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 banks widen their deposit spreads as Treasury supply increases, leading to a net deposit outflow. At the same time, reliance on wholesale funding decreases. The effect is heterogeneous in nature - banks in more competitive markets experience larger outflows. The explanatory power of Treasury supply is not driven by monetary policy and bank-specific investment opportunities. Our empirical findings are rationalized with a model in which banks’ market power stems from the presence of inattentive depositors. Consistent with “The Deposits Channel of Monetary Policy” (Drechsler et al., 2016), the model and empirics predict the opposite effect for Fed Fund rate hikes: there is a larger response in less competitive markets. Our results also shed light on the effect of extending the scope of monetary policy through the Reverse Repurchase (RRP) Facility on monetary policy passthrough.

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I have nothing to disclose

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1 Introduction

There has been a growing recent literature exploring the liquidity provision function of banks (Diamond and Dybvig, 1983, Gorton and Pennacchi, 1990). This literature sees banks as transforming illiquid real assets into liquid assets that are valued by the non-financial sector and comprise a stable source of funding for banks. Bank funding capacity, funding structure and systemic risk are then driven by the liquidity needs of the non-bank sector. Drechsler et al. (2016) have shown how bank market power allows monetary policy to pass through to bank balance sheets through influencing the market price of liquidity. At the same time, government liquid assets, such as Treasury bonds, also satisfy the demand for liquidity and enter the equilibrium determination of the price and quantity of liquidity transformation (Krishnamurthy and Vissing-Jorgensen, 2015, Greenwood et al., 2010).

This paper provides a coherent framework to compare and contrast the impact of government supplied liquidity on bank liquidity provision with that of monetary policy in the presence of bank market power. While existing work has focused on time series fluctuations (Nagel, 2016, Krishnamurthy and Vissing-Jorgensen, 2015), we also explore the cross-section to remove co-movements in the aggregate economy. This allows us to identify and quantify how Treasury supply crowds out bank deposit funding but with opposite effects on financial stability and the distribution of bank funding capacity as monetary tightening.

To predict how banks respond to changes in Treasury supply and monetary policy, we develop a simple model in which banks set deposit rates to compete with other banks and Treasuries for investors’ funding. When Treasury yields rise following an increase in Treasury supply, banks raise deposit rates to alleviate the deposit outflow. In areas where many banks compete for deposits, deposit rates are already set relatively competitively so that further increases following more attractive Treasury yields are limited. Hence, the Treasury-deposit spread widens by more and deposits flow out in greater volumes as more banks compete for deposits. The opposite trend emerges when the Fed funds rate increases: the Fed funds-deposit spread widens by less and deposit funding contracts less when deposit competition intensifies. This is because bank asset returns primarily increase due to monetary policy rate hikes, whereas
Treasury-only make up a small portion of commercial banks’ balance sheet assets.\(^{1}\) Therefore, to capture the higher marginal benefit from securing deposit funding, banks in competitive regions raise rates by more than banks in less competitive regions following policy rate hikes.\(^{2}\)

To verify our model predictions in the data, we compare branches of the same bank to remove confounding by macroeconomic conditions that could be co-moving with government supplied liquidity, e.g., bank loan supply. We find that branches in more competitive deposit markets indeed experience larger outflows when government liquid asset supply increases and smaller outflows when monetary policy rates increase. The passthrough of government liquidity supply therefore persists and bears opposite distributional effects when jointly analyzed with changes in monetary policy.

We complement Drechsler et al. (2016), who show that increases in the Fed funds rate reduce bank liquidity provision. Our model, although quite different than that in Drechsler et al. (2016), also predicts that Fed funds rate hikes reduce bank deposit creation and that the impact is stronger in less competitive areas. At the same time, our model generates larger deposit outflows in more competitive areas when Treasury yields change. These opposite trends arise because banks’ asset side returns are predominantly determined by the policy rate and not Treasury yields. Our empirical work thereby confirms Drechsler et al. (2016)’s deposits channel of monetary policy, as well as the different passthrough of Treasury supply to bank funding.

The difference in passthroughs is particularly important for understanding the effect of the Reverse Repo (RRP) Facility, which is an extension of the scope of monetary policy to include non-bank intermediaries, on the banking market equilibrium. Changes in the RRP rate do not have the same impact as changes in the Fed funds rate. We show that the impact of the RRP rate on bank leverage and funding composition is more akin to that of the Treasury yield because non-banks included in the RRP Facility, such as money market mutual funds, invest

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\(^{1}\)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. See Figure 2.

\(^{2}\)In other words, banks in more competitive regions have less market power and need to compete with each other more aggressively by raising rates, resulting in a smaller increase in the Fed funds-deposit spread and a more reduced deposit outflow. The results and explanations are line with Drechsler et al. (2016).
a significant portion of their assets in Treasury securities. Our model and empirics provide a better guide in this regard.

In addition, the difference in passthroughs is essential for knowing how the level, distribution and composition of bank leverage changes with government-supplied liquidity and monetary policy and for correctly identifying the types of institutions that lever most in response to changes in liquidity premia. We find that while Fed funds rate hikes spur reliance on wholesale funding and relative growth in wholesale-dependent banks, higher levels of government-supplied liquidity curbs the relative expansion of wholesale funding and wholesale-funding reliant banks. These results also imply that jointly raising the RRP rate with the target Fed funds rate can reduce the buildup of potentially risky wholesale funding associated with traditional monetary tightening using just the Fed funds rate.

The aggregate time series provides preliminary evidence: as Treasury supply increases, deposit spreads widens, deposit volume falls, and wholesale funding ratios drop. The transmission channel, however, is unclear because increases in government-supplied liquidity are not exogenous. It could be due to our conjecture - depositors switching from deposits to Treasuries because bank market power limits the increase in deposit rates in response to increases in Treasury yield. But it could also be due to other macroeconomic variables and monetary policy that co-move with Treasury supply and also affect the volume of deposits.\(^3\) To shed light on the mechanism at play, we develop a search model of imperfect deposit competition and identify the model predictions in the cross-section.

Our theory builds on the seminal model of Stahl (1989), in which imperfect competition arises from the presence of inattentive depositors, who do not pay attention to deposit rates. There are also more sophisticated attentive investors, who allocate wealth across Treasuries, corporate bonds, and choose the local bank offering the highest rate for their deposits. However, banks are unable to distinguish between retail depositors and offer one retail deposit rate. When Treasury supply increases the Treasury yield, the presence of inattentive depositors incentivizes banks to raise rates less than one-to-one. As a result, deposits become less attractive to attentive

\(^3\)For example, the real interest rate channel from macroeconomics maintains that public debt funds public expenditure, which crowds out private investments by firms, thereby reducing the demand for bank loans and deposit funding.
investors, who substitute deposits for Treasuries, which causes retail deposit volume to fall.\(^4\)

When more banks compete in local deposit markets, deposit rates are more competitive to begin with and banks are less willing to further raise rates when Treasury supply increases.\(^5\) Thus, the Treasury-deposit spread widens by more and the outflow of retail deposits is more pronounced when retail deposit markets are more competitive.

The same liability-side channel is present for changes in monetary policy such that Fed funds rate hikes induce an overall outflow of deposits. However, it is dwarfed by asset-side considerations in the cross-section. Banks’ asset returns increase significantly with policy rate hikes whereas Treasury yields only have a minimal effect because commercial banks only hold a small share of assets in Treasuries.\(^6\) To capitalize on the higher marginal benefit from funding, banks are incentivized to increase their deposit rates more aggressively to secure their deposit base when deposit competition stiffens. Thus, when monetary policy tightens, the Fed funds-deposit spread widens by less and deposits flow out less in areas of higher deposit competition.

We use within-bank, across-branch variation in deposit volumes and rates to test our model predictions. Looking at branches of the same bank eliminates confounding by time-varying investment opportunities at the bank level, which could co-move with Treasury supply in the time series.\(^7\) The remaining variation observed across branches of the same bank should then be due to banks’ pricing strategies for the level of local deposit competition. In the baseline specification, we use a standard Herfindahl Index (HHI) as a measure for local deposit competition at the county level. We also control for the impact of Fed funds rate changes across branches of the same bank to clearly distinguish between the effects of monetary policy and Treasury supply.

Our estimation results confirm the model predictions. When Treasury supply increases,

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\(^4\)In the language of Drechsler et al. (2016), the outflow of attentive retail investors out of the deposits market renders the remaining deposit base less price sensitive and deposit demand more inelastic.  
\(^5\)Intuitively, when deposit markets are more competitive, there is less improvement in the attractiveness of Treasuries as an outside option as Treasury supply increases than when deposit markets are less competitive.  
\(^6\)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).  
\(^7\)The assumption is that funds can be freely transferred within branches of the same banks.
banks widen their deposit spreads by more and experience larger 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 HHI 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 HHI, which comprises about a quarter of the time series crowding-out effect. To calculate the time series result, we follow Drechsler et al. (2016) to multiply the semi-elasticities of deposits with respect to the deposit spreads by the effect of Treasury supply on deposit spreads to obtain a 118.0 bps drop in deposit growth for a one standard deviation increase in Treasury growth.

At the same time, as our model and the results by Drechsler et al. (2016) predict, the cross-sectional impact of Fed funds rate changes runs in the opposite as that for Treasury supply: banks widen their deposit spreads by more and suffer larger deposit outflows at branches in less competitive, i.e. more concentrated, areas. Empirically, the effect of Fed fund rate changes on deposits remain significant after controlling for Treasury supply, and a one standard deviation increase in Fed fund rate changes causes branches in counties at the 25th percentile of HHI to experience a 22.4 bps smaller drop in deposit growth compared to branches of the same bank in counties at the 75th percentile of deposit market competition. In comparison, the average time series effect is 299.0 bps for a one standard deviation increase in Fed fund rate changes, implying that for the same one standard deviation increase, the aggregate effect of Treasury growth is about 40% of that for Fed fund rate hikes. Taken together, Treasury supply and monetary policy are both important determinants of the banking market equilibrium but bring about opposite distributional effects.

We run a number of tests to check whether alternative explanations drive our results. First, we control for investor characteristics at the county level to ensure that the Herfindahl Index, our measure for deposit competition, is not driven by investor sophistication. Further, we weigh Treasuries by their repo haircut to account for differences in liquidity and safety for Treasuries of different maturities. Another worry is the confounding by loan market competition. We alleviate this concern by focusing on larger banks with branches in higher income counties that are lending more to larger borrowers that tend to be less constrained by geography. We repeat the analysis focusing on banks with minimal repo funding to eliminate any impact through the
cost of repo funding, for which Treasury securities serve as collateral. Statistical significance is preserved across different specifications while economic magnitudes are minimally affected.

Further, Treasury supply and monetary tightening affect bank funding structure in opposite ways. In the model, banks can choose to raise wholesale funding from institutional investors, who are fully attentive to all deposit rates. When Treasury supply increases, institutional investors’ funds flow out more because these investors are more price sensitive. On the other hand, banks increase their reliance on wholesale funding after Fed fund rate hikes. This stems from banks’ more aggressive deposit rate hikes in the wholesale market to capitalize on their asset-side returns, which increase substantially with the Fed funds rate. These predictions are confirmed in the data, where a one standard deviation increase in Treasury growth curbs the wholesale funding ratio by 34.4 bps, whereas a one standard deviation increase in Fed funds rate corresponds to a 30.5 bps higher wholesale funding rate.

These differences become especially relevant when considering the effect of the Reverse Repurchase (RRP) Facility, by which the Federal Reserve extended its set of counterparties for conducting monetary policy to include non-bank intermediaries. After September 2013, non-bank intermediaries such as money market mutual funds can directly lend to the Fed via reverse repos at the RRP rate. Given the novelty of the program, an important policy question has been to understand how changes in the RRP rate may affect the banking sector and the economy.

Our model and estimates provide some answers to this question. We show that the effects of the RRP Facility resembles changes in the Treasury yield because a significant portion of non-bank counterparties’ balance sheets comprise of government securities. Guided by the model, we apply the pre-RRP crowding-out sensitivities from Treasuries to quantify the impact of this newly introduced monetary policy tool to be 7% of that of Fed funds rate changes. This implies that raising the RRP rate in tandem with the target Fed funds rate improves passthrough to bank deposit funding growth by 7%. The passthrough to bank funding structure is also affected. With the RRP Facility, monetary tightening no longer leads to a buildup of wholesale funding but is accompanied by a higher proportion of stable retail deposit funding in the banking sector. This highlights the financial stability benefits of the RRP Facility in addition to the
improvement in the overall passthrough efficiency.

**Literature Review**

Our paper contributes to a few 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 et al., 2010, 2015, 2016, Carlson et al., 2014, Sunderam, 2014). We provide better identified empirical support for the liquidity provision role of banks. The literature so far has mostly used time series variation to show a negative correlation between government liquidity and aggregate bank-supplied liquid assets, but one concern is that macroeconomic shocks, such as recessions, which impact deficits and Treasury supply, may also drive bank funding through non-liquidity channels, e.g., firms demanding fewer bank loans. We generate predictions for the cross section and verify them using variations across branches of the same bank. This removes the confounding by changing macroeconomic conditions for each bank to identify the passthrough to bank deposits.

Further, while the issuer of private safe debt has so far been thought of as a representative firm or sector, we identify the importance of imperfect competition between providers of safe assets. Specifically, we focus on commercial banks, which hold illiquid long-term assets financed by liquid short-term liabilities, and show that their market power in deposit markets determines the aggregate passthrough of Treasury supply to bank funding. In addition, cross-sectional heterogeneity in local deposit competition also induces significant distributional effects on the cost of deposit funding across regions.

Imperfect deposit competition also informs the discussion on private safe assets and financial stability. Stein (2012) finds that the production of private safe asset can be excessive from a social welfare point of view, while Gorton (2010), Gorton and Metrick (2012), Sunderam

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8Banks have long been thought of as playing an important role in the transformation of illiquid long-term assets into liquid short-term debt demanded by depositors (Diamond and Dybvig, 1983, Gorton and Pennacchi, 1990, Dang et al., 2009). The banking literature has also shown the importance of retail deposits as a stable funding source for banks Kashyap et al. (2002), Hanson et al. (2015).
Kacperczyk et al. (2017) illustrate how the demand for safe and liquid assets fueled the expansion of shadow banks. In the wake of the financial stability concerns, (Greenwood et al., 2015, 2016, Carlson et al., 2014) derive optimal responses in the maturity of government debt and the production of safe assets by the Federal Reserve. We show that differences in investor sophistication between deposit categories lead to variation in crowd-out sensitivity, in ways that cannot be fully accounted by maturity or substitutability. Retail deposits, which are FDIC insured and easily withdrawn, are crowded out less than wholesale types of funding because less attentive retail depositors create more market power for banks. This is an important consideration given the different financial stability implications of wholesale and retail bank deposits.

Our findings imply that in the presence of imperfect deposit competition, Treasury supply is an important factor affecting bank deposit funding in addition to monetary policy, which has been the focus of the existing literature. A number of papers examine frictions in deposit rates adjustments following changes in the policy rate (Berger and Hannan, 1989, Hannan, 1991, Neumark and Sharpe, 1992, Yankov, 2014). More recently, Drechsler et al. (2016) show permanent widening in the Fed funds-deposit spread following Fed fund rate hikes arising from imperfect deposit competition. We show, theoretically and empirically, that imperfect deposit competition drives the widening of the Treasury-deposit spread when Treasury yields increase, rendering Treasury supply as an important determinant of bank deposit funding. We motivate investor inattention as a source of imperfect deposit competition following Duffie and Krishnamurthy (2016), build a new framework to compare the passthrough of both Treasury supply and monetary policy, and obtain theoretical predictions confirmed by the data and consistent with Drechsler et al. (2016).

Finally, we contribute to the recent and growing literature on the effects of the RRP Facility. While a number of papers, such as Anbil and Senyuz (2018) and Anderson and Kandrac (2017), have focused on the RRP Facility’s effects on financial stability we analyze its impact on monetary policy passthrough, which is the primary goal of its implementation. Our empirical estimation can quantify the add-on effect on passthrough efficiency as mentioned in Duffie

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9 Among retail deposits, time deposits can only be withdrawn after a set date or with a notice of withdrawal. However, our results also hold for retail savings deposits, which are not subject to the withdrawal constraint.
and Krishnamurthy (2016) and extends the result to capture distributional effects and funding structure implications.

This paper is organized as followed. Section 2 examines the aggregate time series, while Section 3 develops a model of imperfect deposit competition to rationalize the observed trends and guide the subsequent empirical strategy. Section 4 explains 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. Section 7 applies the model and empirics to analyze the Reverse Repurchase (RRP) Facility and Section 8 concludes.

2 Time Series Trends

The aggregate time series displays an obvious correlation: Treasury growth rates are negatively correlated with deposit growth (Figure 1(a)). In other words, Treasury growth crowds out deposit growth. Figure 1(c) shows that the negative comovement with Treasury growth is even more pronounced for wholesale types of funding than for core deposits. The differences in crowd-out sensitivities are reflected in the wholesale funding ratio of banks. As seen from Figure 1(d), the fraction of wholesale funding decreases with Treasury growth.

Variations in Treasury-deposit spreads shed light on why the negative correlation between Treasury growth and deposit growth is observed. Figure 1(b) plots year-over-year changes in the spreads between Treasury yield and different deposit rates. The pattern suggests a larger widening of spreads as Treasury growth picks up, consistent with banks raising deposit rates less than the rise in Treasury yields following increases in Treasury supply. Since the Treasury-deposit spread represents the opportunity cost of holding deposits, a larger spread should induce substitution away from deposits and into Treasuries as shown in the figure. This is consistent with a supply-side crowd-out effect because Treasury-deposit spread and the quantity of deposits move in opposite directions.

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However, other variables could be co-moving in the time series. For example, movements in monetary policy rates that are correlated with changes in Treasury supply could be driving the trends in deposit spread and deposit volume. Looking at the period after August 2008 can partially alleviate this concern because even though the interest on excess reserves remained constant, the deposit spread continued to increase with Treasury growth. A deeper concern is that both fiscal and monetary policy could be reacting to the underlying macroeconomy, which affects the demand for bank loans, and thus the demand for deposit funding by banks. Further, standard macroeconomics would suggest that public spending financed by public debt crowds out private investment via the real interest rate channel. Again, this would reduce the demand for loans and ultimately the demand for bank deposit funding.

To shed light on the transmission mechanism for the observed trends, the next section develops a micro-foundation for the crowding-out of deposits by Treasury supply through imperfect deposit competition to guide the subsequent empirical identification.

3 Baseline Model

We present a model to rationalize the empirical relationship between Treasury supply and bank deposits and to derive the effect of bank market power. It is a search-based model of imperfect deposit competition in the spirit of Stahl (1989) and Duffie and Krishnamurthy (2016), where banks compete locally for retail deposits and nationally for wholesale deposits. For simplicity, we focus our attention on symmetric local deposit markets in the model but will allow for county-specific heterogeneities in deposit competition in the empirical estimation. Later on, in Section 6, we further extend the baseline version of the model to apply it to understanding the effects of the Fed’s new Reverse Repurchase (RRP) Facility.

3.1 Model Setup

There are three types of investors holding bank deposits: slow retail investors, fast retail investors, and institutional investors. Different investors vary in their search technologies.

\footnote{As mentioned earlier, the empirical section will also take into account the potential endogeneity between bank loan demand, Treasury supply and monetary policy.}
Retail depositors’ attention is limited to their local market. Let there be $K$ local markets at the national level. In each of these $K$ markets, let a fraction $1 - \mu$ of depositors be “slow” in nature, so they have to incur a search cost, $c$, for checking deposit rates at any one bank. Realistically, retail investors inattentive to deposit rates are also unlikely to invest in a diversified portfolio, so we assume that all their wealth, $W_s$ per capita, is invested in bank deposits.

Other retail investors are more sophisticated. Let the remaining fraction of investors at the local level, $\mu$, be “fast” in the sense that they can costlessly scan the deposit rates offered by all $M$ banks in the local region and choose the highest offered rate. In addition to holding deposits, they also invest in Treasuries and illiquid assets such as corporate bonds and loans, which we will collectively refer to as loans for simplicity. In reality, these holdings may as well be indirect, e.g., via passthroughs like money market mutual funds.

Formally, fast retail investors maximize utility over final wealth $W$ and liquidity services $L$ according to a constant elasticity of substitution (CES) aggregator:

$$\max \ (W^{\frac{\rho-1}{\rho}} + \lambda L^{\frac{\rho-1}{\rho}})^{\frac{\rho}{\rho-1}},$$

where, following Drechsler et al. (2016), $\lambda$ is a share parameter, and $\rho$ is the elasticity of substitution between wealth and liquidity services. We take wealth and liquidity as complements so that $\rho < 1$.

Liquidity services are themselves derived from holding Treasuries, $T_f$, and deposits, $D_f$, also according to a CES aggregator:

$$L = (T_f^{\frac{\epsilon-1}{\epsilon}} + \delta D_f^{\frac{\epsilon-1}{\epsilon}})^{\frac{\epsilon}{\epsilon-1}},$$

where $\epsilon$ is the elasticity of substitution between Treasury and deposits and $\delta$ measures the liquidity of deposits relative to Treasuries. We follow the literature and take deposits and Treasuries as imperfect substitutes (Kacperczyk et al., 2017, Duffie and Krishnamurthy, 2016, Krishnamurthy and Vissing-Jorgensen, 2015). Hence, $\epsilon > 1$.

Finally, given initial wealth $W_f$, the highest deposit rate among $M$ local banks $r^*$, Treasury yield $g$ and loan rate $\phi$, we can express fast investors’ budget constraint as
\[ W = (1 + \phi)W_f - T_f(\phi - g) - D_f(\phi - r^*), \]

where \( T_f(r^*; \phi, g) \) and \( D_f(r^*; \phi, g) \) denote the Treasury and deposit holdings of fast investors, respectively. Loan rate \( \phi \) is the return on illiquid bonds and loans. It can be thought of as the Fed funds rate, \( i \), plus a premium, \( \Delta \). Given a premium, \( \Delta \), changes in the Fed funds rate will be fully reflected in the changes to loan rates and bond yields. In practice, most bank loans are priced off the prime loan rate, which is the Fed funds rate plus a premium. Figure 2 demonstrates this relationship.

Institutional investors face the same portfolio choice problem as fast investors but can costlessly check for and pick the highest deposit rate at the national level, where there are \( N \) banks. We can think of them as nationally operating cash pools and hedge funds. Given initial wealth, \( W_w \), and wholesale deposit rate, \( r_b \), denote institutional demand for deposits and Treasuries as \( D_w(r_b; \phi, g) \) and \( T_w(r_b; \phi, g) \), respectively.

Banks obtain funding from both retail depositors and institutional depositors to invest in loans at rate \( \phi \) and Treasuries at return \( g \). Again, \( \phi \) is benchmarked by the Fed fund rate, \( i \). Banks further enjoy a liquidity premium of \( m\log(1 - x) \) for holding Treasuries, where \( x \) is the ratio of loans to total assets. The liquidity premium is motivated by the business model of commercial banks, which requires some safe assets as a liquidity buffer and to meet regulatory requirements. In the data, the US commercial banking sector on average holds about 4% of total assets in Treasury securities (Figure 3).\(^{13}\)

Given their asset returns, banks decide which deposit rates to offer. Importantly, while they can distinguish retail investors from institutional ones, they are unable to price discriminate between slow and fast retail depositors.\(^{14}\) As a result, banks optimally offer a competitive Bertrand rate to institutional investors and draw from a distribution of rates for their retail

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\(^{13}\) Among others, Hanson et al. (2015) rationalized why banks predominantly hold illiquid assets and only a small portion of liquid assets like Treasuries.

\(^{14}\) In practice, banks set different institutional versus retail account rates, but any given type of retail account offers the same rate to everyone at a given time and location. The model prediction should be thought of as applying to a given type of deposit account. In the estimation, we will explicitly differentiate between different types of retail deposit rates.
deposit base. Since Bertrand competition drives wholesale profits to zero, $r_b$ equals the marginal asset side return. Consider a symmetric equilibrium, where every bank offers the same deposit rate distribution of $[\bar{r}, \overline{\bar{r}}]$ in the retail deposit market, then we can write the bank’s problem as:

$$\max_x D_{\text{retail}}(r; \phi, g)[(1 + \phi)x + (1 - x)(1 + g) + m\log(1 - x) - (1 + r)],$$

where \( D_{\text{retail}}(r; \phi, g) = \mu D_f(r; \phi, g) F^{M-1}(r; \phi, g) + (1 - \mu) \frac{W_s}{M}. \)

The last equation shows that banks’ retail deposit base is comprised of slow retail investors’ funds, \( \frac{W_s(1-\mu)}{M}, \) and fast retail investors’ funds, \( D_f(r; \phi, g). \) The latter is only obtained if a bank’s offered rate, \( r, \) is the highest among \( M \) banks, which occurs with probability \( F^{M-1}(r; \phi, g). \)

### 3.2 Model Solution

We start by solving fast depositors’ maximization problem to derive their deposit supply function:

$$D_f(r^*; \phi, g) = \frac{\delta^e (1 + \phi) W_f}{(\phi - r^*)^e [(\phi - g)^{1-e} + \delta^e (\phi - r^*)^{1-e}] + \lambda^{-e} \delta^e (\phi - g)^{1-e} + \delta^e (\phi - r^*)^{1-e} \frac{\phi - g}{1 - e}}.$$

Similarly, their demand for Treasuries is

$$T_f(r^*; \phi, g) = \frac{(1 + \phi) W_f}{(\phi - g)^e [(\phi - g)^{1-e} + \delta^e (\phi - r^*)^{1-e}] + \lambda^{-e} \delta^e (\phi - g)^{1-e} + \delta^e (\phi - r^*)^{1-e} \frac{\phi - g}{1 - e}}.$$

Based on fast depositors’ deposit supply, banks calculate their expected retail deposit base at any given rate \( r \) as

$$D_{\text{retail}}(r; \phi, g) = \mu D_f(r; \phi, g) F^{M-1}(r; \phi, g) + (1 - \mu) \frac{W_s}{M},$$

and then solve.
\[
\max_x D_{retail}(r; \phi, g)[(1 + \phi)x + (1 + g)(1 - x) + m\log(1 - x) - (1 + r)]
\]

to obtain their optimal loan ratio:

\[
x^*(\phi, g) = 1 - \frac{m}{\phi - g}.
\]

Now, when deciding on the distribution of retail deposit rates, banks must be indifferent between any two rates \(r\) and \(r'\) in the range \([\bar{r}, \overline{r}]\). In other words, denoting bank profit as \(\pi_{bank}(\phi, g, r)\), we have

\[
\pi_{bank}(\phi, g, r) = \pi_{bank}(\phi, g, r') \quad \forall r, r' \in [\bar{r}, \overline{r}],
\]

where the lower bound is determined by slow retail depositors’ indifference condition:

\[
G(\bar{r}) = W_s \int_{\bar{r}}^{\overline{r}} (r - \bar{r})dF(r; \phi, g, \bar{r}) = c.
\]

As for wholesale funding, Bertrand competition implies

\[
r_b = g + (\phi - g)x^* + m\log(1 - x^*).
\]

Given \(r_b\), institutional investors’ demand for deposits, \(D_w(r_b; \phi, g)\), and their demand for Treasuries, \(T_w(r_b; \phi, g)\), are identical to the demands of retail fast depositors.

Finally, the market clearing of Treasuries determines the equilibrium Treasury yield. Denoting total Treasury supply as \(S\), we have:

\[
\frac{N}{M} \int_{\Xi} \mu T_f(r; \phi, g) dF^M + T_w(r_b; \phi, g) + \frac{N}{M} D_{totbase}(1 - x^*) = \frac{S}{1 + g},
\]

where

\[
D_{totbase} = D_w(r_b; \phi, g) \frac{M}{N} + (1 - \mu)W_s + \int_{\Xi} \mu D_f(r; \phi, g) dF^M.
\]
3.3 Calibration Results

Search models in the sense of Stahl (1989) generally do not have analytical solutions, so we calibrate the model under parameter values consistent with our data to illustrate our results. Table 13 lists sample moments from the data that have guided our choice of parameters.\(^{15}\)

First, our model predictions in the time series are consistent with the crowding-out of deposits in the data.

*Result I:* When Treasury supply increases, the Treasury-deposit spread increases, and deposits are crowded out. When the Fed funds rate increases, the Fed funds-deposit spread increases, and deposits are crowded out.

Intuitively, when Treasury supply increases, Treasury yields rise and attract fast retail depositors to substitute into holding Treasuries. To alleviate deposit outflow, banks raise their deposit rates, but they raise them less than one-to-one because of the presence of inattentive slow investors, who are attached to their bank independent of the offered rate. As a result, the Treasury-deposit spread widens, fast and institutional depositors substitute out of deposits, and the aggregate deposit volume drops. This effect is illustrated in Figure 4.\(^{16}\)

Monetary policy rate hikes have a similar effect. Loan rates, which are floored by the Fed funds rate, make up a larger fraction of banks’ balance sheets than Treasuries, but deposit rates still increase by less than the initial Fed funds rate hike because of the presence of inattentive slow depositors. Thus, when the Fed fund rate, \(i\), increases the loan rate, \(\phi\), the Fed funds-deposit spread widens and deposit volume declines as shown in Figure 5. This result is the same as in Drechsler et al. (2016), whose explanation centers around the deposit demand curve becoming more inelastic as Fed funds rate increases. Interpreted through our model, deposit demand becomes more inelastic because the outflow of attentive retail investors from the deposit market leaves behind a less price sensitive depositor base.

\(^{15}\)Several preference parameters do not have sample counterparts, and although our results are qualitatively robust to reasonable perturbations, there may exist parameter combinations where there is no solution or where the solution differs.

\(^{16}\)The magnitudes in this section are for illustration only. Please refer to the empirical estimation for quantitative predictions.
In the cross-section however, the composition of banks’ asset side drives a wedge between the effect of Treasury supply increases and monetary policy rate hikes on deposit spreads and volume.

Result II: When Treasury supply increases, the Treasury-deposit spread widens more and deposit outflow becomes more pronounced as the number of banks competing for deposits increases. When the Fed funds rate increases, the Fed funds-deposit spread widens less and deposit outflow becomes less pronounced as the number of banks competing for deposits increases.

Since deposit rates are already more competitive when more banks compete for deposits in the same region, the marginal increase in deposit rates after investors’ outside option of holding Treasuries improves is more limited. This explains why spreads increase by more and deposits flow out in higher volumes in more competitive areas as Treasury supply increases (Figure 6).

There is another incentive arising from the asset side of banks’ balance sheets. When returns on assets increase substantially, banks become more aggressive in securing deposit funding to capitalize on the increase in returns. As competition intensifies, banks need to raise their bid more aggressively to retain fast depositors.\textsuperscript{17} The asset-side channel is more subdued in the case of Treasury supply increases because Treasuries only make up a small proportion of commercial banks’ assets (Figure 3). In contrast, the bulk of commercial banks’ assets is comprised of loans so when the loan rate increases due to a Fed funds rate hike, the asset-side consideration dominates and banks aggressively raise rates to secure their funding.\textsuperscript{18} This results in a smaller widening of the Fed funds-deposit spread and a reduced outflow of deposits in more competitive areas (Figure 7). Our prediction agrees with Drechsler et al. (2016), who use another model of imperfect competition to derive that increases in the Fed funds rate, which floors loan rates, induce smaller deposit losses in areas with more deposit competition.

The final prediction concerns the funding model of banks.

Result III: When Treasury supply increases, the ratio of wholesale funding decreases. As the Fed funds rate increases, the ratio of wholesale funding increases.

\textsuperscript{17}This is in line with banks competing more against each other by raising deposit rates when bank market power declines as in Drechsler et al. (2016).

\textsuperscript{18}Figure 2 shows how bank loan rates are anchored by the Fed funds rate.
This result follows because the rate of deposit outflow is zero for slow investors, positive for fast investors and highest for institutions, which are the most price sensitive. Interpreting slow and fast investors as retail and institutions as wholesale investors, we find that Treasuries lead to a lower ratio of wholesale funding for banks as seen in Figure 8.

The asset-side channel again dominate for changes in the policy rate. When the Fed funds rate increases, banks are highly incentivized to secure their deposit funding in order to profit from the higher loan returns. To attain this goal, banks raise wholesale rates more aggressively because the presence of price-insensitive slow investors reduces the efficiency of retail deposit rate hikes. Figure 9 illustrates this result.

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 is from US Call Reports provided by the Federal Reserve Bank of Chicago. Our sample is from January 1994 to December 2016. The data contains quarterly data on the income statements and balance sheets of all US commercial banks. We match bank-level Call Reports to branch-level RateWatch and FDIC data using the FDIC bank identifier.

Data on deposit volumes is from the Federal Deposit Insurance Corporation (FDIC). It covers the universe of U.S. 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 is also available.

Data on deposit rates is 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 the 2.5K savings accounts, the 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.

County data. We collect data on county characteristics from the 2000 US Census and County Business Patterns. Relevant demographic variables include median age, median income and the proportion of college graduates.

4.2 Definition of Key Variables

Branch HHI: We measure deposit market competition using a standard Herfindahl index (HHI). 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 10(a) illustrates that there is significant variation in deposit competition across the US, while Figure 10(b) shows that it stays relatively constant over our sample period. We assign to each bank branch the HHI of the county in which it is located and refer to it as the branch HHI.

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 11 shows the distribution of bank HHI, which is centered at around 0.2 and has almost all of its weight below 0.6.

Deposit growth: 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. For Call Report data, the annual deposit growth rate is calculated quarterly.\(^{19}\)

Deposit spread: Deposit spread is calculated as either the Treasury yield benchmark less the deposit rate or the Fed funds rate less the deposit rate. We choose Treasury yields with maturities corresponding to each deposit category.\(^{20}\)

Treasury growth: The log difference of Treasury volume outstanding in a year. To capture Treasuries available to the US private sector, we exclude foreign official holdings, intragovernmental holdings and Federal Reserve holdings. We treat Treasuries as homogeneous in the

\(^{19}\)Consistent with Drechsler et al. (2016), we use deposit growth to remove persistence in deposit levels.

\(^{20}\)Consistent with Drechsler et al. (2016), we use changes in deposit spreads to remove persistence in rates.
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 suffer 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 12 plots the average sensitivity of deposit growth towards changes in Treasury growth for branches located in different counties, where counties are divided into 20 bins by their level of deposit competition. The average sensitivity, $\gamma_h$, of branches in bin $h$ is obtained from:

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

where the dependent variable is the deposit growth of branch $i$ at time $t$.

Consistent with the theory, Figure 12 shows that branches in more competitive areas, i.e., lower HHI percentile, on average experience a larger dip in deposit growth following periods with higher Treasury growth than those in less competitive areas, i.e., higher HHI percentile.

Also in line with the theory, branches in more competitive areas widen deposit spreads by more than branches in less competitive areas as competition intensifies (Figure 13). Sensitivities for time deposit and savings deposit spreads are obtained similarly as before:

$$\Delta DepSpread_{it} = \alpha_i + \gamma_h \mathbb{1}(bin_h) \times TSYGrowth_t + \theta_t + \epsilon_{it}$$
The above specifications 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 worrying 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 14 plots the 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 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 et al. (2016), who show that a bank’s lending in a given county is not related to local deposit-market concentration. It is corroborated by the banking literature, which shows that banks channel deposits to areas with high loan demand (Gilje et al., 2016).

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

$$
\text{DepGrowth}_{it} = \alpha_i + \eta_c + \lambda_{st} + \delta_{jt} + \beta_1 TSYGrowth_t \cdot HHI_c + \beta_2 \Delta FFR \cdot HHI_c + \epsilon_{it} \quad (1)
$$

$$
\Delta\text{DepSpread}_{it} = \alpha_i + \eta_c + \lambda_{st} + \delta_{jt} + \beta_1 TSYGrowth_t \cdot HHI_c + \beta_2 \Delta FFR \cdot HHI_c + \epsilon_{it} \quad (2)
$$

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.

Results for deposit volume from Equation (1) are reported in the first two columns of Table 1. 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 changes in the Fed funds rate into account, as indicated in column 2. 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 hikes have the largest impact on deposit growth in the least competitive areas, which agrees with our model predictions and the results in Drechsler et al. (2016).

The magnitude of coefficients reveals a strong distributional effect of Treasury growth and Fed funds rate hikes. For a one standard deviation increase in Treasury growth, a branch located in a county at the 25th percentile of HHI, which is 0.18, experiences a 20.2 bps larger drop in deposit growth relative to a branch of the same bank located in a county at the 75th percentile, which is 0.39. As we will show, this makes up almost a fifth of the average time series crowding-out effect, demonstrating that regions experience significantly different degrees of deposit outflow depending on their level of deposit competition. In contrast, a one standard deviation increase in Fed funds rate changes causes a 22.4 bps smaller drop in deposit growth for branches of the same bank in counties at the 25th percentile of HHI relative to those in counties at the 75th percentile of HHI.

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%. Nevertheless, columns (3) and (4) of Table 1 show that the qualitative results in the full sample of bank branches agree with those for the subsample.

Tables 2 and 4 present within-bank estimates for various Treasury-deposit spreads and Fed funds-deposit spreads. As expected from the results on deposit volume, Treasury-deposit
spreads widen more in competitive areas as Treasury growth increases; whereas Fed funds-deposit spreads widen more in concentrated areas. Notice that in both regressions, the coefficients on both interaction terms are significant, meaning that changes in Treasury growth and monetary policy each affect the spread of deposits relative to both Treasuries and Fed funds. The results for monetary policy rate hikes are again consistent with those in Drechsler et al. (2016). Extending the analysis to the full sample does not alter the significance of the results as seen in Tables 3 and 5.

For the overall effects of Treasury growth, we follow Drechsler et al. (2016) 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 cross-elasticities of -9.23 and -10.53, respectively for deposit growth with respect to Treasury-deposit spread and Fed-funds-deposit spread increases. On average, these two spreads widen by 0.41 bps and 0.45 bps, respectively, for a 100 bps increase in Treasury growth, which implies that a one standard deviation increase in Treasury growth corresponds to a 118.04 bps drop in deposit growth. Using the same approach, a one standard deviation increase in Fed funds rate hikes leads to a 299.04 bps drop in deposit growth. Juxtaposing the two channels, the effect of Treasury growth on bank deposits is substantial at more than a third of that for monetary policy rate hikes.

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 the market power of banks to determine 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. County fixed effects can take care of the time-invariant components, but there may still be an interaction effect with changes in Treasury supply. In our model, the proportion of slow, fast and institutional investors would affect the sensitivity towards changes in Treasury supply.

We repeat the analysis controlling for characteristics of the local clientele that can proxy for investor attention. We use county-level measures from the 2000 US Census and County
Business Patterns data, including the proportion of residents above 65 years old, median income level and percentage of the population with a college degree. Table 6 shows that the effect of imperfect competition as measured by 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 to understanding the effective market power of banks.

5.4 Maturity Structure of Treasuries

Another concern is that the maturity of Treasuries matters in determining the crowding-out of deposits, whereas we have been treating Treasury supply as homogeneous. Greenwood et al. (2010), for example, only consider short-term private safe debt and public safe debt as substitutes.

To incorporate differences in substitutability, we use haircuts on Treasury collateral in repo transactions to weigh Treasuries of different maturities. Examining haircut data from the New York Fed’s website, we find that haircuts remain rather stable over time. Because this time series dataset only goes back to 2010, we follow the estimates in Krishnamurthy and Vissing-Jorgensen (2012) that bills and non-bills have a haircut of 2% and 5%, respectively. This yields a haircut-weighted Treasury supply series, which is used to obtain the results in Table 7. The estimates remain qualitatively unchanged and statistically significant.

5.5 Loan Market Competition

Our identification rests on the premise that banks efficiently allocate funds across branches to invest in loans and assets. This assumes that the competition for loans is more national in nature so that coefficients of the county-level HHI can be interpreted as the effect of deposit market competition. Competition for the average loan is certainly less geographically dependent than that for the average unit of deposit, but some loan categories are likely more tied to the competitive environment of the local region than others, e.g., small business loans and mortgages. Completely resolving this issue would require detailed branch-level loan data, which is not reported in the US. Instead, we provide an indirect check by examining a subsample of above-median income counties. These counties are larger, wealthier and rely less on local
relationship lending, which alleviates potential confounding concerns. The corresponding coefficients are reported in columns 1 and 2 of Table 8, and they remain robust. We further look at another subsample that only includes above-median sized banks because larger banks tend to lend to larger borrowers, who are less likely bound to banks in the same county. The last two columns of Table 8 show that the results remain significant and comparable in magnitude within the subsample of larger banks.

5.6 Treasuries as Collateral

Another issue is that changes in Treasury supply not only affect banks through the returns on the Treasury portion of their assets but also via the availability of collateral for repo financing. To alleviate this concern, we purge the sample of banks that rely heavily on repo financing and repeat the analysis. Table 9 shows results excluding banks above the third quartile of repo financing as a fraction of their balance sheet size. The baseline results continue to hold.

6 Effects on Bank Funding Structure

The recent financial crisis has illustrated how a reliance on short-term wholesale funding increases banks’ funding liquidity risks. A number of new regulations like 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 are able to raise and thus becomes a determinant of the composition of bank leverage and the concentration of funding risk.

Our model implies that the elasticity of deposit outflows with respect to Treasury supply depends on the attentiveness of the investor base and the nature of deposit competition i.e., local versus national, both of which differ by deposit category. Table 10 offers evidence for heterogeneous crowd-out sensitivities. Core deposits, including checking, savings and small time deposits, are mainly servicing retail depositors and display the lowest sensitivity towards changes in Treasury growth.\textsuperscript{21} Wholesale funding, which is mostly provided by institutional

\textsuperscript{21}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
investors, is about four times more responsive to Treasury growth than core deposits. This relationship is graphically reflected in Figure 15(a), which shows that the crowding-out effect by Treasuries on wholesale types of funding is stronger than that for core deposits as long as the HHI is below 0.6. This is the case for over 99% of banks, as evident from the distribution of bank-level HHI in Figure 11.

In contrast, Table 10 and Figure 15(b) reveal the opposite effect for monetary policy: hikes in the Fed funds rate crowd out core deposits by more than wholesale funding. This is because banks seeking to capitalize on the higher asset-side returns following Fed funds rate hikes find it more efficient to raise wholesale funding rates, which are not affected by the frictions of retail depositors, and therefore wholesale funding flows out less. These results are aligned with the findings in Drechsler et al. (2016).

The variation in crowd-out sensitivities implies that higher levels of government-supplied liquidity steers the ratio of wholesale funding in the opposite direction of monetary policy rate hikes. Because institutional deposit account types are more affected by Treasury growth, whereas core deposit growth takes the largest hit from monetary policy rate hikes, the ratio of wholesale funding on banks’ balance sheets decreases with Treasury growth and increases with larger Fed fund rate hikes. Table 11 illustrates this effect. Quantitatively, changes in the wholesale funding ratio dip by 34.4 bps following a one standard deviation increase in Treasury growth, but increase by 30.5 bps after a one standard deviation increase in Fed funds rate hikes.

Heterogeneous crowd-out sensitivities also bring about distributional effects for banks adopting different funding structures. Higher policy rates would disproportionately cut growth in retail deposit-reliant banks, which are mostly focused on lending to small- and medium-sized firms and households, while spurring relative growth in large banks reliant on wholesale funding. Higher Treasury supply, however, would cut growth the most at these wholesale-reliant institutions, but have a smaller effect on banks reliant on core deposits. To see this effect empirically, we divide banks into five groups according to their ratio of wholesale funding and interact the group dummies with Treasury growth and Fed funds rate changes. The coefficients are graphically illustrated in Figures 16(a) and 16(b). The left axis plots the mean wholesale average of its branch-level HHIs.
funding ratios while the right 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 hikes have the opposite effect.

The above findings are especially important in light of the view that monetary tightening by central banks to contain credit booms also leads banks to increase their reliance on wholesale funding and concentrate growth in wholesale-reliant banks, which is precisely what post-crisis liquidity regulations intended to curtail (cite). We show that an expansion government-supplied liquidity would achieve tightening in the the same sense of an overall deposit outflow, while reducing the reliance on wholesale funding and discouraging growth of wholesale-reliant banks. These factors should be taken into consideration when designing new monetary policy tools, one of which we will explore in the following subsection.

7 Application to the Reverse Repurchase Facility

This section extends and applies estimates from the baseline model to uncover the effect of the RRP Facility. The RRP Facility was an unprecedented extension of the scope of the monetary policy in the US. It expanded the Federal Reserve’s set of counterparties beyond depository institutions and primary dealers to also include money market mutual funds, allowing them to directly lend to the Fed through reverse repo transactions.

The goal of the RRP Facility is to improve monetary policy passthrough but direct analysis of its effectiveness has been limited. One challenge is that the announcement and implementation happened in multiple stages so that individual event studies cannot quantify the effect. Further, there is a limited sample for study since the RRP Facility was only introduced in September 2013 and various other regulatory changes occurred shortly afterwards, e.g., the Liquidity Coverage Ratio (LCR) and the Supplementary Leverage Ratio (SLR) were both implemented in 2014.

Our framework allows for an indirect assessment, which 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 in our baseline model of deposit
competition. Similar to Duffie and Krishnamurthy (2016), we abstract away from the minimal Treasury holdings by banks for simplicity so that the bank optimization problem becomes:

$$\max_x D_{retail}(r; \phi, g)(1 + \phi)$$  \hspace{1cm} (3)

An introduction of the RRP Facility would allow money market mutual funds, and thus fast and institutional investors, to invest at the RRP rate $i_{rrp}$ set by the central bank with no limit on supply. Money market mutual funds can hold on to their Treasuries or lend them to the Fed, depending on which offers a higher rate of return. When $g = i_{rrp}$, RRP absorbs the residual demand and the RRP rate floors the effective Treasury yield. Let $g_o$ be the Treasury yield satisfying the following equilibrium:

$$\frac{N}{M} \int_0^\tau \mu T_f(r; \phi, g_o)dF^M + T_w(r_b; \phi, g_o) = \frac{S}{1 + g_o},$$

where the first and second expression denotes demand for Treasuries by fast retail depositors and institutional investors, respectively. Then, if $i_{rrp} < g_o$, investors would not seek out the RRP Facility and the equilibrium Treasury yield would just be $g_o$. If $i_{rrp} > g_o$ however, then the Treasury yield would become $i_{rrp}$ and the demand by fast and institutional investors can be rewritten as $\frac{N}{M} \int_0^\tau \mu T_f(r; \phi, i_{rrp})dF^M$ and $T_w(r_b; \phi, i_{rrp})$, respectively.

Therefore, when the RRP rate offered is effective, it will replace the original Treasury yield in all equations of deposit demand by retail and fast investors. In practice, the RRP rate offered exceeds the one-month Treasury yield most of the time (see Figure 17).\(^{23}\) In other words, all the comparative statics of deposits with respect to Treasury yield before the implementation of the RRP can proxy for the impact of changes in the RRP rate, $i_{rrp}$, on bank deposit funding.

Guided by the model prediction, we can now analyze the effect of the RRP Facility on mon-

\(^{22}\)This assumption is a close approximation of the real world because Treasuries only comprise about 4\% of commercial banks’ balance sheets, which are mainly comprised of loans (See Figure 3). It is also consistent with our calibration results, where Treasuries make up between 4.6\% and 5.4\% of bank balance sheets across variations in Treasury supply.

\(^{23}\)This 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.

27
etary policy passthrough to bank deposit funding by repeating our empirical specifications with a sample ending in 2013Q3. As before, we first obtain cross-elasticities for deposit growth with respect to Treasury-deposit spread and Fed funds-deposit spread increases as in the baseline (Table 12). For a 100 bps increase in the Treasury yield, these spreads rise by 69.9 bps and drop by 31.6 bps, respectively. Then, a 100 bps increase in the Treasury yield lowers bank deposit growth by 12.3 bps. The same calculation yields a 175.7 bps drop in deposit growth for a 100 bps increase in the Fed funds rate. 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 passthrough to bank deposit growth by an additional 7%.

The RRP Facility not only improves the overall passthrough efficiency of monetary policy but also impacts the passthrough to bank funding structure. As Section 6 has shown, standard rate hikes lead to an increased reliance on bank wholesale funding because core deposits are crowded out more. Hikes in the RRP rate, however, resemble increases in Treasury supply and yields so that deploying the RRP Facility can reduce and revert the potentially risky buildup in wholesale funding arising with monetary policy tightening.

8 Conclusion

This paper identified the passthrough of government liquidity provision to bank liquidity provision through imperfect deposit competition. It complements The Deposits Channel of Monetary Policy (Drechsler et al., 2016) to establish Treasury supply and monetary policy as important yet different determinants of the volume and structure of bank funding.

To establish causation, we removed 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 branches in more concentrated regions suffer the largest drop in deposit growth after Fed funds rate hikes. 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. However, as monetary policy rates are higher, the ratio of wholesale funding increases.
We provide a theoretical framework to microfound our empirical analysis in which imperfect deposit competition arises from incomplete attention of retail depositors. This inattention awards banks with market power to not fully pass through increases in the Fed funds rate and Treasury yields to retail investors, for whom corporate bonds and Treasuries are imperfect substitutes to deposits. The model generates predictions in line with the empirical estimates and rationalizes the different effects of Fed funds rate hikes and Treasury growth as a result of commercial bank balance sheets being primarily invested in loans rather than Treasuries.

We applied our model and empirical estimates to infer the effect of extending the access of monetary policy through the RRP Facility. We showed that the effect of the RRP Facility is akin to changes in the Treasury yield, used the pre-RRP sensitivity estimates to quantify its effect, and found it to be around 7% of that of conventional monetary policy. This indirect inference approach can avoid direct estimation based on a short sample period with numerous regulatory changes. Nevertheless, the flexibility of a reduced form model is still limited. A more structural approach would allow for a more in-depth analysis and a richer set of counterfactuals.

This paper has focused on frictions in deposit markets because depositors, especially retail depositors, have limited attention and geographic mobility, rendering imperfect competition a salient feature. Borrowers, e.g., firms, tend to be more efficient at screening loan rates than depositors. Yet in some markets, imperfect competition for loans is also nontrivial, e.g., small business lending and residential mortgages. Future work can consider exploring 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

Sriya Anbil and Zeynep Senyuz. The regulatory and monetary policy nexus in the repo market. 2018.


Vladimir Yankov. In search of a risk-free asset. 2014.
9 Tables

Table 1: 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. For columns (1) and (2), the sample consists of all banks with branches in two or more counties. For columns (3) and (4), 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. Δ 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</th>
<th>≥ 2 Counties</th>
<th>All Counties</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>Δ Target FF * HHI</td>
<td>-0.007***</td>
<td>-0.015***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.002)</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
This table estimates the effect of Treasury supply on the Treasury-deposit spread. The data is at the branch-quarter level and covers 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. ∆ 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>
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<th>3m CD</th>
<th>6m CD</th>
<th>12m CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth * HHI</td>
<td>-2.717***</td>
<td>-1.427***</td>
<td>-0.784***</td>
<td>-0.320*</td>
<td>-0.216</td>
</tr>
<tr>
<td></td>
<td>(0.328)</td>
<td>(0.271)</td>
<td>(0.218)</td>
<td>(0.173)</td>
<td>(0.154)</td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td>0.528***</td>
<td>0.484***</td>
<td>0.320***</td>
<td>0.283***</td>
<td>0.216***</td>
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<tr>
<td></td>
<td>(0.036)</td>
<td>(0.033)</td>
<td>(0.025)</td>
<td>(0.020)</td>
<td>(0.017)</td>
</tr>
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<td>202,856</td>
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<td>216,666</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.960</td>
<td>0.884</td>
<td>0.875</td>
<td>0.863</td>
<td>0.844</td>
</tr>
<tr>
<td>Bank Time FE</td>
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<td>Yes</td>
</tr>
<tr>
<td>State Time FE</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Branch FE</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>County FE</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SE Cluster</td>
<td>County</td>
<td>County</td>
<td>County</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: Deposit Spread and Treasury Supply: All Counties

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. \( \Delta \) 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>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Saving</td>
<td>MM</td>
<td>3m CD</td>
<td>6m CD</td>
<td>12m CD</td>
</tr>
<tr>
<td>TSY Growth * 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 * 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>
<tr>
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<td>480,499</td>
<td>522,482</td>
<td>523,215</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.934</td>
<td>0.818</td>
<td>0.792</td>
<td>0.769</td>
<td>0.737</td>
</tr>
<tr>
<td>Bank Time FE</td>
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<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>State Time FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Branch FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>County FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SE Cluster</td>
<td>County</td>
<td>County</td>
<td>County</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 4: Deposit Spread and Monetary Policy: ≥ 2 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 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. ∆ 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 * 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 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. ∆ 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>
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<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TSY Growth * HHI</strong></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><strong>∆ Target FF * HHI</strong></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
Table 6: Deposit Volume and Treasury Supply: Local Clientele (≥ 2 Counties)

This table estimates the effect of local clientele features on deposit growth. The data is 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 is 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>-0.061**</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.018)</td>
<td>(0.025)</td>
<td></td>
</tr>
<tr>
<td>TSY Growth * College</td>
<td>-0.000</td>
<td>0.002***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>(0.002)</td>
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<td>∆ Target FF * Age</td>
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<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>
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<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
Table 7: Deposit Volume and Treasury Supply: Haircut (≥ 2 Counties)

This table estimates the effect of the maturity structure of Treasuries on deposit growth. The data is at the branch-year level and covers 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 is the log change in Treasury supply as measured by a weighted haircut volume. We use CRSP treasury master file to divide total treasury volume into categories with remaining maturity of less than one-year and over one-year and then multiply by their respective haircut rates. 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. The data is from the FDIC, TreasuryDirect, CRSP and Krishnamurthy and Vissing-Jorgensen (2012). 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>
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<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth * HHI</td>
<td>0.085**</td>
<td>0.084**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.037)</td>
<td>(0.037)</td>
<td></td>
</tr>
<tr>
<td>Δ Target FF * HHI</td>
<td></td>
<td>-0.007***</td>
<td>-0.007***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.003)</td>
<td>(0.003)</td>
</tr>
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<td>Observations</td>
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<td>1,503,914</td>
<td>1,503,852</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.338</td>
<td>0.338</td>
<td>0.338</td>
</tr>
<tr>
<td>Bank Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>State Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Branch FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>County FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SE Cluster</td>
<td>County</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: Loan Market Competition (≥ 2 Counties)

This table estimates the effect of Treasury supply on deposit growth for counties with above median income (columns 1 and 2) and for branches of above-median-sized banks (columns 3 and 4). The data is at the branch-year level and covers 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 is the log change in Treasury supply. Branch HHI measures market concentration in the county where a branch is located. ∆ 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></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth * HHI</td>
<td>0.159*</td>
<td>0.157*</td>
<td>0.264*</td>
<td>0.266*</td>
</tr>
<tr>
<td></td>
<td>(0.086)</td>
<td>(0.086)</td>
<td>(0.150)</td>
<td>(0.150)</td>
</tr>
<tr>
<td>Δ Target FF * HHI</td>
<td>-0.014***</td>
<td></td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td></td>
<td>(0.011)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>724,552</td>
<td>724,552</td>
<td>43,929</td>
<td>43,929</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.353</td>
<td>0.353</td>
<td>0.492</td>
<td>0.492</td>
</tr>
<tr>
<td>Bank Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>State Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Branch FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>County FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SE Cluster</td>
<td>County</td>
<td>County</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 9: 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. ∆ 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></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>-0.010**</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.005)</td>
</tr>
<tr>
<td>Observations</td>
<td>365,810</td>
<td>365,810</td>
</tr>
<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 10: Crowd-Out Sensitivity by Deposit Type

This table estimates the effect of Treasury supply on deposit growth for different types of deposits. The data is 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 it is located in. ∆ 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. The data is 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 bank.

<table>
<thead>
<tr>
<th></th>
<th>Core Deposits</th>
<th>Time Deposits</th>
<th>Wholesale Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth</td>
<td>-0.1289***</td>
<td>-0.2017***</td>
<td>-0.4899***</td>
</tr>
<tr>
<td></td>
<td>(0.013)</td>
<td>(0.018)</td>
<td>(0.027)</td>
</tr>
<tr>
<td>TSY Growth * HHI</td>
<td>0.3116***</td>
<td>0.3062***</td>
<td>0.7542***</td>
</tr>
<tr>
<td></td>
<td>(0.044)</td>
<td>(0.059)</td>
<td>(0.098)</td>
</tr>
<tr>
<td>∆ Target FF</td>
<td>-0.0123***</td>
<td>0.0124***</td>
<td>0.0236***</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.002)</td>
</tr>
<tr>
<td>∆ Target FF * HHI</td>
<td>0.0119***</td>
<td>-0.0195***</td>
<td>-0.0065</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.004)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>Observations</td>
<td>965,376</td>
<td>962,237</td>
<td>957,909</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.020</td>
<td>0.022</td>
<td>0.015</td>
</tr>
<tr>
<td>Bank FE</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bank Controls</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SE Cluster</td>
<td>Bank</td>
<td>Bank</td>
<td>Bank</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
Table 11: Treasury Supply and the Wholesale Funding Ratio

This table estimates the effect of Treasury supply on wholesale funding. The data is at the bank-year level and covers the years 1994 to 2016. The 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. 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 it is located in. ∆ Target FFR is the change in the Fed funds target rate. The data is 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 bank.

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSY Growth</td>
<td>-0.030***</td>
<td>-0.036***</td>
</tr>
<tr>
<td>(0.001)</td>
<td>(0.002)</td>
<td></td>
</tr>
<tr>
<td>TSY Growth * Bank HHI</td>
<td>0.029***</td>
<td></td>
</tr>
<tr>
<td>(0.009)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>∆ Target FFR</td>
<td>0.002***</td>
<td>0.002***</td>
</tr>
<tr>
<td>(0.000)</td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>∆ Target FFR * Bank HHI</td>
<td></td>
<td>-0.001**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.001)</td>
</tr>
</tbody>
</table>

Observations 1,007,682 966,954
R-squared 0.011 0.010
Bank FE Yes Yes
Bank Controls Yes Yes
SE Cluster Bank Bank

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Table 12: 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 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. The data is from Ratewatch, 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></td>
<td>Total</td>
<td>Savings</td>
<td>Time</td>
</tr>
<tr>
<td>TSY Growth * HHI</td>
<td>0.204***</td>
<td>-0.755**</td>
<td>-0.261**</td>
</tr>
<tr>
<td></td>
<td>(0.044)</td>
<td>(0.316)</td>
<td>(0.131)</td>
</tr>
<tr>
<td>Δ Target FF * HHI</td>
<td>-0.010***</td>
<td>0.469***</td>
<td>0.271***</td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.032)</td>
<td>(0.020)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,177,773</td>
<td>188,411</td>
<td>197,197</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.360</td>
<td>0.886</td>
<td>0.864</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
10 Figures
Figure 1: Treasury Supply and Bank Deposits in the Aggregate Time Series

Panel (a) plots year-over-year changes in the total deposits of commercial banks against Treasury growth. Panel (b) plots year-over-year changes in the spread between Treasury yields and deposit rates of the same maturity against Treasury growth. Panel (c) plots year-over-year changes in wholesale funding, deposits, and Treasury supply. Panel (d) plots year-over-year changes in the ratio of wholesale funding and Treasury supply. The wholesale funding ratio is defined as large time deposits over total deposits. Deposit and wholesale funding volumes are obtained from the Federal Reserve Board’s H.8 release. The sample is from January 1986 to December 2016. Deposit rates are available from RateWatch beginning in 1997.
Figure 2: Bank Prime Loan Rate and Fed Funds Rate

This figure plots the average monthly Fed funds rate and bank prime loan rate from 1982 to 2018.

Figure 3: Composition of Bank Asset Holdings

This figure shows the asset composition of the US commercial banking sector from 1980 to 2018. Data is from the Flow of Funds.
These figures present calibration results on the effect of Treasury supply on deposit spread and deposit volume. Treasury supply is in percentages of a baseline level of 2500. Deposit spread is the difference between the Treasury yield and the retail deposit rate. Results are for nine banks per county. Values of the remaining parameters are given in Table A1.

(a) Deposit Spread  
(b) Deposit Volume

This figure presents calibration results on the effect of the Fed funds rate on deposit volume and deposit spread. Deposit spread is the difference of the loan rate and the retail deposit rate. The loan rate equals the Fed funds rate plus a constant margin so that increases in the loan rate reflect increases in the Fed funds rate. Values of the remaining parameters are given in Table A1.

(a) Deposit Spread  
(b) Deposit Volume
Figure 6: Effect of Deposit Competition on the Passthrough of Treasury Supply to Deposits

These figures present calibration results on the effect of deposit competition on the widening of deposit spreads and outflows of deposits as Treasury supply increases. The blue line corresponds to the changes in deposit spread and deposit volume when Treasury supply increases by 50 units from a baseline level of 3150. Values of the remaining parameters are given in Table A1.

(a) Change in Deposit Spread

(b) Change in Deposit Volume

Figure 7: Effect of Deposit Competition on the Passthrough of the Fed Funds Rate to Deposits

These figures present calibration results on the effect of deposit competition on the widening of deposit spreads and outflows of deposits as the loan rate increases from 9.5% to 9.75% due to a 0.25% increase in the Fed funds rate. Values of the remaining parameters are given in Table A1.

(a) Change in Deposit Spread

(b) Change in Deposit Volume
Figure 8: Treasury Supply and the Wholesale Funding Ratio

This figure presents calibration results on the effect of Treasury supply on the ratio of wholesale funding, which is defined as the ratio of institutional deposits over total deposits. Treasury supply is in percentages of a baseline level of 2500. Results are for nine banks per county. Values for the remaining parameters are given in Table A1.

Figure 9: Fed Funds Rate and the Wholesale Funding Ratio

This figure presents calibration results on the effect of the Fed funds rate on the ratio of wholesale funding, which is defined as the ratio of institutional deposits over total deposits. Increases in the loan rate on the x-axis reflect an equivalent increases in the Fed funds rate. Results are for nine banks per county. Values for the remaining parameters are given in Table A1.
This figure presents information on county-level deposit competition in the US. Subfigure (a) displays a color-coded map, where each shade corresponds to a range of the average county HHI from 1997 to 2016. Panel (b) plots the first, second and third quartile of county-level HHI over time from 1997 to 2016. Data is from the FDIC.

(a) Average County-level Herfindahl Index

(b) County-level Herfindahl Index from 1997 to 2016
This figure plots the distribution of the bank-level Herfindahl Index. Bank HHI measures the average market concentration of the bank’s branches, where each branch takes the HHI of the county it is located in. Data is from the FDIC.
Figure 12: Sensitivity of Deposit Growth by Deposit Competition

This figure plots deposit growth sensitivities towards Treasury growth against county-level HHI. The data is at the branch-year level and covers years 1994 to 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 is from the FDIC and TreasuryDirect.
This figure plots deposit spread sensitivities towards Treasury growth against county-level HHI. Panels (a) and (b) show results for time and savings deposits, respectively. The data is 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 taken as the baseline for comparison. Data is from RateWatch, FDIC and TreasuryDirect.
Figure 14: Example of Deposit Spreads for Two Branches of Huntington Bank

This figure plots the 3-month Treasury-3-month CD spread 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). This is a period when Treasury growth increased by 3.24% from 2004Q4 to 2005Q1. Data is from Ratewatch, FDIC and TreasuryDirect.
Figure 15: Crowd-Out Sensitivity by Deposit Type

This figure plots the crowd-out sensitivities for different types of deposits against bank HHI. The data covers the years 1994 to 2016. Crowd-out sensitivities are obtained from the bank level regression of deposit growth on Treasury growth and Fed fund rate changes interacted with Bank HHI as detailed in Table 11. Solid lines indicate point estimates while dotted lines show the 95% confidence interval. Bank HHI measures the average market concentration of the bank’s branches, where each branch takes the HHI of the county it is located in. Core deposits are comprised of checking, savings and small time deposits (less than 100K). Wholesale funding is comprised of large time deposits, Fed funds, repo borrowing, and other borrowed money. Data is from the FDIC, Call Reports and TreasuryDirect.
Figure 16: Bank-Level Crowd-Out Sensitivity by Wholesale Funding Ratio

This figure shows how crowd-out sensitivities vary with the level of wholesale funding. 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 blue line (right axis) marks the crowd-out sensitivities for each quintile group. In panel (a), they 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), they 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 is from the FDIC, Call Reports and TreasuryDirect.
Figure 17: Treasury Yield and the Reverse Repurchase Facility Rate

This figure compares the one-month Treasury yield with the RRP Facility rate. Data is from FRED and the New York Federal Reserve website.
Table 13: Parameter Values

This table lists parameter values used to calibrate the search model. They are chosen to realistically reflect the distribution of wealth, the balance sheet of commercial banks and investor preferences.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\epsilon$</td>
<td>3</td>
<td>Elasticity of substitution between Treasuries and deposits for investors</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.5</td>
<td>Liquidity of deposits relative to Treasuries for investors</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.001</td>
<td>Utility weight for liquidity services relative to wealth for investors</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.5</td>
<td>Elasticity of substitution between liquidity and wealth for investors</td>
</tr>
<tr>
<td>$\mu$</td>
<td>0.67</td>
<td>Fraction of fast retail depositors</td>
</tr>
<tr>
<td>$c$</td>
<td>0.001</td>
<td>Search cost for slow retail depositors</td>
</tr>
<tr>
<td>$\phi$</td>
<td>0.085</td>
<td>Bank loan rate</td>
</tr>
<tr>
<td>$m$</td>
<td>0.006</td>
<td>Liquidity premium parameter for banks’ Treasury holdings</td>
</tr>
<tr>
<td>$W_o$</td>
<td>7000</td>
<td>Wealth of institutional investors (total)</td>
</tr>
<tr>
<td>$W_f$</td>
<td>5</td>
<td>Wealth of retail fast investors (per county)</td>
</tr>
<tr>
<td>$W_s$</td>
<td>1</td>
<td>Wealth of retail slow investors (per county)</td>
</tr>
<tr>
<td>$K$</td>
<td>3000</td>
<td>Number of counties</td>
</tr>
</tbody>
</table>