The Demand for Money, Near-Money, and Treasury Bonds

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Abstract

Bank-created money, shadow-bank money, and Treasury bonds all satisfy investor's demand for a liquid transaction medium and safe store of value. We measure the quantity of these three forms of liquidity and their corresponding liquidity premium over a sample from 1926 to 2016. We empirically examine the links between these different assets, estimating the extent to which they are substitutes, and the amount of liquidity per-unit-of-asset delivered by each asset. We construct a new broad monetary aggregate based on our analysis and show that it helps resolves the money-demand instability and missing-money puzzles of the monetary economics literature. Our empirical results inform models of the monetary transmission mechanism running through shifts in asset supplies, such as quantitative easing policies. Our results on the substitutability of bank and shadow-bank money also inform analyses of the coexistence of the shadow-banking and regulated banking system.

Keywords: Liquidity Premium; Money; Governemnt Debt; Shadow Banking.

JEL classification: E41, E44, E63, G12.

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In a modern financial system, many financial assets provide the liquidity services traditionally associated with money.[1] One of the lessons from the Global Financial Crisis of 2008 is that money creation can migrate outside the commercial banking system, with securities such as repurchase agreements and asset-backed commercial paper filling the traditional roles of money (Gorton (2010); Lucas and Stokey (2011)). Academic research has begun to formally explore the expanded universe of monetary financial assets. Krishnamurthy and Vissing-Jorgensen (2012) show that U.S. government bonds satisfy investors' need for trading liquidity and a safe store-of-value, two of the central functions of money. Greenwood, Hanson and Stein (2015) show that these services are particularly high for short-term government bonds. Gorton, Lewellen and Metrick (2012), Krishnamurthy and Vissing-Jorgensen (2015) and Greenwood, Hanson and Stein (2015) show that privately issued safe assets, including bank debt and commercial paper are a substitute for the services provided by government debt. Nagel (2016) shows that monetary policy impacts the liquidity premium on U.S. government bonds. Drechsler, Savov and Schnabl (2018) shows that monetary policy impacts not just the level of deposit rates but also the spreads on deposits relative to other rates, while Li, Ma and Zhao (2019) show that the supply of government bonds impacts these deposit spreads.

This paper contributes to this literature. Following Nagel (2016) we consider a liquidity aggregate of the form:

$$Q_t = \left((1-\lambda_t)(\frac{D_t}{P_t})^{\rho} + \lambda_t(\frac{B_t}{P_t})^{\rho} \right)^{\frac{1}{\rho}}. \tag{1}$$

Here D_t are nominal bank deposit holdings (checking plus savings), B_t are nominal government bond holdings, P_t is the price level, and λ_t is the fraction of liquidity services provided by each asset. The first exercise in this paper is to estimate ρ which measures the substitutability between bank deposits and government bonds. We also estimate λ_t which measures the liquidity services per unit of asset of government bonds relative to bank deposits. We then turn to a broader aggregate. We measure the quantity of financial sector debt issued by banks and shadow banks, but excluding traditional bank deposits. This measure includes repurchase agreements, commercial paper, and short-term debt of the government sponsored enterprises and is from Krishnamurthy and Vissing-Jorgensen (2015). We denote this measure as D_t^{NB} and consider an aggregate Q'_t:

$$Q'_t = \left((1-\lambda_t)(\frac{D_t}{P_t})^{\rho} + \lambda_t(\frac{B'_t}{P_t})^{\rho} \right)^{\frac{1}{\rho}}. \tag{2}$$

[1]Throughout this paper, we use the word "liquidity services" as short-hand for the services provided by financial assets as a transaction medium, a safe store of value, and collateral services.

where,

$$B'_t = \left((1-\mu_t)(\frac{D_t^{NB}}{P_t})^{\eta} + \mu_t(\frac{B_t}{P_t})^{\eta} \right)^{\frac{1}{\eta}}. \tag{3}$$

We estimate ρ, η, as well as μ_t and λ_t.

We report three principal results. First, we estimate ρ to be around 0.6 for the sample we analyze running from 1926 to 2016. The value is also quite stable over this long period. Bank issued money and government bonds provide similar but not identical services. The result is in contrast to Nagel (2016) who estimates a value of $\rho = 1$ (i.e. perfect substitutes). A way of understanding this result is to note that bank deposits provide transaction services which government bonds do not, while government bonds provide collateral services which bank deposits do not.

Second, we estimate η to be near one in a sample from 1974 to 2016. That is, non-transaction financial sector debt and Treasury bonds are near perfect substitutes. One way of understanding the $\eta = 1$ result is that both non-transactional financial sector debt and Treasury bonds are a safe store of value. Note that $\eta = 1$ does not imply that these assets provide the same quantity of liquidity services per unit of asset. That characteristic is measured by μ, which we estimate to be on average 0.57, indicating that per-unit-of-asset, government bonds provide roughly 1.5 times the liquidity services of non-transaction financial sector debt.

Our last result is that estimating a money demand function using either Q_t or Q'_t as the monetary aggregate delivers stable estimates over the entire sample. As noted by Goldfeld and Sichel (1990), Teles and Zhou (2005), and Lucas and Nicolini (2015), the stability of the money demand function breaks down around 1980, when money is measured as M1 (currency plus transaction deposits). These authors tie the breakdown to the growth of money market funds. Our results build on this point by considering the liabilities of the shadow-bank sector, which includes money market funds but is broader, and the quantity of government bonds.[2]

Our empirical results inform theoretical work. First, quantitative easing changes the relative supplies of government bonds, bank deposits, and private assets held by investors. In theoretical models such as Williamson (2012), Gorton and He (2016), Rocheteau, Wright and Xiao (2018), Piazzesi and Schneider (2018), and Diamond (2020), shifts in the supplies of these assets are central to the monetary transmission mechanism. Our results provide quantitative guidance on which assets are the relevant ones to be considered, and the degree of

[2]Our work also builds on the literature on how to aggregate different components of money. See Fisher (1922), Barnett (1980), and Barnett, Offenbacher and Spindt (1984). The monetary search literature provides a foundation for the imperfect substitution across different types of money, as in Lagos and Wright (2005) and Geromichalos and Herrenbrueck (2016).

substitutability of these assets. If, for example, $\rho = 1$, then quantitative easing policies that aim to impact the liquidity premium on bonds can be replicated via conventional monetary policy. Likewise, the optimal mix between Treasury bills, the Fed's reverse repo facility and bank reserves, as in the analysis of Greenwood, Hanson and Stein (2015) and Duffie and Krishnamurthy (2016), depends on the substitutability of these assets. Thus, the values of ρ and η are important to modeling the monetary transmission mechanism. Second, as discussed in Lucas (2001), the quantitative values of the interest and income elasticity of money demand are needed to answer questions such as, what is the optimal growth rate of money, and, what is the welfare cost of inflation. For example, the welfare cost of inflation, as in Lucas (2001), will depend in part on the ability of private agents to use alternatives to currency for liquidity needs. We provide new estimates based on a broad liquidity aggregate which delivers a stable money demand function and is thus better suited to answering these questions. Last, for a collection of issues surrounding banking regulation, the substitutability of bank deposits, non-bank debt, and government bonds is central. If government bonds and bank deposits are perfect substitutes in providing liquidity services, then there is less reason that government policy encourage issuance of private bank deposits. Arguments in favor of narrow banks and increasing bank capital requirements are thus strengthened. Our results more broadly inform analyses of the role of shadow-banks in creating money (Gorton and Metrick (2012), Krishnamurthy and Vissing-Jorgensen (2015), Sunderam (2015), Moreira and Savov (2017), Xiao (2020), dAvernas and Vandeweyer (2020)) and studies of the coexistence of the shadow-banking and regulated banking system, as in Hanson et al. (2015) and Begenau and Landvoigt (2021).

The remainder of the paper is structured as follows: Section 1 presents the model and empirical specification. Section 2 estimates the level of substitution between bank deposits and Treasuries. Section 3 broadens the liquidity aggregate to include shadow-bank deposits and estimates a demand function for this aggregate. Section 4 analyzes the statistical power of our estimation method. Section 5 concludes. An appendix detailing data sources and providing a number of robustness checks of our results follows.

1. The Model

In this section, we present our model. Then we discuss how to map the model to the data, and how we estimate the model.

1.1. *Model Setup*

The model is composed of investors, commercial banks, a government, and a central bank. We model a representative investor, a stand-in for the non-financial sector, that chooses consumption and investment, receiving utility from its holdings of bank deposits and government bonds. The liquidity demand is modeled along the lines of Sidrauski (1967) money-in-the-utility function formulation. As in Barnett (1980), we consider the case where the investor receives utility over a liquidity aggregate. The model formulation is closely related to Nagel (2016) and the liquidity aggregate contains Treasuries[3]. Specifically, we strip out the decision problems by the government and the central bank, and adopt a general utility function $u(C_t, Q_t)$ (consumption C_t and liquidity Q_t), while Nagel (2016) uses log utility (all of the results also go through under log utility).

Investors directly hold the majority of deposits and a large fraction of Treasuries either directly or indirectly through passthrough institutions. We assume that the deposit rate i_t^d is a linear function of the nominal interest rate i_t. Such a connection can be microfounded by bank monopoly power or bank regulation. For example, in Nagel (2016), regulatory reserve requirements pin down,

$$i_t^d = \delta i_t \quad \delta < 1. \tag{4}$$

We are agnostic on the microfoundation and will instead use data to estimate δ.[4]

The representative investor has utility function:

$$E_0[\sum_{t=1}^{\infty} \beta^t u(C_t, Q_t),] \tag{5}$$

which composes both real consumption C_t and a liquidity aggregate Q_t. The liquidity aggregate is composed of both deposits and bonds,

$$Q_t = \left((1 - \lambda_t)(\frac{D_t}{P_t})^{\rho} + \lambda_t(\frac{B_t}{P_t})^{\rho} \right)^{\frac{1}{\rho}}, \tag{6}$$

where D_t is the nominal deposits holding, B_t is the nominal bond holdings (we will use "bonds" interchangeably with "Treasuries" to correspond to the notation B_t in the model), and P_t is the price level. Note that we will omit currency holdings in our definition of D_t.

[3]One important aspect of Treasury liquidity is the convenience of rehypothecation in the repo market, which leads to a high "collateral multiplier" (Infante and Saravay, 2020) similar to the money multiplier.

[4]In the data, for both checking and savings deposits, the deposit spread $i_t - i_t^d$ is well approximated by i_t, and more than 90% of the spread's time-series variation is explained by i_t. The relationship is robust even after the introduction of interest on excess reserves (IOER). One explanation for such a robust connection is the monopoly power of commercial banks (Drechsler, Savov and Schnabl, 2017).

We are interested in how financial assets such as Treasury bonds as well as financial sector debt are used to meet liquidity and portfolio needs, and less interested in the narrow role of currency to purchase small-ticket goods. Piazzesi and Schneider (2018) document the massive payment volume in financial sector claims.

The λ_t component reflects time-varying liquidity of bonds relative to bank deposits. For example, in a "flight-to-safety", large investors may prefer bonds to holding uninsured bank deposits. The substitution between bonds and deposits is, in general, more stable than these demand fluctuations, and thus modeled as a constant[5] $\rho \in (-\infty, 1]$. The elasticity of substitution is equal to $1/(1-\rho)$, and is thus monotone in ρ. It is numerically convenient to work with ρ rather than the elasticity of substitution.

When $\rho = 1$, deposits and bonds are perfect substitutes, and the liquidity aggregate is linear in both deposits and bonds,

$$Q_t|_{\rho=1} = (1-\lambda_t)(\frac{D_t}{P_t}) + \lambda_t(\frac{B_t}{P_t}). \tag{7}$$

When $\rho \to 0$, deposits and bonds are neither substitutes nor complements,

$$Q_t|_{\rho=0} = (\frac{D_t}{P_t})^{1-\lambda_t}(\frac{B_t}{P_t})^{\lambda_t}. \tag{8}$$

In this Cobb-Douglas case, the investor's portfolio allocation into deposits and bonds are fixed fractions of the investor's wealth. Thus, the return on bonds or deposits is irrelevant to the portfolio holdings. When $\rho < 0$, bonds and deposits are complements, with a limit of the Leontief function as $\rho \to -\infty$.

Investors are subject to the budget constraint

$$\begin{aligned} &\underbrace{D_{t-1}(1+i^d_{t-1})}_{\text{deposit return}} + \underbrace{B_{t-1}(1+i^b_{t-1})}_{\text{bond return}} + \underbrace{A_{t-1}(1+i_{t-1})}_{\text{risk-free lending return}} + \underbrace{I_t}_{\text{income}} = \\ &\underbrace{P_t C_t}_{\text{consumption}} + \underbrace{D_t + B_t + A_t}_{\text{investment}} + \underbrace{T_t}_{\text{transfer}}, \end{aligned} \tag{9}$$

where i_t is the risk-free borrowing and lending rate, i^d_t is the deposit rate, and i^b_t is the one-period bond yield. In each period t, the investor collects returns from deposits, bonds, and lending, and earns income. Then the investor consumes, lends, and invests in liquid assets, including deposits and bonds. The final term is a non-distortionary transfer from the government to the investors, which can be either positive or negative.

From the budget constraint, it is clear that given a level of consumption, by substituting

[5] In the empirical exercise, we will estimate ρ across different subsamples.

one unit of lending into deposits at time t, the investor earns a marginal liquidity benefit $\partial u(C_t, Q_t))/\partial Q_t \cdot \partial Q_t/\partial D_t$, but at the opportunity cost of losing $(i_t - i_t^d)$ on asset returns. Similarly, by substituting one unit of lending into bonds, the investor earns an additional liquidity benefit $\partial u(C_t, Q_t)/\partial Q_t \cdot \partial Q_t/\partial B_t$, but at the opportunity cost of losing $(i_t - i_t^b)$. Thus the first-order conditions on holdings of deposits and bonds are:

$$u_Q{}'(C_t, Q_t)Q_t^{1-\rho}(1-\lambda_t)(\frac{D_t}{P_t})^{\rho-1} = u_C{}'(C_t, Q_t)\frac{i_t - i_t^d}{1+i_t}, \tag{10}$$

$$u_Q{}'(C_t, Q_t)Q_t^{1-\rho}\lambda_t(\frac{B_t}{P_t})^{\rho-1} = u_C{}'(C_t, Q_t)\frac{i_t - i_t^b}{1+i_t}. \tag{11}$$

By dividing the first-order condition of bonds by the first-order condition of deposits on both sides and rewriting, we find:

$$i_t - i_t^b = \frac{\lambda_t}{1-\lambda_t}(\frac{B_t}{D_t})^{\rho-1}(i_t - i_t^d). \tag{12}$$

We will estimate (12) instead of the first order conditions in (10) and (11). Note equation (12) does not depend on the utility specification $u(C, Q)$. The economic relation described by (12) comes from assuming bonds and money in the utility function.

We have not specified the government and the central bank's policy functions because they are not required to estimate ρ. The equality (12) is a first-order condition that holds irrespective of these policy functions and the underlying drivers of the liquidity premium.

Equation (12) has implications for the time-series variation in the liquidity premium that depend on ρ. Suppose bank deposits and Treasuries are perfect substitutes ($\rho = 1$). Then Treasury supply B_t has no impact on the liquidity premium $i_t - i_t^b$, given a fixed deposit spread $i_t - i_t^d$ which is a function of the central bank policy rate i_t. By choosing the nominal interest rate i_t, the central bank can simultaneously set the liquidity premium of government bonds. Next suppose $\rho = 0.5$. Then both Treasury supply B_t and the nominal interest rate i_t have an independent impact on the liquidity premium of Treasury bonds. Moreover, in this $\rho < 1$ case, the marginal impact of a change in the deposit spread on the liquidity premium depends on the ratio B_t/D_t. Effectively, interest rate changes depend on the slope of the liquidity-demand curve, which depends on quantities outstanding. Likewise, changes in $\frac{B_t}{D_t}$ depend on the current interest rate, which reflects how high or low the liquidity premium is at a given point. The key to our approach to equation (12) is recognizing these interactions between quantities and spread, which will be missed if we worked with a linearized version of (12).

1.2. Data and Measurement

We collect data on the quantity of deposits, Treasury bonds, the Treasury liquidity premium and the deposit spread. Because the frequency of these data differs across series, to retain the maximum information, we construct the sample at a monthly frequency, setting quantity variables the same in a single quarter when the data is quarterly, and the same in a single year when the data is yearly.

The Treasury liquidity premium measure follows Nagel (2016) in construction, and we extend the measure to 2016 so that this measure covers 1920–2016 at a monthly frequency. For the sample after 1991, the liquidity premium is measured as the yield spread between the 3-month general collateral (GC) repo rate and the 3-month Treasury bill rate. The 3-month repo loan is collateralized by Treasuries and thus is virtually free of credit risk. Compared with a three-month Treasury bill, a 3-month Treasury-backed repo is less liquid. For the period before 1991, the three-month repo data are not available. We use 3-month Banker's Acceptance, which contains minimal default risk because they are backed by the credit of both banks and the borrowing firm. Therefore, before 1991 the liquidity premium is measured as the yield spread between the 3-month banker's acceptance and the 3-month Treasury bill. Finally, we winsorize the liquidity premium at 0.5% and 99.5% quantile so that neither extremely large nor small values affect our results.

Figure 1 plots the Treasury liquidity premium series. We note that the liquidity premium looks relatively constant during the World War II period. During this period, the Fed was a key factor in price determination in the Treasury market. The Fed promised to buy (or sell) Treasury bills at 3/8% (substantially below typical peacetime rates of 2% to 4%). The Fed also offered discount loans to banks against Treasury collateral at 50 basis points below the general discount rate. Both steps likely had a significant influence on both Treasury bill rates and other money market rates. These measures also incentivized banks to buy government debt. See Krishnamurthy and Vissing-Jorgensen (2015) and Whittesley (1943) for details. We include the WWII period in our main specifications, but present a robustness check where we drop the WWII period as well as restrict the sample to the period after the Treasury-Federal Reserve Accord of 1951.

We consider two measures of Treasury supply. From equation (12), we note that the quantity variable should be B_t/D_t where B_t corresponds to the market value of Treasury securities held by the agent for whom the model applies. We take this agent to reflect the non-bank sector, who demands Treasuries and bank deposits to satisfy liquidity needs. Thus, the relevant quantity measure for Treasuries is the non-bank private sector's holdings of Treasuries. We construct this measure as the total quantity of Treasury debt, excluding intra-governmental holdings such as the Social Security Trust Fund, minus bank and Federal

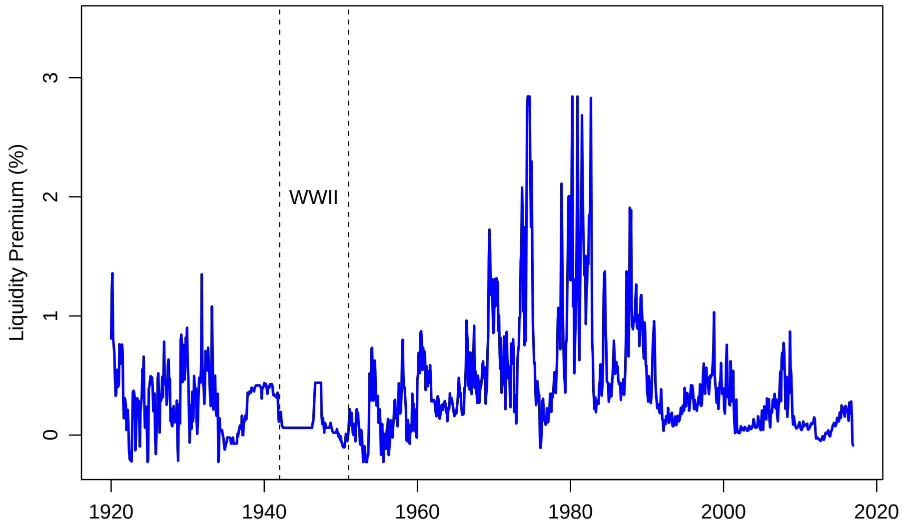


Fig. 1. **Treasury Liquidity Premium**. This figure plots the spread between 3-month general collateral (GC) repo rate and 3-month Treasury bill rate from 1991 to 2016, and 3-month general Banker's Acceptances and 3-month Treasury bill rate from 1920 to 1991.

Reserve holdings. We construct this measure using book values, and then multiply by a factor equal to the ratio of market to book value of all Treasuries outstanding at each date. This multiple is available beginning in 1942, and varies from 0.90 to 1.10. Prior to 1942, we use a multiple of one. While our results are not sensitive to using market or par values, the economics of the model call for using the market value. We call this measure the "net Treasury" supply. The data on Federal Reserve and bank holdings are from the flow of funds after 1953, and from FRASER historical data before 1952. The data frequency is yearly from 1920 to 1952, and quarterly from 1953 to 2016. To the extent that bank holdings of Treasuries are endogenous to the liquidity premium, estimation of (12) will be biased. We construct a second measure, referred to as "Total Treasury" supply, which is the total quantity of Treasury debt, at par value, excluding intra-governmental holdings, but including bank and Federal Reserve holdings. We use the total Treasury supply as an instrument to deal with the endogeneity concern.

Next, we discuss our measure of D_t. Bank deposits are the primary liquid asset for most investors in the U.S.[6] We measure bank deposits as the sum of checking, savings (including money market deposit accounts), and small time deposits. We obtain monthly data after 1959 from *Federal Reserve Economic Data* (*FRED*) and yearly data covering 1934 to 1959

[6]We exclude currency in our measurement. In Jan 2021, the total amount of deposits is about \$16 trillion while total currency in circulation is \$2 trillion. A significant quantity of the currency in circulation is held outside the U.S., such as in developing countries where the banking system is underdeveloped or not trusted. Refer to this Fed Blog for more information.

from the *Federal Deposit Insurance Corporation* (*FDIC*) historical bank data. Thus,

$$D_t = D_{\text{checking},t} + D_{\text{saving},t} + D_{\text{small time},t}. \tag{13}$$

We plot this series in Figure 2.

We also consider a broader measure of deposits, based on Krishnamurthy and Vissing-Jorgensen (2015). Their measure includes large time deposits, wholesale bank deposits such as repos, Eurodollars, and commercial paper, as well as short-term debt issued by shadow banks, such as money market funds and the government sponsored enterprises. The construction of the measure nets out intra-financial sector holdings of debt, so that the measure corresponds to the non-financial sector holding of short-term financial sector debt.[7] We refer to this measure as "KVJ deposits."

As noted earlier, D_t is likely to be correlated with the liquidity premium, potentially leading to a bias in estimation. We will use total Treasury supply as an instrument for $\frac{B_t}{D_t}$ in our estimation. We also consider regressions, similar to Nagel (2016) and Greenwood, Hanson and Stein (2015), where we use seasonal variation in Treasury receipts as an instrument.

Figure 2 plots the four quantity series we use, all plotted as fractions to GDP. The two measures for Treasury supply comove, with gaps noticeable during the World War II period when banks purchased a considerable quantity of Treasury debt, and during the last decade, when changes in financial regulation have incentivized banks to hold more Treasury debt and the Fed significantly increased its holding of Treasuries due to unconventional monetary policies. The two deposit measures also move together, but they clearly begin to separate post-1980 with the rise of non-bank intermediation. The KVJ Deposits measure captures the non-bank or "shadow bank" sector. Finally, we note that these quantities vary at a low frequency. This observation is important in estimation, as we make clear.

On the price side, the aggregate deposit spread is

$$i_t - i_t^d = \frac{D_{\text{checking},t}}{D_t}(i_t - i_{\text{checking},t}) + \frac{D_{\text{saving},t}}{D_t}(i_t - i_{\text{saving},t}) + \frac{D_{\text{small time},t}}{D_t}(i_t - i_{\text{small time},t}) \tag{14}$$

An alternative aggregation based on a CES aggregator is provided in Appendix B, where we show that the main results are robust to this different aggregation.

Deposits spread data are available after 1987, but this short period is insufficient for the

[7] Krishnamurthy and Vissing-Jorgensen (2015) construct the "net short-term debt" of the financial sector as the sum across each firm in the financial sector (banks and non-bank) of:

$$\text{short-term debt liabilities} - (\text{short-term debt assets} + \text{government supplied liquid assets}).$$

We use the net short-term debt measure and add back the government-supplied liquid assets, which then corresponds to the short-term debt liabilities of the financial sector held by the non-financial sector.

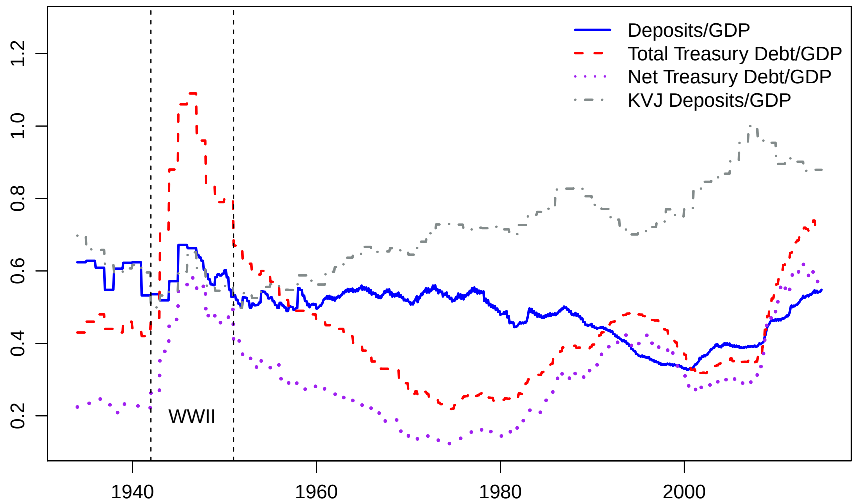


Fig. 2. **Treasury Debt and Financial Sector Deposits.** This figure plots our two measures of B_t, relative to GDP, as Total Treasury Debt/GDP and Net Treasury Debt/GDP. We also plot our two measures of D_t, as the sum of checking, savings, and time deposits (Deposits) and the broad measure of financial sector debt (KVJ deposits), again as a ratio to GDP.

main purpose of the paper. We have noted that deposit spreads vary with the level of the interest rate, a relation that can arise from bank regulation (Nagel, 2016) or deposit market competition (Drechsler, Savov and Schnabl, 2017). We project the deposits spread defined in equation (14) on the federal funds rate, which is available back to the 1920s. The projection coefficient is obtained by a linear regression of the monthly deposit spread data after 1987 onto the federal funds rate (without constant term)[8]. We find that the R^2 in this regression is about 80%. Therefore, we use the following linear approximation:

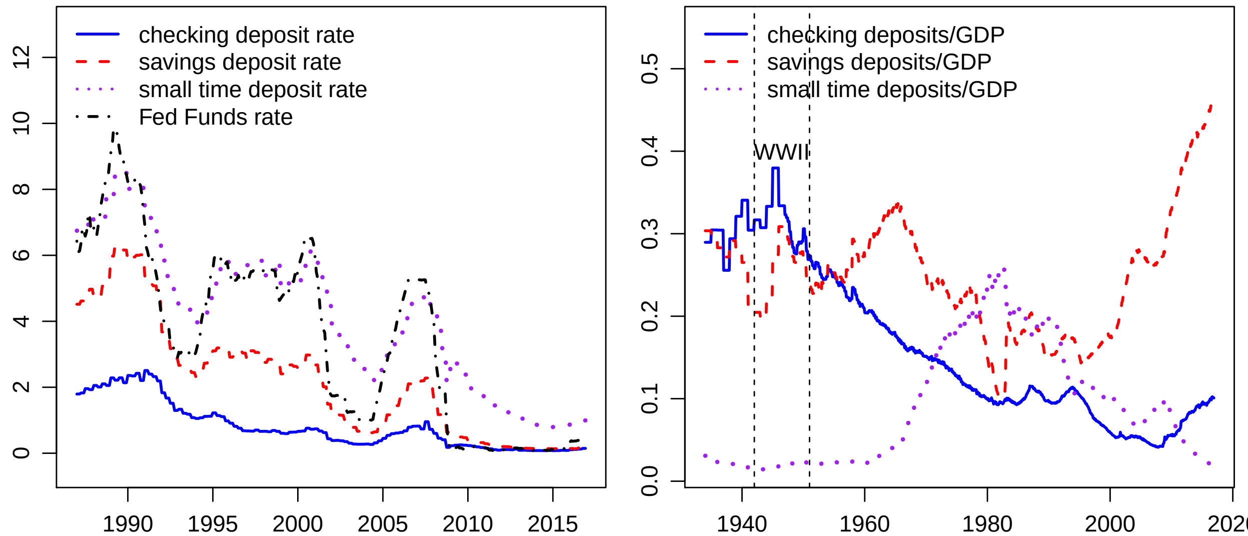
$$i_t - i_t^d \approx 0.34 i_t \tag{15}$$

Before the banking deregulation of the early 1980s, Regulation Q restricted the payment of explicit interest on demand deposits, but banks often paid *implicit interest* to sidestep the restriction. Startz (1979) finds that accounting for this implicit interest results in a deposits spread half of the nominal interest rate, which is similar to our estimated sensitivity in (15). Therefore, we will use the approximation in (15) throughout the sample period from the 1920s to 2016. Our main results are robust to having a different approximation before and after regulation Q. [9]

[8]If we include the constant term, the coefficient is similar and the constant term is insignificant. Our results are similar using this alternative projection.

[9]Refer to Appendix C.9 for details.

Figure 3 plots the individual deposit rate data in the left panel and the corresponding deposit quantities in the right panel.



(a) Rates

(b) Volume

Fig. 3. **Comparison of Deposit Rates and Volume.** Panel (a) compares different deposit rates and the Fed Funds rate at a quarterly frequency. Deposits rates are calculated as interest expenses over the total amount of deposits for each category, using the Call Report data. Panel (b) compares the quantities of different deposits as fractions of GDP. Data are from Flow of Funds at a monthly frequency.

Finally, we use monthly *Chicago Board Options Exchanges Volatility Index* (*VIX*) to approximate the flight-to-liquidity shock λ_t, following Nagel (2016). We assume the form

$$\frac{\lambda_t}{1-\lambda_t} = \beta_\lambda \cdot \mathrm{VIX}_t \tag{16}$$

and estimate the coefficient β_λ. The idea here is that Treasuries are fully guaranteed by the government, while checking and savings deposits are not insured above the FDIC insurance limit. In a crisis, the "flight-to-quality" effect drives up the liquidity share for Treasury, and thus the Treasury liquidity premium. The VIX data are only available since 1990. For the periods before 1990 when the VIX index is not available, we use a linear projection of VIX on realized volatility of the S&P 500 index, where the projection coefficients are estimated using the post-1990 data. The construction is limited by the data availability of the S&P index and starts from 1926, and we use monthly average VIX throughout the sample.

Summarizing, the model in equation (12) prescribes the following empirical relationship:

$$lp_t \propto \text{VIX}_t(\frac{B_t}{D_t})^{\rho-1} i_t, \tag{17}$$

where lp_t is the Treasury liquidity premium.

2. Model Estimation

In this section, we estimate ρ, the coefficient of substitution between Treasuries and deposits in equation (12) as well as λ_t, which parameterizes the liquidity services-per-unit-of-asset of Treasuries and bank deposits.

2.1. Interaction between Supply and Fed Funds Rate

We first replicate the results of Nagel (2016), which estimates a linearized version of equation (17). The first three columns of Table 1 should be compared to Table III of Nagel (2016). The estimates are quite close to that table, and the discrepancies are likely due to slight differences in data and sample.[10] In the first column, we see that the federal funds rate strongly comoves with the liquidity premium. In column (2), we see that Treasury supply has significant explanatory power for the liquidity premium, as shown in Krishnamurthy and Vissing-Jorgensen (2012). In the third column, the Krishnamurthy and Vissing-Jorgensen (2012) result is overturned: Treasury supply loses its explanatory power if the federal funds rate is included in the regression. Indeed, the coefficient of log(Total Tsy/GDP) in column (3) is near zero and statistically insignificant.

Columns (4) and (5) replace the quantity variable in the regression. In column (4), we follow the theory and use the net Treasury variable to correspond to the Treasury holdings of the non-bank sector. In column (5), we use Net Treasury/Deposits as the measure of $\frac{B_t}{D_t}$, as prescribed by equation (17). Using the theoretically motivated quantity variable improves the fit in the regression: the R^2 rises from 60% in (2) to 64% in (5). Additionally, the quantity variable is a statistically significant driver of the liquidity premium, in line with Krishnamurthy and Vissing-Jorgensen (2012).

Table 2 shows that accounting for the non-linear terms in equation (17) are important in the estimation. Relative to Table 1 we extend the sample to 2016. The first three columns show the linear regression with the extended sample. The coefficient on the Treasury supply variable changes slightly and remains significant. The rest of the columns include non-linear

[10]Our sample starts from 1926 when the S&P 500 index is available in WRDS, while Nagel (2016) further goes back to 1920. We also winsorize the liquidity premium series.

Table 1: Replication of Nagel (2016) Table III

	Dependent variable: liquidity premium$_t$				
	(1)	(2)	(3)	(4)	(5)
FFR$_t$	10.78		10.76	10.29	9.94
	(1.06)		(1.12)	(1.03)	(0.90)
VIX$_t$	1.17	0.37	1.17	1.08	1.45
	(0.21)	(0.30)	(0.22)	(0.22)	(0.33)
$\log(\frac{\text{Total Tsy}_t}{\text{GDP}_t})$		−48.65	−0.29		
		(14.41)	(5.22)		
$\log(\frac{\text{Net Tsy}_t}{\text{GDP}_t})$				−8.26	
				(5.44)	
$\log(\frac{\text{Net Tsy}_t}{\text{Deposits}_t})$					−17.41
					(6.22)
Constant	−27.97	−12.42	−28.10	−35.39	−39.08
	(6.91)	(11.57)	(7.64)	(9.11)	(9.57)
Observations	1,032	1,032	1,032	1,032	936
R^2	0.60	0.20	0.60	0.61	0.64

Notes: The liquidity premium is in basis points. It is measured as the spread between three-month bankers acceptance and three-month T-bill before 1991, and the spread between the three-month GC term repo and three-month T-bill afterward. We winsorize the liquidity premium at 0.5% and 99.5% quantiles. FFR is the effective federal funds rate in percentage points. VIX represents CBOE S&P 500 implied volatility index. Before 1990, the index is not available, so we calculate a proxy index as the projection of VIX on the realized volatility of the S&P 500 index's daily return in each month from 1926 to 1990, where the projection coefficients are estimated with data after 1990. For the log(Total Tsy/GDP) term, GDP is the U.S. nominal GDP, and Total Tsy is the total amount of government debt, excluding intra-governmental holdings. Net Tsy is the total market value of Treasuries excluding intra-governmental holdings, minus bank and Federal Reserve holdings. Deposits include checking, savings, and small-time deposits. The sample period is from 1926 to 2011 (we limit the data at 2011 to make results in this table more comparable to Nagel (2016)) for columns 1-5, and 1934–2011 for column 6 (deposits data are available starting from 1934). HAC standard errors with 12 lags are shown in parentheses.

terms. In column (5), we include both log(Net Tsy/Deposits) and the interaction between the federal funds rate and log(Net Tsy/Deposits). The coefficient on the federal funds rate falls, while the interaction term is negative and highly significant. We also note that the regression R^2 rises from 60% in column (1) to 68% in column (5).

We can interpret these higher-order terms by expanding (12). To a first-order approximation around the average value of B_t/D_t (denoted by x_0), we get

$$(\frac{B_t}{D_t})^{\rho-1} \approx x_0^{\rho-1} + x_0^{\rho-1}(\rho-1)\left(\log(\frac{B_t}{D_t}) - \log(x_0)\right). \tag{18}$$

In this case, the coefficient on $\log(B_t/D_t)$ is proportional to $x_0^{\rho-1}(\rho-1)$, and the Nagel (2016) result that supply has no explanatory power for the liquidity premium leads to the conclusion that ρ is not statistically different than one. If we include more terms from the expansion of (17), we find

$$lp_t \propto (1-(\rho-1)\log(x_0)) \cdot \mathrm{VIX}_t i_t + (\rho-1)\cdot \mathrm{VIX}_t \log(\frac{B_t}{D_t}) i_t \tag{19}$$

In column (6) of Table 2, we report a regression based on the higher-order terms in equation (19). Including these interaction terms substantially improves the fit of the model: the R^2 in column (6) is 71%, despite only including two explanatory variables. The coefficients on the triple-interaction term are also significantly negative as the theory suggests. The significant and negative coefficient on the triple-interaction term is robust to including the individual terms, FFR_t, VIX_t, or log(Net Tsy/Deposits) in the regression.

In terms of economics, when $\rho \neq 1$, the interaction terms capture that the marginal impact of a change in the deposit spread depends on the quantity of bonds and deposits. For example, with more bonds outstanding, liquidity premia are smaller and the marginal impact of a change in monetary policy is likewise smaller. The same logic applies in reverse for a change in the quantity of bonds. Thus, including the interaction terms is economically meaningful.

In statistical terms, a linear regression with the federal funds rate and bond supply will ascribe most of the explanatory power for the liquidity premium to the federal funds rate. In the data, there is considerable high frequency variation in both the federal funds rate and the liquidity premium. The maximum value of the federal funds rate is more than 100 times its minimum value. In contrast, the Treasury supply is slow-moving. Thus in a linear regression, it will be difficult to pick-out a relationship between Treasury supply and the liquidity premium. Section 4 makes this point explicit via regressions on simulated data.

We next consider a log specification that can explicitly deal with these interaction effects.

Table 2: The Interaction Effects between Treasury Supply and the Fed Funds Rate

	Dependent variable: liquidity premium					
	(1)	(2)	(3)	(4)	(5)	(6)
FFR_t	10.51		9.68	5.75	4.89	
	(1.01)		(0.88)	(1.23)	(1.42)	
VIX_t	1.13	1.12	1.37	1.36	1.36	
	(0.20)	(0.59)	(0.33)	(0.30)	(0.30)	
$\log(\frac{\text{Net Tsy}_t}{\text{Deposits}_t})$		−45.38	−14.54		10.72	
		(12.98)	(6.01)		(7.43)	
$\mathrm{FFR}_t*\log(\frac{\text{Net Tsy}_t}{\text{Deposits}_t})$				−4.83	−6.31	
				(1.37)	(1.92)	
$\mathrm{VIX}_t*\mathrm{FFR}_t$						0.28
						(0.05)
$\mathrm{VIX}_t*\mathrm{FFR}_t*\log(\frac{\text{Net Tsy}_t}{\text{Deposits}_t})$						−0.26
						(0.05)
Constant	−25.33	−6.52	−33.73	−23.80	−18.80	3.87
	(6.34)	(12.83)	(8.92)	(6.91)	(6.42)	(2.66)
Observations	1,092	996	996	996	996	996
R^2	0.60	0.22	0.64	0.67	0.68	0.71

Notes: Variable explanations are provided in the notes of Table 1. The sample period is 1926–2016 for column 1, and 1934–2016 (restricted by the data coverage of deposits) for column 2–6. HAC standard errors with 12 lags are shown in parentheses.

Taking logs of both sides of (17), we have,

$$\log(lp_t) \propto \log(\text{VIX}_t) + (\rho - 1)\log\left(\frac{B_t}{D_t}\right) + \log(i_t) \tag{20}$$

and we thus estimate a linear regression in logs, with independent variables of VIX_t, $\log\left(\frac{B_t}{D_t}\right)$, and $\log(i_t)$.

Before turning to the results, we offer a word of caution with the log specification. The model prescribes that since Treasury bonds offer more liquidity services than the less liquid repo and Bankers Acceptance, the liquidity premium should be positive. In the data, the liquidity premium is occasionally negative, likely due to measurement error. If this measurement error is additive, then when taking logs, the measurement error blows up for liquidity premia near zero. In the table that follows, we drop observations with a nonpositive liquidity premium. The results are similar if we winsorize nonpositive liquidity premiums. We present a GMM estimation of equation (17) in Section 2.3 that avoids these issues (and significantly improves the model's fit).

The results are shown in Table 3. The supply variables in log terms are highly significant, as can be seen in columns (4) and (5). The R^2 also rises with the inclusion of the supply variables.

From equation (17), the coefficient on the log term of supply corresponds to $\rho - 1$. Thus, for the bank deposit measure, we find that $\rho = 0.42$, with a confidence interval of $[0.27, 0.57]$, while for the broad financial sector debt measure, we find that $\rho = 0.48$, with a confidence interval of $[0.28, 0.68]$. In both cases, the results indicate that money and Treasury bonds are imperfect substitutes. The broad deposit measure also appears to a better substitute for Treasuries. We investigate this possibility further in Section 3.

We also note that the coefficient on log(FFR) is below one, which does not accord with predictions of the theory. There are at least two plausible reasons. One reason is that FFR is not a perfect proxy of the actual deposit liquidity value (i.e. the deposit spread), and the classical measurement-error problem leads to an attenuation bias. Indeed, despite the high R^2 in using the FFR to proxy for the deposit spread, the standard deviation of the residual error is about 48 basis points. The other reason is that we have winsorized or eliminated negative liquidity premium, and this approach tends to shrink the coefficients. The first issue is not a major concern for us since we are focused on estimating ρ, which is not affected by a measurement error on $i_t - i_t^d$ as long as it is orthogonal to the quantity ratio. The second issue is more problematic, since the same bias may appear in the coefficient of log(bond/deposit). A formal way to address the second problem is to use GMM and estimate (17) directly. We follow this approach in Section 2.3.

Table 3: Log Regressions Using Different Debt/Deposits Measures

	Dependent variable:				
	(1)	(2)	(3)	(4)	(5)
$\log(\text{FFR}_t)$	0.58			0.48	0.52
	(0.08)			(0.08)	(0.09)
$\log(\text{VIX}_t)$	0.63	0.52	0.07	0.73	0.47
	(0.16)	(0.26)	(0.19)	(0.22)	(0.17)
$\log(\frac{\text{Net Tsy}_t}{\text{Deposits}_t})$		−1.14		−0.58	
		(0.23)		(0.15)	
$\log(\frac{\text{Net Tsy}_t}{\text{KVJ Deposits}_t})$			−1.23		−0.52
			(0.22)		(0.20)
Constant	−3.76	−3.48	−2.75	−4.24	−3.77
	(0.51)	(0.77)	(0.55)	(0.66)	(0.49)
Observations	996	903	974	903	974
R^2	0.40	0.25	0.28	0.46	0.46

Notes: "KVJ deposits" are the amount of financial sector short-term liabilities as in Krishnamurthy and Vissing-Jorgensen (2015). Other variable explanations are provided in the notes of Table 1. The main sample period is 1926–2016, but shrinks when data availability is constrained by dependent variables. HAC standard errors with 12 lags are shown in parentheses.

2.2. Instrumental Variables Estimation

The results we have presented are subject to an endogeneity concern. Both the net Treasury supply and bank deposits reflect choices of banks, that are plausibly driven by the liquidity premium. Thus, OLS will lead to a biased estimate of ρ, and we need an instrument. We first present regressions using the total supply of Treasuries, set by fiscal policy, as the instrument. It is unlikely that this total supply responds to the liquidity premium, so that the endogeneity concern is allayed with this instrument. There is still a possibility of omitted variable bias, to the extent that both fiscal policy and changes in liquidity demand are correlated with the business cycle. We follow Greenwood, Hanson and Stein (2015) and Nagel (2016) by running a difference specification where we use seasonal variation in tax receipts as an instrument for Treasury supply, and using changes in Federal Funds future as an instrument for monetary policy shocks.

Table 4 presents the results using Total Treasury/GDP and log(Total Treasury/GDP) as the instruments for the quantity ratios. Note that while we have argued that this regressor is not the appropriate measure for the non-bank holdings of Treasury securities in equation (12), it is the regressor used in Nagel (2016). The first stage in the instrumental variables regression, reported in the appendix establishes relevance: shifts in total Treasury supply strongly correlate with shifts in the debt-to-deposits ratio and the F-statistic is well above 10. We use both $\log(\text{Total Tsy}_t/\text{GDP}_t)$ and $\text{Total Tsy}_t/\text{GDP}_t$ as instruments to capture a non-linear relationship in the first-stage.

Panel A of the table presents the log specification. Columns (1) and (2) are the same OLS regressions as columns (4) and (5) of Table 3. Columns (3) and (4) present the IV. The estimate of ρ is 0.21 in column (3), with a one standard-error range of $[-0.11, 0.53]$. The estimate in column (4) is 0.61 with a range of $[0.39, 0.83]$. The broader deposit measure is a closer Treasury substitute than the narrow deposit measure.

Panel B of the table presents the regression in levels, akin to Nagel (2016). We primarily note that these IV regressions support the existence of a supply effect for the liquidity premium, in contrast to the result from that paper.

We next follow Greenwood, Hanson and Stein (2015) and construct an instrument using monthly dummies that capture the strong cyclical variations in T-bill supply. As these authors show, the cyclicality is driven by calendar cycles in tax receipts. The instrument can additionally deal with any omitted variable biases in our estimation. Furthermore, we instrument FFR changes with expected changes from the federal funds futures market as in Nagel (2016). Specifically, we take average price difference in month $t-2$ of federal funds futures for month $t-1$ and t to instrument for the actual changes of FFR from $t-1$ to t. The results are in Table 5. These regression results use the monthly differences of variables

Table 4: OLS and IV Regressions in Logs

Panel A:	*Dependent variable:* log(liquidity premium$_t$)			
	OLS		IV	
	(1)	(2)	(3)	(4)
log(FFR$_t$)	0.48	0.52	0.44	0.55
	(0.08)	(0.09)	(0.10)	(0.09)
$\log(\frac{\text{Net Tsy}_t}{\text{Deposits}_t})$	−0.58		−0.79	
	(0.15)		(0.32)	
$\log(\frac{\text{Net Tsy}_t}{\text{KVJ Deposits}_t})$		−0.52		−0.39
		(0.20)		(0.22)
log(VIX$_t$)	0.73	0.47	0.73	0.52
	(0.22)	(0.17)	(0.23)	(0.17)
Observations	903	974	903	974
R^2	0.45	0.46	0.43	0.46

Panel B:	*Dependent variable:* liquidity premium$_t$			
	OLS		IV	
	(1)	(2)	(3)	(4)
FFR$_t$	0.09	0.10	0.20	0.19
	(0.01)	(0.01)	(0.03)	(0.03)
$\log(\frac{\text{Net Tsy}_t}{\text{Deposits}_t})$	−0.19		−0.36	
	(0.06)		(0.26)	
$\log(\frac{\text{Net Tsy}_t}{\text{KVJ Deposits}_t})$		−0.05		−0.39
		(0.05)		(0.19)
VIX$_t$	0.01	0.01	0.02	0.02
	(0.003)	(0.002)	(0.01)	(0.01)
Observations	903	974	903	974
R^2	0.63	0.60	0.54	0.52

Notes: "KVJ deposits" are the amount of financial sector short-term liabilities as in Krishnamurthy and Vissing-Jorgensen (2012). Other variable explanations are provided in the notes of Table 1. We instrument log(Debt/Deposits) by log(Total Tsy/GDP) and (Total Tsy/GDP) in columns (3) and (4). The main sample period is 1934–2016, while the availability of deposits data can shrink the sample size. HAC standard errors with 12 lags are shown in parentheses.

given the nature of the instrument. The first stage in these regressions is reported in the appendix.

Panel B in the table replicates Table IV in Nagel (2016). For comparison, we only use data from 1991 to 2011, and use T-bill/GDP as the quantity measure. Both OLS and IV results are quite similar to Nagel (2016), although there are slight discrepancies that we have not been able to resolve. The general pattern is that the change in the quantity is highly significant in both the OLS and IV regressions, but the coefficients are larger in the IV regressions. This difference is plausibly due to the omitted variable concern: in a crisis, Treasury supply expands and liquidity premia rise, giving rise to a positive relation between supply and liquidity premia in the OLS regressions. The instrument deals with this issue and recovers the true relation, which is more negative than the OLS result.

In Panel A, we follow our theoretical model and use the ratio of Treasuries to deposits as the quantity measure, while continuing to use the same instruments. We note again the strong statistical significance of the quantity variable, and the larger-magnitude coefficient on the IV result compared to the OLS result.

2.3. GMM Estimation

We next turn to a GMM estimation of the model. The GMM results are broadly consistent with the results we have presented thus far, indicating a value of ρ slightly larger than one-half. Additionally, the standard errors of the estimate of ρ are lower, while the regression R^2s are higher than our earlier specifications. As we show via simulation in Section 4, the GMM estimation has more power than the other approaches we have presented.

The optimality condition of the representative investor in the model gives equation (12). Under the assumption that the model describes the liquidity premium and that the residual represents a measurement error, instruments for the GMM may include s_t, VIX_t, B_t/D_t, and the constant 1, which are in the information set of the investor at date t. Therefore, the moment conditions are:

$$E[\varepsilon_t \cdot \begin{pmatrix} s_t \\ \text{VIX}_t \\ B_t/D_t \\ 1 \end{pmatrix}] = 0. \tag{21}$$

There are two parameters (β_λ, ρ) to be estimated while there are four moment conditions. Therefore, the above orthogonality conditions result in an over-identified system. We check the model fit with the standard GMM J-test.

Given the bias concern with the OLS regressions, it is possible that the measurement error

Table 5: Difference Regressions: OLS and IV.

Panel A: *Dependent variable: Δliquidity premium$_t$*

	OLS				*IV*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ΔFFR_t	9.56		7.06	9.40	8.61		6.60	8.48
	(3.86)		(3.38)	(4.44)	(3.43)		(3.38)	(3.40)
$\Delta \log(\frac{\text{T-bill}_t}{\text{Deposits}_t})$		-52.18	-45.73	-42.32		-105.98	-103.46	-89.32
		(16.05)	(17.75)	(17.89)		(24.47)	(25.56)	(28.19)
$\Delta \log(\frac{\text{T-bill}_{t-1}}{\text{Deposits}_{t-1}})$				51.49				95.64
				(17.99)				(27.97)
ΔVIX_t	0.52	0.62	0.61	0.56				
	(0.18)	(0.22)	(0.22)	(0.19)				
R^2	0.08	0.10	0.11	0.16				
Weak instruments test								
CD statistic					17.12	11.4	10.74	8.27
Critical value					6.56	6.56	6.23	5.87
Observations	247	247	247	246	246	246	246	246

Panel B: Replication of Table IV in Nagel (2016)

	OLS				*IV*			
ΔFFR_t	9.56		6.79	9.84	8.61		6.30	10.60
	(3.86)		(3.35)	(4.39)	(3.43)		(3.29)	(3.52)
$\Delta \log(\frac{\text{T-bill}_t}{\text{GDP}_t})$		-50.11	-43.38	-39.34		-89.84	-86.96	-79.22
		(15.24)	(16.70)	(17.28)		(22.76)	(23.92)	(24.67)
$\Delta \log(\frac{\text{T-bill}_{t-1}}{\text{GDP}_{t-1}})$				51.32				56.64
				(16.63)				(18.66)
ΔVIX_t	0.52	0.62	0.60	0.56				
	(0.18)	(0.22)	(0.22)	(0.19)				
R^2	0.08	0.10	0.11	0.16				
Weak instruments test								
CD statistic					17.12	12.36	11.5	8.69
Critical value					6.56	6.56	6.23	5.87
Observations	247	247	247	246	246	246	246	246

Notes: T-bill is the total value of T-bills outstanding. Definitions of other variables are provided in the notes of Table 1. Data are at monthly frequency and limited to the range 1991–2011 to be comparable with Nagel (2016). In the weak instrument tests, a higher Crag-Donald statistic means that the instrument is less likely to be weak. The critical values for the tests are from Table I of Stock and Yogo (2002). Newey West standard errors with 12 lags are reported in the parentheses.

Table 6: GMM Estimation of ρ

	Measurement of B/D			
	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$
	(1)	(2)	(3)	(4)
ρ	0.632	0.681	0.664	0.601
	(0.099)	(0.213)	(0.159)	(0.184)
β_λ	0.011	0.010	0.012	0.009
	(0.001)	(0.003)	(0.002)	(0.002)
p-value of J-test	0.712	0.689	0.934	0.814
Total Treasury IV?	No	No	Yes	Yes
Variations explained	70.2%	68.6%	70%	69.2%
Observations	996	972	996	972

Notes: KVJ deposits is the measure of financial sector short-term liabilities in Krishnamurthy and Vissing-Jorgensen (2012). Refer to Table 1 for other variable definitions. In column (1) and (2), we estimate the GMM system as in equation (21). In column (3) and (4), we use Total Tsy/GDP and (Total Tsy/GDP)^2 as instruments instead of the B_t/D_t ratio, i.e., we replace the moment

$$E[(B_t/D_t)\cdot\varepsilon_t]=0$$

by

$$E[(\text{Total Tsy}_t/\text{GDP}_t)\cdot\varepsilon_t]=0$$
$$E[(\text{Total Tsy}_t/\text{GDP}_t)^2\cdot\varepsilon_t]=0$$

HAC standard errors with 12 lags are reported in parentheses.

is not orthogonal to B_t/D_t. For example, a liquidity demand shock that is not captured by changes in VIX will lead to a misspecified estimation equation, and if the banking sector's Treasury holdings and deposit issuance are a function of this demand shock, the measurement error will not be orthogonal to B_t/D_t. To deal with this concern, we follow our earlier IV strategy and use Total Treasury Supply/GDP (which is not a function of bank holdings), and its square, as instruments in place of B_t/D_t.

Results are shown in Table 6. We apply the two-step GMM method and a heteroskedasticity and autocorrelation consistent (HAC) residual covariance structure of 12 lags. The model fits the data well, as the J-tests have large p-values.

The estimates of ρ are around 0.6, consistent with earlier estimates. There are no statistically significant differences across the four specifications in the table, and the instruments have no detectable effect on the estimate of ρ. This last point is perhaps not surprising given that the regression R^2 is about 70%, so the likelihood of model measurement error is also low. All of the estimates are statistically different from both zero and one. Thus, we conclude that both bank money and the broad financial sector debt measure are imperfect substitutes for Treasuries.

We also note that the non-linear model fits the data much better than the log-linear model of the previous sections as well as the model of Nagel (2016). We get an R^2 of around 45% in the log-linear model. This fit is far worse than the $R^2 = 70.2\%$ from the non-linear model. Therefore, the GMM estimation captures meaningful variation in the liquidity premium that is missed by the log-linear model.

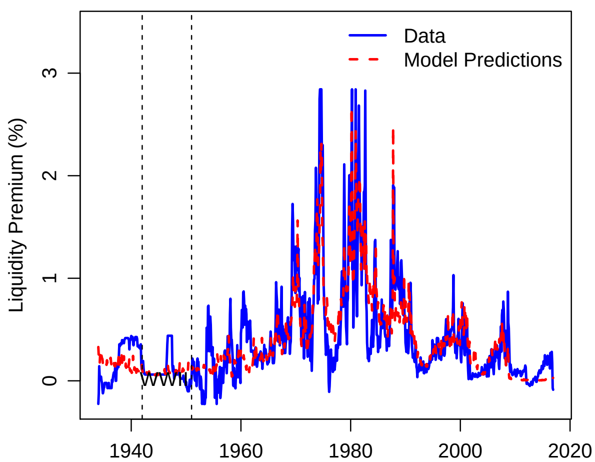
Table 7: Model Explanatory Power from Different Components

Model Inputs	Fractions of Variations Explained
Only Net Tsy/Deposits	11.1%
Only FFR	57.1%
Only VIX	0.0%
Net Tsy/Deposits + FFR	63.4 %
Net Tsy/Deposits + VIX	12.1 %
FFR + VIX	63.0%
Full Model	70.2%

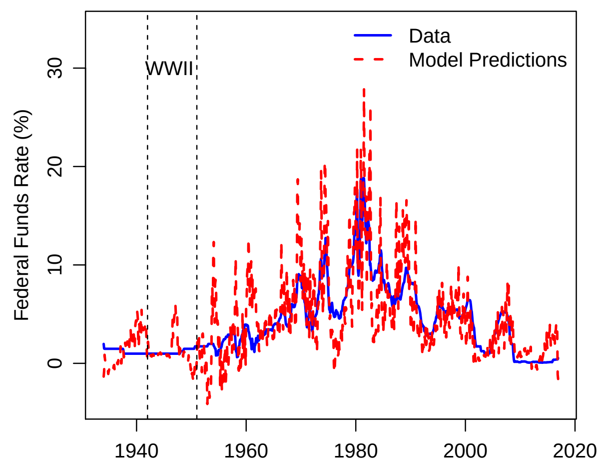
Notes: Refer to Table 1 for variable definitions. We calculate the variations explained by various model components, using parameters estimated from column (1) of Table 6. For example, in the first case, among the input data, we set VIX_t and s_t to their mean values and only allow the variations in B_t/D_t. Then we calculate the fraction of variation explained by these partial inputs.

To provide a sense for how much each component of the model contributes to the explanatory power of the liquidity premium, we list the explained fraction of variation due to different model components in Table 7. The fraction of variation is calculated as 1 - residual variance / total variance. With only Net Treasury/Deposits data as inputs (FFR and VIX are set as their time-series averages, respectively), the fraction of variation explained is 11.1%. With both Net Treasury/Deposits and FFR, the model explains 63.4% of the liquidity premium variation. With all of the independent variables, the model explains 70.2% of the variation in the liquidity premium.

In the left panel of Figure 4, we plot the model generated liquidity premium using all three explanatory variables as well as the actual liquidity premium. The federal funds rate component of the model in equation (12) helps explain the high-frequency ups and downs, while the quantity of Treasuries/deposits modifies the general shape of the predicted liquidity premium and helps explain the liquidity premium at a low frequency. Finally, the variation in VIX, capturing the flight-to-quality effects, help explain spikes in the liquidity premium. The right panel of the Figure plots the model predicted federal funds rate, using the liquidity premium, VIX, and the supply variable as explanatory variables. The model fit is also quite good for the federal funds rate. A point worth making is that the fit, estimated over the entire sample, works as well pre-1980 as post-1980. The fit for the federal funds rate suggests that our model may help lead to a stable estimate for money demand. We explore this possibility in Section 3.



(a) Liquidity Premium



(b) FFR

Fig. 4. **Model Predictions versus Data.** This figure compares the model predicted Treasury liquidity premium and federal funds rate versus the data counterparts. The model generates the liquidity premium as $lp_t = s_t \beta_\lambda \mathrm{VIX}_t (B_t/D_t)^{\rho-1}$, where s_t is the deposits spread, VIX_t is the constructed VIX, B_t/D_t is the Treasury/deposits ratio, and (β_λ, ρ) are set to the estimated values in column 3 of Table 6. The model generates the federal funds rate as $r_t = lp_t / \left(\beta_\lambda \mathrm{VIX}_t (B_t/D_t)^{\rho-1}\right)/\delta$, where δ is the projection coefficient of deposits spread on FFR.

The λ_t in the model measures the liquidity services provided by one unit of Treasury bonds, while $1 - \lambda_t$ measures the liquidity services provided by one unit of bank deposits. Given that deposits are generally perceived as a more convenient form of transactions, we may expect that the share of Treasury liquidity should be below 50%, i.e., $\lambda_t < 50\%$. In Figure 5, we plot the estimated λ_t, which comes from the measurement equation

$$\frac{\lambda_t}{1 - \lambda_t} = \beta_\lambda \mathrm{VIX}_t \tag{22}$$

using the estimated $\beta_\lambda = 0.012$. As shown in Figure 5, despite the sizable variation in the liquidity premium, the measured λ_t is never above 0.5, consistent with our assertion.

The 10-year moving average of measured λ_t is also quite stable. Over the entire sample, λ_t averages 0.174.

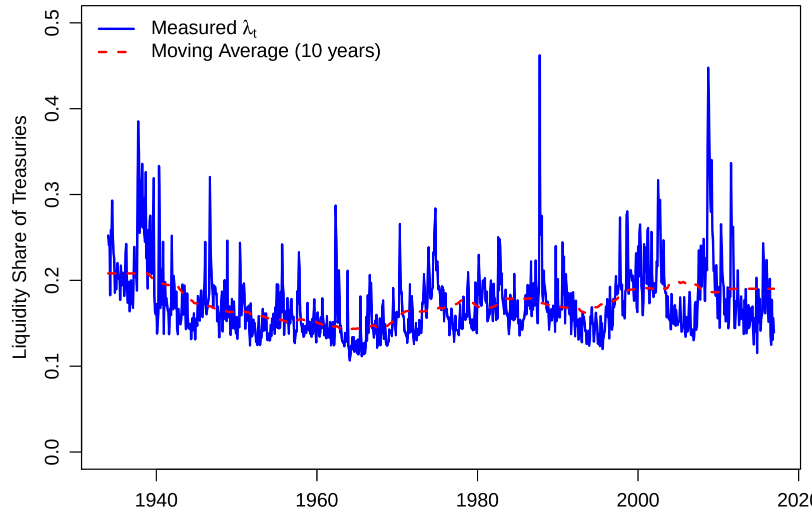


Fig. 5. The Liquidity Share of Treasuries (λ_t in the model)

2.4. Subsample Analyses

We present results for different subsamples in Table 8. In columns (1) and (2), we drop the WWII period where we have noted that the Fed played an unusually large role in setting prices in the money market. In columns (3) and (4), we consider only the sample post Fed-Treasury accord of 1951. This regression also drops the period surrounding the Great Depression. In columns (5) and (6), we consider only the sample after 1980, with the ending of Regulation Q. We present results for both measures of money. The analysis paints a consistent picture: the value of ρ is around 0.6 across samples and for both measures of deposits.

3. Money, Near-Money, and Bonds

In this section, we expand our results in two directions. First, we consider how to expand our estimation to incorporate other assets that provide liquidity services. Our results here should be seen as a step in the direction of tracing out the full set of assets that provide liquidity services. Second, we use these results to construct a new monetary aggregate and revisit existing questions regarding the stability of the money demand equation.

Table 8: Subsample Analyses

	No WWII		Post Accord		Post 1980	
	Measure of B/D					
	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$
	(1)	(2)	(3)	(4)	(5)	(6)
ρ	0.639	0.592	0.624	0.542	0.638	0.584
	(0.141)	(0.174)	(0.122)	(0.157)	(0.118)	(0.163)
β_λ	0.012	0.009	0.011	0.009	0.011	0.009
	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)
p-value of J-test	0.728	0.794	0.669	0.73	0.1	0.062
Variations explained	69.1%	68%	70.4%	69.5%	67.6%	67.6%
Observations	876	852	780	756	432	408

Notes: This table shows subsample GMM estimations of parameters ρ and β_λ. Columns of "No WWII" excludes the period around WWII (1942–1951), and columns of "Post Accord" restrict the sample to post-1951. In all columns, we use total Treasury/deposits and (total Treasury/deposits)^2 as instruments in place of B/D. HAC standard errors with 12 lags are reported in parentheses.

3.1. Near Money

We have shown that Treasuries and bank deposits are imperfect substitutes, providing different liquidity services. Where do other money-market assets fall? In earlier sections, we report that the coefficient estimate for ρ for KVJ-deposits was somewhat higher than for bank deposits. The KVJ-deposit measure includes assets such as money market funds, repos, commercial paper, and GSE debt. These are likely more similar to Treasury bonds than traditional transaction deposits. In this section, we investigate a nested demand system that places Treasury bonds and non-bank debt in an inner layer, and bank deposits in the outer layer.

Agents derive utility over C_t and Q_t as in our baseline model, but we redefine Q_t. The aggregate liquidity bundle is,

$$Q'_t = \left((1-\lambda_t)(\frac{D_t}{P_t})^\rho + \lambda_t(\frac{B'_t}{P_t})^\rho\right)^{\frac{1}{\rho}}. \tag{23}$$

where,

$$B'_t = \left((1-\mu_t)\cdot\left(D_t^{NB}\right)^\eta + \mu_t \cdot B_t^\eta\right)^{1/\eta}. \tag{24}$$

Here D_t is the total amount of deposits as defined in previous sections, B'_t is the amount of "composite bonds", which is a CES aggregator over non-bank deposits, D^{NB}_t, and Treasuries, B_t. We measure D_t as checking, savings, and time deposits. We measure D^{NB}_t as KVJ-deposits minus D_t.

Denote the yield on Treasury bonds as i^{Tsy}_t and the yield on non-bank deposits as i^{NB}_t. Then the first order condition over Treasury bonds and non-bank deposits implies,

$$i_t - i^{\text{Tsy}}_t = \frac{\mu_t}{1-\mu_t}(\frac{B_t}{D^{NB}_t})^{\eta-1}(i_t - i^{NB}_t). \tag{25}$$

Using the notation $\ell^{\text{Tsy}}_t = i_t - i^{\text{Tsy}}_t$ and $\ell^{NB}_t = i_t - i^{NB}_t$, we can rewrite this equation as,

$$\ell^{\text{Tsy}}_t = \frac{\mu_t}{1-\mu_t}(\frac{B_t}{D^{NB}_t})^{\eta-1}\ell^{NB}_t. \tag{26}$$

Moreover, we define the liquidity premium index for the bundled "bond" as

$$\ell^B_t = \left((1-\mu_t)^{-\frac{1}{\eta-1}}\left(\ell^{NB}_t\right)^{\frac{\eta}{\eta-1}} + \mu_t^{-\frac{1}{\eta-1}}\left(\ell^{\text{Tsy}}_t\right)^{\frac{\eta}{\eta-1}}\right)^{(\eta-1)/\eta} \tag{27}$$

With this definition, then we arrive at another estimation equation:

$$\ell^B_t = \frac{\lambda_t}{1-\lambda_t}(\frac{B'_t}{D_t})^{\rho-1}\ell^D_t \tag{28}$$

We proxy for the relative demand ratio, $\lambda_t/(1-\lambda_t)$ and $\mu_t/(1-\mu_t)$ using VIX:

$$\frac{\lambda_t}{1-\lambda_t} \approx \beta_\lambda \text{VIX}_t$$

$$\frac{\mu_t}{1-\mu_t} \approx \beta_\mu \text{VIX}_t$$

In total, we need to estimate four parameters, ρ, η, β_λ, and β_μ. We estimate these parameters from the equation system (26), (27), and (28).

For estimation purpose, we denote data with tilde and write the estimation versions of (26), (27), and (28) as

$$\tilde{\ell}^{\text{Tsy}}_t = \frac{\mu_t}{1-\mu_t}(\frac{B_t}{D^{NB}_t})^{\eta-1}\tilde{\ell}^{NB}_t + \varepsilon^{\text{Tsy}}_t \tag{29}$$

$$\tilde{\ell}^B_t = \left((1-\mu_t)^{-\frac{1}{\eta-1}}\left(\tilde{\ell}^{NB}_t\right)^{\frac{\eta}{\eta-1}} + \mu_t^{-\frac{1}{\eta-1}}\left(\tilde{\ell}^{\text{Tsy}}_t\right)^{\frac{\eta}{\eta-1}}\right)^{(\eta-1)/\eta} \tag{30}$$

$$\tilde{\ell}^B_t = \frac{\lambda_t}{1-\lambda_t}(\frac{B'_t}{D_t})^{\rho-1}\tilde{\ell}^D_t + \varepsilon^B_t \tag{31}$$

The moment conditions are:

$$E[\begin{pmatrix} \mu_t \\ B_t/D_t^{NB} \\ \ell_t^{NB} \\ 1 \end{pmatrix} \varepsilon_t^{\text{Tsy}}] = 0 \tag{32}$$

$$E[\begin{pmatrix} \lambda_t \\ B_t'/D_t \\ \ell_t^{D} \\ 1 \end{pmatrix} \varepsilon_t^{B}] = 0 \tag{33}$$

We also redefine the measures of the liquidity premium. In previous sections, we measure the Treasury liquidity premium as the spread between repo (and Banker's Acceptances) and Treasuries. However, to the extent that repo is also priced to reflect liquidity services, repo rates will also reflect a liquidity premium, and this measure will underestimate the full Treasury liquidity premium. We use P2-rated commercial paper (P2CP) as the benchmark rate for an asset that does not offer any liquidity services, and construct the Treasury liquidity premium as the spread between 90-day P2CP and 90-day Treasury bills. Note that a disadvantage of using this spread is that it will also reflect credit risk and thus adds some noise to our estimation procedure. This is one reason that we have used repo rates as the benchmark in previous sections. The other reason is that P2CP data is only available monthly from 1974 onwards. We obtain this data from the Federal Reserve.

We measure the Treasury liquidity premium as the spread between 90-day P2CP rate and 90-day T-bill rate.

We construct the non-bank deposit liquidity premium in two different ways:

- The spread between 90-day P2-rated commercial paper (P2CP) and 90-day P1-rated (or "AA-rated") commercial paper (P1CP).
- The spread between 90-day P2CP rate and the average money-market mutual fund (MMF) rate.

The MMF rate data are from Xiao (2020) at a monthly frequency. The MMF data are only available from 1987. Additionally, while the P2CP-P1CP spread is always positive, the P2CP-MMF rate has three negative observations in our sample, likely due to measurement error. We set these observations to zero so that the liquidity premium index in (27) is well-defined.

We measure the deposit spread in a similar manner as in earlier sections. We first regress the P2CP-deposit spread (the spread between 90-day P2CP rate and the average deposit rate) on the federal funds rate using the data we have on the deposit spread post-1987. We use the regression result to project the deposit spread for the entire period, including the pre-1987 period. The projection approach also guarantees that the deposit spread remains positive. [11]

As a first step, we estimate the "inner CES aggregator" between Treasuries and non-bank deposits, as specified by equation (32). As in other specifications, we instrument the quantity ratio moment by total Treasury/GDP and (total Treasury/GDP)^2 to alleviate endogeneity concerns.

Results are reported in Table 9. We see that the estimated values of η in different specifications are quite close to one, i.e., perfect substitutes. The value of $\eta = 1$ for the MMF regression arises because we restrict that $\eta \leq 1$ in our estimation. Otherwise, the results do not depend on the choice of spread or instruments.

Table 9: GMM Estimation of the Substitution Between Non-bank Deposits and Treasuries

	Measurement of non-bank liquidity premium			
	P2CP−P1CP	P2CP−MMF	P2CP−P1CP	P2CP−MMF
	(1)	(2)	(3)	(4)
η	0.873	1.000	0.911	1.000
	(0.151)	(0.178)	(0.159)	(0.141)
β_μ	0.120	0.041	0.113	0.042
	(0.016)	(0.002)	(0.015)	(0.002)
Variation Explained	51.4%	70.7%	50.8%	70.7%
Total Treasury IV?	No	No	Yes	Yes
Observations	462	306	462	306

Notes: This table shows the GMM estimations of parameters η and β_μ. The GMM specifications is in (32). We restrict $\eta \leq 1$ in the estimation so the results will be economically meaningful. In column (3) and (4), we instrument quantity ratio by total Treasury/GDP and (total Treasury/GDP)^2. HAC standard errors with 12 lags are reported in parentheses.

Next, we turn to the full model, described by the four parameters, η, ρ, β_μ, and β_λ, estimated from the moment conditions in (32) and (33). Because the results may be sensitive

[11] Figure 10 of the Appendix plots the deposit volumes, along with the volume of MMF outstanding, as well as the measures of the liquidity premia based on P2CP.

to the initial conditions for the GMM minimization algorithm, we use all permutations of point estimates from Table 9 and Table 6 (in total there are 4×4=16 different combinations) as initial values for the GMM algorithm and select the result that minimizes the GMM objective function. The estimation results are in Table 10. We find a value of η near one across all the specifications, consistent with the results in Table 9. The standard errors of estimated η are tight for all of the specifications. The estimated values of ρ are a little lower than the 0.6 of earlier estimates, but this difference is not statistically significant. Additionally, the standard errors are much wider in the versions where we use total Treasury as instruments. Note that our estimation of the more complicated model of this section is based on a shorter sample than earlier results. The table also reports goodness of fit measures for both of the liquidity premia explained by the model, the Treasury liquidity premium and the liquidity premium on the bundled bond (equation(31)).

Table 10: GMM Estimation of the Nested Model

	Measurement of non-bank liquidity premium			
	P2CP−P1CP	P2CP−MMF	P2CP−P1CP	P2CP−MMF
	(1)	(2)	(3)	(4)
ρ	0.628	0.566	0.632	0.655
	(0.173)	(0.237)	(0.548)	(0.466)
β_λ	0.024	0.042	0.011	0.043
	(0.002)	(0.003)	(0.002)	(0.003)
η	0.764	0.997	0.873	0.997
	(0.105)	(0.081)	(0.090)	(0.056)
β_μ	0.094	0.039	0.120	0.035
	(0.007)	(0.001)	(0.006)	(0.001)
Total Treasury IVs?	No	No	Yes	Yes
R^2 for Tsy Liq Prem	0.66	0.53	0.64	0.53
R^2 for Q' Liq Prem	0.47	0.29	0.5	0.28
Observations	486	306	486	306

Notes: This table shows the GMM estimations of parameters ρ, β_λ, η, and β_μ. The GMM specifications are in (32) and (33). In column 3 and 4, we instrument quantity ratios ($\text{Tsy}_t/\text{non-bank}_t$ and B_t/D_t) by total Treasury/GDP and (total Treasury/GDP)^2. We report the R^2 fit of both the Treasury liquidity premium (equation (29)) and the composite bonds premium (equation (31)). HAC standard errors with 12 lags are reported in parentheses.

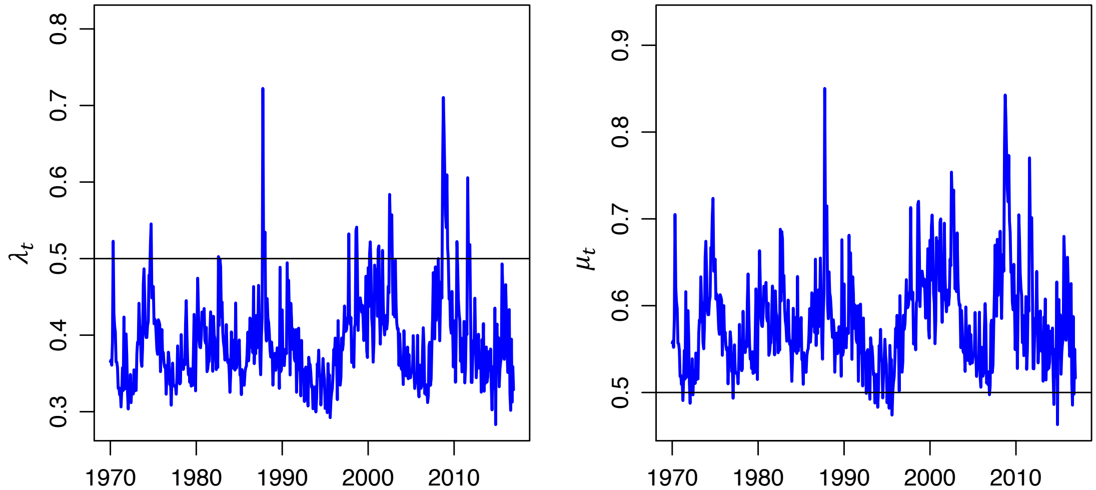


Fig. 6. Time Series of Estimated Relative Liquidity

Next, we use the estimated coefficients from column (1) of Table 10, β_λ and β_μ, and plot the implied λ_t and μ_t series in Figure 6:

$$\lambda_t = \frac{\beta_\lambda \text{VIX}_t}{1 + \beta_\lambda \text{VIX}_t}$$

$$\mu_t = \frac{\beta_\mu \text{VIX}_t}{1 + \beta_\mu \text{VIX}_t}.$$

Here λ_t measures the relative liquidity per-unit-of-asset of composite bonds and deposits. Similarly, μ_t measures the relative liquidity Treasures and non-bank deposits. From Figure 6, we see that most of the time $\lambda_t < 0.5$ with an average value of 0.35, so the composite bonds offer less liquidity compared to deposits. On the other hand, $\mu_t > 0.5$ in the majority of periods with an average value of 0.56, indicating that Treasuries offer more liquidity services compared to non-bank deposits.

3.2. *A new liquidity aggregate*

There is a large literature estimating money-demand equations, in which a measure of money (typically M1/P or M2/P) is regressed against the opportunity cost of money (typically the nominal commercial paper rate) and GDP. The literature aims to measure the interest-rate and income elasticity of money demand. See Goldfeld and Sichel (1990)'s chapter in the Handbook of Monetary Economics. The literature is interested in these elasticity estimates because they are needed to answer questions such as, what is the optimal growth rate of money, and, what is the welfare cost of inflation (e.g., see Lucas (2001)). Many authors have commented on the instability of traditional money demand functions (see Goldfeld and Sichel (1990), Teles and Zhou (2005), Lucas and Nicolini (2015)). The finding in the literature is that while there is a stable relation between real money demand, the nominal interest rate, and real income, in the period before 1980, this relation breaks down post-1980. The most prominent puzzle in the literature is the "missing money" of the post-1980 period, when interest rates fell and money balances rose, but not as strongly as earlier estimates would have predicted. Resolutions of this puzzle have centered on recognizing that, prompted by the banking deregulation of the 1980s, a broader set of assets than checkable deposits offer monetary services. Teles and Zhou (2005) and Lucas and Nicolini (2015) expand the definition of money to include money market deposit accounts and measure the interest rate spread on these accounts as the opportunity cost of money. They show that growth in these accounts are the "missing-money" from other estimates, and including these accounts leads to a stable money-demand curve. Krishnamurthy and Vissing-jorgensen (2013) note that accounting for the impact of Treasury supply on bank money may help with the missing money puzzle.

In this section, we construct a new broad liquidity aggregate based on our analysis and show that the demand for this aggregate is stable despite financial innovation. Our approach is similar to Teles and Zhou (2005) and Lucas and Nicolini (2015) in that we broaden the monetary aggregate. We are different in that we consider Treasury bonds along with the KVJ measure of non-bank deposits as the new components of the monetary aggregate. We also drop currency from the aggregate, in keeping with our focus on traded financial assets. The appendix reports results where we include currency. Finally, and central to the results of this paper, we allow that these assets may be imperfect substitutes.

We specialize the model to a functional form that is common in the monetary economics literature:

$$u(C_t, Q_t) = \frac{C_t^{1-\gamma_C}}{1-\gamma_C} + \frac{Q_t^{1-\gamma_Q}}{1-\gamma_Q} \tag{34}$$

Then the FOC for the deposit spread (for $\rho \neq 0$) gives,

$$\log\left(\frac{i_t - i_t^d}{1+i_t}\right) = \gamma_C \log(C_t) - (1-\rho)\log\left(\frac{D_t}{P_t}\right) + \frac{1}{\rho}(1-\rho-\rho\gamma_Q)\log(Q_t) + \log(1-\lambda_t)\,. \tag{35}$$

We rewrite this equation to describe the demand over the liquidity aggregate, Q_t:

$$\frac{1}{\rho}(\gamma_Q + \rho - 1)\log(Q_t) = -\log\left(\frac{i_t - i_t^d}{1+i_t}\right) + \gamma_C \log(C_t) - (1-\rho)\log\left(\frac{D_t}{P_t}\right) + \log(1-\lambda_t)\,. \tag{36}$$

We note the typical case studied in the money-demand literature sets $Q_t = m_t$ (real value of money) and omits ρ, in which case equation (35) is:

$$\gamma_Q \log(m_t) = -\log\left(\frac{i_t - i_t^d}{1+i_t}\right) + \gamma_C \log(C_t) \tag{37}$$

The literature typically runs regressions of $\log(m_t/\text{real GDP}_t)$ on $\log((i_t - i_t^d)/(1+i_t))$ and $\log(\text{real GDP}_t)$ in order to estimate γ_Q and γ_C.

We construct two monetary aggregates, Q_t and Q'_t. The first aggregate is from our baseline, defining Q_t as in (6), with B_t equal to net Treasury supply, D_t is the deposit measure, and ρ set to be 0.60, which is the common value across our different specifications. We construct the aggregate with λ_t varying over time with VIX. The second aggregate is based on the nested specification, defining Q'_t as in (23) and using the average value of ρ and η from our nested estimations in Table 10 to construct Q'_t. We again consider time-varying weights for μ and λ.[12]

The first and second columns of Table 11 present the instability finding in the literature. We regress the log of real money balances to GDP, where money is measured as M1 (currency and checking deposits), on the log of the deposit spread and the log of real GDP. The estimate for the interest elasticity in the first row changes considerably from the pre-1980 sample to the post-1980 sample, in line with the instability finding in the literature. The first panel of Figure 7 presents a scatter plot annual averages of $\log(m_t/\text{real GDP}_t)$ against the $\log(\text{spread}_t)$. As the spread falls in the post-1980 sample, we would have expected based on the pre-1980 results that money balances would have risen. But they do not, resulting in the "missing money" puzzle.

Our results illustrated in Panels (b) and (c) of Figure 7 indicate that the expanded liquidity aggregates, Q and Q', help resolve the missing money puzzle. Columns (3) through (6) of Table 11 present these results in regression form. We note that the interest rate elasticity of money demand is now quite similar across the two sub-samples for both liquidity aggregates. From columns (3) and (4), we see that the income elasticity however still changes across the sub-samples, going from roughly unit elasticity (note that our LHS in the regression is $Q_t/\text{real GDP}_t$ so the income elasticity is one plus the coefficient on $\log(\text{real GDP}_t)$) in the pre-1980 sample to 0.64 in the post-1980 sample.

In the appendix, we also report the impact of including currency in our new monetary aggregates. We include currency in D_t and otherwise aggregate non-bank debt and Treasury bonds following the same procedure. The results are consistent with those we report in this

[12]The Appendix reports these results where we construct Q_t and Q'_t based on holding μ and λ constant over time.

Table 11: Money Demand Regressions

	Dependent variable:					
	$\log(m_t/\text{real GDP}_t)$		$\log(Q_t/\text{real GDP}_t)$		$\log(Q'_t/\text{real GDP}_t)$	
	pre 1980 (1)	post 1980 (2)	pre 1980 (3)	post 1980 (4)	pre 1980 (5)	post 1980 (6)
$\log(\frac{\text{deposit spread}_t}{1+i_t})$	-0.317	-0.087	-0.094	-0.117	-0.065	-0.099
	(0.012)	(0.006)	(0.008)	(0.004)	(0.007)	(0.003)
$\log(\text{real GDP}_t)$	-0.172	-0.512	-0.010	-0.359	-0.012	-0.349
	(0.016)	(0.030)	(0.011)	(0.022)	(0.011)	(0.018)
$\log(\text{VIX}_t)$			0.015	-0.077	0.030	-0.043
			(0.013)	(0.016)	(0.012)	(0.013)
Constant	0.033	2.751	-0.691	2.679	-0.742	2.479
	(0.131)	(0.278)	(0.115)	(0.204)	(0.109)	(0.167)
Observations	552	444	552	444	552	420
R^2	0.894	0.409	0.498	0.673	0.364	0.677

Notes: This table presents the money demand regressions with different definitions of money, where m_t is the real quantity of money including currency and checking deposits, Q_t is the real value of liquidity bundle as in equation (6), and Q'_t is the real value of liquidity bundle as in equation (23). Newey-West standard errors with 12 lags are reported in parentheses.

(a) $\log(m_t/\text{real GDP}_t)$ (b) $\log(Q_t/\text{real GDP}_t)$ (c) $\log(Q'_t/\text{real GDP}_t)$

Fig. 7. Quantity of Liquidity and the Opportunity Cost of Holding Liquidity. The y-axis is $\log(\text{deposit spread}_t/(1+\text{FFR}_t))$ across all three panels. Data are annual averages, with the years marked on the figure.

section: the demand for our new broad aggregate is stable compared to that of the demand for M1. See Table 25 of the appendix.

4. Comparisons of Estimation Methods

Our estimation implies that ρ is around 0.6. Applying the Wald test to the null hypothesis,

$$H0 : \rho = 1, \tag{38}$$

based on the estimates from column (1) of Table 6, we find a Wald statistic $W = 13.7$, with a p-value of $2{\times}10^{-4}$. The model strongly rejects the null hypothesis that deposits and Treasuries are perfect substitutes, contradicting the conclusion in Nagel (2016) that Treasuries and bank deposits are close to perfect substitutes. Testing the hypothesis $H0 : \rho = 0$ yields an even smaller p-value, indicating that we can also reject that ρ is zero. In what follows, we further explore the statistical power of our approach to estimating ρ.

4.1. *Probability of False Positive*

We first note that our estimate of ρ is robust to nonlinear least squares that directly minimizes the sum of squared model prediction errors as well as GMM with different moment conditions. Refer to Appendix C for details.

In this section, we ask, suppose that the true model has $\rho = 1$, what is the probability that the GMM estimation wrongly finds $\hat{\rho} \leq 0.64$ (the average value of ρ in Table 6)? For this purpose, we first estimate the model

$$lp_t = \beta_\lambda s_t VIX_t + \tilde{\varepsilon}_t \tag{39}$$

Next, we apply a stationary block bootstrap on $\tilde{\varepsilon}_t$ 5,000 times to generate 5,000 different time series of the liquidity premium. With the GMM estimation and an underlying model of (12), we generate 5,000 different estimates of ρ. Then we calculate the probability of finding $\hat{\rho}$:

$$P(\hat{\rho} \leq 0.64 | \rho = 1) = \frac{\#\text{ of estimations smaller than } 0.64}{\#\text{ of estimations}} = 0.6\% \tag{40}$$

We conclude that it is unlikely that the true ρ equals to 1 but our estimates reveal a ρ less than 0.64.

4.2. Sources of Differences

There are two main differences between our approach and Nagel (2016). First, we use log(Net Treasuries/deposits) instead of log(Total Treasuries/GDP). As noted, the former variable more closely aligns with the theory, and as we have shown, using this variable sharpens our results. The second difference has to do with the interaction effect we have discussed. Theoretically, the nominal interest rate and Treasury supply interact in driving the liquidity premium, as illustrated by equation (12), and this interaction term is missed in Nagel (2016)'s linearized model.

To understand how these differences contribute to the different estimate in this paper, we compare three estimation methods:

1. Linear regression using bond/GDP ratio: liquidity premium ~ FFR + log(Total Debt/GDP) + VIX. This regression is the same as Nagel (2016).

2. Linear regression using bond/deposit ratio: liquidity premium ~ FFR + log(Net Debt/Deposit) + VIX.

3. GMM: direct estimation of equation (12) using GMM with moment conditions (21).

We compare these estimation methods in two dimensions.

Significance of the Quantity Variable

Using the average of the estimated values across columns in Table 6 and equation (12), we bootstrap the residuals and then summarize the statistical properties of the different estimation methods.

There are different ways to implement the bootstrap. A simple bootstrap with replacement works for i.i.d. residuals. However, in the data, the residuals of the liquidity premium have a strong time-series correlation that is well represented by a stationary autoregressive process. In the statistics literature, the method designed for this case is stationary bootstrapping (Politis and Romano, 1994), which preserves stationarity and time series correlation, based on the assumption that the time series is stationary and weakly dependent.

We repeat the stationary bootstrap 5,000 times,[13] each with a different random seed. For each bootstrap, the three methods are used to estimate the impact of the supply variable, which is the coefficient of log(Net Debt/GDP) in the first approach, the coefficient of log(Net Debt/Deposits) in the second approach, and $\rho - 1$ in the third approach.

Figure 8 presents the results. It is apparent that method 3 implies higher confidence in $\rho < 1$ than method 2 and method 1. The average t-stat is about -1.0 using the first linear regression method, -1.9 using the second linear regression method, -3.8 using GMM (-3.1 using GMM with IV). Furthermore, with method 1, the probability of finding that ρ is above 1 is 13.2%, while such a probability drops to 1.7% for method 2 and 0.02% for method 3.

Thus, we are more likely to wrongly conclude that bonds and deposits are almost perfect substitutes based on the supply factor's insignificance using the first linear regression method, even if the underlying truth is far from perfect substitutes.

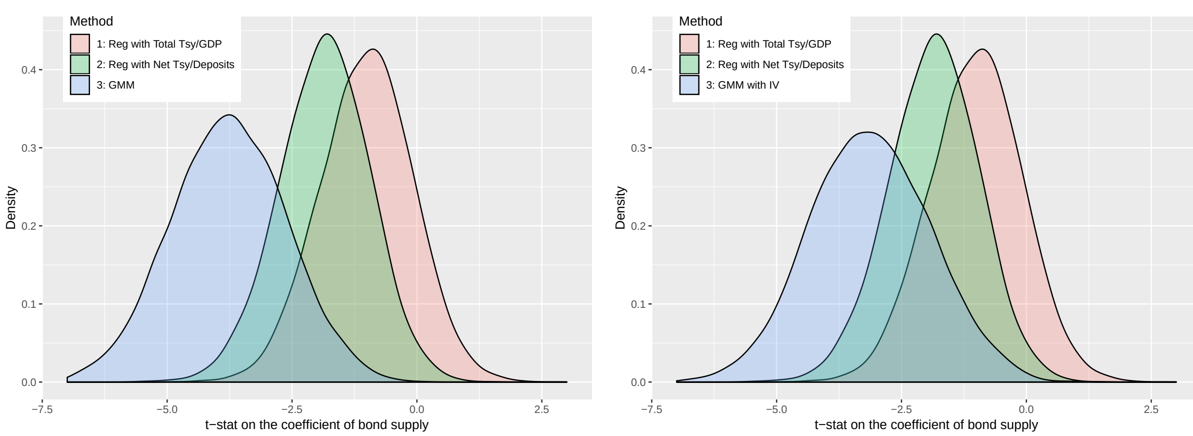


Fig. 8. **Comparing t-stats under Three Different Methods.** This figure shows the density of t-stats on the estimated coefficient of bond supply, which is the coefficient of log(Net Debt/GDP) in method 1, the coefficient of log(Net Debt/Deposits) in method 2, and $\rho - 1$ in method 3. Block-bootstrap residuals are used for simulation analysis and we assume the underlying model has ρ equal to the average estimation results in Table 6.

[13]Results are similar if we use more than 5,000 rounds.

Implied Substitution Effect

Next, we compare the implied $\hat{\rho}$ in three different methods. In the first method, suppose the coefficient on log(Net Debt/GDP) is β_1. Then

$$\hat{\rho}^{(1)} = \frac{\partial(\log(lp))}{\partial \log(\text{Net Debt/GDP})} + 1 = \frac{\partial(lp)}{\partial \log(\text{Net Debt/GDP})}\frac{1}{lp} + 1 = \beta_1 \frac{1}{lp} + 1 \tag{41}$$

is an approximation for ρ. In the second method, suppose the coefficient on log(Net Debt/Deposits) is β_2, then

$$\hat{\rho}^{(2)} = \frac{\partial(\log(lp))}{\partial \log(\text{Net Debt/Deposits})} + 1 = \frac{\partial(lp)}{\partial \log(\text{Net Debt/Deposits})}\frac{1}{lp} + 1 = \beta_2 \frac{1}{lp} + 1 \tag{42}$$

is an approximation for ρ. In the third method, we directly estimate $\hat{\rho}^{(3)} = \hat{\rho}$. Then we compare $\hat{\rho}^{(1)}$, $\hat{\rho}^{(2)}$, and $\hat{\rho}^{(3)}$ in Figure 9. The results indicate that the GMM estimated results have the least bias and result in the least estimation error. Linear regressions with Treasuries/deposits yield $\hat{\rho}$ with a slight bias relative to the true value and result in a larger estimation error. Finally, the linear regression method using Treasuries/GDP as in Nagel (2016) yields biased results and has the largest error.

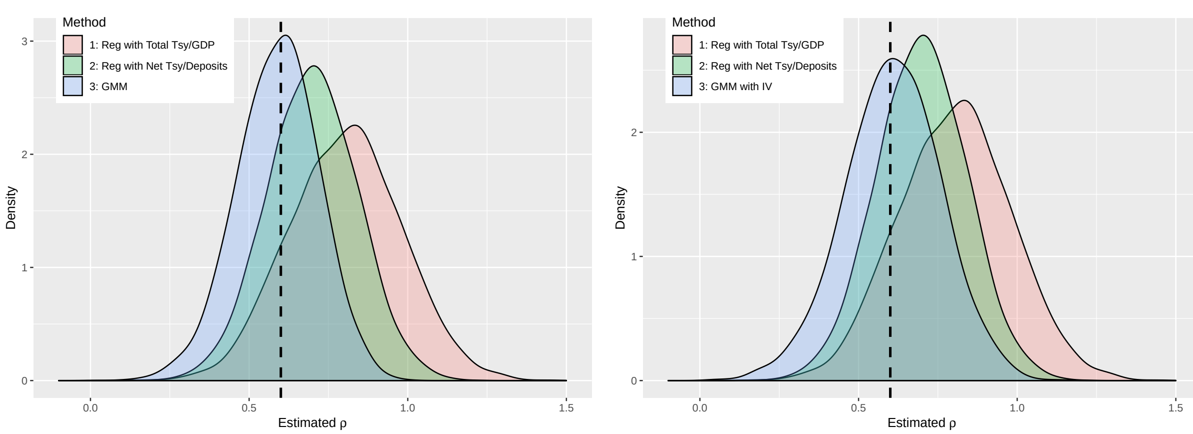


Fig. 9. **Comparing Estimated ρ under Three Different Methods.** This figure shows the density of the implied ρ under three different methods. Block-bootstrap residuals are used for simulation analysis and we assume the underlying model has ρ equal to the average estimation results in Table 6

5. Conclusions

Bank deposits, non-bank short-term safe debt, and Treasury bonds all provide liquidity services to investors. They provide different types of these services, as evidenced by our results that bank deposits and Treasury bonds are imperfect substitutes. They also provide different amounts of liquidity services per-unit-of-asset, as evidenced by our estimates of μ and λ, with Treasury bonds notably providing a larger amount of liquidity services than non-bank debt. We view our analysis as furthering a research area which has been active over the last decade of broadening the definition of money to grapple with the complexities of a modern financial system. This research is directly relevant for understanding many monetary and banking issues; some prominent examples include, understanding how quantitative easing works and mapping out the potential benefits of a central bank-issued digital currency.

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Appendix A. Model Derivations

In this section, we derive the baseline first-order conditions of the representative investor in (10) and (11). Then we show how to incorporate other types of assets.

A.1. Baseline Results

The Lagrangian of the investor optimization problem is

$$E[\sum_{t=1}^{\infty} \beta^t \left(\begin{array}{l} u(C_t, Q_t) + \lambda_t \left(-P_t C_t - D_t - B_t - A_t + \cdots\right) \\ +\lambda_{t+1} \left(D_t(1+i_t^d) + B_t(1+i_t^b) + A_t(1+i_t) + \cdots\right) \end{array} \right)]. \tag{A-1}$$

The first order condition on consumption is

$$\frac{\partial u(C_t, Q_t)}{\partial C_t} = \lambda_t P_t. \tag{A-2}$$

The first order condition on lending is

$$E_t[\lambda_{t+1}](1+i_t) - \lambda_t = 0. \tag{A-3}$$

The first order condition on deposit holding is

$$\frac{\partial u(C_t, Q_t)}{\partial Q_t} \frac{\partial Q_t}{\partial D_t} - \lambda_t + E_t[\lambda_{t+1}](1+i_t^d) = 0. \tag{A-4}$$

The first order condition on bond holding is

$$\frac{\partial u(C_t, Q_t)}{\partial Q_t} \frac{\partial Q_t}{\partial B_t} - \lambda_t + E_t[\lambda_{t+1}](1+i_t^b) = 0. \tag{A-5}$$

Combining Equations (A-2), (A-3), and (A-4), we get

$$\frac{\partial u(C_t, Q_t)}{\partial D_t} = \frac{\partial u(C_t, Q_t)}{C_t} \frac{1}{P_t} \frac{i_t - i_t^d}{1+i_t}. \tag{A-6}$$

Similarly, from (A-2), (A-3), and (A-5), we have

$$\frac{\partial u(C_t, Q_t)}{\partial B_t} = \frac{\partial u(C_t, Q_t)}{C_t} \frac{1}{P_t} \frac{i_t - i_t^b}{1+i_t}. \tag{A-7}$$

When $\rho \neq 0$, by expanding the definition of Q_t, we have

$$\frac{\partial u(C_t, Q_t)}{\partial D_t} = \frac{\partial u(C_t, Q_t)}{\partial Q_t} Q_t^{1-\rho}(1-\lambda_t)(\frac{D_t}{P_t})^{\rho-1}\frac{1}{P_t}. \tag{A-8}$$

$$\frac{\partial u(C_t, Q_t)}{\partial B_t} = \frac{\partial u(C_t, Q_t)}{\partial Q_t} Q_t^{1-\rho}\lambda_t(\frac{B_t}{P_t})^{\rho-1}\frac{1}{P_t}. \tag{A-9}$$

When $\rho = 0$,

$$Q_t = (\frac{D_t}{P_t})^{1-\lambda_t}(\frac{B_t}{P_t})^{\lambda_t}, \tag{A-10}$$

and therefore the derivatives are

$$\frac{\partial u(C_t, Q_t)}{\partial D_t} = \frac{\partial u(C_t, Q_t)}{\partial Q_t}(1-\lambda_t)\frac{Q_t}{(D_t/P_t)}\frac{1}{P_t}, \tag{A-11}$$

$$\frac{\partial u(C_t, Q_t)}{\partial B_t} = \frac{\partial u(C_t, Q_t)}{\partial Q_t}\lambda_t\frac{Q_t}{(B_t/P_t)}\frac{1}{P_t}. \tag{A-12}$$

Combining (A-8) and (A-9) with (A-11) and (A-12), we have

$$\frac{\partial u(C_t, Q_t)}{\partial Q_t} Q_t^{1-\rho}(1-\lambda_t)(\frac{D_t}{P_t})^{\rho-1} = \frac{\partial u(C_t, Q_t)}{\partial C_t}\frac{i_t - i_t^d}{1+i_t}, \tag{A-13}$$

$$\frac{\partial u(C_t, Q_t)}{\partial Q_t} Q_t^{1-\rho}\lambda_t(\frac{B_t}{P_t})^{\rho-1} = \frac{\partial u(C_t, Q_t)}{\partial C_t}\frac{i_t - i_t^b}{1+i_t}, \tag{A-14}$$

for all $\rho \in \mathbb{R}$.

A.2. Allowing for Other Assets in Liquidity

The first order conditions may remain the same when we introduce other assets into the CES aggregator of liquidity. For example, suppose we include cash M_t that change the aggregator Q_t into

$$Q_t = \left((1-\lambda_t)(\frac{D_t}{P_t})^{\rho} + \lambda_t(\frac{B_t}{P_t})^{\rho} + \xi_t(\frac{M_t}{P_t})^{\rho\chi}\right)^{\frac{1}{\rho}}. \tag{A-15}$$

Then the derivatives of Q_t over D_t and B_t are still going to the the same as (A-8) (A-9) for $\rho \neq 0$, and (A-11) (A-12) for $\rho = 0$. The opportunity costs for holding bonds and deposits are still the same. Therefore, the first order conditions are still the same as (A-13) and (A-14).

In general, we can add more liquid assets into the liquidity substitution bundle without affecting the estimation of the elasticity of substitution between Treasuries and bank deposits.

Appendix B. Data Construction

B.1. Quantities

- Checking deposits: all checking accounts in commercial banks. Data series downloaded from FRED, with identifier "TCDSL", from 1959-2016. Before 1959, we obtain data from the FDIC historical bank dataset, https://banks.data.fdic.gov/explore/historical, by selecting "Choose a report – Commercial Banks – Financial – Deposits – Domestic Demand".

- Savings deposits: all saving accounts in commercial banks, including money market deposit accounts. Data series downloaded from FRED, with identifier "SAVINGSL", from 1959-2016. Before 1959, we obtain data from the FDIC historical bank dataset with similar procedures as the checking deposits (select "Deposits – Domestic Savings").

- Time deposits: all time deposits at banks and thrifts with balances less than $100,000. Data series downloaded from FRED, with identifier "STDSL", from 1959-2016. Before 1959, we obtain data from the FDIC historical bank dataset with similar procedures as the checking deposits (select "Deposits – Domestic Time").

- Total debt (book value): Treasury debt held by the public (FRED identifier "FYGFDPUN") from 1970 to 2016. Before 1970, we use the total debt measure in Nagel (2016), which originally comes from Bohn (2008). Both pre- and post- 1970 measures exclude Social Security Trust Funds holdings.

- Net Tsy (market value): We first calculate the book value as "Total debt' minus bank holding and Federal Reserve holdings of Treasuries, which leads to a measure of non-bank private sector holding of Treasuries. Then we translate the book value into market values using the market-to-book ratio of all marketable Treasury securities (Data on market and book values are provided by Federal Reserve Bank of Dallas, https://www.dallasfed.org/research/econdata/govdebt#tab3.).

- Nominal and real GDP: After 1947, quarterly data are downloaded from FRED with identifiers "GDP" and "GDPC1". For 1929-1946, yearly data are downloaded from FRED with identifiers "GDPA" and "GDPCA". Then we concatenate the two data series to get nominal and real GDP from 1929 to 2016.

- M1: a monetary aggregate that includes currency in circulation and checking deposits. Currency in circulation is from FRED with the identifier "CURRCIR", available from 1917 to 2021 at a monthly frequency.

- KVJ deposits: the financial sector liability as measured by Krishnamurthy and Vissing-Jorgensen (2012). Krishnamurthy and Vissing-Jorgensen (2015) construct the "net short-term debt" of the financial sector as the sum across each firm in the financial sector (banks and non-bank) of:

  short-term debt liabilities − (short-term debt assets + government supplied liquid assets).

  We use the net short-term debt measure and add back the government-supplied liquid assets, which then corresponds to the short-term debt liabilities of the financial sector held by the nonfinancial sector.

B.2. Rates

- Federal funds rate (FFR): Monthly effective FFR in percentage, with FRED identifier "FEDFUNDS", from 1954 to 2016. From 1920 to 1954, monthly data is from Nagel (2016).

- Liquidity premium: after 1991, liquidity premium is measured as the yield spread between three-month Repo (collateralized by Treasuries) and three-month Treasuries. Since the original repo series in Bloomberg discontinued in 2016, the liquidity premium series ends in 2016. From 1920 to 1991, liquidity premium is measured as the yield spread between three-month banker acceptance and three-month Treasury bills.

- 3 month T-bill rate: secondary-market rate for 3-month T-bill downloaded from FRED, with the identifier "TB3MS". Data cover 1934 to 2021.

- Deposit rates: we obtain monthly data on commercial bank checking, saving, and small-time interest expenses from bank call reports covering 1986 to 2013. Checking deposit rates are calculated as the commercial bank checking interest expense over total checking volume. Saving and small-time deposit rates are defined in a similar way.

- P1CP: 90-day P1-rated (equivalent to AA-rated) commercial paper rates obtained from FRED. The data have two FRED identifiers: the first one is from 1971 to 1997 with the identifier "WCP3M", and the second one is from 1997 to 2021 with the identifier "RIFSPPNAAD90NB".

- P2CP–P1CP spread: P2CP data are directly from FRED for the post-1998 period, with the identifier "RIFSPPNA2P2D90NB". Before 1998, the data are from researchers at the Federal Reserve Board.

- Money market funds rate: we obtain the aggregate money-market rate from Xiao (2020) for the period 1987–2012. The original data in that paper are from iMoneyNet and cover almost all MMFs after 1987.

B.3. Aggregation Among Saving and Checking Deposits

The money aggregation literature (Barnett, 1980; Spindt, 1985; Goldfeld and Sichel, 1990) considers how to aggregate different forms of money. Following this literature, we consider a CES aggregate over saving and checking:

$$d_t = 2(\delta(d_{\text{checking},t})^{\kappa} + (1-\delta)(d_{\text{saving},t})^{\kappa})^{\frac{1}{\kappa}}, \tag{B-1}$$

where the multiplier 2 is to make sure that the aggregate quantity does not shrink to a 1/2 mechanically due to definition. For example, when $\delta = 1/2$ and components are perfectly substitutable with $\kappa = 1$, we expect $d_t = d_{\text{checking},t} + d_{\text{saving},t}$, instead of $d_t = 0.5d_{\text{checking},t} + 0.5d_{\text{saving},t}$.

The methodology to estimate relationship (B-1) is the same as estimating the substitution between money and deposits. By taking first order conditions on both checking and saving deposits, and divide both sides, we get

$$\frac{i_t - i_{\text{checking},t}}{i_t - i_{\text{saving},t}} = \frac{\delta}{1-\delta}\left(\frac{d_{\text{checking},t}}{d_{\text{saving},t}}\right)^{\kappa-1}. \tag{B-2}$$

Using the same GMM method as we have used, we find $\kappa = 1$, and $\delta = 2/3$, and the model explains about 84% variation in the checking deposit spread. It is mainly for the internal coherence of the methodology to estimate the elasticity of substitution between checking and savings deposits. A simple aggregation with $\kappa = 1$ and $\delta = 1/2$, which is used in the definition of different money aggregates, result in a similar level of substitutability between treasuries and "money".

We estimate the substitution between saving and checking deposits using equation

$$\frac{i_t - i_{\text{checking},t}}{i_t - i_{\text{saving},t}} = \frac{\delta}{1-\delta}\left(\frac{d_{\text{checking},t}}{d_{\text{saving},t}}\right)^{\kappa-1}. \tag{B-3}$$

In the data, we find that the checking deposit spread is well approximated by a constant multiplying the saving deposit spread, which implies that the left-hand-side of the above equation should be a constant, although the ratio of checking and saving is changing over time. Thus a good estimation if $\kappa = 1$.

If we use GMM to estimate the above model, results are quite close to $\kappa = 1$, as shown in Table 12. The moment conditions are

$$E[\epsilon_t \cdot \begin{pmatrix} \frac{d_{\text{checking},t}}{d_{\text{saving},t}} \\ i_t \\ 1 \end{pmatrix}] = 0, \tag{B-4}$$

with

$$\epsilon_t = (i_t - i_{\text{checking},t}) - \frac{\delta}{1-\delta}\left(\frac{d_{\text{checking},t}}{d_{\text{saving},t}}\right)^{\kappa-1}(i_t - i_{\text{saving},t}). \tag{B-5}$$

We will pick the economically meaningful and round value $\kappa = 1$, and round value $\delta/(1-\delta) = 2$, which implies $\delta = 2/3$. Thus we are confident to use the following aggregation:

$$d_t^\rho = \delta d_{1,t} + (1-\delta)d_{2,t}, \tag{B-6}$$

and the aggregate d_t^ρ, with the weighted spread as

$$s = \delta s_{1,t} + (1-\delta)s_{2,t}. \tag{B-7}$$

Table 12: GMM Estimation for the Substitution Between Saving and Checking Deposits

Parameters for estimation	Estimated values
κ	1.000***
	(0.387)
$\delta/(1-\delta)$	2.053***
	(0.487)
Observations	372
R^2 of explaining checking spread	93%

Notes: This table shows the estimated parameters for the substitution between saving and checking deposits, using GMM with moment conditions listed in (B-4). Newey West standard errors with 12 lags are reported in parentheses. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Appendix C. Additional Results

This section provides additional results and robustness checks.

C.1. First-Stage Regressions

In Table 13, we report the first stage for the level regressions of Table 4. The F-statistic for both first-stages is well above the standard threshold of 10.

Table 13: First Stage for Level Regressions in Table 4

	Dependent variable:	
	$\log(\frac{\text{Net Tsy}}{\text{Deposits}})$	$\log(\frac{\text{Net Tsy}}{\text{KVJ Deposits}})$
	(1)	(2)
$\log(\frac{\text{Total Tsy}}{\text{GDP}})$	2.205	1.099
	(1.283)	(0.404)
$\frac{\text{Total Tsy}}{\text{GDP}}$	−2.761	−0.199
	(2.372)	(0.753)
Constant	2.597	0.161
	(2.281)	(0.699)
Observations	996	1,140
R^2	0.519	0.864

In Table 14, we show the first stage for difference regressions in Table 5. We find that the monthly dummies are strongly related to the changes in T-bill ratios, while the federal funds futures IV (price difference in month $t-2$ of federal funds futures for month $t-1$ and t) is strongly related to changes in FFR from $t-1$ to t.

C.2. Alternative Measures of the Deposits Spread

In our main text, we use the projection of deposit spread on FFR throughout the whole sample. In this subsection, we present our results with an alternative construction where we use the raw deposit spread data whenever data are directly available and the projection on FFR if not. Estimation results are shown in Table 15. We find that coefficients are broadly similar, but the R^2s are lower, indicating that the projection method throughout the sample helps reduce the noise in the deposit spread measure.

Table 14: First Stage for Difference Regressions in Table 5

	Dependent variable:				
	$\Delta\log(\frac{\text{T-bill}_t}{\text{GDP}_t})$	$\Delta\log(\frac{\text{T-bill}_{t-1}}{\text{GDP}_{t-1}})$	$\Delta\log(\frac{\text{T-bill}_t}{\text{Deposit}_t})$	$\Delta\log(\frac{\text{T-bill}_{t-1}}{\text{Deposit}_{t-1}})$	ΔFFR_t
	(1)	(2)	(3)	(4)	(5)
M1	0.035	0.006	0.025	0.017	−0.006
	(0.012)	(0.009)	(0.013)	(0.009)	(0.035)
M2	0.028	0.041	0.018	0.041	0.036
	(0.012)	(0.010)	(0.012)	(0.010)	(0.024)
M3	−0.063	0.033	−0.060	0.034	−0.005
	(0.013)	(0.008)	(0.013)	(0.008)	(0.021)
M4	0.006	−0.057	−0.004	−0.044	−0.005
	(0.010)	(0.011)	(0.010)	(0.011)	(0.025)
M5	−0.005	0.012	−0.015	0.012	0.007
	(0.009)	(0.008)	(0.009)	(0.008)	(0.025)
M6	0.018	0.001	0.018	0.001	−0.039
	(0.010)	(0.006)	(0.011)	(0.006)	(0.026)
M7	0.036	0.023	0.024	0.034	−0.025
	(0.012)	(0.008)	(0.013)	(0.008)	(0.022)
M8	−0.008	0.041	−0.019	0.040	−0.010
	(0.011)	(0.010)	(0.011)	(0.010)	(0.029)
M9	0.030	−0.003	0.031	−0.003	−0.083
	(0.012)	(0.011)	(0.012)	(0.011)	(0.038)
M10	0.043	0.035	0.034	0.047	−0.034
	(0.012)	(0.012)	(0.012)	(0.011)	(0.033)
M11	−0.005	0.049	−0.016	0.050	−0.086
	(0.009)	(0.010)	(0.009)	(0.010)	(0.031)
FFfutures_IV	−0.021	−0.018	−0.009	−0.003	1.146
	(0.015)	(0.013)	(0.016)	(0.012)	(0.143)
Constant	−0.009	−0.014	−0.003	−0.019	−0.018
	(0.008)	(0.005)	(0.008)	(0.005)	(0.023)
Observations	335	336	335	336	335
R^2	0.352	0.352	0.330	0.329	0.403
F Statistic	14.5	14.6	13.2	13.2	18.1

Table 15: GMM Estimations with Concatenated Deposit Spread

	Measurement of B/D			
	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$
	(1)	(2)	(3)	(4)
ρ	0.589	0.690	0.535	0.467
	(0.130)	(0.247)	(0.159)	(0.207)
β_λ	0.011	0.011	0.011	0.008
	(0.001)	(0.003)	(0.002)	(0.002)
p-value of J-test	0.287	0.170	0.680	0.216
Total Treasury IV?	No	No	Yes	Yes
Variations explained	66.2%	62.3%	66.6%	64.4%
Observations	996	972	996	972

Notes: This table shows the two-step GMM estimations of parameters ρ and β_λ. Model specifications is in (21) and (C-1), but we instrument quantity ratio by total Treasury/GDP and (total Treasury/GDP)^2. Deposit spread is the actual average deposit spread as defined in (14) whenever data are available, and the projection of deposit spread on FFR otherwise. Other variable definitions are provided in Table 1 and 3. Newey-West standard errors with 12 lags are reported in parentheses.

C.3. Alternative Measures of the Treasury Liquidity Premium

In this section, we redo the main estimation with alternative liquidity premium measures. We only consider alternative liquidity premium measures with at least 30 years of data to ensure statistical confidence. This leaves us the following choices:

1. CD/T-bill 3M spread, which is the yield spread between 3-month certificates of deposit and 3-month T-bill.

2. Note/bill spread, the yield spread between 3-month Treasury notes and bills.

3. GSW/T-bill 3M spread, which is the yield spread between the implied 3-month Treasury yield from the widely-used fitting algorithm in Gürkaynak, Sack and Wright (2007) and 3-month T-bill rate. We follow the same construction as Lenel, Piazzesi and Schneider (2019).

All of the above data are obtained from Nagel (2016). We report the GMM estimation results in Table 16. As shown in the first column, when we use CD/T-bill 3M as the liquidity premium measure, the estimate of ρ is 0.533. When we use note/bill spread (second column), the estimated ρ is 1.056 although the estimation fit is very poor, reflected in the large standard error and low R^2. The fit is also poor when using the on/off spread in column (3). In the time series, both the note/T-bill spread and on/off spread are more volatile and likely have other non-money demand factors driving their variation. For example, the on/off spread is negative in around 25% of the sample and the note/T-bill spread is negative in around 22% of the sample. Finally, the estimate using the GSW/T-bill spread is in the range of our baseline estimates, although the estimation fit is relatively poor.

C.4. Alternative Measures of λ_t

We next consider other functions and data to proxy for VIX. A priori, there is no reason that the VIX should drive λ in the functional form prescribed by (22). We instead consider a functional form:

$$\frac{\lambda_t}{1-\lambda_t} = \beta_\lambda (\text{proxy}_t)^\kappa \tag{C-1}$$

where "proxy" here denotes either the VIX index, the BAA–AAA credit spread, which reflects credit risk premium in the corporate sector, or intermediary market leverage, which reflects bank vulnerability and has been widely used in the intermediary asset pricing literature as a factor of the pricing kernel. We construct bank market leverage as 1/bank capital ratio using data from He, Kelly and Manela (2017). These latter two variables capture the

Table 16: GMM Estimation with Alternative Measures of ℓ_t

	Treasury Liquidity Premium Measures		
	CD-Tbill 3M	Note-Bill Spread	GSW-Tbill 3M
	(1)	(2)	(3)
ρ	0.533	1.056	0.727
	(0.090)	(0.620)	(0.245)
β_λ	0.015	0.002	0.006
	(0.001)	(0.0004)	(0.001)
p-value of J-test	0.712	0.059	0.543
Variations explained	60.1%	7%	13.9%
Observations	631	432	667

Notes: This table shows the two-step GMM estimations of parameters ρ and β_λ. Model specifications is in (21) and (C-1), but we instrument quantity ratio by total Treasury/GDP and (total Treasury/GDP)^2. CD-Tsy 3M and Note-Bill spread are obtained from Nagel (2016), where "CD" denotes certificate of deposits. GSW-Tsy 3M is the spread between implied 3-month Treasury yield from the fitting algorithm in Gürkaynak, Sack and Wright (2007) and 3-month Tbill rate. HAC standard errors with 12 lags are reported in parentheses.

Table 17: GMM Estimation with Alternative Measures of λ_t

	Proxy for λ_t					
	VIX		Credit Spread		Bank Leverage	
Measurement of B/D	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$
	(1)	(2)	(3)	(4)	(5)	(6)
ρ	0.692	0.635	0.669	0.606	0.612	0.604
	(0.171)	(0.191)	(0.230)	(0.260)	(0.222)	(0.252)
β_λ	0.015	0.014	0.218	0.174	0.105	0.084
	(0.008)	(0.008)	(0.041)	(0.055)	(0.039)	(0.033)
κ	0.930	0.874	0.193	0.160	0.233	0.243
	(0.160)	(0.167)	(0.129)	(0.144)	(0.129)	(0.140)
p-value of J-test	0.891	0.833	0.838	0.784	0.633	0.470
Variations explained	69.8%	69.1%	63%	62.9%	64.3%	63.8%
Observations	996	972	996	972	996	972

Notes: This table shows the two-step GMM estimations of parameters ρ, β_λ, and κ. Model specifications is in (21) and (C-1), but we instrument quantity ratio by total Treasury/GDP and (total Treasury/GDP)^2. Credit spread is the BAA–AAA corporate bond credit spread by Moody. Bank leverage is the inverse of intermediary capital ratio from He, Kelly and Manela (2017), where we extend the measure to before 1970s by projecting it to the daily returns of 49 industrial portfolios from Kenneth French's website. The sample period is 1934–2016 for column 1,3,5, and 1934–2014 for column 2,4,6. Newey-West standard errors with 12 lags are reported in parentheses.

idea that the "safety" of deposits may vary over time and influence the relative moneyness of deposits and Treasuries.

Estimation results are presented in Table 17. As shown in column (1), the estimated $\kappa \approx 1$ using VIX, which supports our baseline specification where we implicitly impose $\kappa = 1$. More importantly, across all of the specifications, the estimated ρ is around 0.6, and the regression R^2 are high and also quite similar across these alternative proxies, indicating that all of these proxies work in a similar fashion.

C.5. Robustness of Estimation Method

In the main text, we have used two-step GMM to estimate an over-identified system in (21). As robustness checks, we will use different combinations of moment conditions. We list the individual moment conditions as follows:

$$E[\varepsilon_t] = 0. \tag{C-2}$$

$$E[\varepsilon_t \cdot s_t] = 0, \tag{C-3}$$

$$E[\varepsilon_t \cdot \mathrm{VIX}_t] = 0, \tag{C-4}$$

$$E[\varepsilon_t \cdot (B_t/D_t)] = 0, \tag{C-5}$$

For robustness checks, we will use the same GMM methods, but with subsets of the four moment conditions (C-2), (C-3), (C-4), and (C-5). Another method is the generalized least square that finds the best fit of the model for the data, with the objective

$$\min_{\rho,\beta_\lambda} \frac{1}{T} \sum_{t=1}^{T} \varepsilon_t^2 \tag{C-6}$$

As a result, the first order conditions include

$$\frac{1}{T} \sum_{t=1}^{T} \varepsilon_t \cdot s_t \cdot \mathrm{VIX_t} (\frac{B_t}{D_t})^{\rho-1} = 0 \tag{C-7}$$

$$\frac{1}{T} \sum_{t=1}^{T} \varepsilon_t \cdot s_t \cdot \mathrm{VIX_t} (\frac{B_t}{D_t})^{\rho-1} \log(\frac{B_t}{D_t}) = 0 \tag{C-8}$$

Results are shown in Table 18. We find that the estimated values are, in general, quite similar to different combinations of the moment conditions in (C-2) to (C-5). The NLS estimations are also close to the GMM estimations in Table 6.

C.6. Effect of VIX

In Table 19, we illustrate our log regression results without VIX. In columns 1-3, we use the full sample, while in columns 4-6, we exclude the WWII period (1942-1951). In all cases, the coefficients on the log quantity variable (which maps to $\rho - 1$ in the model) imply a ρ significantly different from 1, ranging from 0.4 to 0.76.

In Table 20, we show how our baseline results in Table 6 change when we remove VIX variations from the model. Across all scenarios, we find that estimations of ρ remain very similar to Table 6, although the standard errors are all larger than the corresponding columns in Table 6.

Based on the results in Table 19 and Table 20, we conclude that VIX helps with reducing

Table 18: Robustness Checks with Different Moment Conditions and Estimation Methods

	Estimation Methods							
	GMM1	GMM2	GMM3	GMM4	GMM5	GMM6	GMM7	NLS
ρ	0.74	0.24	0.61	0.71	0.60	0.61	0.59	0.59
	(0.28)	(1.91)	(0.10)	(0.26)	(0.11)	(0.10)	(0.11)	(0.11)
β_λ	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	(0.003)	(0.01)	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Variation explained	0.68	0.68	0.7	0.68	0.7	0.7	0.7	0.7
p-value	NA	NA	NA	0.65	0.36	0.76	0.62	NA
Observations	996	996	996	996	996	996	996	996

Notes: Column GMM1 to GMM7 shows the estimations of ρ using GMM with different moment conditions. GMM1 uses (C-2) and (C-3). GMM2 uses (C-2) and (C-4). GMM3 uses (C-2) and (C-5). GMM4 uses (C-2), (C-3) and (C-4). GMM5 uses (C-2), (C-3) and (C-5). GMM6 uses (C-3), (C-4) and (C-5). GMM7 uses (C-2), (C-3), (C-4) and (C-5). The last column uses nonlinear least squares (NLS) with objective function (C-6). HAC standard errors with 12 lags are reported in parentheses.

the estimation errors, but does not significantly change the estimated value of ρ.

C.7. Plots of Near-Money Quantities and Spreads

In Figure 10, we show the quantities and spreads used in Section 3. Quantities include KVJ net deposits, MMF, and bank deposits, where KVJ net deposits is defined as KVJ deposits (broadly-defined financial sector short-term liabilities in Krishnamurthy and Vissing-Jorgensen (2015)) minus bank deposits. Both KVJ net deposits and MMF are measures of the shadow banking sector. Spreads include P2CP–P1CP spread, P2CP–MMF spread, P2CP–T-bill spread, and P2CP–deposit spread. The P2CP–deposit spread is a projection of the original spread (P2CP 3 month rate minus average deposit rate) onto the FFR.

C.8. Substitution Between T-bills and Bank Deposits

Given that the total amount of Treasurys is mainly driven by longer-maturity bonds, the main result suggests a medium elasticity of substitution between longer-maturity bonds and deposits. To study the substitution between T-bills and bank deposits, in this subsection, we implement an estimation based on T-bill/deposits, instead of Treasuries/deposits. Results are shown in Table 21. We find that ρ estimated using "Net Tsy/Deposits" is smaller than

Table 19: Liquidity Premium Regressions in Log Terms (without VIX)

	Dependent variable: log(liquidity premium$_t$)					
	Full Sample			Excluding the WWII Period		
	(1)	(2)	(3)	(4)	(5)	(6)
$\log(\text{FFR}_t)$	0.45	0.46	0.49	0.44	0.42	0.50
	(0.09)	(0.09)	(0.09)	(0.08)	(0.08)	(0.08)
$\log(\frac{\text{Net Tsy}_t}{\text{GDP}_t})$	−0.47			−0.32		
	(0.18)			(0.16)		
$\log(\frac{\text{Net Tsy}_t}{\text{Deposits}_t})$		−0.58			−0.51	
		(0.18)			(0.17)	
$\log(\frac{\text{Net Tsy}_t}{\text{KVJ Deposits}_t})$			−0.61			−0.41
			(0.19)			(0.18)
Constant	−2.43	−2.12	−2.44	−2.14	−1.96	−2.20
	(0.27)	(0.17)	(0.21)	(0.25)	(0.15)	(0.21)
Observations	1,055	903	1,033	951	799	929
R^2	0.39	0.43	0.44	0.36	0.43	0.39

Notes: Refer to Table 1 for variable definitions. This table shows the basic regression (excluding VIX) in log terms. Column 1–3 uses the full sample while Column 4–6 excludes the WWII period (1942–1951). Newey-West standard errors with 12 lags are shown in parentheses.

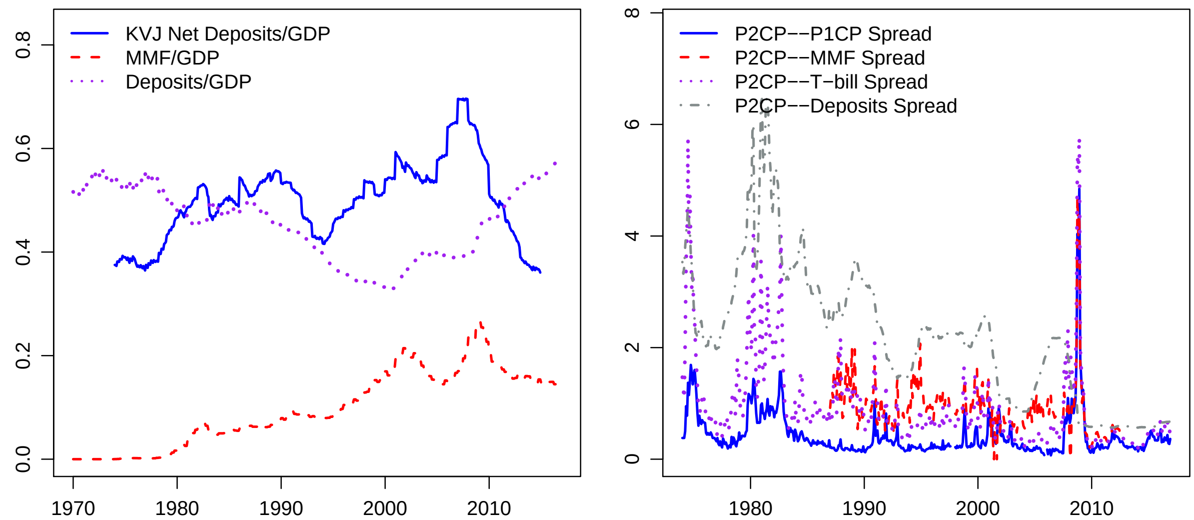
Table 20: GMM Estimations of ρ without VIX

	Measurement of B/D			
	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$	$\frac{\text{Net Tsy}}{\text{Deposits}}$	$\frac{\text{Net Tsy}}{\text{KVJ Deposits}}$
	(1)	(2)	(3)	(4)
ρ	0.657	0.642	0.672	0.597
	(0.134)	(0.252)	(0.213)	(0.232)
β_λ	0.012	0.010	0.012	0.009
	(0.001)	(0.003)	(0.002)	(0.003)
p-value of J-test	0.904	0.853	0.911	0.93
Total Treasury Instrument?	No	No	Yes	Yes
Variations explained	63.8%	63.2%	63.7%	63.6%
Observations	996	972	996	972

Notes: Refer to Table 1 and 6 for variable definitions. We set the relative demand as

$$\frac{\lambda_t}{1-\lambda_t} = \beta_\lambda \cdot \text{mean(VIX)}$$

In other words, we shut off the variations in VIX. As a result, the moment related to VIX is dropped in all estimations. In column 3 and 4, we instrument the quantity ratio by total Treasury/GDP and (total Treasury/GDP)^2.



(a) Quantity (b) Spread

Fig. 10. Near-Money Quantity and Spread Measures.

that in Table 6, while ρ estimated using "Net Tsy/KVJ Deposits" is larger than that in Table 6. However, the differences are not statistically significant.

Table 21: Estimations with T-bills

	Measurement of B/D			
	$\frac{\text{T-bills}}{\text{Deposits}}$	$\frac{\text{T-bills}}{\text{KVJ Deposits}}$	$\frac{\text{T-bills}}{\text{Deposits}}$	$\frac{\text{T-bills}}{\text{KVJ Deposits}}$
	(1)	(2)	(3)	(4)
ρ	0.377	0.996	0.649	0.674
	(0.214)	(0.314)	(0.292)	(0.653)
β_λ	0.007	0.016	0.009	0.007
	(0.002)	(0.011)	(0.004)	(0.011)
p-value of J-test	0.072	0.204	0.170	0.127
Total Treasury IV?	No	No	Yes	Yes
Variations explained	68.3%	64.6%	67.3%	65%
Observations	840	816	840	816

Notes: This table shows the two-step GMM estimations of parameters ρ and β_λ when we measure B_t as T-bills. Data are at a monthly frequency and cover 1947–2017. In column (1) and (2), we estimate the GMM system as in equation (21). In column (3) and (4), we use Total Tsy/GDP and (Total Tsy/GDP)^2 as instruments instead of the B_t/D_t ratio. HAC standard errors with 12 lags are reported in parentheses.

C.9. *Varying the Projection of Deposits Spread on FFR before 1986*

In 1986, all deposits rate ceilings are abandoned, and the deposits spread data inflow of funds start to be available. Therefore, the only uncertainty brought by the approximation of deposits spread via FFR is before 1986. We examine how the projection coefficient δ affects our main results while keeping the post-1986 deposit spread data the same.

We vary the δ from 0.3 to 0.6 (including the actual projection coefficient 0.38) and show how estimates change accordingly in Table 22. We find that as δ increases beyond 0.38, the estimated ρ increases, but the p-value and R both decline, indicating a worse approximation. For δ between 0.3 and 0.5, the estimated coefficient is close to the main results in Table 6. For $\delta = 0.7$, the standard error on ρ increased significantly while the p-value drops.

Table 22: Adjusting the pre-1986 Deposit Spread Projection

	Projection Coefficient of Deposit Spread on FFR				
	δ =0.3	δ =0.38	δ =0.4	δ =0.5	δ =0.6
	(1)	(2)	(3)	(4)	(5)
ρ	0.458	0.585	0.613	0.784	1.011
	(0.146)	(0.180)	(0.189)	(0.228)	(0.260)
β_λ	0.011	0.010	0.010	0.009	0.010
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
p-value of J-test	0.688	0.559	0.515	0.33	0.209
Variations explained	66.6%	66.6%	66.4%	64.9%	62.3%
Observations	996	996	996	996	996

Notes: This table shows the GMM estimations of parameters ρ and β_λ when we vary the projection coefficient δ for the period before 1986. We instrument the quantity ratios B_t/D_t (measured as deposits/net Treasury) by total Treasury/GDP and (total Treasury/GDP)^2. HAC standard errors with 12 lags are reported in parentheses.

In Figure 11, we show p-values and R^2 as a function of δ. We find that the post-1986 projection coefficient, $\delta = 0.38$, is also the close to the best approximation of deposit spread in terms of the model's p-value and R^2.

C.10. *Multiplicative Residuals*

In the main specification (17), we assume that the residual is additive to the model prediction. Another possible specification is that the residual is multiplicative. We report

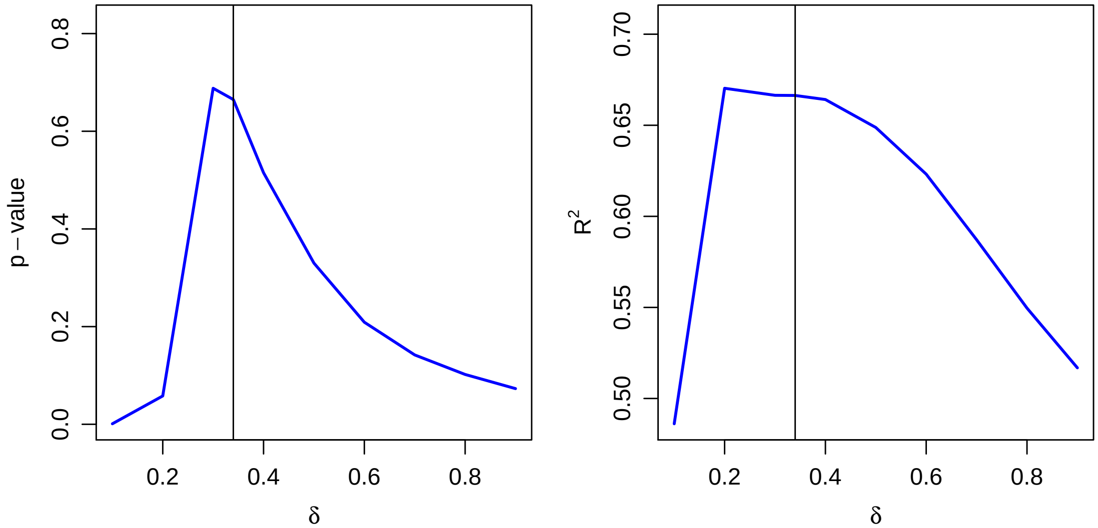


Fig. 11. Model Fit under Different Deposit Spread Projection Coefficients (δ)

the main GMM estimation under that specification in Column 1 of Table 23. The estimated ρ is 0.5 and still quite different from 1. However, the model fit is much worse and the p-value is only 0.0002, which implies that we should reject the model as a reasonable description of the data. The reason for the poor fit is that the interest rate is extremely low after the 2008 financial crisis and multiplicative residuals have a structure break from the pre-2008 period. To address this concern, we use three different methods. First, we restrict the estimation to the pre-2008 data (Column 2); Second, we introduce a "level-shift" parameter β_{level} (Column 3) so that the specification becomes

$$lp_t = \left(\beta_\lambda s_t \text{VIX}_t (\frac{B_t}{D_t})^{\rho-1} + \beta_{level} \mathbf{1}_{t \geq 2008} \right) \varepsilon_t. \tag{C-9}$$

Third, we introduce a "multiplicative-shift" parameter β_{multi} (Column 4) so that the specification becomes

$$lp_t = \beta_\lambda s_t \text{VIX}_t (\frac{B_t}{D_t})^{\rho-1} \cdot (1 + \beta_{multi} \mathbf{1}_{t \geq 2008}) \varepsilon_t. \tag{C-10}$$

As shown in Table 23, using only pre-2008 data significantly improves the p-value of J-test over the full-sample analysis, indicating the problem with post-2008 data in the multiplicative-residual model. This improvement can also be achieved by the level-shift parameter or the multiplicative-shift parameter, as shown in columns 3 and 4. Furthermore, the estimated substitution parameter ρ is low across all specifications and confirms the robustness of our main conclusion that Treasuries and deposits are imperfect substitutes.

Table 23: GMM Estimations with Multiplicative Residuals

	Estimated Values			
Parameters	(1) full sample	(2) pre-2008	(3) level-shift	(4) multi-shift
ρ	0.40	0.51	0.59	0.27
	(0.56)	(0.26)	(0.73)	(0.63)
β_λ	0.01	0.01	0.01	0.01
	(0.003)	(0.002)	(0.01)	(0.003)
Observations	996	900	996	996
p-values	0.133	0.605	0.122	0.075

Notes: This table shows the two-step GMM estimations of parameters ρ and β_λ, assuming that the residual of the model prediction is multiplicative. Column 1,3, and 4 use monthly data from 1934 to 2017. Column 2 uses monthly data from 1934 to 2008. The specification in Column 3 introduces a "level-shift" parameter as in (C-9) and the specification in column 4 introduces a "multi-shift" parameter as in (C-10). HAC standard errors with 12 lags are reported in parentheses.

C.11. Money-Demand Regressions

In Section 3, we use the time-varying μ_t and λ_t. In this appendix section, we will show that the time-series variations in μ_t and λ_t is not important in the money-demand regressions. Then we will show the impact of including currency in circulation into the monetary aggregate.

In Table 24, we replicate the same regressions as in Table 11, but set λ_t and μ_t as constants and equal to their average values implied by β_λ, β_μ, and VIX_t. We find that results are very similar, so even without the time-varying relative liquidity proxies, we are still able to achieve a stable money-demand relationship using our new definitions of liquidity bundles.

To further illustrate this point, in Figure 12, we show the money demand relationships using constant λ_t and μ_t. We find that the plots are very similar to those in Figure 7.

Finally, we consider currency in circulation, which we have thus far omitted but is customary to include in monetary aggregates. We include currency in D_t and otherwise aggregate non-bank debt and Treasury bonds following the same procedure. These new aggregates are denoted as $\bar{Q}$ and $\bar{Q}'$. Then we regress $\log(\bar{Q})$ and $\log(\bar{Q}')$ on the same regressors as in Table 11. We find that the inclusion of currency stabilizes the demand function further, as is evident in Table 25.

Table 24: Money Demand Regressions with Constant μ_t and λ_t

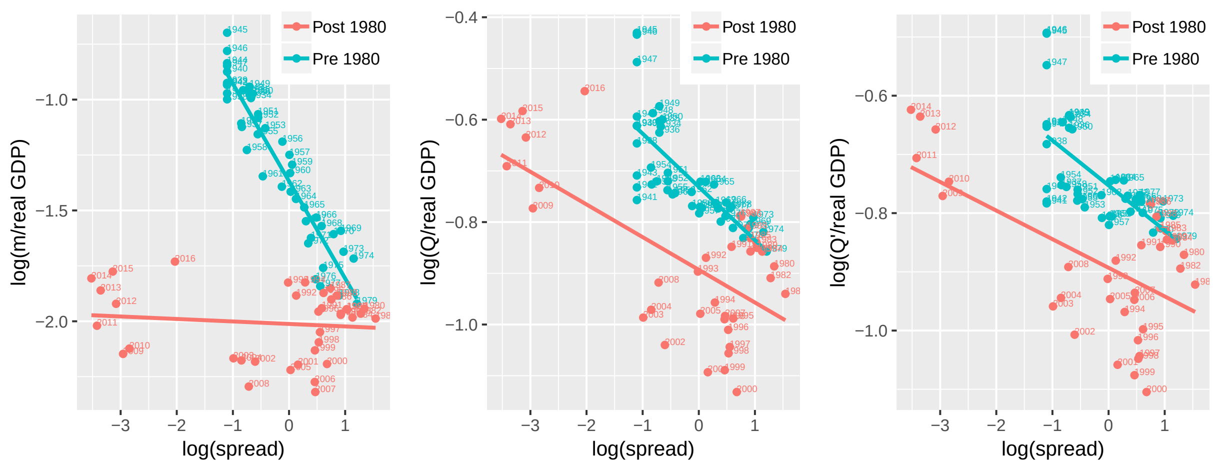
	Dependent variable:					
	$\log(m_t/\text{real GDP}_t)$		$\log(Q_t/\text{real GDP}_t)$		$\log(Q'_t/\text{real GDP}_t)$	
	pre 1980 (1)	post 1980 (2)	pre 1980 (3)	post 1980 (4)	pre 1980 (5)	post 1980 (6)
$\log(\frac{\text{deposit spread}_t}{1+i_t})$	−0.317	−0.089	−0.090	−0.115	−0.062	−0.098
	(0.012)	(0.006)	(0.008)	(0.004)	(0.007)	(0.003)
$\log(\text{real GDP}_t)$	−0.173	−0.515	−0.006	−0.340	−0.010	−0.335
	(0.016)	(0.030)	(0.011)	(0.021)	(0.011)	(0.018)
$\log(\text{VIX}_t)$			0.023	−0.076	0.035	−0.043
			(0.013)	(0.016)	(0.012)	(0.013)
Constant	0.040	2.785	−0.745	2.509	−0.777	2.363
	(0.131)	(0.280)	(0.115)	(0.202)	(0.109)	(0.165)
Observations	552	444	552	444	552	420
R^2	0.894	0.409	0.560	0.671	0.440	0.676

Notes: This table presents the money demand regressions with different definitions of money, where m_t is the real quantity of money including currency and checking deposits, Q_t is the real value of liquidity bundle as in equation (6), and Q'_t is the real value of liquidity bundle as in equation (23). We set λ_t and μ_t as constant and equal to their mean values. HAC standard errors with 12 lags are reported in parentheses.

Table 25: Money Demand Regressions (including currency in circulation)

	Dependent variable:					
	$\log(m_t/\text{real GDP}_t)$		$\log(\bar{Q}_t/\text{real GDP}_t)$		$\log(\bar{Q}'_t/\text{real GDP}_t)$	
	pre 1980 (1)	post 1980 (2)	pre 1980 (3)	post 1980 (4)	pre 1980 (5)	post 1980 (6)
$\log(\frac{\text{deposit spread}_t}{1+i_t})$	−0.317 (0.012)	−0.087 (0.006)	−0.120 (0.008)	−0.110 (0.004)	−0.093 (0.008)	−0.093 (0.003)
$\log(\text{real GDP}_t)$	−0.172 (0.016)	−0.512 (0.030)	−0.005 (0.012)	−0.287 (0.020)	−0.006 (0.012)	−0.278 (0.016)
$\log(\text{VIX}_t)$			0.015 (0.014)	−0.072 (0.014)	0.029 (0.013)	−0.040 (0.011)
Constant	0.033 (0.131)	2.751 (0.278)	−0.640 (0.124)	2.092 (0.185)	−0.686 (0.117)	1.907 (0.146)
Observations	552	444	552	444	552	420
R^2	0.894	0.409	0.618	0.704	0.541	0.715

Notes: This table presents the money demand regressions with different definitions of money, where m_t is the real quantity of money including currency and checking deposits. $\bar{Q}_t$ follows the same construction as equation (6) for Q_t but we incorporate currency in circulation into D_t. Another liquidity aggregate, $\bar{Q}'_t$, follows the same construction as equation (23) for Q'_t but we include currency in circulation into the construction of D_t. Newey-West standard errors with 12 lags are reported in parentheses.



(a) $\log(m_t/\text{real GDP}_t)$ (b) $\log(Q_t/\text{real GDP}_t)$ (c) $\log(Q'_t/\text{real GDP}_t)$

Fig. 12. Quantity of Liquidity and the Opportunity Cost of Holding Liquidity. The y-axis is $\log(\text{deposit spread}_t/(1+\text{FFR}_t))$ across all three panels. Data are annual averages, with the years marked on the figure.