The Passthrough of Treasury Supply to Bank Deposit Funding

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Abstract

We demonstrate the passthrough of Treasury supply to deposit funding through bank market power. We show that an increase in Treasury supply leads to a net deposit outflow. At the same time, reliance on wholesale funding decreases. The effect is heterogeneous—banks in more competitive markets experience stronger deposit outflows. The explanatory power of Treasury supply is not driven by monetary policy and bank-specific investment opportunities. We rationalize our empirical findings with a model of imperfect deposit competition. Consistent with Drechsler, Savov and Schnabl (2017), the model and empirical evidence predict the opposite effect for monetary policy rate hikes: there is a larger response in less competitive markets.

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1 Introduction

One of the central roles of the banking sector is to provide liquidity: illiquid real assets are transformed into liquid deposits that are valued by the non-financial sector (Diamond and Dybvig, 1983). Bank funding capacity and funding stability are then driven by the liquidity needs of the non-bank sector. Monetary policy passes through to bank balance sheets through influencing the market price of liquidity (Drechsler, Savov and Schnabl, 2017). Simultaneously, government debt also satisfies the demand for liquidity and enters the equilibrium determination of liquidity transformation (Krishnamurthy and Vissing-Jorgensen, 2015, Greenwood, Hanson and Stein, 2010).

We provide a coherent framework to compare and contrast the respective passthroughs of government-supplied liquidity and monetary policy to bank liquidity provision in the presence of bank market power. Understanding the differences in passthroughs to bank funding is important because financial crisis and economic downturns are often addressed by a combination of fiscal stimulus financed by government debt and policy rate cuts. This combination of policy reactions became evident again amidst the COVID-19 pandemic, as an additional $3 trillion in Treasuries is being issued in the second quarter of 2020, while the Federal Reserve has decreased the policy rate by 150 basis points in a matter of weeks.

However, empirically determining the impact of government-supplied liquidity on bank liquidity provision is challenging precisely because Treasury supply tends to expand during economic downturns. Over time, bank deposits may shrink when Treasury supply expands because banks have fewer lending opportunities in recessions. This lending effect could mask the crowding-out of deposits due to Treasuries, which stems from the substitutability of Treasuries and deposits in providing liquidity services to households. While the literature has mostly focused on time-series variation (Krishnamurthy and Vissing-Jorgensen, 2015, Nagel, 2016), we develop a simple model to predict how the crowding-out of deposits by Treasuries depends on local deposit competition and then identify the impact of Treasury supply through cross-sectional variations in deposit rates and volumes. By comparing how branches of the same bank located in deposit markets of varying competitiveness respond to changes in Treasury supply, we eliminate confounding by time-varying macroeconomic conditions at the bank-level (e.g., loan demand).

We find that the increased supply of Treasuries shrinks banks’ ability to raise deposits and that the effect increases with deposit competition. We jointly consider the effect of monetary policy and show that interest rate cuts expand bank deposits, but that the impact declines with deposit competition. As a result, monetary easing can only partially offset the...
contraction in deposits that follows an expansion in government-supplied liquidity. However, this offset comes at the cost of distorting the distribution of bank funding capacity. More competitive deposit markets experience the most pronounced crowding out of deposits following a surge in Treasury supply while benefiting the least from the deposit expansion after policy rate cuts. Our model suggests that these results arise because Treasury supply primarily affects investors’ demand for deposits, while policy rates mainly influence banks’ supply of deposits. Our empirical and theoretical findings confirm the Deposits Channel of Monetary Policy first elucidated by (Drechsler, Savov and Schnabl, 2017) while establishing the independent and different passthrough of Treasury supply to bank deposit funding.

The passthroughs of Treasury supply and monetary policy also bear important financial stability implications because they alter bank funding composition. Wholesale types of funding contract by more than retail deposits following heightened Treasury issuance. This may improve financial stability because wholesale funding is a source of vulnerability, as evidenced in the 2008 financial crisis. In contrast, retail deposits are more sensitive than institutional depositors are to changes in monetary policy. The larger influx of retail deposits following monetary easing lowers the ratio of wholesale funding, which benefits long-run financial stability.

Our empirical results are guided by a simple model that sheds light on the mechanisms at play and provides testable predictions for the cross-section. In the model, Treasuries and deposits are substitutes in providing liquidity to investors, and deposits are supplied by different banks with imperfect competition. Investors can also hold a benchmark capital market bond available at the monetary policy rate (i.e., the Fed funds rate). The Fed funds–Treasury spread and the Fed funds–deposit spread can thus be viewed as the opportunity cost of holding Treasuries and deposits, respectively. When Treasury supply increases, the demand for deposits drops because Treasuries and deposits are substitutes in liquidity provision. For the same shift in demand, if bank deposit competition is more intense, the outflow of deposits becomes more pronounced because the elasticity of the aggregate deposit supply increases with deposit competition. At the same time, the Fed funds–deposit spread drops by less, which implies that the opportunity cost of holding deposits relative to Treasuries, captured by the Treasury–deposit spread, increases by more.

In contrast, increases in the Fed funds rate primarily shrink the aggregate supply of bank deposits so that higher supply elasticity (i.e., more intense deposit competition) leads to

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1 Although later in our sample, the Federal Reserve sets the interest on excess reserves (IOER) to target the Fed funds rate, we will be using the Fed funds rate interchangeably with the monetary policy rate for simplicity.
a less pronounced drop in deposit volumes because banks lend to firms at the Fed funds rate plus a margin. When the Fed funds rate is higher, banks’ profit margins from lending are squeezed, and therefore they reduce the aggregate supply of deposits accordingly.\textsuperscript{2} A similar bank-asset-side effect also exists for Treasury supply increases, but it does not change the overall crowding-out effect as long as banks’ demand for Treasuries is limited. This is consistent with the data, as commercial banks invest mostly in loans and only a small fraction in Treasuries so that their asset returns are predominantly influenced by the Fed funds rate.\textsuperscript{3}

Our model also points to the opposite effect caused by increases in Treasury supply versus monetary tightening on the banking sector’s wholesale funding ratio. Wholesale investors are more sensitive to deposit rate changes, which leads to a more elastic deposit supply curve relative to retail deposit categories. Since a more elastic deposit supply magnifies the effect of Treasury supply but diminishes that of the Fed funds rate, government-supplied liquidity curbs the reliance on wholesale funding, whereas monetary tightening (easing) raises (decreases) the ratio of wholesale funding.

The aggregate time series provides preliminary evidence for our model predictions. After residualizing both Treasury growth and deposit growth against Fed funds rate changes, we find that Treasury growth is negatively correlated with total deposit growth, with the negative correlation being stronger for wholesale deposits. Although we have conditioned on changes in the monetary policy rate, there is no guarantee that government-supplied liquidity is exogenous in the time series. Thus, the exact transmission channel remains unclear. One possibility is that deposits and Treasuries are substitutes as we conjectured. However, it could also be that other macroeconomic variables co-move with Treasury supply and deposit volume. For example, economic downturns may drive both an increase in Treasury issuance to fund government stimulus and a decline in firms’ demand for bank loans, which reduces banks’ funding needs and thus their supply of deposits.

Therefore, we use within-bank, across-branch variation in deposit volumes and rates to verify our model predictions. Looking at branches of the same bank eliminates confounding by investment opportunities at the bank level, which could co-move with Treasury supply over time. The identification assumption is that funds can be freely transferred within branches of the same banks, so that remaining variation observed across branches of the same bank are due to banks’ pricing strategies under different levels of local deposit competition.

\textsuperscript{2}Notice that this effect is not due to a shift in firms’ demand for loans; instead, it is through changes in the loans fundable holding constant the firm loan demand curve.

\textsuperscript{3}From 1980 to 2018, US commercial banks, on average, held less than 4% of total assets in Treasuries and more than 64% in loans (Figure 3). The bank prime loan rate, which is the standard benchmark rate for commercial and residential loans, is determined by the Fed funds rate plus a premium (Figure 2).
In the baseline specification, we use a standard Herfindahl Index (HHI) to measure deposit competition at the county level. We also control for Fed funds rate changes to clearly distinguish between the effects of monetary policy and Treasury supply. Finally, we show that our estimates are robust to alternative specifications considering heterogeneities in investor sophistication and the maturity structure of Treasuries.

Our estimation results confirm the model predictions. When Treasury supply increases, banks widen their Treasury–deposit spreads by more and experience more substantial outflows at branches located in more competitive areas. Fixing the Fed funds rate, a one standard deviation increase in Treasury growth causes branches in counties at the 25th percentile of the HHI (i.e., more competitive) to experience a 20.2 bps larger drop in deposit growth compared to branches of the same bank in counties at the 75th percentile of the HHI (i.e., less competitive). In aggregate, we find a 64.4 bps drop in deposit growth for a one standard deviation increase in Treasury growth.\(^4\)

The distributional effect of Fed funds rate changes is opposite to that of Treasury growth. A one standard deviation increase (decrease) in the Fed fund rate changes causes branches in counties at the 25th percentile of the HHI (i.e., more competitive) to experience a 22.4 bps smaller decrease (increase) in deposit growth than branches of the same bank in counties at the 75th percentile (i.e., less competitive) of deposit market competition. In comparison, the average time series effect is 151.5 bps for one standard deviation in Fed funds rate changes.

Taken together, when a one standard deviation in monetary easing is coupled with a one standard deviation in Treasury growth, deposit expansion would be lower by more than 40% than in the case of monetary easing alone, which is especially significant in economic downturns when funding is scarce. Moreover, in the cross-section, the distribution of bank funding is distorted, with more competitive regions experiencing the most significant cuts in deposit funding due to Treasury growth and the least deposit inflow following monetary easing.

Treasury supply and monetary policy also have significant impacts on the structure of bank funding. On the one hand, when Treasury supply increases, institutional investors’ funds flow out more because these investors are more price sensitive. On the other hand, following changes in the Fed funds rate, retail deposits respond more strongly. The data confirms these predictions. We find that a one standard deviation increase in Treasury growth curbs the change in the wholesale funding ratio by 32.8 bps. In contrast, a one standard

\(^4\)To obtain the time-series result, we follow Drechsler, Savov and Schnabl (2017) to multiply the semi-elasticities of deposits to the deposit spreads by the effect of Treasury supply on deposit spreads.
deviation increase in Fed funds rate changes corresponds to a 26.6 bps larger change in the wholesale funding ratio. In other words, when monetary easing and government funding through the issuance of Treasuries are combined during a financial downturn, the dependence on wholesale funding is reduced, which improves the funding stability of the banking sector.

In an extension exercise, we show that these differences in passthrough become especially relevant when considering the effect of the Reverse Repurchase (RRP) Facility, through which the Federal Reserve extended its set of counterparties for conducting monetary policy.\footnote{Since September 2013, non-bank intermediaries such as money market mutual funds can lend directly to the Fed via reverse repos at the RRP Facility rate.} We show that the effects of the RRP Facility rate resemble the effects of changes in Treasury yields because government securities make up a significant portion of money market mutual funds’ balance sheets, and the RRP rate offers an alternative return on Treasuries through reverse repos with the Fed. We find that deposit sensitivity to the RRP rate is about a quarter of the deposit sensitivity to the Fed funds rate. This implies that raising the RRP rate in tandem with the target Fed funds rate improves passthrough to bank deposits by about a quarter.

**Literature Review**

Our paper contributes to several strands of research. We build on the safe asset literature that has demonstrated an aggregate demand for money-like convenience services by Treasuries (Krishnamurthy and Vissing-Jorgensen, 2012, Greenwood and Vayanos, 2014, Duffee, 1996), and has shown that Treasury supply crowds-out safe and liquid debt issued by the private sector (Krishnamurthy and Vissing-Jorgensen, 2015, Greenwood, Hanson and Stein, 2010, 2015, 2016, Carlson et al., 2014, Sunderam, 2014). The literature has mostly used time-series variation to show a negative correlation between government liquidity and aggregate bank-supplied liquid assets. Instead, we generate predictions for the cross-section and verify them using variations across branches of the same bank. This cross-section identification removes the confounding effect of macroeconomic conditions and bank-level investment opportunities, thus isolating the effect of Treasury supply on bank funding.

Our results confirm the effect of monetary policy on the liquidity premium while establishing the distinct and different passthrough of Treasury supply. Prior theoretical work by Holmström and Tirole (1998, 2011) show that a shortage of government-supplied liquid assets increases the liquidity premium. More recently, Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood, Hanson and Stein (2010) have focused on the importance of Treasury supply in driving the premium on liquid assets, while Nagel (2016) and Drechsler, Savov and
Schnabl (2017) emphasize the importance of monetary policy. Using a coherent theoretical and empirical framework, we show that both policies affect the premium on bank deposits because depositors view deposits from different banks as imperfect substitutes for each other and for Treasuries.

Further, we inform the discussion on the effect of publicly supplied safe assets on financial stability. Gorton (2010), Gorton and Metrick (2012), Sunderam (2014), and Kacperczyk, Perignon and Vuilleme (2017) illustrate how the demand for safe and liquid assets fueled the expansion of shadow banks, while Greenwood, Hanson and Stein (2015, 2016) derive optimal responses in the production of safe assets to the maturity structure of government debt. We show that the provision of public safe assets reduces banks’ wholesale funding ratios. The reduced reliance on wholesale funding can contribute to the funding stability of banks (Egan, Hortacsu and Matvos, 2017), which is important for the extension of long-term loans to firms (Li, Loutska and Strahan, 2019). Our results on wholesale funding are robust to excluding repos backed by Treasuries, whose response has been thoroughly analyzed by Infante (2019).

This paper is organized as follows: Section 2 examines the aggregate time series, and Section 3 develops a model of imperfect deposit competition to rationalize the observed trends and guide the subsequent empirical strategy. Section 4 explains the data sources used in estimating the crowding-out of deposits in Section 5. Section 6 examines the effect of Treasury supply on the ratio of wholesale funding, and Section 7 concludes. For the extension exercise on the Reverse Repurchase Facility, please refer to Appendix A

2 Aggregate Trends

We begin by examining the aggregate relationship between Treasury supply and deposit funding. Figure 1a is a binned scatterplot of total deposit growth against Treasury growth from 1964 to 2019. Both variables are residualized against changes in the Fed funds rate,

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7There is also a vast macro-finance literature on the provision of public liquidity and the financial sector. See for example Bianchi and Bigio (2014), Quadrini (2017), Lenel, Piazzesi and Schneider (2019), Diamond (2020) and Benigno and Robatto (2019).

8In this paper, we will use growth rates, because variables like Treasury supply and deposit volume display strong persistence over time. To measure the Treasuries available to US private investors, we calculate...
which is another crucial determinant of deposit funding (Drechsler, Savov and Schnabl, 2017). The negative relationship depicted in the graph is in line with Treasuries, the public safe asset, crowding out bank deposits funding, a privately issued substitute for the public safe asset. The negative co-movement with Treasury growth is even more pronounced for wholesale types of funding. As Figure 1b shows, periods with higher Treasury growth also have lower ratios of wholesale funding in the banking sector. The wholesale funding ratio is measured as large time deposits over total deposits. Again, all variables are residualized against changes in the Fed funds rate.

Variations in the spread between Treasuries and deposits shed light on why we observe a negative correlation between Treasury growth and deposit growth. Figure 1c is a binned scatterplot of changes in the Treasury–deposit spread with Treasury supply growth, both of which are residualized against the Fed funds rate. The pattern suggests the widening of Treasury–deposit spreads as Treasury growth picks up. This is consistent with Treasuries crowding out deposits as a substitute good, where the price of Treasuries drops by more than that of deposits, giving rise to a higher opportunity cost of holding deposits.

While these trends are consistent with the crowding-out effect between substitutes, other variables could be co-moving in the time series to bring about similar aggregate observations. For example, economic downturns may drive both an increase in the issuance of Treasuries to fund government stimulus and a shift in firms’ demand for bank loans.

To shed light on the transmission mechanism, in the next section, we develop a microfoundation for the crowding-out of deposits by Treasury supply to guide the subsequent empirical identification.

3 Model

We build a model to study the impact of Treasury supply and monetary policy on bank deposits in the presence of bank market power. In Appendix A, we further extend the baseline model to determine the impact of the Federal Reserve’s RRP Facility.

The model features imperfect deposit competition and investor liquidity demand for Treasuries and deposits. There are two types of agents: households demanding deposits and 
\( N \) banks of mass \( 1/N \) competing to supply deposits.\(^9\) Banks optimize their profits, taking

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\[^9\]We follow Drechsler, Savov and Schnabl (2017) to assume that banks are of mass \( 1/N \) to ensure that the effect of increasing the number of banks does not mechanically operate through the total volume of deposits, but through the extent of deposit competition.
into account the deposit response at different deposit rates. Households optimize over wealth and liquidity benefits of holding deposits and Treasuries. This setting can be thought of as a local deposit market, which corresponds to a county in our later empirical estimation.

### 3.1 Demand for Deposits

Households hold deposits from bank $i \in \{1, 2, \cdots, N\}$ at $r^D_i$ and government bonds at $r^G$ to satisfy their demand for liquidity. They also invest in a third benchmark asset, capital market bonds, which provide no convenience but a return of $r$ set by the central bank monetary policy. The opportunity cost of holding deposits issued by bank $i$ and government bonds can thus be denoted as the Fed funds–deposit spread, $s_i = r - r^D_i$, and the Fed funds–Treasury spread, $\ell = r - r^G$. Aggregate deposits $D$ and government bonds $G$ are imperfect substitutes for households with a degree of substitutability $\sigma > 1$:

$$ L = \left( D^{\frac{\sigma - 1}{\sigma}} + \delta G^{\frac{\sigma - 1}{\sigma}} \right)^{\frac{\sigma}{\sigma - 1}}, \quad (1) $$

where $\delta$ measures the liquidity of Treasuries relative to deposits. Aggregate deposits $D$ are made up of individual bank deposits that are imperfect substitutes for each other with the elasticity of substitution $\eta > 1$:

$$ D = \left( \frac{1}{N} \sum_{i=1}^{N} D_i^{\frac{\sigma - 1}{\eta}} \right)^{\frac{\eta}{\eta - 1}}. \quad (2) $$

Households distribute their deposit holdings across banks to minimize the average cost of holding deposits, $s = \sum_{i=1}^{N} s_i D_i / N$. Imposing symmetry in equilibrium, we have $s = s_i$, $D = D_i$, and the same demand elasticity for individual banks$^{11}$:

$$ \frac{\partial \log(D_i)}{\partial \log(s_i)} = \frac{N - 1}{N - \eta}. \quad (3) $$

In aggregate, the representative household maximizes the sum of wealth and liquidity value

$$ \max_{D,G} \quad W_1 + \log(L) $$

s.t.

$$ W_1 = W_0(1 + r) - D \cdot s - G \cdot \ell. \quad (4) $$

$^{10}$Formally, $D_i$ and $D$ represent the rate of deposit production. Since the aggregate banking sector has mass 1, the aggregate deposit production rate $D$ is the same as the aggregate deposit quantity.

$^{11}$Refer to Appendix B.1 for derivation details.
Solving the above problem, we obtain the aggregate demand for deposits and Treasuries:

\[ D = \frac{1}{s + \ell^{-(\sigma-1)}(\delta s)^\sigma} \]  \hspace{1cm} (5)  

\[ G = \frac{1}{\ell + s^{-(\sigma-1)}(\ell/\delta)^\sigma} \]  \hspace{1cm} (6)

These solutions imply that deposits and Treasuries are substitutes so a drop in the cost of one reduces the demand for the other. We add one regularity assumption that the effect of changing the own cost of deposits (Treasuries) is greater than that of changing the cost of its substitute, i.e., Treasuries (deposits).\(^\text{12}\)

### 3.2 Supply of Deposits and Bank Market Power

Banks fund with deposits \(D_i\) and invest in loans \(Q_i\).\(^\text{13}\) On the deposits side, they are subject to a downward-sloping deposit demand curve described in the previous subsection. On the asset-side, they face a downward-sloping loan demand curve:\(^\text{14}\)

\[ Q(r_i) = \bar{Q} - 2\beta r_i. \]  \hspace{1cm} (7)

Banks earn the spread between lending and borrowing and choose deposit rates to maximize profits \((Q^{-1}(D_i) - r_i^D)D_i\), where \(Q^{-1} = \bar{Q} - D_i/(2\beta)\) is the inverse loan demand curve, and the lending-deposit spread is \(Q^{-1}(D_i) - r_i^D = Q^{-1}(D_i) - r + s_i^D\). Solving the individual bank optimization and imposing symmetry, we obtain the aggregate deposit supply:

\[ \hat{D}(s, r) = \frac{\bar{Q}}{2} + \beta \left( (1 - \frac{N}{(N-1)\eta})s - r \right). \]  \hspace{1cm} (8)

Equation (10) shows that deposit supply contracts with the Fed funds rate \(r\). The reason is that an increase in \(r\) cuts into banks’ profit margin of lending, thereby reducing their incentive to raise deposits.

\(^{12}\)Refer to the online Appendix C.3 for further discussions of this regularity assumption.

\(^{13}\)In this baseline setup, banks do not have a special demand for Treasuries and therefore do not hold Treasuries. This assumption is relaxed in Appendix C.5, where we add banks’ demand for Treasuries and verify the main results.

\(^{14}\)The use of a downward-sloping loan demand curve is in line with the extension model of Drechsler, Savov and Schnabl (2017). We chose our specific formulation to keep the exposition simple.
The slope of the aggregate supply curve is
\[
\hat{D}_s'(s, r) = \beta \left(1 - \frac{N}{(N - 1)\eta}\right) \triangleq \beta \cdot C,
\]
(9)
where \(C\) is defined as the deposit competition index, which increases with the number of banks \(N\) as well as with the degree of substitution between banks \(\eta\). We note that \(C > 0\) is increasing in both \(N\) and \(\eta\) as long as \(\eta(N - 1)/N > 1\) (i.e., there is an upward sloping supply curve). In other words, aggregate deposit supply becomes more elastic when more banks compete for deposits in a given market or when bank deposits are better substitutes for each other. In contrast, when there are fewer competitors or when bank deposits are not close substitutes for each other, banks have more market power and the aggregate supply of deposits is more inelastic.

A higher level of competition gives rise to a more elastic supply curve not only in our model but also in general settings. For example, the relationship is preserved under Cournot competition as well as general demand curve specifications. Please refer to online Appendix B.1 and B.2 for details.

3.3 Market Clearing
In equilibrium, deposits and Treasury markets clear:
\[
D(s, \ell) = \hat{D}(s, r),
\]
(10)
\[
G(s, \ell) = G_0,
\]
(11)
where \(G_0\) is the government’s supply of bonds and \(r\) is the monetary policy rate determined by the central bank. They determine the equilibrium Fed funds–deposit spread \(s^*\), the Fed funds–Treasury spread \(\ell^*\), and the quantity of deposits \(D^*\).

3.4 Impact of Treasury Supply on Deposit Markets

**Proposition 1.** The equilibrium deposit quantity decreases with Treasury supply, and the magnitude of this effect increases with deposit competition \(C\), i.e.,
\[
\frac{\partial D^*}{\partial G_0} < 0, \quad \frac{\partial}{\partial C} \left(\frac{\partial D^*}{\partial G_0}\right) < 0.
\]
(12)

The equilibrium Fed funds–deposit spread decreases with Treasury supply, and the mag-
The magnitude of this effect decreases with deposit competition \( \mathcal{C} \), i.e.,
\[
\frac{\partial s^*}{\partial G_0} < 0, \quad \partial \left( \frac{\partial s^*}{\partial G_0} \right) / \partial \mathcal{C} > 0.
\] (13)

The equilibrium Treasury-deposit spread increases with Treasury supply, and the magnitude of this effect increases with deposit competition \( \mathcal{C} \), i.e.,
\[
\frac{\partial (s^* - \ell^*)}{\partial G_0} > 0, \quad \partial \left( \frac{\partial (s^* - \ell^*)}{\partial G_0} \right) / \partial \mathcal{C} > 0.
\] (14)

Intuitively, Treasuries compete with deposits in providing liquidity to investors, so an increase in Treasury supply contracts the demand for deposits. The equilibrium change in spreads and deposit quantities then depends on the aggregate deposit supply. When deposit markets are more competitive, the aggregate deposit supply is more elastic, and deposit outflow is more pronounced. At the same time, the liquidity premium on deposits, as reflected by the Fed funds–deposit spread, drops less and thus the opportunity cost of holding deposits relative to Treasuries, as captured by the Treasury–deposit spread, increases by more. Figure 3 illustrates this channel.\(^\text{15}\)

### 3.5 Impact of Monetary Policy on Deposit Markets

**Proposition 2.** The equilibrium deposit quantity decreases with the Fed funds rate, and the magnitude of this effect decreases with deposit competition \( \mathcal{C} \), i.e.,
\[
\frac{\partial D^*}{\partial r} < 0, \quad \partial \left( \frac{\partial D^*}{\partial r} \right) / \partial \mathcal{C} > 0.
\] (15)

The equilibrium Fed funds–deposit spread increases with the Fed funds rate, and the magnitude of this effect decreases with deposit competition \( \mathcal{C} \), i.e.,
\[
\frac{\partial s^*}{\partial r} > 0, \quad \partial \left( \frac{\partial s^*}{\partial r} \right) / \partial \mathcal{C} < 0.
\] (16)

The equilibrium Treasury–deposit spread increases with the Fed funds rate, and the magnitude

\(^{15}\text{The model also predicts that the liquidity premium on Treasuries, as reflected by the Fed funds–Treasury spread, decreases following increases in Treasury supply. We have excluded this result in our main proposition because there is no cross-sectional variation in the Fed funds–Treasury spread for our later empirical tests.}\)
of this effect decreases with deposit competition $C$, i.e.,

$$\frac{\partial(s^* - \ell^*)}{\partial r} > 0, \quad \partial \left( \frac{\partial(s^* - \ell^*)}{\partial r} \right) / \partial C < 0. \quad (17)$$

Notice that the cross-sectional impact of Fed funds rate hikes in Proposition 2 is in the opposite direction as that of Treasury growth in Proposition 1. This difference is because the primary effect of Fed funds rate hikes arises through a decrease in deposit supply. Therefore, stronger deposit competition (a more elastic deposit supply) leads to a less pronounced drop in deposit volume. The decrease in deposit supply stems from the downward-sloping firm loan demand, where the loan rate is set at the policy rate plus a premium. When Fed funds rates rise, the profit margin on loans decreases, and banks reduce their supply of deposits accordingly.  

When banks have more deposit market power, they can squeeze depositors by more to make up for the loss in profit margins on the loans side, leading to more pronounced deposit outflows. Therefore, deposit outflows decrease when deposit competition increases. Refer to Figure 4 for a graphical illustration of this channel.

This deposit-supply channel is not driving the overall impact of Treasury supply. In the model, banks do not invest in Treasuries, and thus their asset-side returns are not directly affected by changes in Treasury yields. For robustness, we allow banks to hold Treasuries and loans in Appendix C.5 and show that the baseline results hold as long as the bank asset-side incentives from investment in Treasuries do not dominate. The assumption that banks have a small liquidity demand for Treasuries is a close proxy for reality, given that commercial banks typically invest only a small fraction of their assets in Treasury securities, and instead, invest mostly in loans. From 1980 to 2018, on average, US commercial banks held less than 4% of their total assets in Treasuries and more than 64% in loans (Figure 2), so bank asset returns are predominantly driven by changes in monetary policy.

Our time-series and cross-sectional results for Fed fund rate hikes verify the findings by Drechsler, Savov and Schnabl (2017), who also attribute the effects to the supply side of deposits. While they microfound the effect through a change in the relative price and substitutability of cash versus deposits, we rely solely on a downward sloping loan demand curve, which is also present in the extension model by Drechsler, Savov and Schnabl (2017).  

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16 Notice that this effect is due not to a shift in firms’ demand for loans, but to changes in loan profit margins holding firm loan demand constant.
3.6 Wholesale Funding and Investor Sophistication

So far, we have assumed a homogeneous investor base, whereas in reality, investors may differ in their levels of sophistication. For example, retail investors may be sleepy in response to changing deposit rates or face a higher cost of switching from one bank to another. Effectively, they are less able or willing to substitute between banks and suffer a lower elasticity of substitution across different bank deposits. In contrast, sophisticated wholesale investors are more attentive to changes in deposit rates and more readily substitute between banks, depending on who offers a higher rate.

To incorporate investor heterogeneity into our model, we let the elasticity of substitution for different deposits be $\eta_W$ and $\eta_R$ respectively for wholesale and retail investors, respectively, where $\eta_R < \eta_W$. If wholesale deposits comprise fraction $\alpha_W$ of bank balance sheets, then the elasticity of banks’ individual deposit demand is $(\alpha_W \eta_W + (1 - \alpha_W) \eta_R) (N - 1)/N$, which implies that a larger fraction of wholesale deposits $\alpha_W$ increases individual deposit demand elasticity as well as deposit market competition $C$. This gives rise to the following proposition:

**Proposition 3.** When the fraction of wholesale funding is higher, the equilibrium deposit quantity decreases more with Treasury supply, i.e.,

$$\frac{\partial \left( \frac{\partial D^*}{\partial G_0} \right)}{\partial \alpha_W} < 0.$$  \hfill (18)

When the fraction of wholesale funding is higher, the equilibrium deposit quantity decreases less with Fed funds rate hikes, i.e.,

$$\frac{\partial \left( \frac{\partial D^*}{\partial r} \right)}{\partial \alpha_W} > 0.$$  \hfill (19)

Taken together, when deposit contraction is achieved by increases in Treasury supply, wholesale types of funding flow out more, decreasing the banking sector’s reliance on wholesale funding. In contrast, monetary tightening increases the wholesale funding ratio because wholesale types of funding flow out less. This contrast in passthroughs of Treasury supply and monetary policy bears important implications for financial stability—coupling Treasury issuance with monetary easing can help improve long-run funding stability through lowering the wholesale funding ratio.

Apart from being more attentive to deposit rates offered by different banks, wholesale investors may also be more inclined to substitute between Treasuries and deposits, whereas
retail investors predominantly stick to a portfolio of bank deposits. Appendix B.5 verifies that a higher degree of substitutability between deposits and Treasuries for wholesale investors would reinforce the result in Proposition 3.

4 Data

Before detailing the estimation strategy, we explain the data sources and the construction of the main variables.

4.1 Data Sources

Bank balance sheet data are from US Call Reports provided by the Federal Reserve Bank of Chicago. Our sample is from January 1994 to December 2016. The data contain quarterly data on the income statements and balance sheets of all US commercial banks. Please refer to Panel D of Table 1 for bank-level summary statistics. We match bank-level Call Reports to branch-level RateWatch and Federal Deposit Insurance Corporation (FDIC) data using the FDIC bank identifier.

Data on deposit volumes are from the FDIC, covering the universe of US bank branches at an annual frequency from June 1994 to June 2016. Information about branch characteristics such as the parent bank, address, and geographic coordinates are also available.

Data on deposit rates are from RateWatch. RateWatch collects weekly branch-level deposit rates by product from January 1997 to December 2016. Our analysis focuses on the most common deposit categories, including 2.5K savings accounts, 25K money market accounts, and 10K CDs with three-month, six-month, and one-year maturities.

Fed funds target rates and Treasury yields are from Federal Reserve Economic Data (FRED). We compute the average of the upper and lower Fed funds target rates after 2008. Treasury volumes are from the TreasuryDirect website.

We collect data on county characteristics from the 2000 US Census and County Business Patterns. Relevant demographic variables include median age, median income, and proportion of college graduates. See Panel A of Table 1 for summary statistics.

4.2 Definition of Key Variables

In the baseline specifications, our proxy for local deposit market competition is the standard HHI, which corresponds to the number of banks in our (symmetric) model. Because investor sophistication is another driver of deposit competition, we further explore the effect of de-
mographic characteristics related to investor sophistication in an extension exercise. We also examine the interaction with wholesale funding in Section 6.

Branch HHI: We assign to each bank branch the HHI of the county in which it is located and refer to it as the branch HHI. This county-level HHI is calculated by summing the squared deposit market shares of all banks that operate branches in a given county in a given year and then taking the average of that amount over all years (1994–2016). Figure 5a shows that the branch HHI stays relatively constant over our sample period.

Bank HHI: Bank HHI is calculated by first taking the weighted average of the bank’s branch-level HHI in each year and then collapsing it by bank. Figure 5b shows the distribution of bank HHI, which is centered at around 0.2 and has almost all its weight below 0.6.

Deposit growth: Deposit growth is the log difference of bank or branch deposit volume in a year. We are limited to using annual deposit growth rates at the branch level because FDIC deposit volumes are only reported annually. Summary statistics are detailed in Panel B of Table 1. Consistent with Drechsler, Savov and Schnabl (2017), we use deposit growth to remove persistence in deposit levels.

Deposit spread: Deposit spread is calculated as either the Treasury yield minus the deposit rate or the Fed funds rate minus the deposit rate. We choose Treasury yields with maturities corresponding to each deposit category. Summary statistics are detailed in Panel C of Table 1. Consistent with Drechsler, Savov and Schnabl (2017), we use changes in deposit spreads to remove persistence in rates.

Treasury growth: Treasury growth is the log difference of Treasury volume outstanding in a year. To capture Treasuries available to the US private sector, we exclude foreign official holdings, intra-governmental holdings, and Federal Reserve holdings. We treat Treasuries as homogeneous in the baseline specifications but allow for more granular breakdowns as a robustness check.

5 Empirical Estimation

This section tests our model empirically. We first explain our identification strategy, which uses variations in deposit spread and deposit volume across branches of the same bank, and then present the estimation results.
5.1 Estimation Strategy

Because the time-series suffers from potential confounding as discussed in Section 2, we turn to verify our model predictions in the cross-section.

We begin by looking at how branches subjected to different levels of deposit competition respond to changes in Treasury supply. Figure 6 plots the average sensitivity of deposit growth to changes in Treasury growth for branches located in different counties, with counties divided into 20 bins by their level of deposit competition. The average sensitivity, $\gamma_h$, of branches in bin $h$ is obtained from

$$DepGrowth_{it} = \alpha_i + \gamma_h 1\{bin_h\} \times TSYGrowth_t + \theta_t + \epsilon_{it},$$

(20)

where the dependent variable is the deposit growth of branch $i$ at time $t$. We include both branch-level fixed effect $\alpha_i$ and time fixed effect $\theta_t$.

Consistent with the theory, Figure 6 shows that branches in more competitive areas (i.e., those with a lower HHI percentile), experience a more substantial deposit outflow in periods of high Treasury growth on average.

Also in line with the theory, branches in more competitive areas widen their Treasury–deposit spreads by more than branches in less competitive areas as Treasury growth increases (Figure 7). Similar to before, sensitivities to the Treasury–time deposit spread and the Treasury–savings deposit spreads are obtained by

$$\Delta DepSpread_{it} = \alpha_i + \gamma_h 1\{bin_h\} \times TSYGrowth_t + \theta_t + \epsilon_{it}.$$  

(21)

Specifications in (20) and (21) both include a time fixed effect to control for changes in deposit rates and volumes due to other reasons, such as banks’ investment opportunities and monetary policy. However, these variables may not affect all banks in the same way, which is especially concerning if the impact correlates with the level of deposit competition. To this end, we further focus on within-bank variation by only comparing branches of the same bank.

We illustrate our identification strategy with a simple example. Figure 8 plots the Treasury–deposit spread of the three-month CD for two different branches of Huntington Bank from October 2004 to April 2005. We observe that as Treasury growth increases by 3.24% from 2004Q4 to 2005Q1, the Treasury–deposit spread in the more competitive county, Macomb, MI, increases more than that in the less competitive county, Hamilton, OH. We
attribute the divergence in deposit spreads across branches to the level of local deposit competition, because changes in the macroeconomic environment should affect the investment opportunities of Huntington Bank as a whole. The implicit assumption here is that deposits are fungible across bank branches, i.e., Huntington bank can raise a dollar of deposits at one branch and lend it at another branch until the marginal returns of lending across its branches are equalized. This assumption is empirically supported by Drechsler, Savov and Schnabl (2017), who show that a bank's lending in a given county is not related to local deposit-market concentration. This is corroborated by the banking literature, which shows that banks channel deposits to areas with high loan demand (Gilje, Loutskina and Strahan, 2016).

To implement the estimation, we include bank-time fixed effects, $\delta_{jt}$, and state-time fixed effects, $\lambda_{st}$, in the following specifications:

\[ \text{DepGrowth}_{it} = \alpha_i + \eta_c + \lambda_{st} + \delta_{jt} + \beta_1 \text{TSYGrowth}_t \times \text{HHI}_c + \beta_2 \Delta \text{FFR} \times \text{HHI}_c + \epsilon_{it}. \] (22)

\[ \Delta \text{DepSpread}_{it} = \alpha_i + \eta_c + \lambda_{st} + \delta_{jt} + \beta_1 \text{TSYGrowth}_t \times \text{HHI}_c + \beta_2 \Delta \text{FFR} \times \text{HHI}_c + \epsilon_{it}. \] (23)

Bank-time fixed effects control for time-varying loan demand at the bank level while state-time fixed effects further limit the comparison to branches in the same state to rule out confounding by state-specific regulation and geopolitical differences. The remaining branch-level variation should then identify different sensitivities to Treasury supply and monetary policy arising from the level of local deposit competition. These are captured by $\beta_1$ and $\beta_2$, respectively.

### 5.2 Baseline Results

We proceed to estimate the differential effect of Treasury supply and monetary policy across branches of the same bank to control for changes in bank-specific lending opportunities that co-move in the time series.

Table 2 reports results for specification (22. Column (1) demonstrates that when comparing branches of the same bank in the same state, Treasury growth causes the crowding-out of deposit growth to a larger extent in more competitive regions (i.e., counties with a lower HHI index). The statistical and economic significance of this result remains after taking into account changes in the Fed funds rate, as indicated in column (2). This verifies the predictions for deposit quantity in Proposition 2. Also, In column (2), also notice that the coefficient for changes in the Fed funds rate is positively significant, meaning that in contrast to the
effect of Treasury growth, Fed funds rate changes have the largest impact on deposit growth in the least competitive areas. This result agrees with our model predictions in Proposition 3 and also with Drechsler, Savov and Schnabl (2017). Within-bank estimation controls for time-varying bank-specific investment opportunities but limits the sample to banks with two or more branches, which decreases the sample size by about 10%. We repeat the analysis for the full sample in online Appendix D and find similar results.

The magnitude of coefficients reveals a strong distributional effect of Treasury growth and Fed funds rate changes. With a one standard deviation increase in Treasury growth, branches located in counties at the 25th percentile of the HHI, which is 0.18, experience a 20.2 bps larger drop in deposit growth relative to branches of the same bank located in counties at the 75th percentile, which is 0.39. As we will show, this makes up almost a third of the average time series crowding-out effect of Treasury growth on deposits, demonstrating that regions experience significantly different degrees of deposit outflows depending on the competitiveness of local deposit markets. In contrast, a one standard deviation increase (decrease) in Fed funds rate changes causes a 22.4 bps smaller contraction (expansion) in deposit growth for branches of the same bank in counties at the 25th percentile of the HHI relative to those in counties at the 75th percentile of the HHI.

These contrasting distributional effects of Treasury supply and monetary policy rate changes are depicted in Figures 9a and 9b. The upper panel groups counties by their decline in deposit growth following a one standard deviation increase in Treasury growth, while the lower panel shows the corresponding result for Fed funds rate hikes. Counties with darker shades in the upper panel suffer more pronounced deposit outflows following Treasury growth because of their more competitive deposit markets. At the same time, these counties also have the lightest shade in the lower panel because they benefit the least from deposit growth expansion following monetary easing. In contrast, more concentrated deposit markets have a lighter shade in the upper panel and a darker shade in the lower panel, indicating smaller deposit outflows following Treasury growth and larger inflows after policy rate cuts. Therefore, when financial crises and economic downturns are addressed by a combination of monetary easing and increased Treasury issuance (e.g., to fund fiscal stimulus), deposits in competitive regions flow out more than in less competitive regions.

Tables 3 and 4 present within-bank estimates for various Treasury–deposit spreads and Fed funds–deposit spreads. Consistent with the predictions on deposit spreads in Proposition 2, coefficients for Treasury growth are negative, implying that Treasury–deposit spreads widen more in competitive areas as Treasury growth increases. Also, in line with Proposition 3, coefficients for Fed funds rate changes are positive, showing that the Fed funds–deposit
spread widens more in concentrated areas with Fed funds rate hikes.

For the overall impact of Treasury growth, we follow Drechsler, Savov and Schnabl (2017) by first calculating the cross-elasticities and then multiplying them by the average time series effect for Treasury–deposit spreads and Fed funds–deposit spreads. Weighing deposit spreads by the volume of time and savings deposits, we obtain a cross-elasticity of -9.23 with respect to Treasury–deposit spread increases. On average, the Treasury–deposit spread widens by 0.61 bps for a 100 bps increase in Treasury growth, which implies that a one standard deviation increase in Treasury growth corresponds to a 64.36 bps drop in deposit growth. Using the same approach, a one standard deviation increase in Fed funds rate hikes leads to a 151.52 bps drop in deposit growth. Therefore, in addition to the distributional effects above, when a one standard deviation in monetary easing is coupled with a one standard deviation in Treasury growth, deposit expansion will be lower by more than 40% than in the case of monetary easing alone.

5.3 Local Clientele and Market Power

So far, we have used the HHI as a measure for imperfect deposit competition. Nevertheless, counties may differ in other ways that influence banks’ market power, which consequently determines the impact of Treasury supply. In particular, the level of sophistication among the local clientele could affect how attentive they are to changes in deposit rates and how likely they are to substitute between banks as well as between deposits and Treasuries, all of which influence banks’ market power. County fixed effects can take care of the time-invariant components, but there may still be an interaction effect with changes in Treasury supply.

We repeat the analysis controlling for characteristics of the local clientele that can proxy for investor sophistication. We use county-level measures from the 2000 US Census and County Business Patterns data, including the proportion of residents over 65, the median income level, and the percentage of the population with a college degree.

Table 5 shows that the effect of imperfect competition as measured by the HHI remains after including the full set of local clientele interaction effects. The coefficients on the county characteristics are also significant and provide an additional dimension for understanding the effective market power of banks. For example, counties with an older population appear less competitive and experience more muted outflows in response to Treasury growth. On the other hand, counties with higher income levels, which positively correlates with investor sophistication, substitute more flexibly from deposits to Treasuries and experience more pronounced deposit outflows. The effect of a college education is relatively limited.
5.4 Maturity Structure of Treasuries

So far, we have treated government-supplied liquidity as a homogeneous quantity, whereas in reality, Treasuries differ in their substitutability with deposits. In particular, Treasury bills have been shown to be more liquid and money-like than Treasuries of longer maturities (Greenwood, Hanson and Stein, 2010, Nagel, 2016, Vandeweyer, 2019, Infante, 2019b). In this subsection, we perform a number of tests to understand the heterogeneity within Treasuries.

We begin by re-estimating our main specification by separately interacting Treasury bill growth and non-bill growth with the HHI. Because of the higher substitutability between deposits and Treasury bills, we expect that the primary effects of crowding out will be stronger for Treasury bills. However, Treasury bills’ interaction with deposit competition in the cross-section could be weaker. This can be understood from the limit case where Treasuries and deposits are perfect substitutes. In that scenario, Treasuries crowd out bank deposits one for one, independent of deposit competition, and the coefficient on the interaction term would be zero.

From the point estimates in columns (1) and (2) of Table 6, we find that the point estimate for the interaction effect of Treasury bills is indeed much smaller than that of non-bills, which is consistent with high substitutability between Treasury bills and deposits. The lack of statistical significance for Treasury bills could be because they lack orthogonal variation from the Fed funds rate at an annual frequency. At an annual level, regressing Treasury bill growth against Fed funds rate changes yields an $R^2$ of about 50%, while the same regression for non-bill growth has an $R^2$ of less than 1%. The high correlation between the Fed funds rate and Treasury bill growth stems partly from the Treasury’s objective to “minimize borrowing costs for the federal government” (Driessen, 2015, The Department of the Treasury, 2019), for which the Treasury Department actively adjusts the issuance of short-term Treasuries according to changes in the Fed funds rate. However, the literature has shown that Treasury bill growth at higher frequency has significant independent variations (Greenwood, Hanson and Stein, 2015). Unfortunately, our deposits data are only available on a yearly basis, rendering a test around specific event dates within the year infeasible.

The economically and statistically significant coefficient in column (2) also extends our understanding of the substitution between longer-term Treasuries and deposits. According to Nagel (2016), once the Fed funds rate is controlled for, the supply of Treasury bills loses explanatory power for variations in the liquidity premium for three-month Treasury bills, which is evidence that short-term Treasury bills are a perfect substitute for money. We complement this result and show that longer-maturity Treasuries and deposits are imperfect
substitutes so that the interaction between non-bill Treasury supply and the HHI is positive and significant.

Another way to consider Treasury heterogeneity is to weigh Treasury securities according to their liquidity properties. Then the volume would be a liquidity-weighted sum that gives more weight to closer substitutes of deposits. We first use haircuts on Treasury collateral in repo transactions to assign liquidity weights. Because the publicly available time-series dataset from the New York Fed does not go back far enough, we follow the estimates in Krishnamurthy and Vissing-Jorgensen (2012), whereby Treasury bills and non-bills have a haircut of 2% and 5%, respectively. Results for this liquidity-haircut-weighted Treasury supply series are detailed in column (3) of Table 6. The estimates remain qualitatively unchanged and statistically significant.

To allow for more granularity in liquidity weights, we further use the term structure of liquidity premia. The key idea is to remove both credit risk and maturity mismatch to measure the liquidity premium for Treasuries of different maturities. These requirements are satisfied by the Resolution Funding Corporation (RefCorp)-Treasury spreads, which are yield spreads between RefCorp bonds and Treasuries of the same maturity. RefCorp was created to fund the bailouts of savings and loan institutions during the Savings and Loan Crisis of late 1980s, and RefCorp bonds are guaranteed by the US government.\textsuperscript{17} Therefore, any observed difference in yields can be attributed to the relative liquidity of Treasuries over RefCorp bonds. We take the term structure from Li and Song (2019) and use the average liquidity premium for Treasury bills, notes, and bonds as weights to calculate a liquidity-premium-weighted Treasury supply. As shown in column (4) of Table 6, the results are qualitatively consistent with our main results in Table 2. Quantitatively, the size of the coefficient drops slightly from 0.084 to 0.069, which is consistent with the weighted Treasury measure, which puts more weight on liquid Treasury bills that have a higher degree of substitutability with bank deposits.

5.5 Treasuries as Collateral

Another issue is that changes in Treasury supply affect banks not only through the returns on the Treasury portion of their assets but also via the availability of collateral for repo financing. This effect is partly due to the repo activities that use Treasuries as collateral (Infante, 2019\textit{a,b}). To alleviate this concern, we purge the sample of banks that rely heavily on repo financing and repeat the analysis. Table 7 shows results excluding banks above the third quartile of repo financing as a fraction of their balance sheet size. The baseline results

\textsuperscript{17}Refer to Longstaff (2002) for more details about RefCorp bonds.
5.6 Slow-Moving Treasury Supply

Treasuries are slow moving in nature, so our previous statistical significance could be driven by time-series correlation. Hence, we use non-overlapping samples to recalculate Treasury growth rates over five years as a robustness check. The results in Table 8 show that the coefficients remain statistically significant. The magnitudes appear larger but become comparable to the baseline when converting from a five-year growth rate back to an annual one.

6 Effects on Bank Funding Structure

The 2007-2008 financial crisis has illustrated how reliance on short-term wholesale funding increases banks’ funding liquidity risks. As a result, several new regulations such as the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR) were introduced to curb the use of runnable funding by financial institutions. We find that government-supplied liquidity influences the type of funding banks can raise and thus becomes a determinant of the composition of bank leverage and the concentration of funding risk.

Our model implies that the sensitivity of deposit outflows to Treasury supply depends on the sophistication of the depositor base. Table 9 offers evidence for heterogeneous crowding-out sensitivities for different types of deposits. Core deposits, including checking, savings, and small-time deposits, mainly service retail depositors and display the lowest sensitivity to changes in Treasury growth.\footnote{Deposit volumes for different deposit types are only available at the bank level, which is why results in this subsection can only be computed at the bank level. We calculate the effective HHI for a bank as the weighted average of its branch-level HHI.} Wholesale funding, mostly provided by institutional investors, is about four times more responsive than core deposits to Treasury growth than core deposits. We include an alternative specification for wholesale funding excluding repos, which may have different interactions with Treasury supply because they are often backed by Treasury collateral, as shown in Infante (2019a).

In contrast, the opposite applies to monetary policy: core deposits respond more than wholesale types of funding to changes in the Fed funds rate. As Proposition 3 shows, banks have more market power over inattentive retail investors, which leads to a larger squeeze in deposits following Fed funds rate hikes. Similarly, when the policy rate drops and banks have more investment opportunities, they can expand their retail deposit base more.
Because institutional deposit types have a stronger crowding-out effect, the ratio of wholesale funding on banks’ balance sheets decreases with Treasury growth. On the other hand, wholesale deposits shrink (expand) less with monetary policy hikes (cuts), leading to a higher (lower) wholesale funding ratio. Table 10 illustrates this effect, where we observe a negative coefficient on Treasury growth but a positive coefficient on changes in the Fed funds rate. Quantitatively, the wholesale funding ratio decreases by 32.8 bps following a one standard deviation increase in Treasury growth, and increases (decreases) by 26.6 bps following one a standard deviation increase (decreases) in the Fed funds rate.

Heterogeneous crowd-out sensitivities also bring about distributional effects for banks that adopt different funding strategies. To check this effect empirically, we divide banks into five groups according to their wholesale funding ratio and interact group dummies with Treasury growth and Fed funds rate changes. The coefficients are illustrated in Figures 10a and 10b. The horizontal axis plots the quintiles of bank wholesale funding ratio, while the vertical axis displays the crowding-out coefficients. As expected, Treasury growth leads to a larger drop in banks’ funding growth as their reliance on wholesale funding increases, whereas Fed funds rate cuts show the opposite effect. These results imply a larger benefit from monetary easing and a more limited loss from Treasury growth for small and medium-sized companies, which tend to borrow from smaller banks reliant on retail deposits, relative to larger companies, which borrow primarily from large wholesale-funded banks.

The above findings also complement the view that monetary tightening to contain credit booms unintentionally leads banks to increase their reliance on wholesale funding, and concentrates growth in wholesale-reliant banks (Choi and Choi, 2016). We show that an expansion in government-supplied liquidity can achieve tightening in the same sense as an overall deposit outflow, but also reduce the reliance on wholesale funding and discourage the growth of wholesale-reliant banks.\footnote{These factors should be considered when policymakers design new monetary policy tools, such as the RRP Facility. Please refer to Appendix A for an analysis of the RRP Facility.}

7 Conclusion

This paper identifies the passthrough of government liquidity provision to bank liquidity provision through imperfect deposit competition. It complements Drechsler, Savov and Schnabl (2017) and establishes Treasury supply as an important and distinct determinant of the volume and structure of bank funding.

To establish causation, we remove confounding by bank-level investment opportunities
by showing that for the same bank, branches in more competitive regions experience more pronounced deposit outflows in response to Treasury growth, while benefiting the least from deposit inflows following monetary easing. We also demonstrate an impact on the structure of bank liabilities, which matters for financial stability and systemic risk. Institutional investors are more sensitive to changes in Treasury issuance, and the ratio of wholesale funding drops when Treasury supply increases. With monetary policy, however, retail deposits respond to a greater extent so that monetary easing can further reduce the banking sector’s reliance on wholesale funding.

We provide a theoretical framework to microfound our empirical analysis in which banks supply deposits with imperfect competition, and investors demand liquidity services provided by deposits and Treasuries. The model generates predictions in line with the empirical estimates and rationalizes the contrasting effects of Fed funds rate hikes and Treasury growth. The key intuition is that Treasury supply mainly shifts investors’ demand for deposits while monetary policy primarily affects banks’ supply of deposits.

This paper has focused on the frictions present in deposit markets due to depositors, especially retail depositors, having limited sophistication and geographic mobility, which makes imperfect competition a salient feature. Borrowers such as firms tend to be more efficient at screening loan rates than depositors. However, in some markets, imperfect competition for loans is also not trivial, e.g., small business lending and residential mortgages. Future work can explore the imperfect competition on both the asset and liability side to understand the interplay and its implications for passthrough. Dynamic models could also explore how banks choose their competitive environment and how that choice interacts with fiscal and monetary policy in equilibrium.

References


Tables and Figures

Table 1: Summary Statistics

This table provides summary statistics at the county, branch, bank, and county-bank levels. All panels provide a breakdown by high and low HHI using the median HHI for the respective sample. Panel A presents county-level characteristics for all U.S. counties with at least one bank branch. The underlying data are from the 2000 census. Panel B presents data on deposit holdings and deposit growth. The underlying data are from the FDIC from June 1994 to June 2016. Panel C presents data on deposit spreads. The underlying data are from Ratewatch from January 1997 to December 2016. Panel D presents data on bank characteristics. The underlying data are from the Call Reports from 1994 to 2016.

<table>
<thead>
<tr>
<th>Panel A: Descriptive Statistics</th>
<th>All Mean SD</th>
<th>Low HHI Mean SD</th>
<th>High HHI Mean SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median income ($)</td>
<td>42156 9748</td>
<td>46257 9932</td>
<td>38007 7561</td>
</tr>
<tr>
<td>Over 65 (%)</td>
<td>14.87 4.11</td>
<td>14.19 3.95</td>
<td>15.57 4.15</td>
</tr>
<tr>
<td>College degree (%)</td>
<td>16.48 7.69</td>
<td>18.94 8.34</td>
<td>14.00 6.04</td>
</tr>
<tr>
<td>HHI</td>
<td>0.32 0.21</td>
<td>0.18 0.05</td>
<td>0.47 0.21</td>
</tr>
<tr>
<td>Observations</td>
<td>3,124 1,562</td>
<td>1,562</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel B: Branch Characteristics (FDIC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposits (mill. $)</td>
</tr>
<tr>
<td>Deposit growth (%)</td>
</tr>
<tr>
<td>Branch-HHI</td>
</tr>
<tr>
<td>Observations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel C: Branch Characteristics (Ratewatch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Treasury - Deposit Spread (sav)</td>
</tr>
<tr>
<td>Δ Treasury - Deposit Spread (CD)</td>
</tr>
<tr>
<td>Δ FFR - Deposit Spread (sav)</td>
</tr>
<tr>
<td>Δ FFR - Deposit Spread (CD)</td>
</tr>
<tr>
<td>Observations</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel D: Bank characteristics (Call Reports)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assets (mill. $)</td>
</tr>
<tr>
<td>Deposits/Liab. (%)</td>
</tr>
<tr>
<td>Branches</td>
</tr>
<tr>
<td>Bank-HHI</td>
</tr>
<tr>
<td>Observations</td>
</tr>
</tbody>
</table>
Table 2: Deposit Volume and Treasury Supply

This table estimates the effect of Treasury supply on deposit growth. Data are at the branch-year level and cover 1994 to 2016. The sample consists of all banks with branches in two or more counties for identification. TSY Growth is the log change in Treasury supply. Branch HHI measures market concentration in the county where a branch is located. Note that a larger HHI means less competition. ∆ Target FF is the change in the Fed funds target rate. Data are from the FDIC and TreasuryDirect. Fixed effects are denoted at the bottom of the table. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th>Branch-Level Deposit Growth (≥ 2 Counties)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>TSY Growth * HHI</td>
<td>0.086**</td>
<td>0.084**</td>
</tr>
<tr>
<td></td>
<td>(0.039)</td>
<td>(0.039)</td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td>-0.007***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>1,503,852</td>
<td>1,503,852</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.338</td>
<td>0.338</td>
</tr>
<tr>
<td>Bank Year FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>State Year FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Branch FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>County FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SE Cluster</td>
<td>County</td>
<td>County</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Table 3: Treasury–Deposit Spread and Treasury Supply: ≥ 2 Counties

This table estimates the effect of Treasury supply on the Treasury–deposit spread. Data are at the branch-quarter level and cover January 1997 to December 2016. The sample consists of all banks with branches in two or more counties. Spread changes for savings and money market deposits are equal to the changes in the three-month Treasury yield minus the changes in deposit rates at the branch level. Spread changes for time deposits are equal to the changes in maturity-matched Treasury yield minus the changes in deposit rates at the branch level. TSY Growth is the log change in Treasury supply. Branch HHI measures market concentration in the county where a branch is located. Note that a larger HHI means less competition. ∆ Target FF is the change in the Fed funds target rate. Data are from RateWatch and TreasuryDirect. Fixed effects are denoted at the bottom of each panel. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th>Δ Treasury - Deposit Spread Change (≥ 2 Counties)</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
</table>
| Saving                                       | Saving MM 3m CD 6m CD 12m CD
| TSY Growth * HHI                            | -2.717*** | -1.427*** | -0.784*** | -0.320* | -0.216 |
|                                              | (0.328)  | (0.271)  | (0.218)  | (0.173) | (0.154) |
| ∆ Target FF * HHI                           | 0.528*** | 0.484*** | 0.320*** | 0.283*** | 0.216*** |
|                                              | (0.036)  | (0.033)  | (0.025)  | (0.020) | (0.017) |
| Observations                                | 191,211 | 206,905 | 202,856 | 216,686 | 216,666 |
| R-squared                                   | 0.960 | 0.884 | 0.875 | 0.863 | 0.844 |
| Bank Time FE                                 | Yes | Yes | Yes | Yes | Yes |
| State Time FE                                | Yes | Yes | Yes | Yes | Yes |
| Branch FE                                    | Yes | Yes | Yes | Yes | Yes |
| County FE                                    | Yes | Yes | Yes | Yes | Yes |
| Time FE                                      | Yes | Yes | Yes | Yes | Yes |
| SE Cluster                                   | County | County | County | County | County |

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Table 4: Fed Funds–Deposit Spread and Monetary Policy: ≥ 2 Counties

This table estimates the effect of monetary policy on Fed funds–deposit spreads. Data are at the branch-quarter level and cover January 1997 to December 2016. The sample consists of all banks with branches in two or more counties. Spread changes are equal to the changes of the Fed funds target rate minus the changes in deposit rates at the branch level. TSY Growth is the log change in Treasury supply. Branch HHI measures market concentration in the county where a branch is located. Note that a larger HHI means less competition. ∆ Target FF is the change in the Fed funds target rate. Data are from RateWatch and TreasuryDirect. Fixed effects are denoted at the bottom of each panel. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th></th>
<th>(1) Saving</th>
<th>(2) Saving MM</th>
<th>(3) Saving 3m CD</th>
<th>(4) Saving 6m CD</th>
<th>(5) Saving 12m CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth * HHI</td>
<td>-2.648***</td>
<td>-1.313***</td>
<td>-0.716***</td>
<td>-0.212</td>
<td>0.081</td>
</tr>
<tr>
<td></td>
<td>(0.344)</td>
<td>(0.284)</td>
<td>(0.239)</td>
<td>(0.186)</td>
<td>(0.173)</td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td>0.577***</td>
<td>0.541***</td>
<td>0.389***</td>
<td>0.340***</td>
<td>0.320***</td>
</tr>
<tr>
<td></td>
<td>(0.039)</td>
<td>(0.035)</td>
<td>(0.027)</td>
<td>(0.022)</td>
<td>(0.021)</td>
</tr>
</tbody>
</table>

Observations 191,211 206,905 202,856 216,686 216,666
R-squared 0.964 0.898 0.898 0.887 0.880
Bank Time FE Yes Yes Yes Yes Yes
State Time FE Yes Yes Yes Yes Yes
Branch FE Yes Yes Yes Yes Yes
County FE Yes Yes Yes Yes Yes
Time FE Yes Yes Yes Yes Yes
SE Cluster County County County County County

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Table 5: Deposit Volume and Treasury Supply: Local Clientele (≥ 2 Counties)

This table estimates the effect of local clientele features on deposit growth. Data are at the branch-year level from 1994 to 2016. The sample consists of all banks with branches in two or more counties. Age is the share of the county population that is aged 65 or older. Income is the natural log of county-level median household income. College is the county share of the population with a college degree. TSY Growth is the log change in Treasury supply. ∆ Target FF is the change in the Fed funds target rate. Data are from the FDIC, TreasuryDirect and 2000 US Census and County Business Patterns. All regressions include state-year, bank-year, branch, county and year fixed effects. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth * HHI</td>
<td>0.118***</td>
<td>0.133***</td>
<td>0.166***</td>
<td>0.125***</td>
</tr>
<tr>
<td></td>
<td>(0.033)</td>
<td>(0.035)</td>
<td>(0.036)</td>
<td>(0.035)</td>
</tr>
<tr>
<td>TSY Growth * Age</td>
<td>0.008***</td>
<td></td>
<td></td>
<td>0.008***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
<td>(0.001)</td>
</tr>
<tr>
<td>TSY Growth * Income</td>
<td></td>
<td>-0.050***</td>
<td></td>
<td>-0.061**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.018)</td>
<td></td>
<td>(0.025)</td>
</tr>
<tr>
<td>TSY Growth * College</td>
<td></td>
<td>-0.000</td>
<td></td>
<td>0.002***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.000)</td>
<td></td>
<td>(0.001)</td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td></td>
<td></td>
<td></td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.002)</td>
</tr>
<tr>
<td>∆ Target FF * Age</td>
<td></td>
<td></td>
<td></td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.000)</td>
</tr>
<tr>
<td>∆ Target FF * Income</td>
<td></td>
<td></td>
<td></td>
<td>-0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.001)</td>
</tr>
<tr>
<td>∆ Target FF * College</td>
<td></td>
<td></td>
<td></td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.000)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,421,135</td>
<td>1,421,135</td>
<td>1,421,135</td>
<td>1,421,135</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.350</td>
<td>0.350</td>
<td>0.350</td>
<td>0.350</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
This table estimates the effect of the maturity structure of Treasuries on deposit growth. Data are at the branch-year level and cover the years 1994 to 2016. The sample consists of all banks with branches in two or more counties. Deposit growth is the log change in deposits at the branch level. TSY Growth (haircut adjustment) is the log change in Treasury supply measured by weighting Treasuries of different maturities according to their haircuts as in Krishnamurthy and Vissing-Jorgensen (2012). TSY Growth (bill only) is the log change in Treasury bill supply. TSY Growth (Treasury non-bills only) is the log change in Treasury notes and bonds supply. TSY Growth (liquidity adjustment) is the log change in Treasury supply measured by weighting Treasuries of different maturities according to their liquidity premium as in Longstaff (2002) and Li and Song (2019). Branch HHI measures market concentration in the county where a branch is located. Note that a larger HHI means less competition. ∆ Target FF is the change in the Fed funds target rate. Data are from the FDIC, TreasuryDirect, CRSP, Krishnamurthy and Vissing-Jorgensen (2012) and Longstaff (2002). Fixed effects are denoted at the bottom of the table. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th>Branch-Level Deposit Growth (≥ 2 Counties)</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth * HHI (bill only)</td>
<td>0.000</td>
<td>(0.016)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSY Growth * HHI (non-bills only)</td>
<td>0.133***</td>
<td>(0.040)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSY Growth * HHI (haircut adjustment)</td>
<td>0.084**</td>
<td>(0.037)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSY Growth * HHI (liquidity adjustment)</td>
<td>0.069*</td>
<td>(0.038)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td>−0.007***</td>
<td>(0.003)</td>
<td>−0.010***</td>
<td>(0.003)</td>
</tr>
</tbody>
</table>

| Observations | 1,503,852 | 1,503,852 | 1,503,852 | 1,503,852 |
| R-squared    | 0.338     | 0.338     | 0.338     | 0.338     |
| Bank Year FE | Yes       | Yes       | Yes       | Yes       |
| State Year FE| Yes       | Yes       | Yes       | Yes       |
| Branch FE    | Yes       | Yes       | Yes       | Yes       |
| County FE    | Yes       | Yes       | Yes       | Yes       |
| Year FE      | Yes       | Yes       | Yes       | Yes       |
| SE Cluster   | County    | County    | County    | County    |

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Table 7: Deposit Volume and Treasury Supply: Repo Funding (≥ 2 Counties)

This table estimates the effect of Treasury supply on deposit growth for banks below the third quartile of repo funding. The data is at the branch-year level. Deposit growth is the log change in deposits at the branch level. TSY Growth is the log change in Treasury supply. Branch HHI measures market concentration in the county where a branch is located. Note that a larger HHI means less competition. ∆ Target FF is the change in the Fed funds target rate. Data are from the FDIC and TreasuryDirect. Fixed effects are denoted at the bottom of the table. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th>Branch-Level Deposit Growth</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth * HHI</td>
<td>0.222***</td>
<td>0.219***</td>
</tr>
<tr>
<td></td>
<td>(0.067)</td>
<td>(0.067)</td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td></td>
<td>-0.010**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.005)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observations</th>
<th>365,810</th>
<th>365,810</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-squared</td>
<td>0.395</td>
<td>0.395</td>
</tr>
<tr>
<td>Bank Year FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>State Year FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Branch FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>County FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SE Cluster</td>
<td>County</td>
<td>County</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Table 8: Deposit Volume and Treasury Supply: Slow-Moving Treasuries (≥ 2 Counties)

This table estimates the effect of slow-moving Treasuries on deposit growth. Data are at the branch-year level and are sampled every five years, from 2000 to 2015. The sample consists of all banks with branches in two or more counties. Deposit growth is the log change in deposits at the branch level. TSY Growth is the log change in Treasury supply. Branch-HHI measures market concentration in the county where a branch is located. Δ Target FF is the change in the Fed funds target rate. Data are from the FDIC and TreasuryDirect. Fixed effects are denoted at the bottom of the table. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th></th>
<th>5Y Branch-Level Deposit Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>TSY Growth * HHI</td>
<td>0.163**</td>
</tr>
<tr>
<td></td>
<td>(0.064)</td>
</tr>
<tr>
<td>Δ Target FF * HHI</td>
<td>0.140***</td>
</tr>
<tr>
<td></td>
<td>(0.014)</td>
</tr>
<tr>
<td>Observations</td>
<td>117,842</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.540</td>
</tr>
<tr>
<td>Bank Year FE</td>
<td>Yes</td>
</tr>
<tr>
<td>State Year FE</td>
<td>Yes</td>
</tr>
<tr>
<td>Branch FE</td>
<td>Yes</td>
</tr>
<tr>
<td>County FE</td>
<td>Yes</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
</tr>
<tr>
<td>SE Cluster</td>
<td>County</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Table 9: Crowd-Out Sensitivity by Deposit Type

This table estimates the effect of Treasury supply on deposit growth for different types of deposits. Data are at the bank-year level and covers the years 1994 to 2016. Deposit growth is the log change in deposits at the bank level. TSY Growth is the log change in Treasury supply. Bank HHI measures the average market concentration of the bank’s branches, where each branch takes the HHI of the county in which it is located in. Note that a larger HHI means less competition. ∆ Target FF is the change in the Fed funds target rate. Core Deposits are comprised of checking, savings and small time deposits (less than $100K). Time Deposits are the sum of small and large time deposits. Wholesale Funding is comprised of wholesale deposits, Fed funds, repo borrowing, and other borrowed money. Wholesale Funding (excl. Repo) comprises wholesale deposits, Fed funds, and other borrowed money. Data are from the FDIC, Call Reports, and TreasuryDirect. Bank controls include log total assets, leverage ratio, and returns on assets. Fixed effects are denoted at the bottom of the table. Standard errors are clustered by banks.

<table>
<thead>
<tr>
<th></th>
<th>Core Deposits</th>
<th>Time Deposits</th>
<th>Wholesale</th>
<th>Wholesale Funding excl. Repo</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth</td>
<td>-0.1289***</td>
<td>-0.2017***</td>
<td>-0.4899***</td>
<td>-0.5097***</td>
</tr>
<tr>
<td></td>
<td>(0.013)</td>
<td>(0.018)</td>
<td>(0.027)</td>
<td>(0.028)</td>
</tr>
<tr>
<td>TSY Growth * HHI</td>
<td>0.3116***</td>
<td>0.3062***</td>
<td>0.7542***</td>
<td>0.6963***</td>
</tr>
<tr>
<td></td>
<td>(0.044)</td>
<td>(0.059)</td>
<td>(0.098)</td>
<td>(0.102)</td>
</tr>
<tr>
<td>∆ Target FF</td>
<td>-0.0123***</td>
<td>0.0124***</td>
<td>0.0236***</td>
<td>0.0228***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.002)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td>0.0119***</td>
<td>-0.0195***</td>
<td>-0.0065</td>
<td>-0.0115</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.004)</td>
<td>(0.007)</td>
<td>(0.007)</td>
</tr>
</tbody>
</table>

| Observations         | 965,376       | 962,237       | 957,909   | 956,742                     |
| R-squared            | 0.020         | 0.022         | 0.015     | 0.014                       |
| Bank FE              | Yes           | Yes           | Yes       | Yes                         |
| Bank Controls        | Yes           | Yes           | Yes       | Yes                         |
| SE Cluster           | Bank          | Bank          | Bank      | Bank                        |

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Table 10: Treasury Supply and the Wholesale Funding Ratio

This table estimates the effect of Treasury supply on changes in wholesale funding ratios. Data are at the bank-year level and cover the years 1994 to 2016. Wholesale Funding Ratio is the ratio of wholesale funding over total deposit funding, where wholesale funding is the sum of large time deposits, repo borrowing, Fed funds, and other borrowed money. Wholesale Funding (excl. Repo) ratio is the ratio of wholesale funding excluding repo, over total deposit funding. TSY Growth is the log change in Treasury supply. Bank HHI measures the average market concentration of the bank’s branches, where each branch takes the HHI of the county in which it is located in. Note that a larger HHI means less competition. ∆ Target FF is the change in the Fed funds target rate. Data are from the FDIC, Call Reports, and TreasuryDirect. Bank controls include log total assets, leverage ratio, and returns on assets. Fixed effects are denoted at the bottom of the table. Standard errors are clustered by banks.

<table>
<thead>
<tr>
<th></th>
<th>Δ Wholesale Funding Ratio</th>
<th>Δ Wholesale Funding (excl. Repo) Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>TSY Growth</td>
<td>-0.030***</td>
<td>-0.036***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>TSY Growth * Bank HHI</td>
<td>0.029***</td>
<td>0.019**</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>∆ Target FFR</td>
<td>0.002***</td>
<td>0.002***</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
</tr>
<tr>
<td>∆ Target FFR * Bank HHI</td>
<td>-0.001**</td>
<td>-0.001**</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,007,682</td>
<td>966,954</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.011</td>
<td>0.010</td>
</tr>
<tr>
<td>Bank FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bank Controls</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SE Cluster</td>
<td>Bank</td>
<td>Bank</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Figure 1: Treasury Supply and Bank Deposits in the Aggregate Time Series

Panel (a) is a binned plot of year-over-year growth in the total deposits of commercial banks against Treasury supply growth from 1964 to 2019. Panel (b) is a binned plot of year-over-year changes in the spread between the 3-month Treasury yield and the three-month CD rates against Treasury supply growth from 1964 to 2019. Panel (c) is a binned plot of year-over-year growth in the ratio of wholesale funding and Treasury supply growth from 1973 to 2019. The wholesale funding ratio is defined as large time deposits over total deposits. All variables are residualized against year-over-year changes in the Fed funds rate to control for the impact of monetary policy. We use several sources to extend the time series for each plot. Treasury supply held by the private sector is available from the Flow of Funds. Total deposit volume is available from the FDIC historical banking data from 1964 onwards. Three-month Treasury yields, the Fed funds rate, and three-month CD rates are available from FRED, with the three-month CD rates available from 1964 onwards. Large time deposits are available from FRED from 1973 onwards.

(a) Deposit Growth and Treasury Supply

(b) Wholesale Funding Ratio

(c) Deposit Spread and Treasury Supply
Figure 2: Composition of Bank Asset Holdings

This figure shows the asset composition of the US commercial banking sector from 1980 to 2018. Data are from the Flow of Funds.
Figure 3: Illustration of the Impact of Treasury Supply on Bank Deposits

This figure illustrates the main channel for the impact of Treasury supply on deposits in Proposition 1.

(a) Less Competitive Region

(b) More Competitive Region

Figure 4: Illustration of the Impact of Fed Funds Rate Hikes on Bank Deposits

This figure illustrates the main channel for the impact of Fed funds rate hikes on deposits in Proposition 2.

(a) Less Competitive Region

(b) More Competitive Region
This figure presents information on county-level and bank-level deposit competition in the US. Subfigure (a) plots the first, second, and third quartiles of county-level HHI over time from 1997 to 2016. Subfigure (b) plots the distribution of the bank-level HHI, which is measured as the weighted average of the bank’s branch-level HHI. Data are from the FDIC.

(a) County-Level Herfindahl Index from 1997 to 2016

(b) Bank-Level Herfindahl Index Distribution
Figure 6: Sensitivity of Deposit Growth by Deposit Competition

This figure plots deposit growth sensitivities to Treasury growth against county-level HHI. Data are at the branch-year level and covers 1994–2016. Counties are first divided into 20 equal-sized bins according to their HHI Index. Then, branch-level deposit growth is regressed against Treasury growth interacted with indicator variables for each bin and controlling for year and branch fixed effects. The coefficients on the indicator variables correspond to the average sensitivity of deposit growth to Treasury growth among bank branches located in a given region of deposit competition. The last bin is taken as the baseline for comparison. Data are from the FDIC and TreasuryDirect.
Figure 7: Sensitivity of Treasury–Deposit Spreads by Deposit Competition

This figure plots deposit spread sensitivities to Treasury growth against county-level HHI. Panels (a) and (b) show results for time and savings deposits, respectively. The data are at the branch-quarter level and covers years 1997 to 2016. Counties are first divided into 20 equal-sized bins according to their HHI Index. Then, branch-level deposit spread changes are regressed against Treasury growth interacted with indicator variables for each bin and controlling for year and branch fixed effects. The coefficients on the indicator variables correspond to the average sensitivity of deposit spread changes to Treasury growth among bank branches located in a given region of deposit competition. The last bin is used as the baseline for comparison. Data are from RateWatch, FDIC and TreasuryDirect.

(a) Sensitivity of Time Deposit Spread

(b) Sensitivity of Savings Deposit Spread
Figure 8: Example of Deposit Spreads for Two Branches of Huntington Bank

This figure plots the spread of three-month Treasuries and three-month CDs at two branches of Huntington Bank from October 2004 to April 2005. One branch is located in Macomb, MI (red), while the other is in Hamilton, OH (blue). During this period, Treasury growth increased by 3.24% from 2004Q4 to 2005Q1. Data are from Ratewatch, the FDIC, and TreasuryDirect.
This figure plots county-level deposit volume pass-through sensitivities to Treasury supply and monetary policy. Panel (a) shows the decrease in deposit growth (bps) due to a one standard deviation increase in Treasury supply growth for each county. Darker shades correspond to a more pronounced effect, which occurs in counties with a lower average HHI (i.e., more competitive counties). Panel (b) shows the decrease in deposit growth (bps) due to a one standard deviation increase in Fed funds rate hikes for each county. Darker shades correspond to a more pronounced effect, which occurs in counties with a higher average HHI (i.e., less competitive counties). Data are from RateWatch, FDIC, and TreasuryDirect.
Figure 10: Bank-Level Crowd-Out Sensitivity by Wholesale Funding Ratio

This figure shows how crowd-out sensitivities vary with the level of wholesale funding. A positive crowding-out sensitivity means that deposits have outflows when Treasury growth rises. The sample is from 1994 to 2016. Banks are first divided into quintiles according to their ratio of wholesale funding. The columns (left axis) indicate the average wholesale funding ratio in each quantile. The horizontal axis marks the quintile group number of crowd-out sensitivities. In panel (a), the crowding-out sensitivities are calculated by regressing deposit growth on Treasury growth interacted with dummy variables for each quintile group and controlling for changes in the Fed funds rate, log of total assets, leverage ratio, return on assets and bank fixed effects. In panel (b), the crowding-out sensitivities are calculated by regressing deposit growth on Fed funds rate changes interacted with dummy variables for each quintile group and controlling for Treasury growth, log of total assets, leverage ratio, return on assets and bank fixed effects. Dotted lines indicate the 95th confidence interval. Data are from the FDIC, Call Reports, and TreasuryDirect.

(a) Treasury Growth

(b) Fed funds Rate change
A Appendix: the Reverse Repurchase Facility

This appendix quantifies the impact of the RRP Facility by applying estimates from the baseline model. The RRP Facility was an unprecedented extension of the scope of US monetary policy. It expanded the Federal Reserve’s set of counterparties beyond depository institutions and primary dealers to include money market mutual funds, allowing them to lend directly to the Fed through reverse repo transactions. While other papers have considered the financial stability implications (Anbil and Senyuz, 2018, Anderson and Kandrac, 2017) and the interaction with segmented reserves markets (Vandeweyer, 2019), our focus will be on the passthrough to bank deposit funding.

There is limited direct analysis of the RRP Facility’s effectiveness in improving passthrough. One challenge is that the announcement of the program and its implementation happened in multiple stages, and thus individual event studies cannot quantify the effect. Another challenge is that various other regulatory changes occurred shortly after the initiation of the RRP Facility in 2013, such as the implementation of the Liquidity Coverage Ratio (LCR) and the Supplementary Leverage Ratio (SLR) in 2014.

Our framework allows for an indirect assessment that uses the estimated crowding-out coefficient from changes in government-supplied liquidity to proxy for the effect of the RRP Facility. To guide our analysis, we introduce the RRP Facility into our baseline model of deposit competition. We provide an intuitive explanation below and refer the reader to Appendix B.6 for a formal proof.

An introduction of the RRP Facility would allow investors to invest at the RRP rate $r_{RRP}$ set by the central bank with no limit on supply through money market mutual funds. Money market mutual funds can hold on to their Treasuries or lend them to the Fed, depending on which offers a higher return.

Denoting the IOER - RRP spread as $\ell_{RRP} = r - r_{RRP}$, the household deposit demand becomes $D(s, \min\{\ell, \ell_{RRP}\})$, as long as investors are indifferent between the money market mutual funds investing in Treasuries or reverse repos with the Federal Reserve. When the RRP Facility offers a rate below the market-clearing rate for Treasuries without the RRP Facility, there is no demand for the Facility, and the original deposit demand function applies. If the RRP Facility offers a rate above the Treasury yield, the market clearing of Treasuries will adjust Treasury yields endogenously so that in equilibrium, $\ell^* = \ell_{RRP} = \ell_0$, where $\ell_0$ solves the original equilibrium system in (10) and (11). In this case, the deposit market clearing will be

$$D(s, \ell_{RRP}) = \hat{D}(s, r), \quad (A-1)$$

which is the same as before the implementation of the RRP Facility. In practice, the RRP rate offered exceeds the one-month Treasury yield most of the time (see Figure 11).20 In other words, all comparative statics of deposits with respect to Treasuries before the RRP Facility’s implementation can proxy for the impact of changes in the RRP rate on bank deposit funding.

Guided by the model prediction, we can now analyze the effect of the RRP Facility on monetary policy passthrough to bank deposit funding by repeating our empirical specifications with a sample ending in 2013Q3 and with Treasury yield as policy variable instead of Treasury supply. As before, we obtain cross-elasticities for deposit growth with respect to increases in the Treasury–deposit

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20This is already a conservative measure because the RRP Facility is overnight and the one-month Treasury yield is higher than Treasury yields of shorter maturities because of term premia.
spread and the Fed funds–deposit spread increases as in the baseline (Table 11). On average, for a 100 bps increase in the Treasury yield, bank deposit growth is lowered by 128 bps, whereas a 100 bps increase in the Fed funds rate cuts deposit growth by 425 bps. This implies that for a given monetary policy rate change, having the RRP Facility rate move in tandem with the target Fed funds rate improves the pass-through to bank deposit growth by about a quarter.

The RRP Facility not only improves the overall pass-through efficiency of monetary policy but also enhances the banking sector’s funding stability. As shown in Section 6, standard rate hikes lead to an increased reliance on bank wholesale funding because core deposits are crowded out more. However, hikes in the RRP rate resemble increases in Treasury supply and yields, and thus deploying the RRP Facility can reduce and reverse the potentially risky buildup in wholesale funding arising from monetary policy tightening.

Figure 11: Treasury Yield and the Reverse Repurchase Facility Rate

This figure compares the one-month Treasury yield with the RRP Facility rate. Data are from FRED and the New York Federal Reserve website.
Table 11: Effect of the Reverse Repurchase Facility

This table estimates the effect of the Reverse Repurchase Facility. The dependent variable in column (1) is deposit growth, which is the log change in deposit volume at the branch-year level. The sample covers 1997 to 2013 and consists of all banks with branches in two or more counties. The dependent variable for columns (2) and (3) are changes in the spread between the Treasury yield and deposit rates at the branch-quarter level. The dependent variable for columns (4) and (5) are changes in the spread between the Fed funds rate and deposit rates at the branch-quarter level. The sample covers 1997Q1 to 2013Q3 and consists of all banks with branches in two or more counties. ∆ TSY and ∆ Target FF are changes in the Treasury yield and the Fed funds target rate, respectively. Branch HHI measures market concentration in the county where a branch is located. Data are from Ratewatch, the FDIC, and TreasuryDirect. All specifications include bank-time, state-time, branch, county, and time fixed effects. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th></th>
<th>Dep Growth</th>
<th>Δ TSY - Dep Spread</th>
<th>Δ FF - Dep Spread</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ TSY * HHI</td>
<td>0.016*</td>
<td>-0.838**</td>
<td>-0.508**</td>
</tr>
<tr>
<td></td>
<td>(0.067)</td>
<td>(0.305)</td>
<td>(0.243)</td>
</tr>
<tr>
<td>Δ Target FF * HHI</td>
<td>-0.018***</td>
<td>0.469***</td>
<td>0.306***</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.032)</td>
<td>(0.024)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,107,828</td>
<td>190,050</td>
<td>185,881</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.354</td>
<td>0.886</td>
<td>0.877</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
B Appendix: Model Derivations

In this section, we provide detailed derivations for the model.

B.1 Derivations for Deposit Demand and Supply Curves

Aggregate Deposit Demand

The first order conditions for problem (4) are
\[ \ell = \delta L^{\frac{1}{\sigma}} G^{\frac{1}{\sigma}} - \frac{1}{\sigma} G, \quad s = L^{\frac{1}{\sigma}} D^{-\frac{1}{\sigma}} \]
which implies
\[ (\frac{G}{D})^{\frac{1}{\sigma}} \delta = \frac{\ell}{s} \]
and
\[ L = (1 + \delta^{\sigma} (\frac{s}{\ell})^{\sigma-1})^{\frac{\sigma}{\sigma-1}} D \]

Plugging in \( L \) and \( G \) as a function of \( D \) into the FOC, we obtain
\[ D = \frac{1}{s + \ell^{-(\sigma-1)} (\delta s)^{\sigma}} , \quad G = \frac{1}{\ell + s^{\sigma-1} (\ell/\delta)^{\sigma}} \]

Demand for Deposits from Individual Banks

Next, we solve the household optimization over individual bank’s deposits. The individual deposit optimization problem is
\[ \min_{D_i, \ i \in \{1, 2, \ldots, N\}} \sum_{i=1}^{N} \frac{1}{N} D_i s_i \]
subject to
\[ D = \left( \frac{1}{N} \sum_{i=1}^{N} D_i \right)^{\frac{1}{\eta}} \]

The FOC over \( D_i \) is
\[ s_i = \mu \cdot D_i^{\frac{1}{\eta}} D_i^{-\frac{1}{\eta}} \]
where \( \mu \) is the Lagrangian multiplier over the constraint (2). The above FOC implies
\[ (\frac{D_i}{D_j})^{\frac{1}{\eta}} = \frac{s_i}{s_j} \]

Since \( s_j = s \) for \( j \neq i \),
\[ D_{j_1} = D_{j_2}, \quad j_1 \neq j_2, \quad \text{for all } j_1, j_2 \neq i \]

Then, solving for \( D_j \) when \( j \neq i \) yields
\[ D_j = \left( \frac{N D_{i}^{\frac{1}{\eta}} - D_{i}^{\frac{1}{\eta}}}{N - 1} \right)^{\frac{n}{\eta-1}} \]
Next, we can express the aggregate deposit $D$ as a function of $D_i$ and plug into equation (B-2):

$$D_i = D \left( \frac{1}{N} \left( 1 + (N - 1) \left( \frac{s_i}{s} \right)^{\eta - 1} \right) \right)^{-\frac{\eta}{\eta - 1}}$$

Taking log, we have

$$\log(D_i) = \log(D) - \frac{\eta}{\eta - 1} \left( \log(1 + (N - 1) \left( \frac{s_i}{s} \right)^{\eta - 1}) - \log(N) \right)$$

Thus the derivative of the optimal $D_i$ over $s_i$ is

$$\frac{\partial \log(D_i)}{\partial \log(s_i)} = -\frac{(N - 1)}{1 + (N - 1) \left( \frac{s_i}{s} \right)^{\eta - 1}}$$

In the symmetric equilibrium, we have $s = s_i$, which implies

$$\frac{\partial \log(D_i)}{\partial \log(s_i)} = -\frac{N - 1}{N - \eta}$$

Denoting demand elasticity as $e$, we have

$$e(N, \eta) = \frac{N - 1}{N - \eta}$$

which is an increasing in both $N$ and $\eta$.

**Aggregate Deposit Supply**

With the inverse loan demand function (7), bank optimization can be expressed as

$$\max_{s_i} \left( s_i + \frac{Q}{2\beta} - r - \frac{\tilde{D}_i}{2\beta} \right) \tilde{D}_i$$  \hspace{1cm} (B-3)

The first order condition implies

$$\frac{s_i}{s_i + \frac{1}{2\beta} Q - r - \frac{1}{2\beta} \tilde{D}_i} = -\frac{\partial \log(\tilde{D}_i)}{\partial \log(s_i)}$$  \hspace{1cm} (B-4)

which characterizes the optimal bank deposit spread choice given the deposit demand function $\tilde{D}_i$. In the symmetric equilibrium, $\tilde{D}_i = D$, and $s = s_i$. We can invert the relationship in (B-4) to obtain the aggregate bank deposit supply as

$$\hat{D}(s, r) = \frac{Q}{2} + \beta \left( \frac{e - 1}{e} s - r \right)$$

which increases with deposits spread $s$ but decreases with the risk-free rate $r$. The slope of the supply curve with respect to deposit spread is

$$\hat{D}_s(s, r) = \beta \frac{e - 1}{e} > 0$$
We define a deposit competition index $C = e^{-1}$ such that

$$\hat{D}_s'(s, r) = \beta C$$

The index $C$ is higher when $e$ is larger. Since $e = e(N, \eta)$ is an increasing function of $N$ and $\eta$, a larger number of banks $N$ and a higher elasticity of substitution across banks both result in a larger $C$. In other words, when the banking sector is more competitive, $C$ is larger.

Note that $C$ enters the supply function $\hat{D}$, but not the demand function $D$. This is because we are considering the aggregate deposit demand and supply. Intuitively, when viewing the banking sector as a whole, households choose their liquid assets between deposits and Treasuries. Such a choice is only affected by the relative attractiveness of deposits and Treasuries, reflected by the average deposit spread $s$ and Treasury convenience yield $\ell$. The elasticity of substitution between banks $\eta$ and the number of banks $N$ will only affect banks’ sensitivity to household demand due to the induced deposit competition among banks, therefore affecting the deposit supply curve $\hat{D}$.

### B.2 Proof of Proposition 1

Taking derivatives over $G$ on the market clearing conditions (10) and (11), we have

$$D_s' s_G' + D_\ell' \ell_G' = \hat{D}_s' s_G'$$

$$G_s' s_G' + G_\ell' \ell_G' = 1$$

Then in equilibrium, the deposit spread and convenience yield response to Treasury supply is

$$s_G' = \frac{1}{G_\ell'} \frac{1}{G_\ell'} - \frac{D_s'}{D_\ell'} + \frac{D_s'}{D_\ell'}$$

$$\ell_G' = \frac{1}{G_\ell'} \frac{1}{G_\ell'} - \frac{D_s'}{D_\ell'} + \frac{D_s'}{D_\ell'}$$

Then we have the quantity sensitivity

$$\frac{\partial D^*}{\partial G_0} = - \frac{1}{-G_\ell'} \frac{\hat{D}_s'}{G_\ell'} - \frac{D_s'}{D_\ell'} + \frac{D_s'}{D_\ell'}$$

With assumption (C-2), we have

$$G_s' G_\ell' - \frac{D_s'}{D_\ell'} > 0$$

Furthermore,

$$\hat{D}_s' > 0, \quad -G_\ell' > 0, \quad \hat{D}_s' > 0$$

As a result, we have

$$\frac{\partial D^*}{\partial G_0} < 0$$
In addition, it is easy to see that \( |\partial D^*/\partial G_0| \) increases in \( \hat{D}'_s \), which increases in \( C \). In summary,

\[
\partial \left( \frac{\partial D^*}{\partial G_0} \right) / \partial C > 0
\]

or equivalently,

\[
\partial \left( \frac{\partial D^*}{\partial G_0} \right) / \partial C < 0
\]

Next, the equilibrium Treasury–deposit spread sensitivity is

\[
\frac{\partial \left( s^* - \ell^* \right)}{\partial G_0} = \frac{1}{-G_{\ell'} D_{\ell} - G_{s'} D_{s} - \hat{D}'_r \hat{D}'_s}
\]

Since

\[
\frac{G_{s'}(s, \ell)}{G_{\ell'}(s, \ell)} \frac{D_{s'}(s, \ell)}{D_{\ell'}(s, \ell)} > -1 - \frac{D_{s'}(s, \ell)}{D_{\ell'}(s, \ell)} > 0
\]

we have

\[
\frac{\partial (s^* - \ell^*)}{\partial G_0} > 0
\]

Furthermore, the above derivative increases with \( \hat{D}'_s \), or increases with deposit competition. As a result, the deposit spread positively responds to the increase in Treasury supply, and the response is stronger with more fierce deposit supply competition.

Finally, the FFR–deposit spread sensitivity is

\[
s_G' = \frac{1}{G_{\ell'} G_{s'} - D_{s'} D_{\ell'}} < 0
\]

and the magnitude decreases in \( C \), which means that the value increases with \( C \), i.e.,

\[
\frac{\partial s_G'}{\partial C} > 0
\]

### B.3 Proof of Proposition 2

Suppose \( \ell^* = \ell(G_0, r) \) is fixed. In other words, \( G_0 \) is adjusted to make sure a change in \( r \) is not affecting \( \ell^* \). After taking derivatives over \( r \) on the equilibrium market clearing condition (10), we have

\[
D_{s'} s_r = \hat{D}'_s s_{r'} + \hat{D}'_r
\]

\[
s_r = \frac{-\hat{D}'_r}{\hat{D}'_s - \hat{D}'_s} > 0
\]

and the magnitude decreases in \( C \). Furthermore,

\[
\frac{\partial D^*}{\partial r} = D_{s'} s_r = D_{s'} \frac{-\hat{D}'_r}{\hat{D}'_s - \hat{D}'_s} < 0
\]

and the outflow sensitivity decreases in \( C \).
If \(G_0\) is fixed instead, then we need to use both market clearing conditions (10) and (11) to get

\[
D_s's_r' + D_\ell'\ell_r' = \dot{D}_s's_r' + \dot{D}_r'
\]

\[
G_s's_r' + G_\ell'\ell_r' = 0
\]

which implies that

\[
s_r' = \frac{-\dot{D}_r'}{\dot{D}_s' - D_s' + D_\ell'G_s'G_\ell'}
\]

which has an additional term in the denominator. All we need is to guarantee that the denominator is positive, which requires

\[
\dot{D}_s' - D_s' + D_\ell'G_s'G_\ell' > 0
\]

By (C-2), we have

\[
-D_s' + D_\ell'G_s'G_\ell' > 0
\]

Therefore,

\[
s_r' > 0
\]

Moreover, the functional form implies that a higher \(C\) results in a smaller \(s_r'\).

Next, the Treasury–deposit spread response is

\[
\frac{\partial(s^* - \ell^*)}{\partial r} = \frac{1 + \frac{G_s'}{G_\ell'}}{\dot{D}_s' - D_s' + D_\ell'G_s'G_\ell'}(-\dot{D}_r') > 0
\]

and the sensitivity decreases with \(C\).

The equilibrium quantity response is

\[
\frac{\partial D^*}{\partial r} = \frac{\dot{D}_r'}{\dot{D}_s' - D_s' + D_\ell'G_s'G_\ell'} < 0
\]

and the magnitude of this response is stronger when \(C\) is smaller (or \(\dot{D}_s'\) is smaller).

### B.4 Proof of Proposition 3

The elasticity of bank \(i\)'s deposit demand is

\[
\frac{\partial \log(\tilde{D}_i^W + \tilde{D}_i^R)}{\partial \log(s_i)} = \frac{\dot{D}_i^W}{\tilde{D}_i^W + \tilde{D}_i^R} \cdot \frac{\partial \log(\tilde{D}_i^W)}{\partial \log(s_i)} + \frac{\dot{D}_i^R}{\tilde{D}_i^W + \tilde{D}_i^R} \cdot \frac{\partial \log(\tilde{D}_i^R)}{\partial \log(s_i)} \tag{B-5}
\]

Denote the deposit market share of wholesale depositors \(W\) as \(\alpha_W\). Then we get the demand elasticity as

\[
e = \frac{N - 1}{N} (\alpha_W \eta_W + (1 - \alpha_W) \eta_R) \tag{B-6}
\]

which implies that a larger fraction of wholesale deposits \(\alpha_W\) will increase the deposit demand elasticity \(e\), and therefore, increases the competition \(C\).
When $\alpha_W$ is larger, since $\eta_W > \eta_R$, we get a higher demand elasticity $e$, or more fierce bank deposit competition $C$, which implies a larger $\hat{D}'_s$. Keeping everything else equal, this implies that the equilibrium deposit response to Treasury supply

$$\frac{\partial D^*}{\partial G_0} = \frac{1}{-G'_\ell \frac{G'_s}{G'_\ell} + \frac{\hat{D}'_s}{D'_s - D'_s} + \frac{D'_s}{D'_s}}$$

increases with $\eta_W$.

The equilibrium response of deposit quantity to federal funds rate is

$$\frac{\partial D^*}{\partial r} = \hat{D}'_s \frac{-D'_s + D'_s \frac{G'_s}{G'_\ell}}{D'_s - D'_s + D'_s \frac{G'_s}{G'_\ell}}$$

which is negative, and the magnitude of the response decreases with $\hat{D}'_s$, keeping everything else equal. Therefore, with a larger $\alpha_W$, the demand elasticity for individual deposit $e$ increases, which implies that $C$ increases, leading to a smaller magnitude of deposit response.

### B.5 Substitution between Treasuries and Deposits

Suppose that the substitution between Treasuries and deposits increase, what is the impact on the crowding-out effect of Treasuries? The answer is in the following proposition.

**Proposition 4** (Crowding-Out Effect and the Substitution between Treasuries and Deposits). Suppose that both $D'_\ell$ and $G'_s$ increases with $\sigma$, the elasticity of substitution between Treasuries and deposits. Then a larger $\sigma$ results in a stronger crowding-out effect of Treasury supply on deposits.

**Proof.** The equilibrium deposit sensitivity to Treasury supply is

$$\frac{\partial D^*}{\partial G_0} = \frac{1}{-G'_\ell \frac{G'_s}{G'_\ell} + \frac{\hat{D}'_s}{D'_s - D'_s} + \frac{D'_s}{D'_s}}$$

We have already proved in Appendix B.2 that the denominator is positive. Since $G'_\ell < 0$, $\hat{D}'_s - D'_s > 0$, the denominator

$$\frac{G'_s}{G'_\ell} + \frac{1}{D'_\ell} (\hat{D}'_s - D'_s)$$

decreases in both $G'_s$ and $D'_\ell$. Therefore, the absolute value of the sensitivity

$$\left| \frac{\partial D^*}{\partial G_0} \right|$$

increases with both $G'_s$ and $D'_\ell$, which provides a sufficient condition for the crowding-out effect to be stronger in the substitution between Treasuries and deposits.

The intuitions in Proposition 4 are very simple: two goods of higher degree of substitution will have stronger crowding-out effects on each other. In Proposition 4, we have assumed the positive
relationship between $D'_\ell$ and $G'_s$ with respect to $\sigma$. This assumption is quite lenient and discussed in what follows.

**Connections to the microfoundation**

When the strength of the substitution effect is measured with the elasticity of substitution in the demand function (i.e., parameter $\sigma$), we have

$$D'_\ell = (\sigma - 1) \frac{(\delta s)^\sigma \ell^{-\sigma}}{(s + \ell^{-(\sigma-1)}(\delta s)^\sigma)^2}$$

$$G'_s = (\sigma - 1) \frac{(\ell/\delta)^\sigma s^{-\sigma}}{(\ell + s^{-(\sigma-1)}(\ell/\delta)^\sigma)^2}$$

If $\ell \approx \delta s$, then both $D'_\ell$ and $G'_s$ increase in $\sigma$. In general, as long as the major impact of $\sigma$ on both $D'_\ell$ and $G'_s$ come from the multiplier term $\sigma - 1$, a larger elasticity of substitution results in higher $D'_\ell$ and $G'_s$, which leads to a larger $|\partial D^*/\partial G_0|$.

**Impact of Federal Funds Rate**

Next, we study the influence of federal funds rate $r$. If the assumption is that Treasury supply keeps $\ell$ the same, then we arrive at the same equation system as the scenario without bank demand for Treasuries. Therefore, all results go through. Now suppose that the Treasury supply $G_0$ itself is kept as constant. Then we have

$$\tilde{G}'_s s'_r + \tilde{G}'_\ell \ell'_r = 0$$

$$D'_s s'_r + D'_\ell \ell'_r = \hat{D}'_s s'_r + \hat{D}'_r + \hat{D}'_\ell \ell'_r$$

which implies that

$$s'_r = \frac{\hat{D}'_r}{\hat{D}'_s - D'_s + D'_\ell \frac{G'_s}{G'_\ell} - \hat{D}'_\ell \frac{G'_s}{G'_\ell}}$$

As long as

$$\hat{D}'_s > |\hat{D}'_\ell|$$

(B-7)

and the version of (C-2) on $\tilde{G}$ holds, $s'_r > 0$, and the derivative with respect to $C$ remains the same. The assumption is that the impact of deposit spread on deposit supply is higher than the impact of convenience yield on bank deposit supply.

The quantity response is

$$\frac{\partial D^*}{\partial r} = D'_s s'_r + D'_\ell \ell'_r$$

$$= -\frac{\hat{D}'_r(-D'_s + \frac{G'_s}{G'_\ell} D'_\ell)}{\hat{D}'_s - D'_s + D'_\ell \frac{G'_s}{G'_\ell} - \hat{D}'_\ell \frac{G'_s}{G'_\ell}}$$

If (B-7) holds, then we have

$$\frac{\partial D^*}{\partial r} < 0$$

We notice that the absolute value still decreases with $C$. Thus, Proposition 2 still holds when banks have a demand for Treasuries.
B.6 Reverse Repo Facility

In this subsection, we formulate the study of reverse repo facility in a more formal way. In reality, the Reverse Repo Facility is only accessible to money market mutual funds. But if money market mutual funds are pass-through of investor preference, effectively we allow for households direct access to the reverse repo facility. Therefore, we do not explicitly model the money market funds, but directly assume that the Reverse Repo Facility is supplying assets with a reverse repo rate \( r_{RRP} \), and the supplying quantity is elastic to achieve the reverse repo rate. Denote the FFR – reverse repo spread as

\[
\ell_{RRP} = r - r_{RRP}
\]

Then the demand function for deposits from households can be rewritten as

\[
D(s, \min\{\ell, \ell_{RRP}\})
\]

since Treasuries and reverse repos are perfect substitutes.

Furthermore, we assume that Treasuries and reverse repos are perfectly substitutable from the households perspective. Denote the solution of \( \ell \) from the original equilibrium system (without reverse repo) in (10) and (11) as \( \ell_0 \). Then there are three scenarios:

- \( \ell_{RRP} > \ell_0 \), in other words, the reverse repo rate is below the Treasury yield. In this case, households do not hold reverse repo at all, and the demand function for deposits becomes \( D(s, \ell) \). In equilibrium, the Treasury convenience yield is \( \ell^* = \ell_0 \).

- \( \ell_{RRP} < \ell_0 \), in other words, the reverse repo rate is above the Treasury yield. In this case, households do not hold Treasuries at all, which implies that the equilibrium demand for Treasuries is 0, below the Treasury supply \( G_0 \). In this scenario, the market clearing of Treasuries will adjust Treasury yields endogenously so that in equilibrium, \( \ell^* = \ell_{RRP} = \ell_0 \).

- \( \ell_{RRP} = \ell_0 \). In this case, we have \( \ell^* = \ell_{RRP} \).

Consequently, there are only two scenarios: (1) If \( \ell_{RRP} > \ell_0 \), we are back to the original solution, and reverse repo facility has zero impact on the equilibrium. (2) If \( \ell_{RRP} \leq \ell_0 \), then \( \ell^* = \ell_{RRP} \), and a decrease in \( \ell_{RRP} \) will decrease Treasury convenience yield at the same time.

Suppose that \( \ell^* = \ell_{RRP} \). Then we can use the deposits market clearing to solve for the deposit spread,

\[
D(s, \ell_{RRP}) = \hat{D}(s, r)
\]

We note that this equation is the same for the model without reverse repo facility. Therefore, once we have estimated the impact of Treasury yield on equilibrium deposit quantity \( D^* \) in the world without reverse repo, we can use the same sensitivity as the equilibrium deposit response to the reverse repo rate. Taking both scenario (1) and (2), we have the following proposition.

**Proposition 5.** Denote the equilibrium deposit quantity with the reverse repo facility as \( D^*_{RRP} \), and without reverse repo facility as \( D^* \). Then we have

\[
\frac{\partial D^*_{RRP}}{\partial \ell_{RRP}} = \begin{cases} 
0 & \text{if } \ell_{RRP} > \ell_0 \\
\frac{\partial D^*}{\partial \ell_0} & \text{if } \ell_{RRP} \leq \ell_0
\end{cases}
\]
Online Appendix to "The Passthrough of Treasury Supply to Bank Deposit Funding".

Wenhao Li, Yiming Ma, and Yang Zhao

C Additional Proofs

In this online appendix, we provide robustness checks to the main model by examining and generalizing model assumptions. We also illustrate how to intuitively understand the relationship between deposit supply curve elasticity and competition.

C.1 Increasing Deposit Supply Elasticity in Alternative Models

Next, we show the generality of the deposit supply elasticity increasing with the number of competing banks. Our main setup is based on Bertrand monopolistic competition. Therefore, as a robustness check, we examine whether deposit supply elasticity increases with $N$ still holds in a model with Cournot competition.

We focus on deposit demand for simplicity. Suppose that the household reverse demand function for deposits is $\tilde{s}(D)$, where $s = \tilde{s}$ is the Fed funds - deposit spread. The total deposit quantity is

$$D = D_1 + D_2 + \cdots + D_N$$

For bank $j$, the optimization problem is

$$\max_{D_j} D_j \cdot \tilde{s}(D_{-j} + D_j) - C_j(D_j)$$

where $C_j(\cdot)$ is the deposit cost function. First order condition implies

$$\tilde{s}(D) + D_j \cdot \tilde{s}'(D) = C'_j(D_j)$$

Suppose that $C'(\cdot)$ satisfies

$$\sum_{j=1}^{N} C'_j(D_j) = \tilde{C}'(\sum_{j=1}^{N} D_j) \quad (C-1)$$

for some convex function $\tilde{C}$. ²

Then summing up all banks’ first order conditions, we get

$$N \tilde{s}(D) + D \cdot \tilde{s}'(D) = \tilde{C}'(D)$$

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²This could be satisfied by a quadratic deposit cost function $C_j(D_j) = aD_j^2 + b_jD_j + c_j$ with $a > 0$ for example. We note that convexity is a common assumption for cost functions. Such a cost function allows for heterogeneity across banks, as reflected by $b_j$ and $c_j$. 

1
where \( \tilde{s} \) denotes the investment deposit demand function, but \( s \) represents the deposit spread in the deposit supply relationship. Denote the aggregate deposit demand elasticity as

\[
e^D = \partial \log(D)/\partial \log(s)
\]

Rewriting the first order condition into a “supply curve”, we have

\[
\tilde{C}'(D) = (N + \frac{1}{\varepsilon^D})s
\]

Given the convexity of \( \tilde{C}(D) \), this implies a positive relationship between \( D \) and \( s \). Furthermore, the sensitivity of \( D \) to \( s \) increases with the number of banks \( N \), consistent with our main model.

### C.2 Robustness to Functional Forms of Deposit Aggregation and Bank Loan Demand

We might be worried that our results are fragile to the assumptions of the specific functional form of the bank loan demand, as well as the household deposit aggregation among different banks. In this part, we show that our results only depend on a parsimonious set of assumptions.

For generality, denote the inverse loan demand function as

\[
r' = f(\text{quantity of loans})
\]

where \( \ell \) is a decreasing and differentiable function. Denote the household deposit demand elasticity as

\[
-\frac{\partial \log(D_i)}{\partial \log(s_i)} = \varepsilon(N)
\]

where \( \varepsilon(N) \) increases with \( N \). Then the bank first order condition implies

\[
\frac{s_i}{f'(\tilde{D}_i) - \tilde{D}_i + s_i - r} = \frac{\partial \log(\tilde{D}_i)}{\partial \log(s_i)} = \varepsilon(N)
\]

which can be simplified as

\[
\tilde{D}_i - f'(\tilde{D}_i) = (1 - \frac{1}{\varepsilon(N)})s_i - r
\]

Imposing symmetry and express the above deposit as “deposit supply” \( \hat{D} \), we have

\[
\hat{D} - f'(\hat{D}) = (1 - \frac{1}{\varepsilon(N)})s - r
\]

Next, we assume that the curvature of inverse loan demand curve is bounded so that

\[
f''(\hat{D}) < 1
\]

and deposits have enough elasticity with respect to local deposit spread,

\[
\varepsilon(N) > 1
\]

Then we have \( \hat{D} \) increasing in \( s \) but decreasing in \( r \). Furthermore, \( \partial \hat{D}/\partial s \) increases in \( N \).
In summary, for our main results, we need the following assumptions of the loan demand function and deposit demand function:

- Inverse loan demand function $f(\cdot)$ is decreasing and has limited curvature.

- Deposit demand elasticity $\varepsilon(N)$ is larger than 1 and increases in $N$.

### C.3 Conditions for the Assumptions on Substitutability

Our main results require the following regularity assumptions:

$$\left| \frac{D_s'}{D\ell'} \right| > 1, \quad \left| \frac{G\ell'}{G_s'} \right| > 1 \quad (C-2)$$

Intuitively, (C-2) is that we need the elasticity of substitution between bank deposits and Treasuries. In what follows, we provide conditions for these assumptions in terms of model primitives.

With the expressions of $G(s, \ell)$ and $D(s, \ell)$ in (5) and (6), we have

$$D\ell' = \frac{(\sigma - 1)(\delta s)^{\sigma} \ell^{-\sigma}}{(s + \ell - (\sigma - 1)(\delta s)^{\sigma})^2}$$

$$D_s' = -\frac{1 + \ell^{-(\sigma - 1)}\delta^s s^{\sigma - 1}}{(s + \ell - (\sigma - 1)(\delta s)^{\sigma})^2}$$

$$G\ell' = -\frac{1 + s^{-(\sigma - 1)}\delta^{-\sigma} \ell^{\sigma - 1}}{((\ell + s - (\sigma - 1)(\ell/\delta)^{\sigma})^2}$$

$$G_s' = -\frac{(\sigma - 1)((\ell/\delta)^{\sigma} s^{-\sigma}}{(\ell + s - (\sigma - 1)((\ell/\delta)^{\sigma})^2}$$

As a result, (C-2) is equivalent to

$$1 + \left( \frac{\ell}{s} + 1 - \sigma \right)(\delta s)^{\sigma} \ell^{-\sigma} > 0$$

and

$$1 + \left( \frac{s}{\ell} + 1 - \sigma \right)(\delta s)^{-\sigma} \ell^{\sigma} > 0$$

There is a variety of conditions that can satisfy the above two inequalities simultaneously. For example, suppose that $\delta s = \ell$, then we need

$$\sigma < 2 + \delta$$

to guarantee the positiveness of both expressions.

Since our current setup is restricted to the log utility in liquidity, the parameter space is quite restricted. In general, the conditions to guarantee Assumption C-2 are quite broad. For example,
suppose that the household optimization problem is changed into

\[
\begin{align*}
\text{max} & \quad W_1 + L^\beta \\
\text{s.t.} & \quad W_1 = x(1 + r) + D(1 + r^D) + G(1 + r^G) \\
& \quad x + D + G = W_0 \\
L &= \left(D^{\frac{\sigma - 1}{\sigma}} + \delta G^{\frac{\sigma - 1}{\sigma}}\right)^{\sigma} \\
\end{align*}
\]

where \( \beta \in (0, 1) \) to guarantee monotonicity and concavity of the function over the liquidity bundle \( L \). First order conditions are

\[
\begin{align*}
L^\beta L^\frac{1}{\sigma} \delta G^{\frac{1}{\sigma}} &= \ell \\
L^\beta L^\frac{1}{\sigma} D^{\frac{1}{\sigma}} &= s \\
\Rightarrow \delta(\frac{G}{D})^{\frac{1}{\sigma}} &= \frac{\ell}{s} \\
\end{align*}
\]

Therefore,

\[
L = \left(1 + \delta(\frac{s}{\ell})^{\sigma - 1}\right)^{\frac{\sigma}{\sigma - 1}} D
\]

Then we can solve \( D \) as

\[
\left(1 + \delta(\frac{s}{\ell})^{\sigma - 1}\right)^{\frac{\sigma}{\sigma - 1}(\beta -1 + \frac{1}{\sigma})} D^{\beta - 1} = s
\]

To guarantee that \( D \) increases in \( \ell \), we need

\[
\beta < 1 - \frac{1}{\sigma}
\]

Then denote

\[
\theta = \frac{\sigma}{\sigma - 1} \frac{\beta - 1 + \frac{1}{\sigma}}{\beta - 1} = \frac{\sigma}{\sigma - 1} + \frac{1}{\sigma - 1} \frac{1}{\beta - 1} > 0
\]

We have

\[
D = s^{-\frac{1}{\sigma - 1}} \left(1 + \delta^\sigma(\frac{s}{\ell})^{\sigma - 1}\right)^{-\theta}
\]

\[
= \frac{1}{s^{\frac{1}{\sigma - 1}}} \left(1 + \delta^\sigma(\frac{s}{\ell})^{\sigma - 1}\right)^\theta
\]

Similarly,

\[
G = \ell^{-\frac{1}{\sigma - 1}} \left(\delta^{-\sigma}(\frac{\ell}{s})^{\sigma - 1} + 1\right)^{-\theta}(\delta^\sigma(1-\theta))
\]

\[
= \frac{\delta^\sigma(1-\theta)}{\ell^{\frac{1}{\sigma - 1}}} \left(\delta^{-\sigma}(\frac{\ell}{s})^{\sigma - 1} + 1\right)^\theta
\]

As a result,

\[
\log(D) = -\frac{1}{1 - \beta} \log(s) - \theta \log(1 + \delta^\sigma(\frac{s}{\ell})^{\sigma - 1})
\]

4
\[
\frac{\partial \log(D)}{\partial \log(s)} = -\frac{1}{1 - \beta} - \theta \frac{\delta^{\sigma} (\sigma - 1) (\xi)^{\sigma - 2}}{1 + \delta^{\sigma} (\xi)^{\sigma - 1}} \frac{s}{\ell}
\]

\[
\frac{\partial \log(D)}{\partial \log(\ell)} = \theta \frac{\delta^{\sigma} (\sigma - 1) (\xi)^{\sigma - 2}}{1 + \delta^{\sigma} (\xi)^{\sigma - 1}} \frac{s}{\ell}
\]

Therefore,

\[
|\frac{\partial \log(D)}{\partial \log(s)}| > |\frac{\partial \log(D)}{\partial \log(\ell)}|
\]

regardless of the parameter \(\sigma\). When \(s\) and \(\ell\) are close, this also directly translates into \(|D'_s| > |D'_\ell|\). Similarly,

\[
\frac{\partial \log(G)}{\partial \log(\ell)} = -\frac{1}{1 - \beta} - \theta \frac{\delta^{\sigma} (\sigma - 1) (\xi)^{\sigma - 2}}{\delta^{\sigma} (\xi)^{\sigma - 1} + 1} \frac{s}{\ell}
\]

\[
\frac{\partial \log(G)}{\partial \log(s)} = \theta \frac{\delta^{\sigma} (\sigma - 1) (\xi)^{\sigma - 2}}{\delta^{\sigma} (\xi)^{\sigma - 1} + 1} \frac{s}{\ell}
\]

which implies

\[
|\frac{\partial \log(G)}{\partial \log(\ell)}| > |\frac{\partial \log(G)}{\partial \log(s)}|
\]

regardless of the parameter \(\sigma\). When \(s\) and \(\ell\) are close, this inequality results in \(|G'_\ell| > |G'_s|\).

C.4 Abstractions and Generality

In the main text, we have set up the model with microfoundations, including how banks compete for deposits at a micro level. Actually, our main results are relying on much simpler assumptions. We can get the results in Proposition 1, Proposition 2, and Proposition 3 directly starting from properties of the supply and demand curves. We only need the following properties for our main results:

1. Deposit and Treasury demand curves are both downward sloping in their own opportunity costs, respectively,

\[
\frac{\partial D(s, \ell)}{\partial s} < 0, \quad \frac{\partial G(s, \ell)}{\partial s} < 0
\]

2. Deposits and Treasurs are substitutable,

\[
\frac{\partial G(s, \ell)}{\partial s} > 0, \quad \frac{\partial D(s, \ell)}{\ell} > 0
\]

3. Among all the derivatives of supply and demand functions, only \(\hat{D}'_s\) is related to \(C\). Furthermore, \(\hat{D}'_s\) is positive, and increases with \(C\).

\[
\hat{D}'_s(s, r) = \hat{D}'_s(s, r; C) > 0, \quad \frac{\partial \hat{D}'_s(s, r)}{\partial C} > 0
\]

4. The sensitivity of deposit supply with respect to the risk-free rate is negative,

\[
\hat{D}'_r(s, r) < 0
\]
C.5 Banks’ Demand for Government Bonds

To think about how banks’ demand for government bonds affect our results, we assume that individual bank has a “Govt-bonds-in-the-utility” function \( v_G(x^G) \), which is increasing and concave in the quantity of government bond holding \( x^G \). Then the problem of bank \( i \) becomes

\[
\max_{x^G, s_i} v_G(x^G) + x^G(r_G - r^D_i) + (D_i - x^G)(Q^{-1}(D_i - x^G) - r^D_i)
\]

Denote the inverse function of \( dv_G/dx^G \) as \( X_G(\cdot) \), which can be interpreted as the bank’s demand function for Treasuries. Given the property of \( v_G(\cdot) \), we know that \( X_G(\cdot) \) is a decreasing function.

Denote the new bank deposit supply function still as \( \hat{D} \), which now depends not only on \( s \) and \( r \), but also on \( \ell \). To get similar results as in Proposition 1 or 2, we need additional assumptions as follows.

Assumption 1. Assume that deposit supply function responds more to deposit spread than Treasury convenience yield,

\[
\left| \frac{\hat{D}'_s}{\hat{D}'_\ell} \right| > 1
\]

Assumption 2. Assume that the relative impact of Treasury convenience yield on the deposit demand function is larger than that on the deposit supply function,

\[
\left| \frac{\hat{D}'_\ell}{\hat{D}'_s} \right| > \left| \frac{\hat{D}'_s}{\hat{D}'_\ell} \right|
\]

Assumption 1 can be interpreted as restricting the magnitude of \( \hat{D}'_\ell \). In other words, we need to restrict how much the bank deposit supply function is affected by the Treasury convenience yield. This sensitivity is directly related to the slope of banks’ liquidity benefit function \( v_G(\cdot) \). If satisfying the liquidity demand of banks is easy, i.e., we have a large \( |(v_G)'| \), then the magnitude of \( \hat{D}'_\ell \) is small. Assumption 2 restricts the relative importance of Treasury convenience yield on bank deposit supply versus on bank deposit demand.

Next, we have the following proposition.


According to Proposition 6, the conditions required by Proposition 1 to still hold are stronger than the conditions required by Proposition 2. Intuitively, this is because the results about FFR and deposit outflows are about bank asset side responses, and therefore, we only need to impose additional assumptions on bank deposits supply. On the other hand, the results about Treasuries rowding out deposits are relying on the substitution between Treasuries and deposits on the demand side. To generate the same results when banks demand Treasuries themselves, we not only need that the bank demand for Treasuries is not too strong, but also that it is smaller than the substitution effect between Treasuries and deposits.
Proof for Proposition 6

Let’s rewrite the optimization problem as

\[ v_G(x^G) + x^G(r^G - r^D_i) + (D_i - x^G) \left( \frac{Q - (D_i - x^G)}{2\beta} - r^D_i \right) \]

\[ \Rightarrow v_G(x^G) + x^G(s_i - \ell) + (D_i - x^G) \left( \frac{-(D_i - x^G)}{2\beta} + g(r) + s_i \right) \]

Then the first order condition over government bond holding \( x^G \) is

\[ v_G'(x^G) = \ell - s_i \] (C-3)

The first order condition over \( s_i \) is

\[ x^G + \frac{\partial D_i}{\partial s_i} \left( \frac{x^G}{\beta} - \frac{D_i}{\beta} + g(r) + s_i \right) + (D_i - x^G) = 0 \]

Using the assumption

\[ \frac{\partial \log(D_i)}{\partial \log(s_i)} = -\eta \]

We can simplify the FOC into

\[ \frac{s_i}{\frac{x^G}{\beta} - \frac{D_i}{\beta} + g(r) + s_i} = -\frac{\partial \log(D_i)}{\partial \log(s_i)} = \eta \]

which implies the aggregate supply curve as

\[ \hat{D} = x^G + \beta \left( g(r) + \frac{\eta - 1}{\eta} s \right) \]

Denote the inverse function of \( v_G'(\cdot) \) as \( X_G(\cdot) \), which is the bank’s Treasury demand function solved from (C-3). By assumption, \( X_G(\cdot) \) is a decreasing function. Plugging in the inverse function, we have

\[ \hat{D} = X_G(\ell - s) + \beta \left( g(r) + \frac{\eta - 1}{\eta} s \right) \]

Therefore, the aggregate deposit supply now depends on \( r, s, \) and \( \ell \). It is easy to see that

\[ \hat{D}_\ell < 0, \quad \hat{D}_r < 0, \quad \hat{D}_s > 0 \]

Furthermore, because of banks’ demand for Treasuries, we need to rewrite the aggregate Treasury demand function as

\[ \tilde{G}(s, \ell) = G(s, \ell) + X_G(\ell - s) \]

which increases in \( s \) and decreases in \( \ell \). Furthermore, we note that

\[ \frac{\tilde{G}_s'}{\tilde{G}_s} = \frac{G_s'}{G_s} - \frac{(X_G)'}{X_G} \]
Given \((C-2)\), \[-G'_\ell > G'_s > 0\]

As a result,
\[
\left| \frac{\tilde{G}'_s}{\tilde{G}'_s} \right| = \left| \frac{G'_s + (XG)'_s}{G'_s - (XG)'_s} \right| = \left| \frac{-G'_s - (XG)'_s}{G'_s - (XG)'_s} \right| > 1
\]

**Impact of Treasury Supply**

First, when we study the impact of \(G_0\), we fix the federal funds rate \(r\). Then the equation system becomes

\[
D(s, \ell) = \hat{D}(s, r, \ell)
\]
\[
\tilde{G}(s, \ell) = G_0
\]

The difference is that we have the additional argument \(\ell\) in the deposit supply function. Taking derivative over \(G_0\), we have

\[
D_s' s_G' + D_\ell' \ell_G' = \hat{D}_s' s_G' + \hat{D}_\ell' \ell_G' = \tilde{G}_s' s_G' + \tilde{G}_\ell' \ell_G' = 1
\]

which implies

\[
s_G' = \frac{1}{\tilde{G}_\ell'} \frac{\hat{D}_s' - D_s'}{\hat{D}_s' - D_s' + (\tilde{D}_s' - D_s') \tilde{G}_s'}
\]
\[
\ell_G' = \frac{1}{\tilde{G}_s'} \frac{D_s' - \hat{D}_s'}{D_s' - \hat{D}_s' + (D_\ell' - \hat{D}_\ell') \tilde{G}_s'}
\]

From Assumption 1, we get

\[
D_s' - \hat{D}_s' + (\tilde{D}_s' - D_s') \tilde{G}_s' / \tilde{G}_\ell' < 0
\]

As a result,

\[
s_G' < 0, \quad \ell_G' < 0
\]

Next, the spread between Treasuries and bank deposits is

\[
s_G' - \ell_G' = \frac{1}{\tilde{G}_\ell'} \frac{(\hat{D}_\ell' - D_\ell') - (D_s' - \hat{D}_s')}{\hat{D}_s' - D_s' + (\tilde{D}_s' - D_s') \tilde{G}_s'}
\]

Assumption 1 implies

\[
(\hat{D}_\ell' - D_\ell') - (D_s' - \hat{D}_s') > 0
\]

Therefore,

\[
\ell_G' - s_G' > 0
\]

Rewrite the difference as

\[
s_G' - \ell_G' = \frac{1}{-\tilde{G}_\ell'} \frac{(\hat{D}_s' - D_s') - (D_\ell' - \hat{D}_\ell')}{\hat{D}_s' - D_s' - (D_\ell' - \hat{D}_\ell') \tilde{G}_s' / \tilde{G}_\ell'}
\]
Since

\[ 0 < \frac{\tilde{G}'}{\tilde{G}''} \]  

and

\[ 0 < \frac{(D_\ell' - \hat{D}_\ell')}{(D_\ell' - \tilde{D}_\ell')} \frac{\tilde{G}'}{\tilde{G}''} < D_\ell' - \hat{D}_\ell' \]

we find that \( s\tilde{G}' - \ell\tilde{G}' \) increases in \( \hat{D}'_s \), which means that it increases with \( C \). Therefore, we recover our results on deposit spreads.

Next, we show that the quantity responses are similar. The total quantity response is

\[
\frac{\partial D^*}{\partial G_0} = D_s' s\tilde{G}' + D_\ell' \ell\tilde{G}'
\]

\[
= \frac{1}{\tilde{G}'} \frac{D_s' \hat{D}_\ell' - D_\ell' \hat{D}_s'}{D_s' - \hat{D}_s' + (\hat{D}_\ell' - D_\ell') \frac{\tilde{G}'}{\tilde{G}''}}
\]

\[
= - \frac{1}{\tilde{G}'} D_\ell' \frac{\hat{D}_s'}{\hat{D}_s' - D_s'} - (D_\ell' - \hat{D}_\ell') \frac{\tilde{G}'}{\tilde{G}''}
\]

According to Assumption 1, we have

\[ D_s' \frac{\hat{D}_\ell'}{\hat{D}_\ell'} - \hat{D}_s' > 0 \]

As a result,

\[ \frac{\partial D^*}{\partial G_0} < 0 \]

Furthermore, the magnitude of the decline

\[ \frac{1}{\tilde{G}'} \frac{D_s' \frac{\hat{D}_s'}{\hat{D}_s'} - \hat{D}_s'}{\hat{D}_s' - D_s'} - (D_\ell' - \hat{D}_\ell') \frac{\tilde{G}'}{\tilde{G}''} \]

increases in \( \hat{D}'_s \), which increases in \( C \).

In summary, even if banks have a demand of holding Treasuries with Assumption 1, the same results as in Proposition 1 still hold.
D Additional Empirical Results

In this section, we show additional empirical results on the full sample of banks.

Table 12: Deposit Volume and Treasury Supply

This table estimates the effect of Treasury supply on deposit growth. The data is at the branch-year level and covers 1994 to 2016. The full sample of banks is used. TSY Growth is the log change in Treasury supply. Branch HHI measures market concentration in the county where a branch is located. Note that a larger HHI means less competition. ∆ Target FF is the change in the Fed funds target rate. The data is from the FDIC and TreasuryDirect. Fixed effects are denoted at the bottom of the table. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th>Branch-Level Deposit Growth (All Counties)</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth * HHI</td>
<td>0.265***</td>
<td>0.264***</td>
</tr>
<tr>
<td></td>
<td>(0.031)</td>
<td>(0.031)</td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td></td>
<td>-0.015***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.002)</td>
</tr>
</tbody>
</table>

| Observations                              | 1,661,292 | 1,661,292 |
| R-squared                                 | 0.234     | 0.234     |
| Bank Year FE                              | No        | No        |
| State Year FE                             | Yes       | Yes       |
| Branch FE                                 | Yes       | Yes       |
| County FE                                 | Yes       | Yes       |
| Year FE                                   | Yes       | Yes       |
| SE Cluster                                | County    | County    |

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
This table estimates the effect of Treasury supply on deposit spreads. The data is at the branch-quarter level and covers January 1997 to December 2016. The sample consists of all banks. Spread changes for savings and money market deposits are equal to the changes in the three-month Treasury yield minus the changes in deposit rates at the branch level. Spread changes for time deposits are equal to the changes in maturity-matched Treasury yield minus the changes in deposit rates at the branch level. TSY Growth is the log change in Treasury supply. Branch HHI measures market concentration in the county where a branch is located. Note that a larger HHI means less competition. \( \Delta \) Target FF is the change in the Fed funds target rate. The data is from RateWatch and TreasuryDirect. Fixed effects are denoted at the bottom of each panel. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th></th>
<th>Saving</th>
<th>MM</th>
<th>3m CD</th>
<th>6m CD</th>
<th>12m CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth ( \times ) HHI</td>
<td>-2.282***</td>
<td>-1.494***</td>
<td>-1.045***</td>
<td>-0.640***</td>
<td>-0.400***</td>
</tr>
<tr>
<td></td>
<td>(0.187)</td>
<td>(0.165)</td>
<td>(0.115)</td>
<td>(0.099)</td>
<td>(0.091)</td>
</tr>
<tr>
<td>( \Delta ) Target FF ( \times ) HHI</td>
<td>0.354***</td>
<td>0.422***</td>
<td>0.228***</td>
<td>0.214***</td>
<td>0.191***</td>
</tr>
<tr>
<td></td>
<td>(0.019)</td>
<td>(0.021)</td>
<td>(0.016)</td>
<td>(0.014)</td>
<td>(0.012)</td>
</tr>
</tbody>
</table>

Observations 480,960 499,507 480,499 522,482 523,215
R-squared 0.934 0.818 0.792 0.769 0.737
Bank Time FE No No No No No
State Time FE Yes Yes Yes Yes Yes
Branch FE Yes Yes Yes Yes Yes
County FE Yes Yes Yes Yes Yes
Time FE Yes Yes Yes Yes Yes
SE Cluster County County County County County

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Table 14: Deposit Spread and Monetary Policy: All Counties

This table estimates the effect of monetary policy on deposit spreads. The data is at the branch-quarter level and covers January 1997 to December 2016. The sample consists of all banks. Spread changes are equal to the changes of the Fed funds target rate minus the changes in deposit rates at the branch level. TSY Growth is the log change in Treasury supply. Branch HHI measures market concentration in the county where a branch is located. Note that a larger HHI means less competition. ∆ Target FF is the change in the Fed funds target rate. The data is from RateWatch and TreasuryDirect. Fixed effects are denoted at the bottom of each panel. Standard errors are clustered by county.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth * HHI</td>
<td>-2.308***</td>
<td>-1.479***</td>
<td>-1.064***</td>
<td>-0.634***</td>
<td>-0.312***</td>
</tr>
<tr>
<td></td>
<td>(0.197)</td>
<td>(0.173)</td>
<td>(0.126)</td>
<td>(0.107)</td>
<td>(0.101)</td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td>0.387***</td>
<td>0.462***</td>
<td>0.273***</td>
<td>0.255***</td>
<td>0.264***</td>
</tr>
<tr>
<td></td>
<td>(0.021)</td>
<td>(0.023)</td>
<td>(0.018)</td>
<td>(0.015)</td>
<td>(0.014)</td>
</tr>
</tbody>
</table>

| Observations            | 480,960 | 499,507 | 480,499 | 522,482 | 523,215 |
| R-squared               | 0.941   | 0.842   | 0.831   | 0.813   | 0.805   |
| Bank Time FE            | No      | No      | No      | No      | No      |
| State Time FE           | Yes     | Yes     | Yes     | Yes     | Yes     |
| Branch FE               | Yes     | Yes     | Yes     | Yes     | Yes     |
| County FE               | Yes     | Yes     | Yes     | Yes     | Yes     |
| Time FE                 | Yes     | Yes     | Yes     | Yes     | Yes     |
| SE Cluster              | County  | County  | County  | County  | County  |

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1