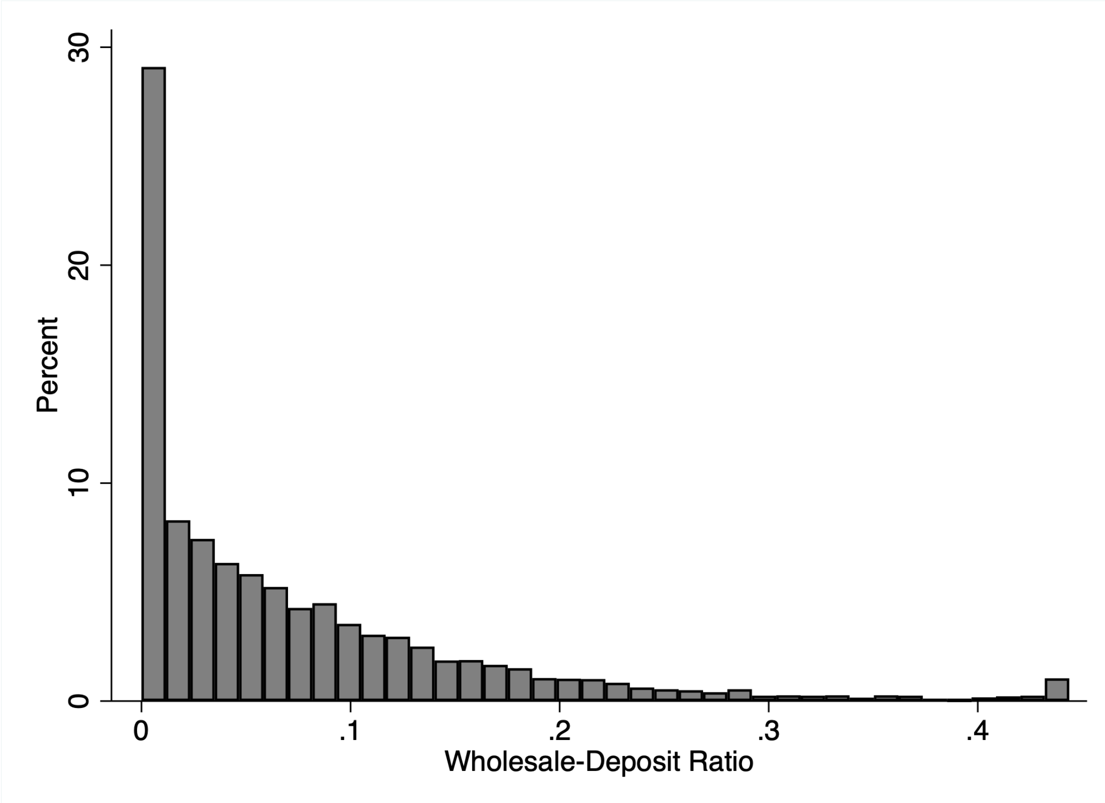
Notes. This figure shows the effect of the federal funds rate on deposit spread (the top panle), the size of deposits and wholesale funding (the bottom panel), in the case where banks are not constrained. Parameters in this numerical examples are $N = 5$, $\eta = 1.1$, $\epsilon = 2$, $\rho = 0.2$, $\lambda = 0.00125$, $\delta = 0.8$, $g^H = 0.1$, $g^L = -0.1$, $p = 0.1$, $c = 0.004$, and $W_0 = 10$.

Figure 2: BINDING CONSTRAINTS: EFFECTS OF MONETARY POLICY



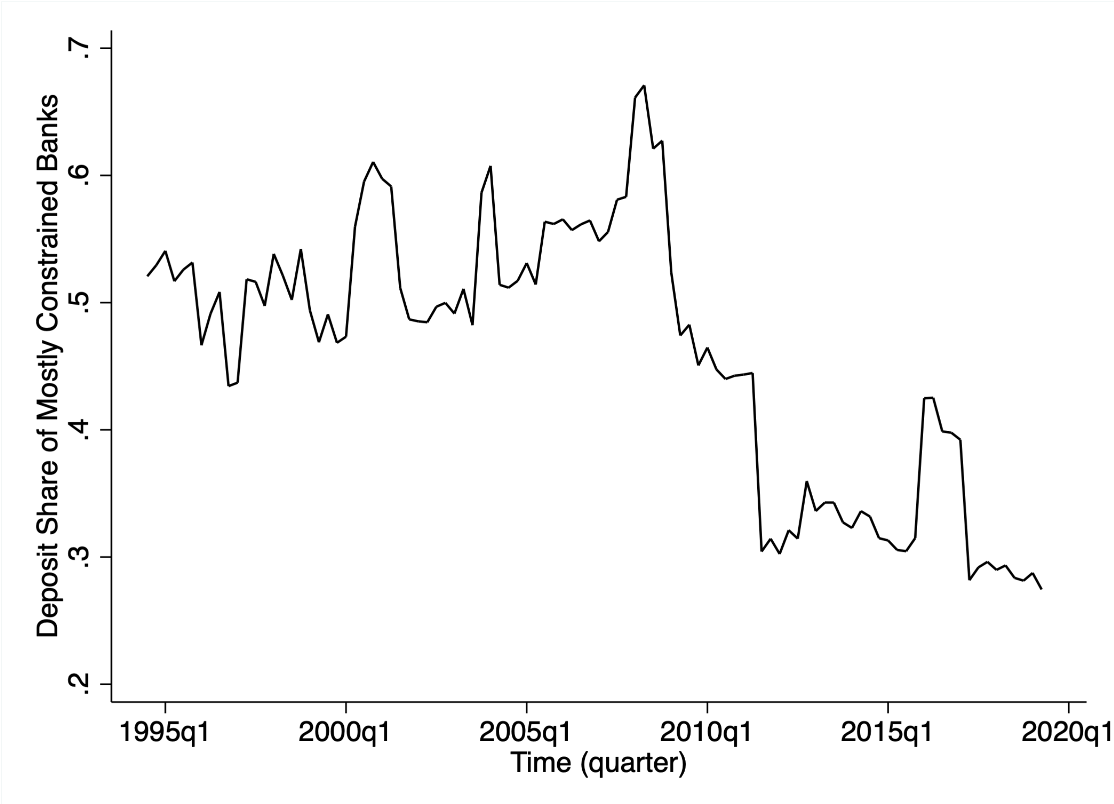
Notes. This figure shows the effect of the federal funds rate on deposit spread (the top panle), the size of deposits and wholesale funding (the bottom panel), in the case where banks are financially constrained. Parameters in this numerical examples are $N = 5$, $\eta = 1.1$, $\epsilon = 2$, $\rho = 0.2$, $\lambda = 0.00125$, $\delta = 0.8$, $g^H = 0.1$, $g^L = -0.1$, $p = 0.1$, $c = 0.001$, and $W_0 = 10$.

Figure 3: DISTRIBUTION OF WHOLESALE-DEPOSIT RATIO AS OF 2007Q2



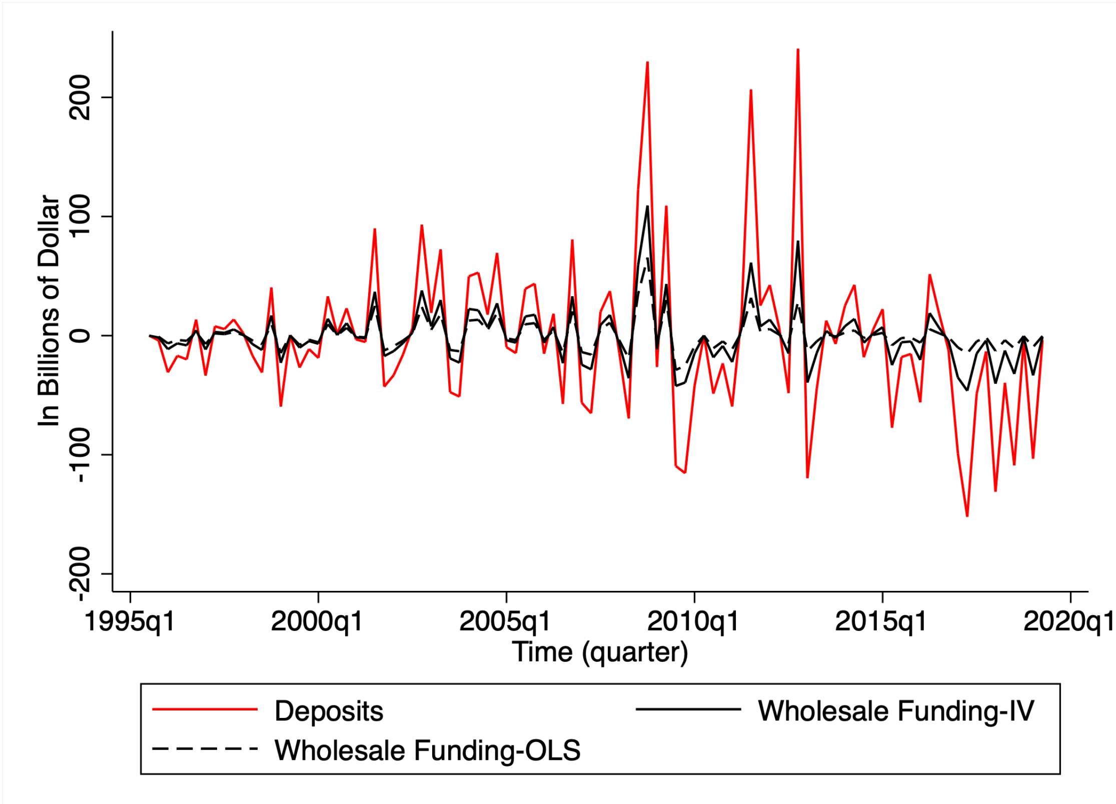
Notes. This figure shows the distribution of wholesale-deposit ratio of all commercial banks as of 2007Q2. Wholesale-deposit ratio is computed as an average between quarter $t-2$ and quarter $t+2$. Data are from Call Reports.

Figure 4: DEPOSIT SHARES OF MOSTLY CONSTRAINED BANKS



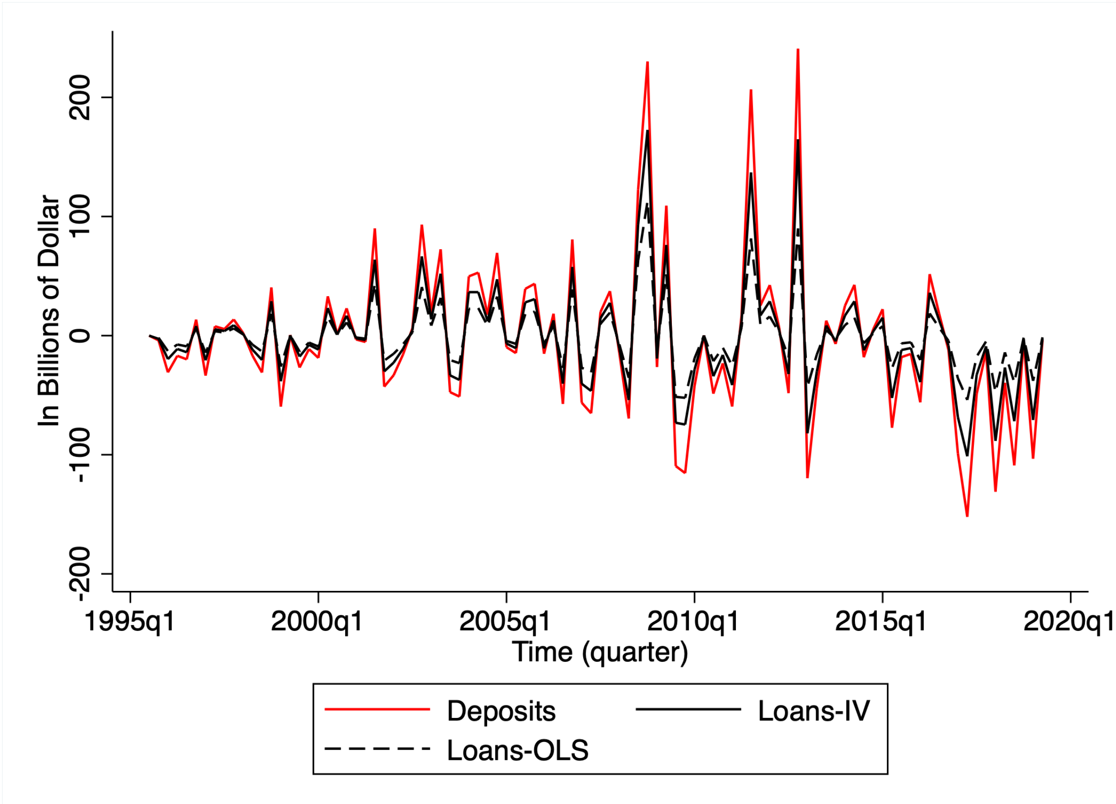
Notes. Data on aggregate deposits from 1994 to 2019 are from Federal Reserve Bank of St. Louis. Deposits are that of domestically chartered commercial banks. Mostly constrained banks are defined as those having the highest decile of wholesale-to-deposit ratio in a given quarter.

Figure 5: DEPOSIT SHOCKS AND THEIR IMPACT ON WHOLESALE FUNDING



Notes. This figure shows quarterly aggregate deposit shocks and their impact on wholesale funding of US commercial banking sector. The red line represents the aggregate deposit shocks. The solid black line plots the effect of deposit shocks on wholesale funding using the IV approach, while the dashed black line plot the effect using OLS.

Figure 6: DEPOSIT SHOCKS AND THEIR IMPACT ON LOANS



Notes. This figure shows quarterly aggregate deposit shocks and their impact on loans of US commercial banking sector. The red line represents the aggregate deposit shocks. The solid black line plots the effect of deposit shocks on wholesale funding using the IV approach, while the dashed black line plot the effect using OLS.

Appendix

.1 Banks' maximization problem

Unconstrained banks.

Proof of Proposition 1.

The first order condition of banks' maximization problem with respect to wholesale funding H_i is

$$0 = \frac{\partial E(\Pi_i)}{\partial H_i} \tag{47}$$

We thus can derive the relationship between H_i and D_i if the constraint does not bind.

$$0 = \frac{1}{2(g^H - g^L)} \left(-\frac{c}{2}(H_i + D_i) + \frac{D_i s_i}{H_i + D_i} - \frac{H_i \mu}{H_i + D_i} + g^H \right) \times \left(-\frac{3c}{2}(H_i + D_i) - \frac{D_i s_i}{H_i + D_i} + g^H + \frac{H_i}{H_i + D_i}\mu \right) \tag{48}$$

Because $H_i + D_i < (g^H - \mu)/c$[11], the term in the first parenthesis is always larger than 0. When the constraint is not binding, the term in the second parenthesis must equal zero.

$$0 = -\frac{3c}{2}H_i^2 + (g^H - 3D_i c + \mu)H_i + D_i(g^H - s_i - \frac{3c}{2}D_i) \tag{49}$$

To make sure we do not have a corner solution at $H_i = 0$, I impose g^H to be sufficiently large such that the marginal benefit at $H_i = 0$ is larger than 0. Mathematically,

$$g^H > s_i + \frac{3c}{2}D_i \tag{50}$$

With the condition $H_i > 0$, we, therefore, can get the relationship between H_i and D_i as

$$H_i = \frac{g^H + \mu - 3D_i c + \sqrt{(g^H + \mu)^2 - 6D_i c(s_i + \mu)}}{3c} \tag{51}$$

As a results, we observe a negative relationship between H_i and D_i. Proposition 1 is proved.

Equilibrium level of spread

To obtain the equilibrium level of s, we need to consider banks' choice on deposits. The

[11] Otherwise the bank can improve expected payoff by marginally decreasing H_i. By doing this, theb bank increases both the probability of not default and the conditional expected payoff shown by Equation (12).

first order condition with respect to deposits D_i should be satisfied too.

$$0 = \frac{\partial E(\Pi_i)}{\partial D_i} \tag{52}$$

We can re-write as

$$\begin{aligned} 0 = \frac{1}{2(g^H - g^L)} & \left(-\frac{c}{2}(H_i + D_i) + \frac{D_i s_i}{H_i + D_i} - \frac{H_i \mu}{H_i + D_i} + g^H \right) \\ & \times \left(2(\frac{\partial s_i}{\partial D_i} D_i + s_i) - \frac{3c}{2}(H_i + D_i) - \frac{D_i s_i}{H_i + D_i} + \frac{H_i \mu}{H_1 + D_i} + g^H \right) \end{aligned} \tag{53}$$

Therefore,

$$0 = 2\left(\frac{\partial s_i}{\partial D_i} D_i + s_i\right) - \frac{3c}{2}\left(H_i + D_i\right) - \frac{D_i s_i}{H_i + D_i} + \frac{H_i \mu}{H_1 + D_i} + g^H \tag{54}$$

Combining the two first-order conditions, we obtain, when the constraint is not binding,

$$\frac{\partial s_i}{\partial D_i} \frac{D_i}{s_i} = -1 \tag{55}$$

The level of the deposit spread s in a symmetric equilibrium can be solved through the deposits market clearing condition, by substituting Equation (55) and Equation (25) into Equation (22).

$$N - \eta(N-1) = \left(\frac{1}{1 + \delta^\epsilon \left(\frac{\bar{r}}{s}\right)^{\epsilon - 1}} \right) \epsilon + \left(\frac{\delta^\epsilon \left(\frac{\bar{r}}{s}\right)^{\epsilon - 1}}{1 + \delta^\epsilon \left(\frac{\bar{r}}{s}\right)^{\epsilon - 1}} \right) \left(\frac{1}{\lambda^\rho s_l^{1-\rho} + 1} \rho + \frac{\lambda^\rho s_l^{1-\rho}}{\lambda^\rho s_l^{1-\rho} + 1} \right) \tag{56}$$

where $s_l = \frac{M}{l} f + \frac{D}{l} s$ is the weighted average of liquidity price. According to first order conditions of households, i.e. Equation (23) and (24), we have

$$s_l = \bar{r} \left(1 + \delta^\epsilon \left(\frac{\bar{r}}{s} \right)^{\epsilon - 1} \right)^{\frac{1}{1-\epsilon}} \tag{57}$$

From the market clearing condition (56), it is obvious that s is a function of $\bar{r}$. In other words, the deposit spread charged by banks varies with federal funds rate due to the changing effective demand elasticity of households. I solve this numerically.

Constrained banks.

Proof of Proposition 2.

When borrowing constraint is binding, we have

$$\overline{H_i} = \frac{\bar{g}-\mu}{c} + \frac{((\bar{g}-\mu)^2 + 2D_i(1+\bar{r}+\mu)c)^{1/2}}{c} - D_i \tag{58}$$

$$0 < \frac{\partial E(\Pi_i)}{\partial H_i}\bigg|_{H_i=\overline{H_i}} \tag{59}$$

Denote function G as

$$G = \frac{c}{2}(\overline{H_i}+D_i)^2 - \bar{g}(\overline{H_i}+D_i) - D_i(1+\bar{r}) + H_i\mu \tag{60}$$

Due to the binding constraint, we have $G = 0$. Therefore,

$$\frac{dH_i}{dD_i} = -\frac{\partial G/\partial D_i}{\partial G/\partial H_i} \tag{61}$$

where

$$\frac{\partial G}{\partial H_i} = c(H_i + D_i) - \bar{g} + \mu \tag{62}$$

$$\frac{\partial G}{\partial D_i} = c(H_i + D_i) - (1+\bar{r}) - \bar{g} \tag{63}$$

Because of Equation (58), we have $c(\overline{H_i}+D_i) > \bar{g}-\mu$. Furthermore, because $H_i+D_i < g^H/c$ and $\overline{H_i} < H_i$, we then have $c(\overline{H_i}+D_i) < g^H$. Thus,

$$\frac{\partial G}{\partial H_i} > 0 \tag{64}$$

$$\frac{\partial G}{\partial D_i} < \underbrace{(1-\delta)(g^H - g^L)}_{<1} - 1 - \bar{r} < 0 \tag{65}$$

Therefore, H_i and D_i are positively correlated when the constraint is binding. Proposition 2 is proved.

The equilibrium level of the deposit spread s is solved by imposing the deposit market clearing condition: combining Equation (58), (54) and (22). Numerical solutions in a symmetric equilibrium ($s_i = s, D_i = D$ for $\forall\ i$) are shown in the model section.

.2 US Bank Investment Opportunities

The period from mid-1990s to pre-GFC was a time when banks experienced excellent investment opportunities. The expansion of investment opportunities for banks was facilitated by the deregulation and technological progress in the banking industry (Becher et al. (2005), DeYoung et al. (2013)). As mentioned earlier, IBBEA in 1990s enabled banks to extend their operations across the state lines, broadening their geographic footprints. Gramm-Leach-Bliley Financial Modernization Act of 1999 further widened the investment opportunity set for commercial banks by allowing them to engage more fully in home mortgage securitization and other nontraditional banking activities. In addition, technological innovation also expanded banks' investment opportunities during this period. For example, in the 1990s, credit scoring was adopted by many banks for small business lending (DeYoung (2007)). This technology was associated with an increase in overall small business lending and enabled banks to make loans to more marginal class of loan applicants (Frame et al. (2001), Berger et al. (2005), DeYoung et al. (2008)). Furthermore, electronic payments technologies and fund transfers replaced paper-based payments (cash and checks) and paper record keeping, which significantly reduced costs of transactions of banks (DeYoung (2007)). As a result, banks witnessed notably high levels of profitability during this period (see Tregenna (2009), Chronopoulos et al. (2015)). High returns, reflecting lucrative lending opportunities, suggest that banks could potentially yield high marginal revenues from issuing additional loans. Hence, banks in this period were likely to be constrained if they did not have sufficient funding to finance all lending opportunities. In fact, Chakraborty et al. (2018) studies the period 1988-2006 and find that banks were constrained, so, when highly profitable lending opportunities arose in mortgage lending, they had to cut their commercial lending.

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