The Term Structure of Liquidity Premium

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Abstract

We analyze the term structure of Treasury liquidity premium (LP). Through a model where illiquidity shocks are alleviated by holding Treasuries, we show that LP term structure is shaped by expectations of future market liquidity, liquidity term premium, and Treasury supply. As predicted, the LP term structure is downward-sloping in recessions but upward-sloping in booms, and forward LP predicts future LP and market liquidity. Furthermore, LP is quantitatively important for monetary policy pass-through: LP dampens the pass-through of interest rate policy yet strengthens the pass-through of quantitative easings. We also use LP to infer the term structure of Treasury safety premium.

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1 Introduction

Recent literature has provided convincing evidence that the superior liquidity of US Treasury securities is significantly valued by investors (e.g., Longstaff, 2004). Due to the additional liquidity value, Treasury yields are lower than the yields of similarly safe assets with the same maturities. This yield differential is often referred to as the Treasury liquidity premium (hereafter abbreviated as "LP"). Despite the wide recognition of the important macroeconomic implications of LP,[1] we are still unclear about some basics of Treasury LP. In particular, how do investors value the superior liquidity of Treasuries of different maturities? What drives the variation of Treasury LP term structure over time? Does the Treasury LP term structure contain information on future LP and future liquidity conditions? What are the differential impacts of different monetary policies on LP across maturities?

In our analysis, we construct the Treasury LP term structure at a given maturity as the yield spread between Resolution Funding Corporation (Refcorp) STRIPS (zero-coupon bonds) and Treasury STRIPS, following the seminal work of Longstaff (2004). Refcorp bonds provide an ideal setting to study the term structure of liquidity premium as they are explicitly guaranteed by the US government and thus are equally safe as Treasuries. At the same time, Refcorp bonds are less liquid than Treasury bonds of the same maturity.[2] Therefore, the differences in their yields reflect the superior liquidity of Treasury securities. For example, the difference between the five-year Refcorp yield and the five-year Treasury yield reflects the market valuation for the superior liquidity of Treasuries over the next five years.[3]

To guide our empirical analysis of the LP term structure, we first build a stylized model of short-term and long-term LP. Our model features representative households subject to time-varying illiquidity shocks that can be alleviated by holding short-term or long-term Treasuries. The model has four intuitive predictions: First, since illiquidity shocks are

[1]See, for example, Krishnamurthy and Vissing-Jorgensen (2011, 2012); Nagel (2016); Jiang et al. (2018); Li (2019).

[2]Refcorp bonds also have similar tax treatment as Treasuries. See Section 2.1 for more details on Refcorp bonds.

[3]As a robustness check, we also use the spread between non-MBS agency STRIPS and Treasury STRIPS. Our findings are robust using this alternative LP measure.

more likely to happen in bad times and the economic conditions are expected to revert to the normal state, the LP term structure is downward-sloping in crises and recessions but is upward-sloping in booms. For a similar reason, the second prediction of the model is that risk premium is positively correlated with the level of LP across maturities but is negatively correlated with the LP term spread.[4] Third, forward LP reflects expectations of future liquidity conditions, thus positively forecasts future short-term LP and future market liquidity. Last, a greater Treasury supply, either long-term or short-term, leads to lower LP across all maturities. A larger long-term Treasury supply also decreases the LP term spread.

With our model in hand, we show empirically that the Treasury LP is economically significant across all maturities from three months to 20 years. At the short end, for example, the LP averages about 27 and 25 basis points (bps) at the three-month and six-month maturities, respectively. Perhaps more interestingly, the LP is also significant at the long end: it averages 28 bps at the 10-year maturity and 27 bps at the 20-year maturity, implying a high valuation of future liquidity by investors. We also find that the LP term structure features a level factor, a slope factor, and a curvature factor, similar to the term structure of Treasury yield. However, variations of LP term spread are largely orthogonal to those of Treasury yield term spread, suggesting that LP term structure contains additional information beyond the Treasury yield curve.

We then analyze the properties of the LP term structure. Aligned with the model predictions, we find that the LP term structure is downward-sloping in recessions and upward-sloping in booms. For example, the term spread between the 20-year LP and the three-month LP averaged at −106 bps at the height of the 2008 financial crisis but averaged at 36 bps in early 2005. Such cyclical behavior is also reflected in the high explanatory power of risk premium on the level and the term spread of LP.[5] We also find that the LP term structure contains information about future short-term LP and future liquidity conditions. For example, forward LP has significant predictive power over the future short-term LP (up to five years) with an average R^2 of about 20%. Moreover, the forward LP strongly predicts future

[4]Similar to the interest rate term structure, LP term spread refers to the spread between long-term LP and short-term LP. Forward LP refers to the future LP that can be locked in advance. See Section 4 for details.

[5]Since our LP measure does not contain credit risks, this connection comes from a deeper economic mechanism as in the model.

market liquidity conditions over the next few years, confirming the model's implication that liquidity premium is closely tied to expected market liquidity.

We then turn to study how monetary policies affect the Treasury LP term structure. Because corporate financing rates include LP on top of Treasury yields, it is critical to understand how LP responds to monetary policies in order to better understand the pass-through of monetary policies to corporate financing rates. We study both interest rate policies and QEs, and we find that LP dampens interest rate policy pass-through but significantly strengthens pass-through of QEs to corporate financing rates.

Specifically, applying monetary policy shocks measured through the federal funds futures, we find that our LP measure negatively reacts to interest rate policy, i.e., higher FFR implies lower LP across the term structure. A similar negative response is also observed if we use the agency/Treasury spread to measure LP. However, this result is in contrast to the literature that studies the relation between FFR and short-term "funding-market-based" LP measures, such as three-month repo/Treasury spread and three-month CD/Treasury spread. That is, although lowering interest rates reduces short-term funding-market-based LP, it can have an opposite effect on the entire term structure of "bond-market-based" LP as captured by our measure.[6] We also explore differences between the two sets of LP measures and discuss potential economic mechanisms that can drive the different responses. Admittedly, the puzzling pattern calls for further investigation in future research.

Compared with interest rate policies, we find that the pass-through of QEs to long-term financing rate is strengthened through LP, although there is large heterogeneity across maturities. Using an event study approach based on QE announcements from 2008 to 2012 as in Krishnamurthy and Vissing-Jorgensen (2011), we find that the LP term structure responds differently to QE announcements, depending on the underlying assets purchased by the Federal Reserve. We discover a common theme that purchasing long-term illiquid assets (relative to Treasuries) by the Federal Reserve reduces long-term LP more than short-term LP, but purchasing long-term Treasuries reduces short-term LP more than long-term

[6] Repos and CDs are short-term funding instruments used by financial intermediaries. On the other hand, the Refcorp/Treasury and agency/Treasury spreads only involve bonds and do not directly reflect the funding costs of intermediaries.

LP. This difference in LP response is likely due to the different impact on Treasury supply.

In the last part of the paper, we further leverage the LP term structure to infer and analyze the Treasury safety premium (SP) across maturities in a granular way. Krishnamurthy and Vissing-Jorgensen (2012) argue that apart from superior liquidity, the superior safety of Treasuries is also valued by investors and is reflected as even lower Treasury yields.[7] Our estimate of the LP term structure allows us to study Treasury SP across different maturities. Specifically, we decompose the so-called "convenience yield" of Treasuries, measured as the spreads between AAA-rated corporate bonds and Treasuries, into three components: the default risk premium, the LP, and the SP.[8]

We find that SP and LP contribute similarly to Treasury convenience yields. For example, the Treasury convenience yield (i.e., the AAA–Treasury spread) is, on average, 84 bps across different maturities, which contains around 19 bps of default premium, 33 bps of LP, and 32 bps of SP. Interestingly, we find that SP is on average upward-sloping over maturities, averaging at 60 bps for maturities longer than ten years, which doubles the short-term SP. This suggests a strong demand for long-term safety, possibly from the long-term preferred-habitat investors such as pension funds, as in Greenwood and Vayanos (2010).

This paper is closely related to the growing literature on the liquidity premium (LP) of Treasury securities. According to Holmström and Tirole (1998), the government performs a unique role in the provision of liquidity, and government debt is especially valued by its high liquidity compared with private debt. This viewpoint is strongly supported in the data (Longstaff, 2004; Krishnamurthy and Vissing-Jorgensen, 2012). Follow-up research also indicates important macroeconomic implications of LP, for example, LP influences risk-taking (Drechsler et al., 2018), drives exchange rates (Jiang et al., 2018), affects financial sector fragility and severity of crises (Li, 2019), contributes to the resolution of no-arbitrage violations (Du et al., 2018; Augustin et al., 2020), and serves as an additional pass-through of monetary policies (Krishnamurthy and Vissing-Jorgensen, 2011; Nagel, 2016; Piazzesi and

[7]For example, long-term SP could arise from preferred-habitat demand from pension funds and insurance companies with long nominal liabilities. Short-term SP could be due to the collateral benefits or information costs of understanding risky investments.

[8]The default component is measured as the difference between CDS spreads of AAA corporate bonds and CDS spreads of the US government of the same maturity.

Schneider, 2017). Furthermore, there is also a growing literature that explores the microeconomic foundations for the liquidity premium (Herrenbrueck, 2019; Lagos and Zhang, 2020). All of these different perspectives over the liquidity premium involve a time dimension related to the term structure of LP. Our contribution is to provide the first empirical analysis of the term structure of LP, which is useful for testing a wide range of related theories in the literature.

Our findings also deepen the understanding of the relationship between monetary policies and LP. Nagel (2016) shows that interest rates are positively correlated with the short-term funding-market-based LP, such as three-month repo/Treasury spread and CD/Treasury spread. The idea is that short-term Treasuries have "moneyness" and are therefore affected by interest rate policies. Vandeweyer (2019) shows that after the implementation of leverage regulation, such connections are weakened due to the balance sheet costs of intermediating liquidity. Our results point to a different category of LP measures, which we call bond-market-based LP as both Refcorp/Treasury and agency/Treasury spreads only involve bonds and do not directly reflect funding spread for financial intermediaries. Our measure is more relevant to corporate financing rates and goes well beyond three months. The striking differences between the two sets of LP measures call for a more thorough investigation of the impact of interest rate on LP.

This paper also provides a new way to isolate liquidity premium and safety premium. While safe assets and safety premium are modeled extensively in some recent work (Caballero et al., 2016; Gorton, 2017; Geromichalos et al., 2018; He et al., 2019), there is a lack of empirical evidence. We fill the gap by providing a high-frequency and granular measure of Treasury safety premium along with different maturities.

The paper proceeds as follows. In Section 2, we explain how we estimate the LP term structure. In Section 3, we present a stylized model of the LP term structure. In Section 4, we analyze the properties of the LP term structure, including cyclicality and information content of the LP term structure. In Section 5, we analyze the influences of interest rate policies and QEs on the LP term structure. In Section 6, we use the LP term structure to infer and analyze Treasury SP. Section 7 provides the concluding remarks. Additional results and robustness checks are in the appendices.

2 Estimation of the LP Term Structure

In this section, we explain how we estimate the term structure of Treasury LP. We find that Treasury LP is economically significant across all the maturities from three months to 20 years. Moreover, the LP term structure features three salient principal components similar to the term structure of Treasury yield, although variations of the two are largely independent.

2.1 Data and estimation of LP

Following Longstaff (2004), we measure the Treasury LP at a given maturity as the yield spread between Resolution Funding Corporation STRIPS (zero-coupon bonds) and Treasury STRIPS.[9] Resolution Funding Corporation (Refcorp) is a government agency that provides funds to the Resolution Trust Corporation, established to finance the bailout of savings and loan associations in the 1980s. The principal amounts of the Refcorp bonds are about $30 billion. Unlike most other agency bonds that usually bear some small credit risk, Refcorp bonds are explicitly guaranteed by the US government. The interest payments of Refcorp bonds are guaranteed by the US Treasury,[10] and the principal amount is secured by zero-coupon US Treasury securities held in a separate custodial account at the Federal Reserve Bank of New York. Therefore, Refcorp bonds are equally safe as Treasuries. Furthermore, Refcorp bonds have the same taxation as Treasuries, and Refcorp bonds are also eligible to be stripped.

Because Refcorp bonds and Refcorp STRIPS are equally safe yet less liquid than Treasuries, the yield spread between Refcorp bonds and Treasuries of the same maturity serves as an ideal measure for Treasury liquidity premium. We obtain daily data on the yield

[9] See Grinblatt and Longstaff (2000) for more details on STRIPS.

[10] Under FIRREA and the Gramm-Leach-Bliley Act of 2000, the Federal Home Loan Bank system is required to pay some portion of the coupon of Refcorp. If the Federal Home Loan Bank system fails to pay the coupons, FIRREA and the Gramm-Leach-Bliley Act require the Treasury to pay the additional amounts.

curve of Treasury STRIPS and the yield curve of Refcorp STRIPS from Bloomberg for the period from April 1991 to May 2020. These yield curves are constructed by Bloomberg based on the quotations and transactions of the zero-coupon bonds at the market close. We obtain monthly data by averaging daily values. We use monthly data for studying the main properties of LP and daily data for event studies such as QE announcements and changes in monetary policy targets.

Table 1 shows the summary statistics of the monthly LP, calculated as the average of daily data in a month.[11] Maturities vary from three months to 20 years. At the very short end, the average three-month liquidity premium is 27 bps, consistent with the earlier evidence that short-term Treasuries carry an economically significant LP. Perhaps more interestingly, we find that the long-term LP is also economically significant. For example, the average 10-year LP is 28 bps, and the average 20-year LP is 27 bps. This long-term LP indicates that the superior liquidity of Treasuries in the far future is also highly valued by investors.

In Figure 1, we plot the monthly three-month LP and 10-year LP. They are representative of the short-term LP and long-term LP. Both time series have strong countercyclical movement and spike in time of financial distress, such as the 2008 global financial crisis and the 2020 COVID-19 crisis. Furthermore, the volatility of the three-month LP is much higher than the 10-year LP.

Through a principal component analysis (PCA), we find that the LP term structure features a factor structure similar to the term structure of Treasury yields. Figure 2(a) shows that 96% of the variations in LP along different maturities are explained by the first three principal components (PCs). Figure 2(b) plots the factor loadings of the first three PCs. Loadings on the first PC are relatively flat. Loadings on the second PC are significantly downward-sloping, while loadings on the third PC exhibit a strong curvature. These three PCs of the LP term structure capture level, slope, and curvature, respectively.

One question is whether variations in the LP term structure are mainly driven by those of the Treasury term structure. In fact, we find that variations of the LP term structure are

[11]The summary statistics of daily data are similar and provided in the appendix. It is also worth noting that there are very few observations (less than 3% in total) of negative LP, which are likely to due to measurement errors. Our results are not affected when removing those negative observations.

mostly orthogonal to those of Treasury yields. To see this, we regress the LP term spread on the term spread of Treasuries, and we report the results in Table 2. The median R^2s in these regressions is 7%.[12] Therefore, we conclude that the LP term structure is not mechanically driven by the Treasury term structure, and it contains independent information.

One alternative measure of Treasury LP we consider is the spread between Treasuries and bonds of other government agencies, such as the Federal Home Loan Bank (FHLB), the Federal National Mortgage Association (Fannie Mae), and the Federal Home Loan Mortgage Corporation(Freddie Mac). To emphasize, the agency bonds are not mortgage-backed securities but their outstanding amount is sizable. According to the data from Securities Industry and Financial Markets Association (SIFMA), the outstanding agency debt is $1.8T in 2019, and the outstanding Treasury debt is about $19T in 2019. In our analysis, we use the agency STRIPS/Treasury STRIPS spread from Bloomberg, which is available from August 1999 to May 2020. While there may be a form of implicit guarantee from the US government, these bonds –unlike Refcorp bonds– are not explicitly guaranteed and thus carry some default risk. Indeed, as shown in Appendix Table B.I, we find that the agency/Treasury spread is about 15 bps to 30 bps higher than the Refcorp/Treasury spread, indicating that agency bonds are not as safe as Refcorp bonds despite being typically rated AAA.[13] We find that most of our results on the LP term structure hold qualitatively based on this alternative measure.

2.2 Discussions of LP measures

Given that both the yield curve of Treasury STRIPS and the yield curve of Refcorp STRIPS are constructed by Bloomberg using the same method, there is little concern about the discrepancy in yield curve construction. Besides, the spreads between Treasury STRIPS and Refcorp STRIPS are also unlikely to be driven by differences in their collateral values. This is because Treasury STRIPS are barely financed at a special repo rate, and the differ-

[12] In Appendix B, we further confirm the low explanatory power of Treasury yield on LP at a daily frequency.

[13] Depending on which GSE issues the bond, there may be differences in tax treatment that could also drive this spread. Longstaff et al. (2011) document the potential impact of tax differences on bond yields and changes in yields.

ences between the repo rates of general Treasury and agency collaterals are often tiny. For example, the repo difference was 0.25 bps from 1991 to 2001. Based on Krishnamurthy et al. (2014) and the tri-party repo data from Bank of New York Mellon, the average difference between the repo rates collateralized by agency bonds and Treasury bonds was about 1 to 2 bps from 2006 to 2020. The haircut differences are also tiny. Therefore, compared to the magnitudes of our LP measure (an average of 26 bps across maturities), the differences in collateral values are too small to drive our results.

Moreover, the differences in the size of the bid-ask spreads do not materially affect the estimation of LP. According to Longstaff (2004), the average bid-ask spread on Treasury STRIPS was about two to three ticks, and the typical bid-ask spread of Refcorp STRIPS was slightly larger than that of Treasury STRIPS by a couple of basis points.[14] While bid-ask spreads on Treasury STRIPS and Refcorp STRIPS are comparable, the market depth and the extent to which institutional investors could readily trade large positions are very different. Treasuries are more liquid than Refcorp bonds.

Conceptually, other assets with similar safety and less liquidity relative to Treasury securities could also be used to measure Treasury LP. Some plausible measures include the on-the-run/off-the-run Treasury spread and the repo/Treasury spread. However, we find that these measures are problematic for measuring long-term LP and the term structure of LP. For example, the on-the-run/off-the-run Treasury spread converges to zero after each auction cycle because the current on-the-run Treasuries gradually become off-the-run. Thus, the on-the-run/off-the-run Treasury spread does not contain information about the liquidity premium beyond the length of auction cycles, which is typically three months. The general repo rates are mostly short-term (less than one to two years), so we can not measure long-horizon LP.

Therefore, we follow Longstaff (2004) and use the yield spreads between Refcorp zero-coupon bonds and Treasury zero-coupon bonds to measure the premium associated with the superior liquidity of Treasuries.

[14] Our own estimation of the later sample shows that the average bid-ask spread of Treasury STRIPS is 2 to 3 bps, and the bid-ask spread of Refcorp STRIPS is, on average, 5 to 6 bps.

3 A Model of the LP Term Structure

In this section, we set up a stylized model to guide our later empirical analysis of the Treasury LP term structure. The model indicates that the LP term structure is mainly shaped by three economic forces: (*i*) expectations of future liquidity conditions; (*ii*) liquidity term premium, captured by the covariance between future short-term LP and the stochastic discount factor (SDF); and (*iii*) short-term and long-term Treasury supply.

3.1 Model setup

The model has two periods with three dates, $t = 0, 1$, and 2. The economy is populated by identical households that make consumption and portfolio choices to maximize the following objective function:

$$\max E[u(c_0) + \rho u(c_1) + \rho^2 u(c_2)]. \tag{1}$$

Here, ρ is the discount rate, and the utility function $u(\cdot)$ is increasing, twice differentiable, and concave. Households receive an endowment of e_t at t.

The households are subject to probabilistic illiquidity shocks. At the end of period 1, a liquidity shock $X_0 \in \{0, 1\}$ arrives with a probability λ_0 (i.e., $P(X_0 = 1) = \lambda_0$), and at the end of period 2, a liquidity shock $X_1 \in \{0, 1\}$ arrives with a probability λ_1. Conditional on λ_t ($t \in \{0, 1\}$), X_t is independent from everything else. For simplicity, we assume that the aggregate fluctuation of this economy is driven by an ergodic two-state Markov chain,[15] $\xi_t \in \{\text{good}, \text{bad}\}$ for $t = 0, 1$, and 2. In particular, the λ_t process is also a Markov chain that depends on ξ_t, with $\lambda(\text{good}) = \lambda_L < \lambda(\text{bad}) = \lambda_H$. This indicates that when the economy is in the good state, the probability of illiquidity shock is lower than that in the bad state. The consumption in the good state is higher than that in the bad state, i.e., $c(\text{good}) = c_H > c(\text{bad}) = c_L$. The timeline of our model is illustrated below.

The costs of illiquidity shocks can be alleviated by holding government bonds of various maturities. Specifically, during the liquidity shock at the end of period 1, the representative

[15] An equivalent statement for this two-state Markov chain is that the transition probability matrix is element-wise positive.

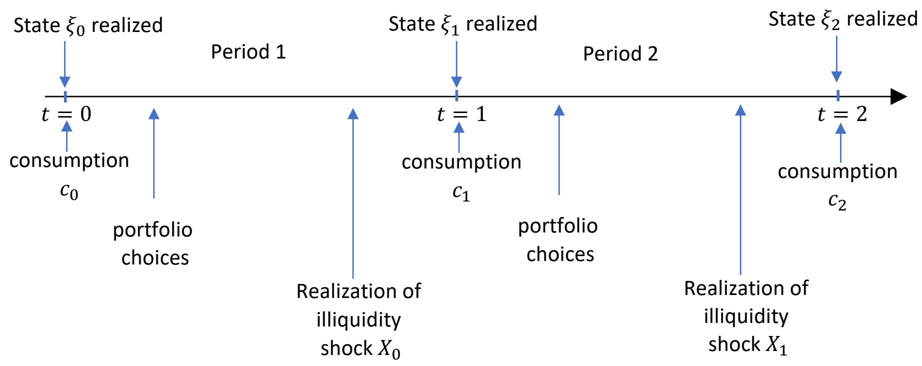

Illustration 1: **Model Timeline**

household incurs a cost of

$$\bar{\kappa} - \kappa_0(b_{0,1}, b_{0,2}). \tag{2}$$

Here, $\kappa_0(b_{0,1}, b_{0,2})$ is interpreted as a "liquidity benefit" function, which is increasing in one-period (short-term) government bond holding $b_{0,1}$, and two-period (long-term) government bond holding $b_{0,2}$. Therefore, a larger holding in any one of them helps reduce illiquidity costs. Furthermore, we assume that κ_0 is concave in $b_{0,1}$ and $b_{0,2}$, respectively, to reflect the declining marginal benefits of holding liquid assets.

Similarly, at the end of period 2, another liquidity shock $X_1 \in \{0, 1\}$ comes with probability λ_1. We assume that the second-period liquidity cost function is

$$\bar{\kappa} - \kappa_1(b_1), \tag{3}$$

where the second term $\kappa_1(b_1)$ is increasing in and concave in the one-period bond holding b_1 (there is no two-period bond at $t = 1$ since the model ends at $t = 2$). All of the assumptions about κ_0 and κ_1 naturally emerge with quadratic transaction costs and are discussed in Appendix A.1.

In our model, short-term and long-term government bonds are substitutable in alleviating illiquidity shock if the cross-partial derivative of κ_t over these two assets are negative. That is, short-term and long-term government bonds are substitutable if and only if

$$\frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,1} \partial b_{0,2}} < 0. \tag{4}$$

The economic meaning of (4) is that the marginal liquidity value of short-term government bonds is decreasing with larger holdings of long-term government bonds and vice versa.

We denote the government bond yields at $t = 0$ as $r_{0,1}$ and $r_{0,2}$ for the one-period and two-period bonds, respectively. At $t = 1$, we only have one-period government bonds and denote the associated yield as r_1. The quantities of government bonds are exogenous. We also denote the risk-free interest rates at $t = 0$ as $\hat{r}_{0,1}$ and $\hat{r}_{0,2}$, respectively, and the risk-free rate at $t = 1$ as $\hat{r}_1$. One can think of these rates as the yields of illiquid but safe bonds, like Refcorp bonds.

We now set up the optimization problem of the representative household as

$$\max E[u(c_0) + \rho u(c_1) + \rho^2 u(c_2)], \tag{5}$$

subject to

$$\begin{cases} w_0 = e_0 - c_0, \\ w_0 \geq b_{0,1} + b_{0,2} + \hat{b}_{0,1} + \hat{b}_{0,2}, \\ w_1 = b_{0,1}(1 + r_{0,1}) + b_{0,2}\dfrac{(1 + r_{0,2})^2}{1 + r_1} + \hat{b}_{0,1}(1 + \hat{r}_{0,1}) + \hat{b}_{0,2}\dfrac{(1 + \hat{r}_{0,2})^2}{1 + \hat{r}_1} \\ \qquad + e_1 - c_1 - X_0 \cdot (\bar{\kappa} - \kappa_0(b_{0,1}, b_{0,2})), \\ w_1 \geq b_1 + \hat{b}_1, \\ w_2 = b_1(1 + r_1) + \hat{b}_1(1 + \hat{r}_1) + e_2 - c_2 - X_1 \cdot (\bar{\kappa} - \kappa_1(b_1)), \\ w_2 \geq 0, \quad b_{0,1} \geq 0, \quad b_{0,2} \geq 0, \quad b_1 \geq 0. \end{cases} \tag{6}$$

By local non-satiation, the inequalities of w_0, w_1, and w_2 are both binding. Furthermore, we work with interior solutions and ignore the nonnegative constraints on government bond holdings. Next, by substituting the investment of the one-period illiquid bonds $\hat{b}_{0,1}$ and $\hat{b}_1$, we get the following consolidated budget constraint:

$$
\begin{aligned}
w_0 &= e_0 - c_0, \\
w_1 &= b_{0,1}(1 + r_{0,1}) + b_{0,2}\frac{(1 + r_{0,2})^2}{1 + r_1} + (w_0 - b_{0,2} - b_{0,1} - \hat{b}_{0,2})(1 + \hat{r}_{0,1}) \\
&\quad + \hat{b}_{0,2}\frac{(1 + \hat{r}_{0,2})^2}{1 + \hat{r}_1} - c_1 + e_1 - X_0 \cdot (\bar{\kappa} - \kappa_0(b_{0,1}, b_{0,2})), \\
w_2 &= b_1(1 + r_1) + (w_1 - b_1)(1 + \hat{r}_1) - c_2 + e_2 - X_1 \cdot (\bar{\kappa} - \kappa_1(b_1)) = 0.
\end{aligned} \tag{7}
$$

In this model, the households hold all of the government bonds, which in equilibrium equal to the total supply. Therefore, in what follows, we interpret the quantities as controlled by the government. For simplicity, we assume that all of these quantities are deterministic.

We define the one-period (short-term) LP at time $t = 0$ as

$$LP_{0,1} = \hat{r}_{0,1} - r_{0,1}. \tag{8}$$

Similarly, the two-period (long-term) LP at time $t = 0$ is defined as

$$LP_{0,2} = \hat{r}_{0,2} - r_{0,2}, \tag{9}$$

and the one-period LP at time $t = 1$ is defined as

$$LP_1 = \hat{r}_1 - r_1. \tag{10}$$

With these definitions, we characterize the short-term LP in the following proposition, with the proofs provided in Appendix A.

Proposition 1. *The one-period liquidity premium at time $t = 0$ is*

$$LP_{0,1} = \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,1}}\lambda_0, \tag{11}$$

and the one-period liquidity premium at $t = 1$ is

$$LP_1 = \frac{\partial \kappa_1(b_1)}{\partial b_1}\lambda_1. \tag{12}$$

As one can see, $LP_{0,1}$ is the product of two terms: The first term measures the marginal value of the one-period government (liquid) bond in reducing illiquidity costs, which is related to the supply of bonds of different maturities. Suppose that the supply of long-term liquid bond, $b_{0,2}$, increases. If long-term bonds and short-term bonds are substitutable, then $LP_{0,1}$ will be smaller. Furthermore, by assumption, a higher short-term bond supply $b_{0,1}$ also reduces $LP_{0,1}$. The second term in (11) is the probability of future illiquidity shock. If illiquidity shock is more likely to happen, then the short-term LP is higher. We have a similar interpretation for LP_1.

Next, we characterize the two-period (long-term) LP.

Proposition 2. *Assume that both r_1 and $\hat{r}_1$ are small. Then, the two-period liquidity premium $LP_{0,2}$ is given by*

$$LP_{0,2} = \frac{1}{2}\left(\lambda_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,2}} + E\left[\frac{u'(c_1)}{E[u'(c_1)]}\lambda_1 \frac{\partial \kappa_1(b_1)}{\partial b_1}\right]\right). \tag{13}$$

According to Proposition 2, the long-term LP is related to the expected liquidity shocks both in the current period and in the future, while the latter carries a risk premium, reflected by the covariance between future marginal utility and the intensity of future liquidity shocks. To connect equation (13) with future short term liquidity premia, we use equation (12) to rewrite it as

$$LP_{0,2} = \frac{1}{2}\left(E[LP_1] + Cov\left(\frac{u'(c_1)}{E[u'(c_1)]}, LP_1\right) + \lambda_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,2}}\right). \tag{14}$$

Thus, the long-term LP is driven by three forces:

- Expectation of future short-term LP. That is, the long-term LP is positively related to the expected future short-term LP.

- Liquidity term premium. That is, if future short-term LP spikes when the marginal utility is high, then the current long-term LP is also higher.

- Supply of government bonds. That is, a larger supply of long-term government bonds $b_{0,2}$ reduces $LP_{0,2}$. Furthermore, if short-term bonds and long-term bonds are substitutable, a larger supply of short-term bonds $b_{0,1}$ also reduces $LP_{0,2}$.

3.2 Model predictions

In this subsection, we study the model's predictions. To this end, we first define the LP term spread as

$$s_0 = LP_{0,2} - LP_{0,1}. \tag{15}$$

From equations (11) and (13), we have

$$s_0 = \frac{1}{2} E\left[\frac{u'(c_1)}{E[u'(c_1)]}\lambda_1 \frac{\partial \kappa_1}{\partial b_1}\right] - \frac{1}{2}\left(2\frac{\partial \kappa_0}{\partial b_{0,1}} - \frac{\partial \kappa_0}{\partial b_{0,2}}\right)\lambda_0. \tag{16}$$

In what follows, we assume that the average marginal liquidity benefits of $b_{0,2}$ and b_1 is the same as the marginal benefit of $b_{0,1}$:

$$\frac{\partial \kappa_1}{\partial b_1} + \frac{\partial \kappa_0}{\partial b_{0,2}} = 2\frac{\partial \kappa_0}{\partial b_{0,1}}. \tag{17}$$

In other words, if an increase in $b_{0,2}$ is persistent, then the total effect of long-term bonds on alleviating the liquidity concern doubles that of the short-term bonds.

With assumption (17), the LP term spread in (15) can be simplified into

$$s_0 = \frac{1}{2}\frac{\partial \kappa_1}{\partial b_1}\left(\underbrace{Cov\left(\frac{u'(c_1)}{E[u'(c_1)]}, \lambda_1\right)}_{\text{liquidity term premium}} + \underbrace{E[\lambda_1]}_{\text{expected future intensity}} - \underbrace{\lambda_0}_{\text{current intensity}}\right), \tag{18}$$

where the liquidity term premium is positive because the marginal utility and the intensity of illiquidity shock change along the same direction across the good and bad states. Then we have the following prediction (proofs are provided in Appendix A.3).

Prediction 1 (Cyclicality of LP Term Spread). *The LP term spread s_0 is negative during recessions ($\xi_0 = bad$) and positive in booms ($\xi_0 = good$).*

This prediction is driven by the cyclical movement in λ_t. In a recession, the current intensity of illiquidity shock λ_0 is higher, $\lambda_0 > E_1[\lambda_1]$, and overwhelms the positive liquidity term premium. Therefore, $s_0 < 0$. In a boom, the current intensity of illiquidity shock $\lambda_0 < E_1[\lambda_1]$, which implies a positive s_0.

Notice that the risk premium (i.e., marginal utility $u'(c_0)$) is also higher in the bad state ($\xi_0 = \text{bad}$). Because of the expectation effect in Prediction 1, higher risk premium predicts higher current liquidity premium but lower LP term spread. The following prediction formalizes this intuition.

Prediction 2 (Risk Premium and LP Term Spread). *A higher risk premium indicates higher current liquidity premium $LP_{0,1}$, but lower LP term spread s_0.*

Next, we study the information content in forward LP, which is defined as

$$f_{0,1} = 2LP_{0,2} - LP_{0,1}. \tag{19}$$

With equation (14), we can write

$$f_{0,1} = E[LP_1] + \text{Cov}\left(\frac{u'(c_1)}{E[u'(c_1)]}, LP_1\right). \tag{20}$$

As a result, the forward LP contains information about the expectation of future short-term LP and the term premium. Given the close connection between short-term LP and current market liquidity condition reflected by the value of the κ function, we also expect that forward LP should predict future market liquidity conditions. We summarize these in the following prediction.

Prediction 3 (Predictability of Future Short-Term LP). *Forward liquidity premium $f_{0,1}$ positively predicts future short-term liquidity premium LP_1.*

The model also has predictions on how the LP term structure changes when the supply of government bonds shifts. According to equation (11) and (13), an increase in the long-term

Treasury supply, $b_{0,2}$, affects both the long-term liquidity premium $LP_{0,2}$ and the short-term liquidity premium $LP_{0,1}$. If the supply increase is persistent, it also affects the future short-term LP. A heterogeneous impact on different maturities may arise if the direct impact and the substitution impact are of different magnitude.

Prediction 4 (Treasury Supply and LP Term Spread)**.** *Suppose long-term and short-term government bonds are substitutable as in equation (4). In the stationary state, a larger long-term Treasury supply $b_{0,2}$ reduces the term spread s_0.*

Prediction 4 illustrates another channel of how quantitative easing affects the liquidity premium. Apart from improving the liquidity conditions of the financial sector and thus reducing the severity of liquidity shocks (interpreted as reducing κ_0 and κ_1), QE also works through affecting the supply of Treasuries. When long-term Treasury supply is reduced, according to Prediction 4, the term spread s_0 increases, making the term structure of LP more upward sloping.

4 Properties of the LP Term Structure

In this section, we test the model predictions based on the LP term structure constructed in Section 2. Consistent with Predictions 1 and 2, we find that the LP term structure is downward-sloping in recessions, and the LP term spread is negatively correlated with measures of risk premium. Consistent with Prediction 3, we find that forward LP strongly predicts future liquidity premium and future market liquidity conditions. We will analyze the response of LP term structure to monetary policy in Section 5.

4.1 The cyclicality of the LP term structure

We first illustrate the cyclicality of the LP term structure. Figure 3 plots the time series of the 20-year/1-year LP term spread. As one can see, variations of the LP term spread are also quite large, ranging from about −80 bps to 50 bps. The LP term spread generally dips during economic recessions and financial crises but increases with buoyant liquidity conditions, such as in 2005. Figure 4 plots the unconditional average LP term structure as well as the average term structure during NBER recessions and during times of high liquidity (defined as the periods where the first principal component of the liquid premium falls in the lowest quintile in the sample). Consistent with Prediction 1, the LP term structure is on average downward-sloping in recessions and is slightly upward-sloping in good times. Importantly, this is not mechanically due to the cyclical variations in Treasury yields, as we have shown in Table 2.[16] Additionally, times of high liquidity (as indicated by a low liquidity premium) are associated with a flatter LP term spread.

4.2 Risk premium and the LP term structure

In this subsection, we show through regression analysis that the shape of the LP term structure is closely related to measures of risk premium. Consistent with Prediction 2 of our model, we find that a higher risk premium implies (*i*) larger LP across maturities and (*ii*) lower LP term spread. These results hold consistently based on different measures of risk premium.

Specifically, we use several risk premium measures in the literature: the BAA/AAA corporate bond credit spread, the CBOE's VIX index, and the market leverage of primary dealers.[17] To isolate the risk premium effect, we control for federal funds rate (FFR) and the debt-to-GDP ratio, which are shown to be highly related to liquidity premium (Krishnamurthy and Vissing-Jorgensen, 2012; Greenwood and Vayanos, 2014; Nagel, 2016).

The regression results are presented in Table 3. In Panel A, we test whether the level of LP is related to risk premia. One can see that the estimated coefficients of the credit spread are consistently significant and positive across all maturities, confirming the model's prediction that the level of LP is positively correlated with risk premium.[18] The positive

[16] For example, Table 2 shows that the 20-year/three-month Treasury yield spread can only explain 4% variation of the LP term spread.

[17] The corporate bond credit spread captures a risk premium component as discussed by the literature on the credit spread puzzle (Chen et al., 2009). The VIX index contains information on stock market volatility and the variance risk premium (Bekaert and Hoerova, 2014). The market leverage of primary dealers proves to be a useful empirical proxy for the intermediary asset pricing kernel (He et al., 2019).

[18] Potentially this positive correlation could be related to differences in the relative liquidity of BAA vs. AAA bonds; while possible, this seems unlikely to drive our results. Additionally, we find similar results with the other risk premium measures.

correlation is also present with the other two risk premium measures, the VIX index and dealer leverage, as shown in Columns (4) to (9).

In Panel B of Table 3, we regress the LP term spreads on the risk premium measures. Specifically, we calculate the k-year term spread as the difference between the k-year LP and the three-month LP. Consistent with Prediction 2, a higher risk premium is associated with lower LP term spreads. This is because, during states of high risk premium, the current liquidity condition is more severe but the economy is expected to recover, resulting in lower long-term LP. Therefore, risk premium is negatively correlated with the LP term spread.

In summary, the cyclicality of the LP term structure is consistent with our model's predictions. Next, we examine the predictive power of the LP term structure on future short-term LP and future market liquidity conditions.

4.3 Does the LP term structure contain information about future liquidity?

Yes. Based on our model, the long-term LP should contain expectations about future short-term LP. In this subsection, we show that forward LP indeed strongly forecasts future short-term LP and future market liquidity conditions, consistent with Prediction 3 of the model.

We first calculate forward LP in a similar spirit as forward interest rate. We denote the k-year LP at time t as $\ell_{t,k}$. Then the forward LP in year k at time t is defined as

$$f_{t,k}^{LP} = k \times LP_{t,k} - (k-1) \times LP_{t,k-1}. \tag{21}$$

That is, $f_{t,k}^{LP}$ is the average LP in year k that one can lock in at time t.

With this, we estimate the following predictive regression as in the interest rate term structure literature (e.g. Fama and Bliss, 1987 or Cochrane, 2009):

$$LP_{t+k-1,1} - LP_{t,1} = \alpha_k + \beta_k (f_{t,k}^{LP} - LP_{t,1}) + \varepsilon_{t+k-1}, \tag{22}$$

where the dependent variable is the change in the one-year LP, and the independent variable is the excess forward LP. We implement regressions with $k = 2, 3, 4$, and 5 at a monthly frequency. We control other factors that the literature shows to be important explanatory variables for the LP, including FFR and the debt-to-GDP ratio.

The regression results are presented in Table 4. We find that the estimated coefficients are significantly positive for all horizons. The forward excess LP variable in those regressions contributes a marginal R^2 of 17% on average (not shown in the table), indicating a high predictive power. Our interpretation of these results is that the LP term structure reflects expectations of future short-term LP.

We further show that the LP term structure can also forecast future market liquidity. We use the bond-market liquidity measures from Trebbi and Xiao (2019), including the yield-curve noise (Hu et al., 2013), the on-the-run/off-the-run Treasury spread, and the Roll (1984) measure.[19] To extract the maximum information from these illiquidity measures, we normalize each measure to have zero mean and unit standard deviation and then consolidate them into a normalized illiquidity index by taking the average of all the indexes. Similar consolidation is also used in Adrian et al. (2017). Alternatively, we estimate the first principal component of the illiquidity indexes.

With this, we estimate the following predictive regressions:

$$\overline{IL}_{t+k} - \overline{IL}_{t+1} = a + b(f_{t,k}^{LP} - LP_{t,1}) + \eta_{t+k}, \tag{23}$$

where $\overline{IL}_t$ is the value of the illiquidity index at time t, $LP_{t,1}$ is the one-year LP at the beginning of time t, and $f_{t,k}^{LP}$ is the forward k-year LP at the beginning of time t. In regression (23), we use the *excess* forward LP (forward LP minus the current one-year LP) to predict the change of market liquidity conditions from $t+1$ to $t+k$.

As shown in Table 5, the excess forward LP predicts changes in market liquidity conditions for 2, 3, 4, and 5 years, and most predictions have high statistical significance. These results further indicate that the LP term structure contains information about market liquidity

[19]We thank Kairong Xiao for providing us the Treasury illiquidity measures in Trebbi and Xiao (2019). The data spans from 1995 to 2014.

conditions in the future, consistent with the model prediction.

5 Monetary Policies and the LP Term Structure

In this section, we study the impact of interest rate policies and quantitative easings (QEs) on the LP term structure. While previous work mostly focuses on the very short end, we analyze the response of the entire LP term structure to central bank policies. Because corporate financing rates include LP on top of treasury yields, it is important to understand how LP responds to monetary policies in order to better understand the pass-through of monetary policies to corporate financing rates.

We find that LP is quantitatively important for the pass-through of interest rate policies and QEs. We highlight two novel results: First, we find a negative response of LP to FFR shocks across most maturities, using either Refcorp/Treasury or agency/Treasury spreads as the LP measure. The economic magnitudes are also quite large: on average, LP dampens 20% of the interest rate pass-through to Refcorp bond yields and 40% of the interest rate pass-through to agency bond yields. This result is contrary to the literature that finds a positive relation between FFR and short-term LP using the "funding-market-based" measures, such as the three-month repo/Treasury and CD/Treasury spreads.

Second, LP strengthens the pass-through of QEs, although the impact of QEs on the LP term structure critically depends on whether purchasing long-term Treasuries or (relatively) illiquid assets by the Federal Reserve. Specifically, the former reduces long-term Treasury supply and decreases short-term LP more than long-term LP, and the latter reduces long-term LP more than short-term LP. The economic magnitude of LP for QE pass-through is also significant: about 40% of the long-term ($\geq$ 5 years) Refcorp yield decline in response to the QE1 announcements was due to the decline in long-term LP, and the fraction is 20% for the announcements of QE2.

5.1 Interest rate policy and the LP term structure

We first study the impact of interest rate policies on the LP term structure. A preliminary approach is to directly regress the LP term structure on FFR, as shown in Table 6. The coefficients are negative and significant across the LP term structure, indicating that rising fed funds rates are associated with a reduction in liquidity premia across maturities. This result maintains whether we use the Refcorp/Treasury spread or agency/Treasury spread to measure LP.[20] As discussed in Section 2.1, (non-MBS) agency bonds are a significant portion of the fixed income market representing approximately 10% of the US Treasury market in market value terms in 2019. Although agency spreads encapsulate a credit risk component, we view these results as affirming the relationship between federal funds rates and LP.

Our results show a consistent negative relationship between the FFR and LP across maturities out to twenty years. These results contrast with Nagel (2016) who finds that the FFR is significantly and positively related to a different set of short-term LP measures, such as the three-month repo/T-bill and CD/T-bill spreads. Why is there such a difference?

Before exploring plausible reasons, we need to address endogeneity concerns in these simple linear regressions that we (and Nagel, 2016) conduct. That is, the regression exercise in Table 6 does not provide causal evidence of a link as macroeconomic conditions or other factors can both influence LP and the Fed policy-making, potentially causing a significant correlation between the two.

To resolve this issue, we resort to the federal funds futures market to measure monetary policy surprises at a daily frequency, following the approach of Kuttner (2001). We then study how LP responds to interest rate surprises. Specifically, interest rate surprises are calculated as the FFR changes during FOMC meetings or new target rate releases, minus the expected interest rate changes derived from the federal funds futures market. We also measure the LP response as the change in LP between the end of the event date and the end of the previous day. In total, we have 251 event dates. As this event study is based on daily data, reverse causality is not a concern because it is unlikely that the Federal Reserve reacts to a one-day LP shock.

[20] Changing the regressions from level to difference yields similar results.

With this, we regress the one-day change in our LP measures on the FFR surprises, and report the results in Table 7. With this causal identification, we still find negative and significant responses of LP to FFR at most maturities. The average sensitivity of LP to FFR surprises in Table 7 is -6 (i.e., a one-percent increase in FFR reduces LP by 6 bps). We also find that the average sensitivity of Refcorp bond yields to FFR surprises is 28 (i.e., a one-percent increase in FFR increases Refcorp yields by 28 bps). If we take the change in Refcorp yields as the benchmark for monetary policy pass-through, we find that LP dampens the interest rate pass-through by $6/28 = 21\%$. Similar calculations based on agency yields reveal a dampening effect of 40%.

We also use this event study approach to re-examine for causality the finding in the literature that FFR is positively associated with a different set of short-term LP measures. We study a large set of such LP measures, including the GCF Repo/three-month T-bill spread, the three-month Bloomberg GC Repo/T-bill spread, the three-month JPM Repo/T-bill spread, the three-month OIS/T-bill spread, and the three-month CD/T-bill spread.[21] The commonality of these measures is that they are all tightly related to the short-term funding market. For example, the three-month repo is a key short-term funding instrument used by broker-dealers, and the three-month CD is a key funding instrument used by commercial banks. Therefore, we refer to these measures as "funding-market-based" LP. On the other hand, we refer to the Refcorp/Treasury and agency/Treasury spreads as "bond-market-based" LP.

Table 8 compares the responses of the two sets of LP measures to interest rate shocks. For robustness, we measure LP changes over one-day, 10-day, and 20-day periods. Since our analysis is based on the FFR surprises, we are able to interpret these results as causal. The contrast between the two sets of LP measures is quite consistent: funding-market-based LP positively reacts to the FFR surprises, while bond-market-based LP negatively reacts to the FFR surprises.[22] It is also worth noting that the magnitudes of responses differ substantially

[21]Here, GCF Repo is an overnight repo index representing inter-dealer repo transactions cleared by Fixed Income Clearing Corporation (FICC). "Three-month GC Repo" is a three-month GC term repo rate index with Treasury as collateral, and data are offered by Bloomberg. "Three-month JPM Repo" is a three-month term repo index that mainly reflects repo funding rate offered by J.P. Morgan to clients. "Three-month OIS" is a swap that exchanges floating federal funds rate in three months into a fixed rate. "Three-month CD" is the three-month certificate of deposits rate index from the flow of funds.

[22]The results are similar if we replace Treasury STRIPS with T-bills in Refcorp/Treasury and agen-

from 1 day to 20 days for all of the funding-market-based LP measures. For example, for the three-month GCF Repo/T-bill spread, the 20-day response is about 20 times the 1-day response, and the larger coefficient over a longer horizon implies sluggish response in LP to FFR change.

To better understand the difference between the two sets of LP measures, in Figure 5, we plot the time series of the funding-market-based LP measures. All these measures comove strongly with each other, suggesting common drivers behind them. In Figure 6, we compare these funding-market-based LP measures with our bond-market-based LP measures.[23] Several key events highlight the differences:

(i) On September 15, 2008, Lehman Brothers filed for Chapter 11 bankruptcy, and the market liquidity evaporated. Both Refcorp/Treasury and agency/Treasury spreads spiked after that event and kept up for several months until the market calmed down. However, funding-market-based LP only had a minor spike that quickly recovered.

(ii) During the European debt crisis in 2011, financial market liquidity was again under distress, but we only observe spikes in the Refcorp/Treasury and agency/Treasury spreads.

(iii) Finally, in March 2020, the COVID shock caused widespread sales of equities and bonds, and again only the Refcorp/Treasury and agency/Treasury LP measures spiked and reflected liquidity distress.

Thus, we argue that our bond-market-based LP measures better reflect the liquidity conditions in the broader bond market, while the funding-market-based LP is more closely tied to financial intermediaries' funding conditions. The two are related but can be highly different under severe market distress. One possible reason is that stresses in the short-term funding market can be quickly addressed by central bank, while the bond markets have limited access to the support.

cy/Treasury spread measures.

[23] Since all funding-market-based LP measures are very similar, we only show GCF Repo/T-bill and GC Repo/T-bill spreads for illustration purpose.

The above distinction can be further understood through a comparison to illiquidity measures in the corporate bond market. The literature has proposed several overall measures of corporate bond liquidity. Feldhütter et al. (2012) construct an overall bond market liquidity measure based on the price impact measure of Amihud (2002) and a measure of roundtrip trading costs (and the variability of these two measures). They find that their liquidity measure outperforms other measures such as the Roll (1984) measure and the illiquidity measure used in Bao et al. (2010). Figure 7 plots the Feldhütter et al. (2012) measures, including the liquidity index for all US-traded corporate bonds and bonds issued by industrial firms, along with the three-month LP. We see that the Feldhütter et al. liquidity measure has the same patterns highlighted above that we observed in the Refcorp/Treasury spread, which were absent in the funding-market-based LP measures: (*i*) a slow recovery in liquidity after the Lehman default, (*ii*) an increase in illiquidity during the European debt crisis, and (*iii*) a spike in illiquidity at the onset of COVID-19.

The opposite responses to interest rates between different LP measures pose challenges to existing theories in the literature. For example, in Nagel (2016), changes in the FFR alter the premium on money, and the substitution between money and other types of liquid assets implies a positive response of LP to FFR in general. In Drechsler et al. (2017), changes in FFR have imperfect pass-through to bank deposit rates due to bank market power, and therefore, LP on deposits also positively reacts to FFR.

While theoretically explaining the phenomenon is beyond the scope of our current paper, we offer some speculative thoughts. A plausible explanation is that the liquidity provision in the bond market requires intermediaries' balance sheets. A lower FFR increases the maturity risks born by those intermediaries as in Vayanos and Vila (2021) so that their liquidity provision in the bond market is reduced, which decreases the liquidity provision to investors and increases LP. The segmentation between the repo market and other asset markets may also play a role (d'Avernas and Vandeweyer, 2021) and is also suggested in Duffee (1992). Testing these possibilities is an interesting direction for future research.

5.2 QEs and the LP term structure

In this subsection, we study the influence of QEs on the LP term structure. Specifically, we use an event study approach to analyze how the LP term structure responds to the QE announcements as in Krishnamurthy and Vissing-Jorgensen (2011) and van Binsbergen et al. (2019). To be consistent throughout the three rounds of QE and to restrict the flexibility in choosing the QE events, we only use the FOMC meeting dates with QE announcements as the QE events.[24] We measure the LP response as the change in LP between the event date and the previous day. It is worth emphasizing that the assets purchased by the Fed differed a lot in the three QEs: In QE1, the Fed purchased much more agency MBS than long-term Treasuries ($1 trillion versus $300 billion). In QE2, the Fed purchased $600 billion long-term Treasuries. QE3 involved in purchasing similar amounts of agency MBS and Treasuries.

To start, we present the cumulative responses of Treasury yields and Refcorp yields to the QE announcements. From Panel (a) of Figure 8, the entire Treasury yield curve declined in responses to the QE1 and QE2 announcements. In contrast, the Treasury yield curve moved up in response to the QE3 announcements, indicating the unintended effects of QE3. From Panel (b) of Figure 8, we observe a similar pattern for the Refcorp yield curve in response to the three rounds of QE announcements.

Panel (a) of Figure 9 shows the cumulative responses of the LP term structure to QE announcements. For QE1, LP along all maturities declined, and the decline was stronger at longer maturities. In terms of magnitude, we find that the cumulative change of LP in response to the QE1 announcements was −48 bps at 20-year maturity, −30 bps at 10 years, and −34 bps at 5 years, while the Refcorp yield declined by 76 bps at 20 years, 104 bps at 10 years, and 77 bps at 5 years. If we take Refcorp bond yield as the benchmark for corporate financing rates (neglecting default premium and safety premium), about 40% of the long-term (≥5 years) financing rate decline in response to the QE1 announcements was due to the changes in long-term LP. This result suggests that the LP channel is important for the pass-through of QE to the real economy.

[24]The event dates for QE1 are 2008-11-25, 2008-12-16, 2009-01-28, and 2009-03-18. The event dates for QE2 are 2010-08-10, 2010-09-21, and 2010-11-03. The event dates for QE3 are 2012-09-13 and 2012-12-12, where we have excluded the tapering dates of QE3.

Referring to the model in Section 3, we interpret the response of the LP term structure to QE1 through three forces. First, through asset purchasing, the Fed supplied more reserves (short-term liquid assets) that reduced LP across all maturities but more on the short-term LP. Second, the MBS purchase improved market liquidity and thus reduced LP. These MBS purchases were at the long end and thus mostly reduced the long-term LP. Third, the purchases of long-term Treasuries reduced liquidity supply at long maturity, thus increased the long-term LP, as in Prediction 4. Because the Fed purchased much more MBS than Treasuries, the second force dominated the third force and led to a larger decrease in long-term LP.

In comparison, in Panel (a) of Figure 9, short-term LP declined more than long-term LP in response to the announcements of QE2, which was mostly about purchasing long-term Treasuries. Here, two forces were likely to affect the LP term structure. The first one is the effect of bank reserves that reduced LP across all maturities but more on the short end. Second, the purchase of long-term Treasuries increased long-term LP as in Prediction 4 of the model. Combining the two forces, the decrease of LP was larger at the short end after the QE2 announcements. Quantitatively, about 20% of the long-term ($\geq$5 years) financing rate decline in response to the QE2 announcement was due to the changes in long-term LP.

Furthermore, LP responses to the QE3 announcements were close to zero across all maturities. Indeed, QE3 was conducted after 2012, when the liquidity conditions had improved significantly. Moreover, the supply of Treasuries and reserves increased by about 8 trillion from 2008 to 2012. Due to the declining marginal benefits, QE3 had little influence on the LP term structure.

Our interpretation of the LP responses to QEs hinges on the difference in assets purchased by the Fed. To provider further evidence, we cluster the QE announcement dates into two groups: one with Treasury purchases, while the other with MBS purchases. Then we sum up the responses and plot them in Panel (b) of Figure 9. We find that results are consistent with our interpretations.[25]

[25]There are other plausible reasons for the heterogeneous responses across different rounds of QEs. QE1 was implemented during the height of the crisis, while QE2 was implemented two years later, and QE3 was implemented even afterward, so the intensity of liquidity concerns differs. Furthermore, QE1 may be associated with a stronger signaling effect since it is the first round of QE policy.

In summary, depending on whether purchasing Treasuries or less-liquid long-term assets, the LP term structure response is different: more response at the long end for purchases of less-liquid assets (relative to Treasuries), while less response at the long end for long-term Treasury purchases. Given the importance of LP in passing through QE policy beyond Treasury yields, these results bear important implications on how QE affects the term structure of financing rates in the broader economy.

6 Decomposition of Treasury Convenience Yield

In this section, we use the LP term structure to infer and analyze the Treasury safety premium (SP) across different maturities. According to Krishnamurthy and Vissing-Jorgensen (2012), investors are also willing to pay for the extreme safety of Treasuries beyond their superior liquidity, known as the Treasury SP. It is worth emphasizing the distinction between SP and default risk premium. Default risk premium is the required compensation for bearing default losses. On the other hand, long-term SP could be due to the preferred-habitat demand from long-term investors, such as pension funds and insurance companies, while short-term SP could originate from the demand for good collaterals in short-term funding.

We provide a new way to isolate Treasury safety premium and liquidity premium across the entire term structure. As illustrated below, we decompose Treasury convenience yield, measured as the spread between AAA-rated corporate bonds and Treasuries, into three components: the default component, the SP component, and the LP component. In this way, we are able to obtain high-frequency estimates of SP across the whole term structure. We find that, on average, the LP and the SP components contribute a similar amount to Treasury convenience yield. Moreover, long-term SP is higher than short-term SP, suggesting strong demand for long-term safe assets (Greenwood and Vayanos, 2010).

6.1 Methodology

We use two approaches to decompose the Treasury convenience yields, i.e., the AAA/Treasury spreads. Under both approaches, we first use the difference between the average CDS

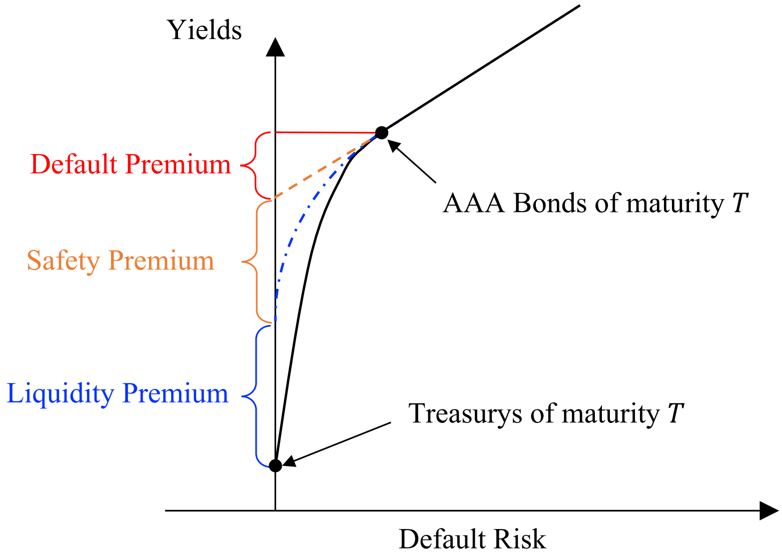

Illustration 2: **Decomposition of Treasury convenience yields**.

rates of AAA-rated firms and the US government CDS rates to measure the default component (see, e.g., Longstaff et al., 2005), and we refer to the residual as the CDS-adjusted AAA/Treasury spread. Under the first "direct subtraction" approach, we directly subtract Treasury LP from the CDS-adjusted AAA/Treasury spread of the same maturity to estimate Treasury SP. Under the second "projection" approach, we project the CDS-adjusted AAA/Treasury spread on Treasury LP, and we use the residuals as our measure of SP.

Admittedly, both approaches are subject to potential estimation errors in different ways. The first approach is only accurate if the liquidity of Refcorp bonds is similar to the liquidity of AAA-rated corporate bonds. The "projection" approach may attribute too much of the AAA/Treasury spread to LP when LP and SP are positively correlated. Despite these drawbacks, we find the two approaches yield similar estimates.

Specifically, we obtain the Bank of America Merrill Lynch AAA-rated corporate bond indexes from Bloomberg. The indexes cover AAA-rated corporate bonds of different maturities, divided into five buckets: 1–3 years, 3–5 years, 5–7 years, 7–10 years, and over 10 years. To estimate the default component of Treasury convenience yield, we obtain CDS spreads on both AAA-rated corporate bonds and the US government from Markit.[26] Because CDS rates are available only after 2002, we restrict the decomposition exercise to the sample period after 2002.

[26]The details of the CDS data are provided in Appendix B.

6.2 Estimating Treasury safety premium

We now estimate Treasury SP from the CDS-adjusted Treasury convenience yield using the two approaches explained above. We list the average values of the three components of Treasury convenience yield in Table 9. Panel A shows the results based on the "direct subtraction" method. We find that the AAA/Treasury yield spread across different maturities is about 84 bps, among which 19 bps is default premium, 32 bps is SP, and 33 bps is LP. SP and LP each contribute about 40% to Treasury convenience yield. Interestingly, the SP over 10 years is 60 bps on average, more than doubles the short-term SP, suggesting strong demand for long-term safe assets (Greenwood and Vayanos, 2010).

In Panel B of Table 9, we find that the projection approach yields similar returns as in Panel A. The average difference is only 2 bps compared to Panel A. Furthermore, based on this alternative estimate, SP is still highly upward-sloping and reaches 69 bps at the long end, about five times the value at 1-3 years. This result confirms that the special demand for long-term safe assets is particularly strong.

7 Conclusion

In this paper, we analyze the term structure of Treasury LP. Our theory indicates that the LP term structure is shaped by expectations of future liquidity conditions, liquidity term premium, and short-term and long-term Treasury supply. To test the theory predictions, we construct the term structure of Treasury LP by measuring the yield differentials between Refcorp STRIPS and Treasury STRIPS of the same maturity following Longstaff (2004).

We find that the Treasury LP is economically significant even at the long-term maturity (e.g., 20 years), suggesting that the superior liquidity of Treasuries in the far future is also highly valued by investors. Consistent with our model predictions, the LP term structure is downward-sloping during recessions and upward-sloping in booms. A higher risk premium is associated with higher LP across maturities, but lower liquidity term spread. We also find that the term structure contains information about future LP and future market liquidity conditions.

While previous work primarily focuses on the very short end, we also analyze the entire LP term structure in response to monetary policies. Because corporate financing rates include liquidity premium on top of treasury yields, understanding how LP responds to monetary policy is essential for understanding how monetary policies affect corporate financing rates. We find that LP is quantitatively important for the pass-through of both interest rate policies and QEs to the real economy. In particular, LP dampens the pass-through of interest rate policy yet strengthens the pass-through of QEs.

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Table 1: **Summary statistics of monthly LP at different maturities.** We calculate the difference between the yield of Refcorp STRIPS and the yield of Treasury STRIPS of the same maturity. The monthly LP is the average of the daily LP during each month. The sample period is from April 1991 to May 2020.

		Refcorp/Treasury Spread (in percent)					
Maturity	N	Mean	St. Dev.	Pctl(10)	Pctl(25)	Pctl(75)	Pctl(90)
3M	350	0.27	0.29	0.01	0.09	0.37	0.61
6M	350	0.25	0.28	0.01	0.07	0.37	0.57
1Y	350	0.23	0.26	0.01	0.05	0.37	0.56
2Y	350	0.22	0.23	0.01	0.05	0.35	0.53
3Y	350	0.25	0.25	0.03	0.07	0.39	0.62
4Y	350	0.25	0.24	0.04	0.07	0.36	0.55
5Y	350	0.25	0.22	0.03	0.06	0.36	0.54
10Y	350	0.28	0.20	0.09	0.12	0.42	0.54
20Y	350	0.27	0.16	0.11	0.15	0.35	0.49

Table 2: **LP term spread and Treasury yield term spread.** We regress the LP term spread on the Treasury yield term spread of the same maturity. The k-year term spread is defined as the spread between the k-year value and the three-month value. Newey-West standard errors with 12 lags are shown in the parentheses. The sample period is from April 1991 to May 2020.

	Term Spread of LP			
	1Y (1)	5Y (2)	10Y (3)	20Y (4)
Treasury Term Spread 1Y	−0.25 (0.09)			
Treasury Term Spread 5Y		−0.04 (0.03)		
Treasury Term Spread 10Y			−0.05 (0.02)	
Treasury Term Spread 20Y				−0.03 (0.02)
Observations	350	350	350	350
Adjusted R^2	0.20	0.04	0.07	0.04

Table 3: **Liquidity premium and risk premium.** We regress LP (Panel A) and LP term spread (Panel B) on various risk premium measures, including the BAA-AAA corporate bond credit spread, the CBOE's VIX index, and the intermediary leverage factor of He et al. (2017). Controls include the federal funds rate and the debt-to-GDP ratio. Newey-West standard errors with 12 lags are shown in the parentheses. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively. The main sample period is from April 1991 to May 2020. Since leverage data from He et al. (2017) stops at October 2017, columns (7)-(9) use data from April 1991 to October 2017.

Panel A	*Liquidity Premium*								
	1Y	10Y	20Y	1Y	10Y	20Y	1Y	10Y	20Y
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Credit Spread	0.43***	0.30***	0.21***						
	(0.06)	(0.06)	(0.04)						
VIX				0.02***	0.01***	0.01**			
				(0.004)	(0.004)	(0.003)			
Leverage							0.03**	0.02	0.01
							(0.01)	(0.01)	(0.01)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	350	350	350	350	350	350	319	319	319
Adjusted R^2	0.51	0.73	0.56	0.49	0.64	0.49	0.37	0.59	0.46

Panel B	*Liquidity Premium Term Spread*								
	1Y-3M	10Y-3M	20Y-3M	1Y-3M	10Y-3M	20Y-3M	1Y-3M	10Y-3M	20Y-3M
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Credit Spread	−0.16***	−0.29***	−0.38***						
	(0.04)	(0.05)	(0.08)						
VIX				−0.002	−0.01***	−0.01***			
				(0.004)	(0.004)	(0.005)			
Leverage							−0.01**	−0.02***	−0.02***
							(0.004)	(0.01)	(0.01)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	350	350	350	350	350	350	319	319	319
Adjusted R^2	0.23	0.39	0.41	0.11	0.29	0.27	0.21	0.37	0.38

Table 4: **Forecasting future short-term LP with forward LP.** We estimate the following regression, $LP_{t+k-1,1} - LP_{t,1} = \alpha_k + \beta_k(f_{t,k}^{LP} - LP_{t,1}) + \epsilon_{t+k-1}$, where the dependent variable is the change in the one-year LP in year k and the independent variable is the excess forward LP, as defined in equation (21). Controls include the federal funds rate and the debt-to-GDP ratio. Newey-West standard errors with 12 lags are shown in the parentheses. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively. The sample spans from April 1991 to May 2020.

	Change of one-year LP in k years			
	(1)	(2)	(3)	(4)
forward excess LP	$k = 2$	$k = 3$	$k = 4$	$k = 5$
2-year	0.67***			
	(0.26)			
3-year		0.49**		
		(0.20)		
4-year			0.64***	
			(0.14)	
5-year				0.74***
				(0.27)
Controls	Yes	Yes	Yes	Yes
Observations	338	326	314	302
Adjusted R^2	0.26	0.19	0.36	0.23

Table 5: **Liquidity premium and future liquidity conditions.** We explore the predictive power of LP for future market liquidity. The illiquidity indexes are normalized and include the yield curve fitting noise, the on-the-run premium, and the Roll measure in Trebbi and Xiao (2019). In columns (1) to (4), the dependent variable is the average of the illiquidity indexes. In columns (5) to (8), the dependent variable is the first PC of the illiquidity indexes. Controls include the federal funds rate and the debt-to-GDP ratio. Standard errors are shown in the parentheses. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively. Data are at a monthly frequency from June 1995 to December 2014 due to the availability of the illiquidity indexes in Trebbi and Xiao (2019).

	Average illiquidity				*First PC of illiquidity*			
	2-year	3-year	4-year	5-year	2-year	3-year	4-year	5-year
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2-year	1.14***				1.00***			
	(0.34)				(0.30)			
3-year		0.34				0.11		
		(0.37)				(0.34)		
4-year			1.33***				1.24***	
			(0.32)				(0.31)	
5-year				2.44***				2.33***
				(0.46)				(0.45)
Observations	211	199	187	175	211	199	187	175
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.39	0.38	0.27	0.20	0.46	0.41	0.28	0.19

Table 6: **The term structure of liquidity premium and FFR.** This table shows the regressions of LP on federal funds rate (FFR). Panel A shows the results based on our main LP measure, the Refcorp STRIPS/Treasury STRIPS spread, which spans April 1991 to May 2020. Panel B shows the results based on the alternative measure, the agency STRIPS/Treasury STRIPS spread, which spans August 1999 to May 2020. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.

Panel A	*Refcorp/Treasury Spread*					
	3M	6M	1Y	5Y	10Y	20Y
	(1)	(2)	(3)	(4)	(5)	(6)
FFR	−5.17***	−5.47***	−5.21***	−5.97***	−5.80***	−4.15***
	(0.67)	(0.62)	(0.58)	(0.44)	(0.38)	(0.31)
Observations	350	350	350	350	350	350
Adjusted R^2	0.15	0.18	0.19	0.35	0.40	0.34

Panel B	*Agency/Treasury Spread*					
	3M	6M	1Y	5Y	10Y	20Y
	(1)	(2)	(3)	(4)	(5)	(6)
FFR	−1.46**	−2.38***	−1.94***	−3.05***	−5.21***	−5.54***
	(0.68)	(0.63)	(0.59)	(0.70)	(0.71)	(0.59)
Observations	250	250	250	250	250	250
Adjusted R^2	0.02	0.05	0.04	0.07	0.18	0.26

Table 7: **Response of the LP term structure to FFR surprises.** This table shows the one-day response of LP to FFR surprises. Panel A shows the results based on our main LP measure, the Refcorp STRIPS/Treasury STRIPS spread. Panel B shows the results based on the alternative LP measure, the agency STRIPS/Treasury STRIPS spread. The main data sample covers FOMC announcement days from April 1991 to May 2020 (251 events), and the FFR surprise is the difference between realized FFR and the expected FFR measured through federal funds futures. The sample is smaller for agency/Treasury spread because agency bond yields are available only after August 1999. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.

	Response of Refcorp/Treasury Spread					
Panel A	3M	6M	1Y	5Y	10Y	20Y
	(1)	(2)	(3)	(4)	(5)	(6)
FFR Surprise	−18.26***	−8.74**	−2.26	0.34	−9.66***	2.58
	(4.97)	(3.42)	(3.00)	(2.65)	(2.45)	(2.61)
Observations	251	251	251	251	251	251
Adjusted R^2	0.05	0.03	0.002	0.0001	0.06	0.004

	Response of Agency/Treasury Spread					
Panel B	3M	6M	1Y	5Y	10Y	20Y
	(1)	(2)	(3)	(4)	(5)	(6)
FFR Surprise	−5.28	−9.99*	−11.87***	−0.55	−13.85***	2.78
	(6.87)	(5.82)	(4.42)	(2.81)	(3.61)	(3.20)
Observations	173	173	173	173	173	173
Adjusted R^2	0.003	0.02	0.04	0.0002	0.08	0.004

Table 8: **FFR surprises and responses of various LP measures.** This table shows the response of funding-market-based LP and bond-market-based LP to the FFR surpises over the one-day, 10-day, and 20-day periods. Specifically, OIS/Tsy is the yield spread between the three-month Overnight Indexed Swap (OIS) and three-month T-bill. GCF Repo/Tsy is the yield spread between overnight GCF Treasury Repo index and three-month T-bill. GC Repo/Tsy is the yield spread between the three-month Treasury GC term repo and three-month T-bill. CD/Tsy is the yield spread between the three-month certificate of deposits (CD) and three-month T-bill. Refcorp/Tsy is the yield spread between the three-month Refcorp STRIPS and three-month Treasury STRIPS. Agency/Tsy is the yield spread between the three-month agency STRIPS and three-month Treasury STRIPS. The data sample in column (1) and (5) covers FOMC announcement days from April 1991 to May 2020 (251 events), and the FFR surprise is the difference between realized FFR and the expected FFR measured through federal funds futures. The sample differs in other columns due to the data limitations of dependent variables. *, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: *1-Day Change*	*funding-market-based*				*bond-market-based*	
	OIS/Tsy	GCF Repo/Tsy	GC Repo/Tsy	CD/Tsy	Refcorp/Tsy	Agency/Tsy
FFR Surprise	1.24	1.63	−8.43	5.40	−18.26***	−5.28
	(5.66)	(38.79)	(7.26)	(11.92)	(4.97)	(6.87)
Observations	251	123	204	187	251	173
Adjusted R^2	0.0002	0.0000	0.01	0.001	0.05	0.003
Panel B: *10-Day Change*	*funding-market-based*				*bond-market-based*	
	OIS/Tsy	GCF Repo/Tsy	GC Repo/Tsy	CD/Tsy	Refcorp/Tsy	Agency/Tsy
FFR Surprise	17.26**	56.97	5.14	80.00***	−16.42	−25.47**
	(8.68)	(49.57)	(9.63)	(15.33)	(10.65)	(11.86)
Observations	251	118	204	185	251	167
Adjusted R^2	0.02	0.01	0.001	0.13	0.01	0.03
Panel C: *20-Day Change*	*funding-market-based*				*bond-market-based*	
	OIS/Tsy	GCF Repo/Tsy	GC Repo/Tsy	CD/Tsy	Refcorp/Tsy	Agency/Tsy
FFR Surprise	18.54**	30.75	10.86	81.25***	−22.02*	−63.26***
	(8.52)	(46.45)	(13.22)	(20.07)	(11.96)	(12.72)
Observations	251	122	203	189	251	174
Adjusted R^2	0.02	0.004	0.003	0.08	0.01	0.13

Table 9: **Decomposition of Treasury convenience yield.** This table shows the decompositions of the AAA/Treasury yield spreads. Columns (1), (3), and (5) show the average safety premium, liquidity premium, and default premium, respectively (in basis points). Columns (2), (4), and (6) show the average safety premium, liquidity premium, and default premium as a fraction of the total Treasury convenience yield (Column (7)). Under the "direct subtraction" method, safety premium is estimated as the CDS-adjusted AAA/Treasury spread minus the Refcorp/Treasury spread. Under the "projection" method, safety premium is estimated as the projection residual of the CDS-adjusted AAA/Treasury spread on the Refcorp/Treasury spread. Due to limitations of CDS data, the sample for this analysis is from January 2002 to June 2019.

Panel A: Based on the Direct Subtraction Method

maturity	*safety premium*		*liquidity premium*		*default premium*		*total*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1-3 years	26	40%	29	44%	11	16%	66
3-5 years	24	34%	32	45%	15	21%	71
5-7 years	28	36%	32	41%	19	23%	79
7-10 years	25	31%	34	42%	22	27%	82
$>$ 10 years	60	49%	36	30%	26	21%	122
average	32	38%	33	40%	19	22%	84

Panel B: Based on the Projection Method

maturity	*safety premium*		*liquidity premium*		*default premium*		*total*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1-3 years	14	21%	41	62%	11	17%	66
3-5 years	18	26%	38	53%	15	21%	71
5-7 years	14	18%	46	59%	19	23%	79
7-10 years	34	42%	26	31%	22	27%	82
$>$ 10 years	69	56%	27	22%	26	22%	122
average	30	33%	36	46%	19	22%	84

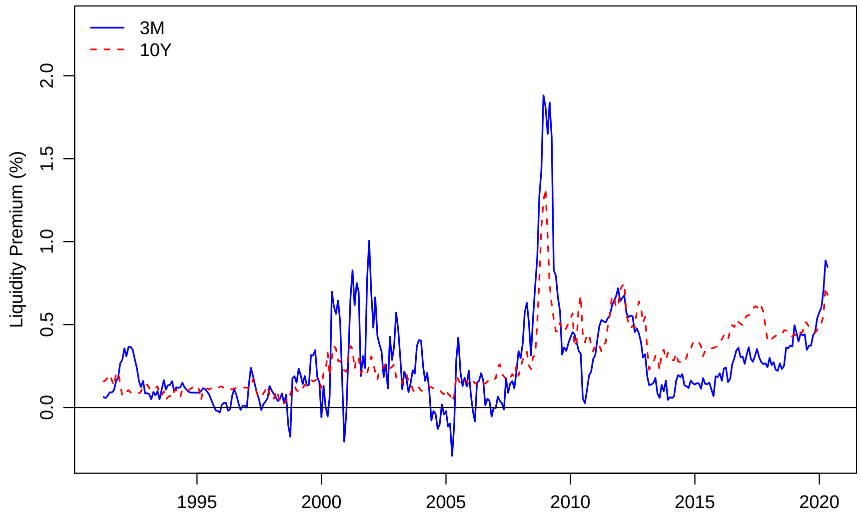
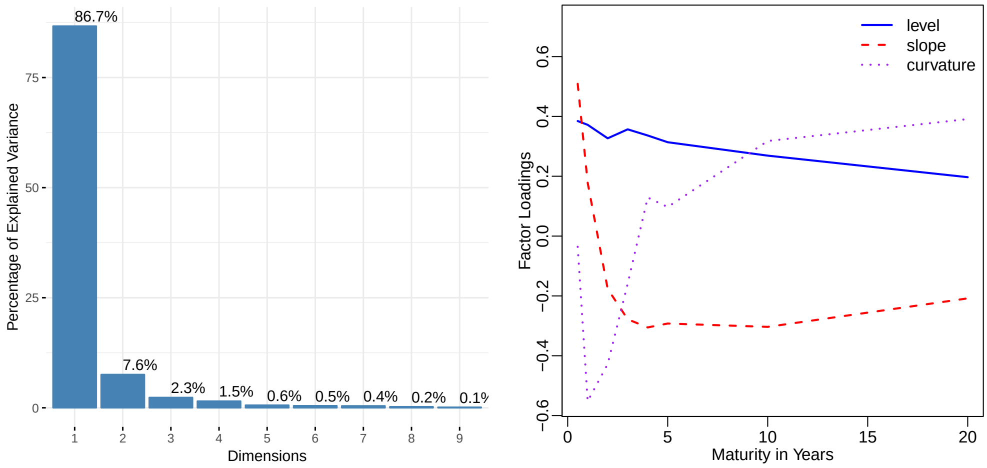


Figure 1: **The monthly three-month and 10-year LP.** We measure LP as the spread between Refcorp STRIPS and Treasury STRIPS of matched maturities. The sample spans from April 1991 to May 2020.



(a) Variations Explained by PCs

(b) Loadings of First Three PCs

Figure 2: **Principal component analysis of LP across maturities**. We conduct a principal component analysis of LP with maturities from three-month to 20-years. The sample spans from April 1991 to May 2020.

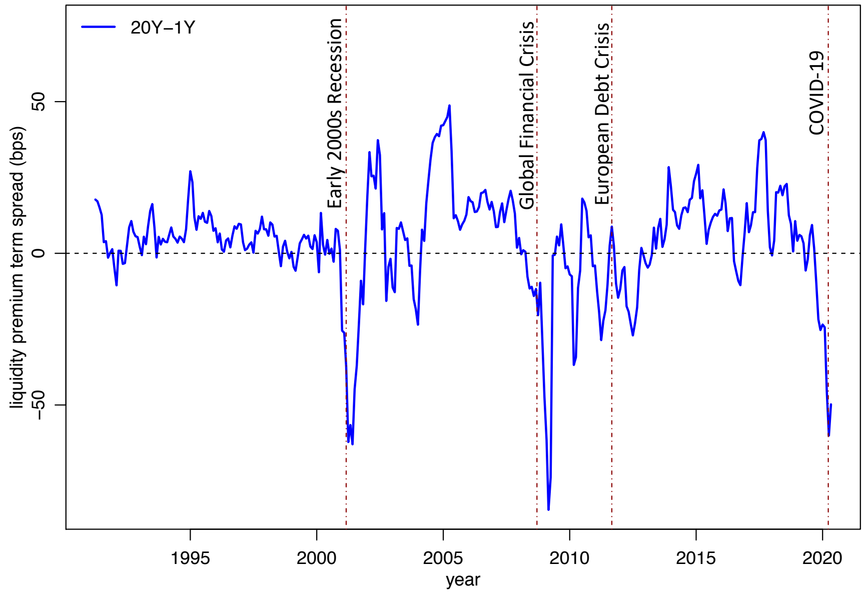


Figure 3: **Time series of the LP term spread.** LP is measured as the yield spread between Refcorp STRIPS and Treasury STRIPS of the same maturity. This figure shows the spread between the 20-year LP and one-year LP, based on monthly data from April 1991 to May 2020.

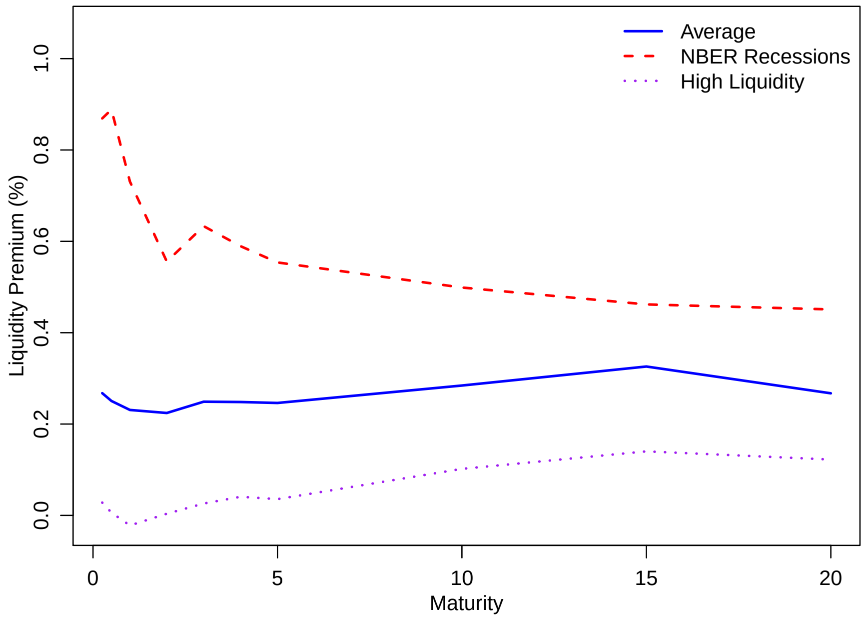


Figure 4: **The LP term structure in different states.** We plot the average LP term structure in the "high-liquidity" states and in NBER recessions. Specifically, the "high liquidity" states refer to the months when the first principal component of the LP term structure falls below its 20% quantile, e.g., most of the year of 2006. The periods of NBER recessions are from the NBER websites. The sample spans from April 1991 to May 2020.

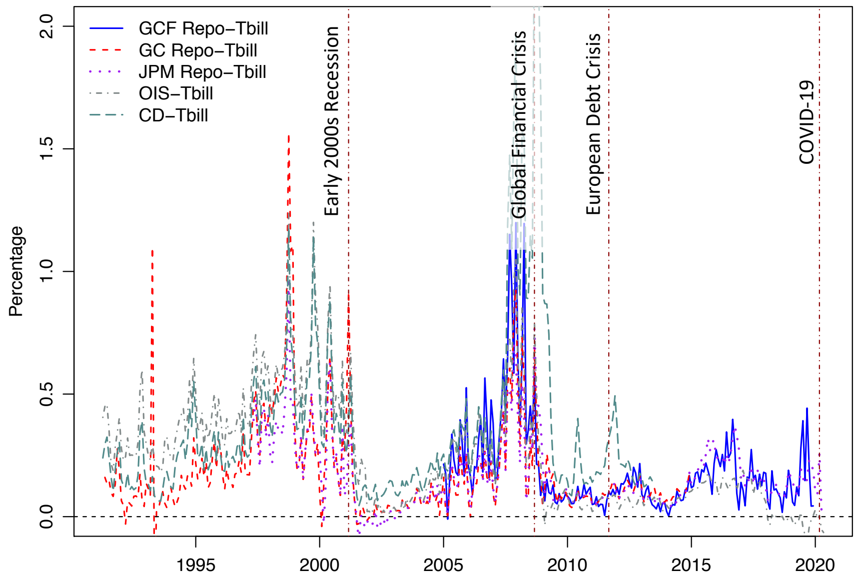


Figure 5: **Funding-market-based measures of LP.** We plot the funding-market-based LP measures (in percent) at a daily frequency from 1991 to 2020. All yields are of three-month maturity except for the GCF Repo index, which is an overnight index.

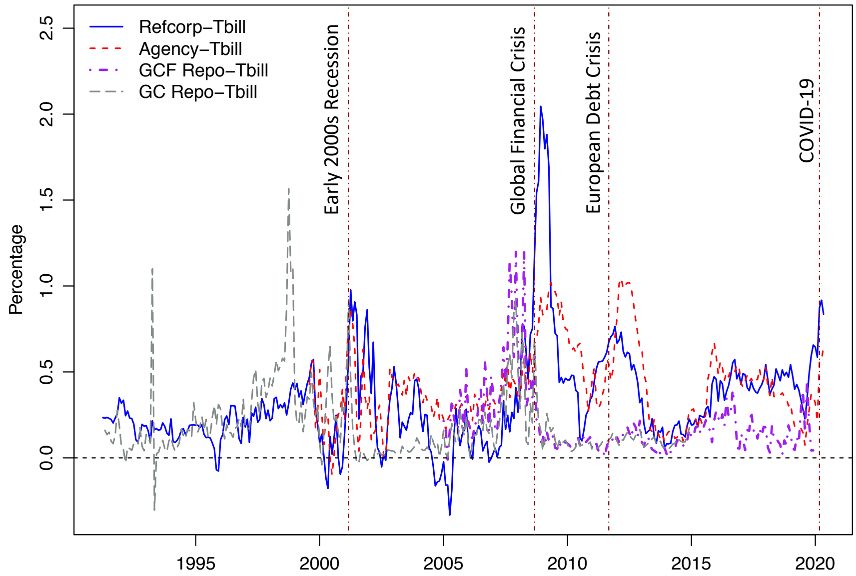


Figure 6: **Compare funding-market-based and bond-market-based LP measures.** We plot the time series of various LP measures (in percent) at a daily frequency from 1991 to 2020. These measures are classified into two groups: (1) bond-market-based measures, including the Refcorp/T-bill and the agency/T-bill spreads; (2) funding-market-based measures, including the GCF Repo/T-bill and GC Repo/T-bill spreads. All yields are of three-month maturity except for the GCF Repo index, which is an overnight index.

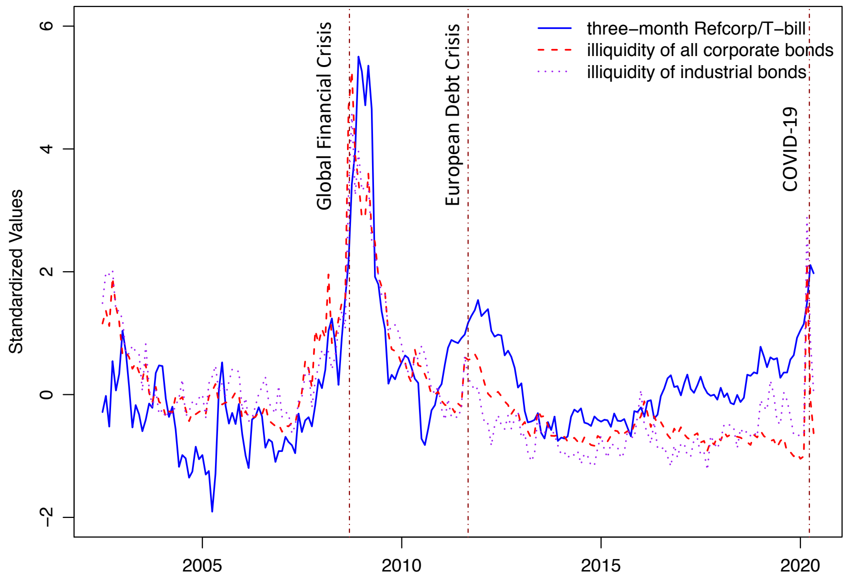
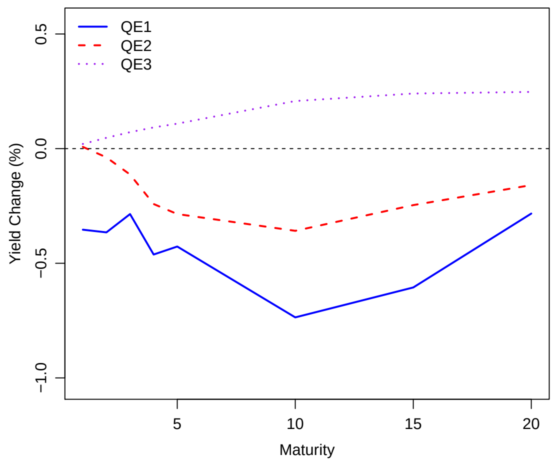
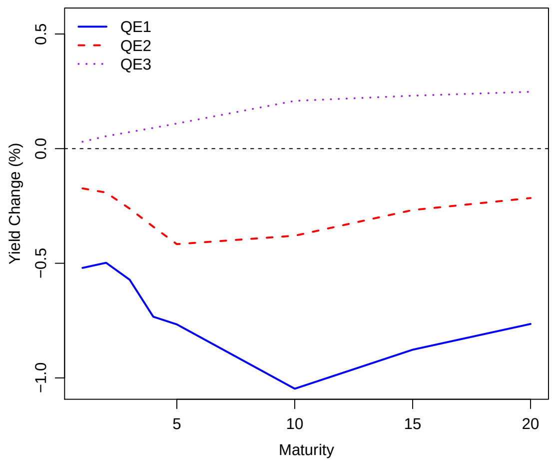


Figure 7: **LP and Corporate Bond Market Liquidity.** We plot three-month LP and two corporate bond market illiquidity measures from Feldhütter et al. (2012). Data are from July 2002 to May 2020.

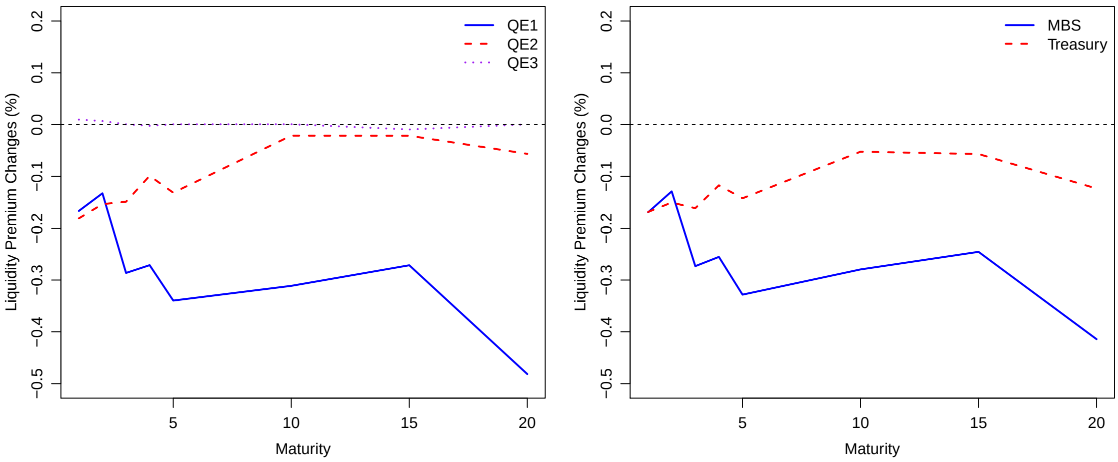


(a) Treasury Yield Changes



(b) Refcorp Bond Yield Changes

Figure 8: **Cumulative responses of yields to QE announcements**. This figure shows the changes in Treasury yields and Refcorp bond yields in response to the QE announcements. We calculate the changes of Treasury yields and Refcorp bond yields during each announcement (the difference between the event date and the day before the event date) and then add up the changes for each round of QE, respectively.



(a) Classified by Rounds of QEs

(b) Classified by Types of Assets

Figure 9: **Cumulative responses of LP to QE announcements**. Panel (a) plots the changes of LP in response to the QE announcements. Panel (b) plots the changes of LP in response to announcements of MBS purchase and Treasuries purchase, respectively. All responses are measured as the cumulative one-day change between event date and the day before the event date.

A Additional Model Details

In this section, we derive the first-order conditions of the household optimization problem and prove the properties of the liquidity premium.

A.1 A microfoundation for κ_0 and κ_1

We will show that the assumptions over κ_0 and κ_1 are satisfied in a model where households are making optimal liquidation decisions.

Suppose that household's total asset value is w_0 at $t = 0$, which is allocated across liquid and illiquid assets. Suppose that both the illiquid asset and government bonds of various maturities have a market impact, and the total cost is

$$\gamma_0(w_0 - b_{0,1} - b_{0,2})^2 + \gamma_1 b_{0,1}^2 + \gamma_2 b_{0,2}^2$$

which captures the typical market impact in a market-microstructure model. For example, the quadratic-holding-cost assumption is used in Vives (2011) and Du and Zhu (2017). Then we define

$$\bar{\kappa} = w_0^2$$

$$\kappa_0(b_{0,1}, b_{0,2}) = -\gamma_0(b_{0,1} + b_{0,2})^2 + 2\gamma_0 w_0(b_{0,1} + b_{0,2}) - \gamma_1 b_{0,1}^2 - \gamma_2 b_{0,2}^2$$

which implies

$$\frac{\partial \kappa_0}{\partial m_0} = 2\gamma_0(w_0 - b_{0,1} - b_{0,2})$$

$$\frac{\partial \kappa_0}{\partial b_{0,1}} = 2\gamma_0(w_0 - b_{0,1} - b_{0,2}) - 2\gamma_1 b_{0,1}$$

$$\frac{\partial \kappa_0}{\partial b_{0,2}} = 2\gamma_0(w_0 - b_{0,1} - b_{0,2}) - 2\gamma_2 b_{0,2}$$

When the portfolio shares of liquid assets, $b_{0,1} + b_{0,2}$, is relatively small, we have all of the above derivatives positive. Furthermore, the second-order derivatives are

$$\frac{\partial^2 \kappa_0}{\partial b_{0,1}^2} = -2(\gamma_0 + \gamma_1) < 0$$

$$\frac{\partial^2 \kappa_0}{\partial b_{0,1}^2} = -2(\gamma_0 + \gamma_2) < 0$$

The cross-partials are

$$\frac{\partial^2 \kappa_0}{\partial b_{0,2} \partial b_{0,1}} = -2\gamma_0 < 0$$

$$\frac{\partial^2 \kappa_0}{\partial b_{0,1}^2} = -2\gamma_0 - 2\gamma_1 < 0$$

Thus we get

$$0 > \frac{\partial^2 \kappa_0}{\partial b_{0,1} \partial b_{0,2}} > \frac{\partial^2 \kappa_0}{\partial b_{0,1}^2}$$

The function κ_1 can be micro-founded in the same way and thus the microfoundation is omitted.

Another way to model the difference between long-term and short-term Treasuries is build on the monetary-search models, e.g. Kiyotaki and Wright (1993), Geromichalos et al. (2016).

A.2 Proof of Propositions 1 and 2

Denote the Lagrangian multipliers on the budget constraints in (7) as μ_0, μ_1, and μ_2. We note that μ_t is state-dependent on ξ_t. The first order conditions on consumption are

$$u'(c_0) = \mu_0, \quad \rho u'(c_1) = \mu_1, \quad \rho^2 u'(c_2) = \mu_2.$$

The first order condition (FOC) on the liquidity holding $b_{0,1}$ is

$$E\left[\mu_1 \left((1 + r_{0,1}) - (1 + \hat{r}_{0,1}) + X_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,1}}\right)\right] = 0. \tag{24}$$

The FOC on $b_{0,2}$ is

$$E\left[\mu_1 \left(\frac{(1 + r_{0,2})^2}{1 + r_1} - (1 + \hat{r}_{0,1}) + X_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,2}}\right)\right] = 0. \tag{25}$$

The FOC on $\hat{b}_{0,2}$ is

$$E\left[\mu_1 \left(\frac{(1 + \hat{r}_{0,2})^2}{1 + \hat{r}_1} - (1 + \hat{r}_{0,1})\right)\right] = 0. \tag{26}$$

The FOC on b_1 is

$$E_1\left[\mu_2 \left((1 + r_1) - (1 + \hat{r}_1) + X_1 \frac{\partial \kappa_1(b_1)}{\partial b_1}\right)\right] = 0, \tag{27}$$

where the expectation is taken with respect to the information at the beginning of period 2. We will solve the demand curve for liquid assets and then the liquidity premium. The consumption process is taken as exogenously given.

Using (24), we have

$$\ell_{0,1} = \hat{r}_{0,1} - r_{0,1} = \frac{1}{E[u'(c_1)]} E\left[u'(c_1) \lambda_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,1}}\right] = \lambda_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,1}}. \tag{28}$$

To solve for the long-term liquidity premium, we need to solve the benchmark interest rates for the illiquid assets. According to (27),

$$\ell_1 = \hat{r}_1 - r_1 = \lambda_1 \frac{\partial \kappa_1(b_1)}{\partial b_1} > 0. \tag{29}$$

From (25) and (26), we have

$$(1+\hat{r}_{0,2})^2 = \frac{E\left[\mu_1(1+\hat{r}_{0,1})\right]}{E\left[\mu_1 \frac{1}{1+\hat{r}_1}\right]}, \tag{30}$$

and

$$(1+r_{0,2})^2 = \frac{E\left[\mu_1\left((1+\hat{r}_{0,1}) - X_0 \frac{\partial \kappa_0(b_{0,1},b_{0,2})}{\partial b_{0,2}}\right)\right]}{E[\mu_1 \frac{1}{1+r_1}]}. \tag{31}$$

To get an intuitive expression for the long-term liquidity premium, we assume that $\hat{r}_1$ and r_1 are small so that

$$\frac{E\left[\mu_1 \frac{1}{1+r_1}\right]}{E[\mu_1 \frac{1}{1+\hat{r}_1}]} \approx \frac{E[u'(c_1)(1-r_1)]}{E[u'(c_1)(1-\hat{r}_1)]} = \frac{1 - \frac{E[u'(c_1)r_1]}{E[u'(c_1)]}}{1 - \frac{E[u'(c_1)\hat{r}_1]}{E[u'(c_1)]}}$$

$$\approx 1 + \frac{E[u'(c_1)\hat{r}_1]}{E[u'(c_1)]} - \frac{E[u'(c_1)r_1]}{E[u'(c_1)]} = 1 + \frac{E[u'(c_1)\ell_1]}{E[u'(c_1)]},$$

and

$$\frac{E\left[\mu_1\left((1+\hat{r}_{0,1}) - X_0 \frac{\partial \kappa_0(b_{0,1},b_{0,2})}{\partial b_{0,2}}\right)\right]}{E[\mu_1(1+\hat{r}_{0,1})]} = \frac{E[u'(c_1)]\left(1+\hat{r}_{0,1} - \lambda_0 \frac{\partial \kappa_0(b_{0,1},b_{0,2})}{\partial b_{0,2}}\right)}{E[u'(c_1)]\,(1+\hat{r}_{0,1})}$$

$$\approx 1 - \lambda_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,2}}.$$

Divide (30) over (31) on both sides, we have

$$\frac{(1+\hat{r}_{0,2})^2}{(1+r_{0,2})^2} = \frac{\left(1 + \frac{E[u'(c_1)\ell_1]}{E[u'(c_1)]}\right)}{1 - \lambda_0 \frac{\partial \kappa_0(b_{0,1},b_{0,2})}{\partial b_{0,2}}}$$

$$\approx 1 + \frac{E[u'(c_1)\ell_1]}{E[u'(c_1)]} + \lambda_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,2}}.$$

Note that

$$\frac{(1+\hat{r}_{0,2})^2}{(1+r_{0,2})^2} \approx 1 + 2(\hat{r}_{0,2} - r_{0,2}).$$

We have

$$1 + 2(\hat{r}_{0,2} - r_{0,2}) = 1 + \lambda_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,2}} + \frac{E[u'(c_1)\ell_1]}{E[u'(c_1)]}$$

and

$$\ell_{0,2} = \frac{1}{2}\left(\lambda_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,2}} + \frac{E[u'(c_1)\ell_1]}{E[u'(c_1)]}\right). \tag{32}$$

Plugging in ℓ_1, we have

$$\ell_{0,2} = \frac{1}{2}\left(\lambda_0 \frac{\partial \kappa_0(b_{0,1}, b_{0,2})}{\partial b_{0,2}} + E\left[\frac{u'(c_1)}{E[u'(c_1)]}\lambda_1 \frac{\partial \kappa_1(b_1)}{\partial b_1}\right]\right). \tag{33}$$

Therefore, the 2-period liquidity premium averages the forces in both periods. It is affected by supply of liquid assets in both period 1 and period 2. Furthermore, the frequencies of liquidity shocks at time 1 and 2 both matter.

A.3 Derivations for the Predictions

Prediction 1

We know that

$$Cov(u'(c_1), \lambda_1) = q_1(1-q_1)(u'(c_L) - u'(c_H))(\lambda_H - \lambda_L) > 0,$$

where q_1 is the probability of a bad state at time $t = 1$, conditional on $t = 0$ state ξ_0. Suppose that $\xi_0 = \text{good}$, then

$$Cov\left(\frac{u'(c_1)}{E_1[u'(c_1)]}, \lambda_1\right) + E_1[\lambda_1] - \lambda_0 = \frac{p_{11}(1-p_{11})(u'(c_L) - u'(c_H))(\lambda_H - \lambda_L)}{(1-p_{11})u'(c_L) + p_{11}u'(c_H)} + p_{11}(\lambda_H - \lambda_L) > 0.$$

Suppose $\xi_0 = \text{bad}$, then

$$Cov\left(\frac{u'(c_1)}{E[u'(c_1)]}, \lambda_1\right) + E[\lambda_1] - \lambda_0 = \frac{-(1-p_{22})(\lambda_H - \lambda_L)u'(c_H)}{p_{22}u'(c_L) + (1-p_{22})u'(c_H)} < 0.$$

Finally, denote the stationary distribution over $\{\text{good}, \text{bad}\}$ as $(\pi, 1-\pi)$. Then the average term structure is

$$E_\pi[Cov(u'(c_1), \lambda_1) + E_0[\lambda_1] - \lambda_0] = \pi(1-\pi)(u'(c_L) - u'(c_H))(\lambda_H - \lambda_L) > 0,$$

where E_π is the expectation with respect to the stationary distribution, under which

$$E_\pi[E_0[\lambda_1]] = E_\pi[\lambda_1] = E_\pi[\lambda_0].$$

Prediction 2

When $\xi_0 = \text{good}$, we have $u'(c_0) = u'(c_H)$ and $\lambda_0 = \lambda_L$. According to Prediction 1, in this scenario,

$$\ell_{0,1} = \frac{\partial \kappa_0}{\partial b_{0,1}} \lambda_L$$

and

$$s_0 > 0.$$

When $\xi_0 = \text{bad}$, we have $u'(c_0) = u'(c_L)$ and $\lambda_0 = \lambda_H$, which implies

$$\ell_{0,1} = \frac{\partial \kappa_0}{\partial b_{0,1}} \lambda_H$$

and

$$s_0 < 0.$$

Therefore, a higher risk premium $u'(c_0)$ implies a higher current liquidity premium $\ell_{0,1}$, but lower liquidity premium term spread.

Prediction 3

The forward liquidity premium is

$$f_{0,1} = E\left[\frac{u'(c_1)}{E[u'(c_1)]} \frac{\partial \kappa_1}{\partial b_1} \lambda_1\right].$$

If $\xi_0 = \text{good}$, then

$$f_{0,1}(\text{good}) = \frac{\partial \kappa_1}{\partial b_1} \frac{p_{11} u'(c_H) \lambda_L + (1 - p_{11}) u'(c_L) \lambda_H}{p_{11} u'(c_H) + (1 - p_{11}) u'(c_L)}.$$

If $\xi_0 = \text{bad}$, then

$$f_{0,1}(\text{bad}) = \frac{\partial \kappa_1}{\partial b_1} \frac{(1 - p_{22}) u'(c_H) \lambda_L + p_{22} u'(c_L) \lambda_H}{(1 - p_{22}) u'(c_H) + p_{22} u'(c_L)}.$$

On the other hand,

$$E[\ell_1 | \xi_0 = \text{good}] = \frac{\partial \kappa_1}{\partial b_1} \left(p_{11} \lambda_L + (1 - p_{11}) \lambda_H\right)$$

and

$$E[\ell_1 | \xi_0 = \text{bad}] = \frac{\partial \kappa_1}{\partial b_1} \left((1 - p_{22}) \lambda_L + p_{22} \lambda_H\right).$$

If

$$p_{11} > 1 - p_{22},$$

Then

$$f_{0,1}(\text{good}) < f_{0,1}(\text{bad}).$$

and

$$E[\ell_1|\xi_0 = \text{good}] < E[\ell_1|\xi_0 = \text{bad}].$$

If

$$p_{11} < 1 - p_{22},$$

then

$$f_{0,1}(\text{good}) > f_{0,1}(\text{bad})$$

and

$$E[\ell_1|\xi_0 = \text{good}] > E[\ell_1|\xi_0 = \text{bad}].$$

In both scenarios, the direction of the forward rate movement is the same as the direction of future expected short-term liquidity premium. Therefore, forward liquidity premium positively predicts expected future short-term liquidity premium.

Prediction 4

From the LP term spread expressions in (16), we get

$$\frac{\partial s_0}{\partial b_{0,1}} = \left(-\frac{\partial^2 \kappa_0}{\partial b_{0,1}^2} + \frac{1}{2} \frac{\partial^2 \kappa_0}{\partial b_{0,1} \partial b_{0,2}} \right) \lambda_0.$$

Under the assumption

$$0 > \frac{\partial^2 \kappa_0}{\partial b_{0,1} \partial b_{0,2}} > \frac{\partial^2 \kappa_0}{\partial b_{0,1}^2},$$

we have

$$\frac{\partial s_0}{\partial b_{0,1}} > 0.$$

Furthermore, in the stationary state,

$$\lambda_0 = E[\lambda_1],$$

and therefore,

$$s_0 = \frac{1}{2} \frac{\partial \kappa_1}{\partial b_1} Cov \left(\frac{u'(c_1)}{E[u'(c_1)]}, \lambda_1 \right).$$

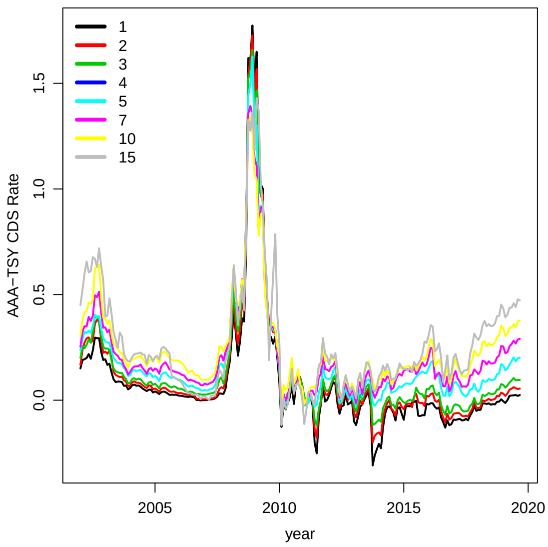
We know that the covariance is positive, and that an increases in two-period government bonds at time 0 will result in the same increase of one-period government bonds at time 1. Therefore, an increase in $b_{0,2}$ will result in a decrease in s_0. Expressed differently, a decrease in $b_{0,2}$ increases the LP term spread s_0.

B Additional Details of Data

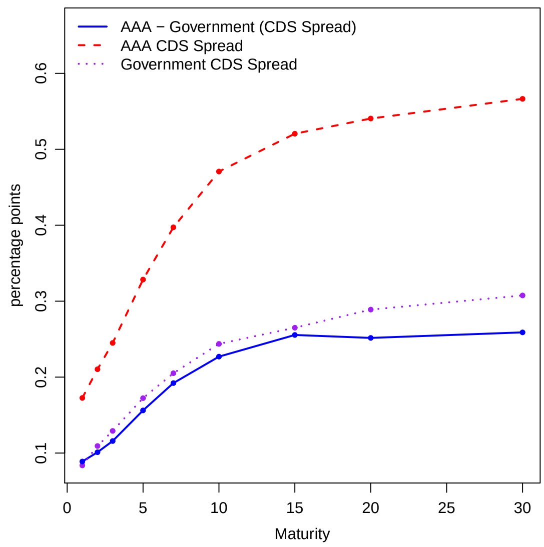
B.1 Data collection

In this section, we provide additional details of the data. Our observations of yields for Refcorp STRIPS, Agency STRIPS, and Treasury STRIPS are obtained from the Bloomberg system. Bloomberg gathers quotations for these zero-coupon bonds from bond dealers and other financial institutions.[27] Bloomberg then estimates the fair value curves for Refcorp, Agency, and Treasury STRIPS. We use the differences between the constant maturity on the Bloomberg fair value curves as our measure of liquidity premium.

Our corporate and government CDS data is from Markit beginning in January 2002. In particular, we get the CDS spreads of senior unsecured debt instruments of AAA-rated firms. Then we calculate the average CDS spread across all the AAA firms. In total, we use 18 AAA-rated firms. Figure B.I(a) shows the time series of the default components of Treasury convenience yield across different maturities. Indeed, the CDS differentials between AAA-rated firms and Treasuries of all maturities spiked during the 2008 financial crisis, indicating serious concerns about the default risks of the U.S. corporate sector. On average, the CDS spreads of AAA bonds and the U.S. government are both upward sloping, as shown in Figure B.I(b). The default components are also upward sloping on average.



(a) AAA–Treasury CDS Spreads



(b) The Term Structure of CDS Spreads

Figure B.I: **CDS spreads of AAA bonds and of the U.S. government**. CDS spreads for both AAA-bonds and the U.S. government are from Markit and cover the period from 2002 to 2020.

[27] According to Longstaff (2004), the prices of Treasury STRIPS are from more than two dozen sources. As the liquidity of Refcorp STRIPS is lower, there are typically seven or eight sources that provide pricing information for Refcorp STRIPS.

B.2 Descriptive statistics of the agency-Treasury spread

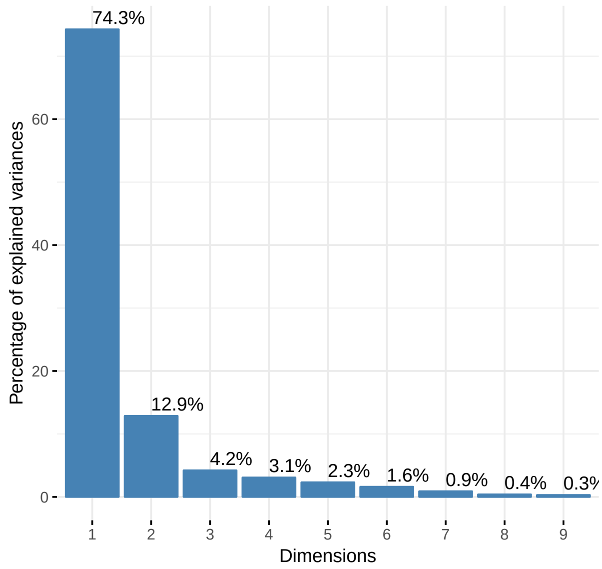
In this section, we provide summary statistics (Table B.I) and describe some basic properties of the agency STRIPS/Treasury STRIPS spread (Table B.II and Figure B.II).

Table B.I: **Summary statistics of monthly agency/Treasury STRIPS spread.** We calculate the difference between the yield of agency STRIPS and the yield of Treasury STRIPS of the same maturity at a daily frequency. The sample spans from August 1999 to May 2020 at a monthly frequency.

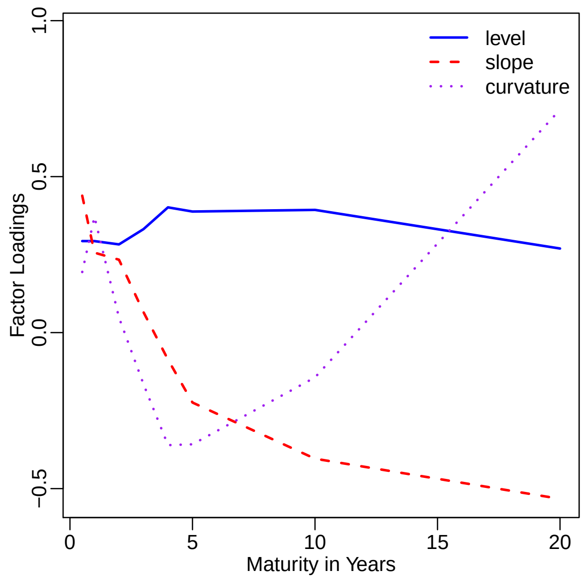
Maturity	N	Mean	St. Dev.	Pctl(10)	Pctl(25)	Pctl(75)	Pctl(90)
			Agency/Treasury Spread (in percent)				
3M	250	0.38	0.21	0.13	0.24	0.45	0.68
6M	250	0.37	0.20	0.18	0.23	0.42	0.66
1Y	250	0.39	0.19	0.22	0.26	0.44	0.66
2Y	250	0.42	0.17	0.26	0.30	0.50	0.68
3Y	250	0.45	0.19	0.29	0.32	0.53	0.72
4Y	250	0.48	0.23	0.27	0.32	0.55	0.84
5Y	250	0.48	0.22	0.28	0.34	0.57	0.79
10Y	250	0.57	0.24	0.33	0.40	0.68	0.91
20Y	250	0.63	0.21	0.35	0.46	0.77	0.87

Table B.II: **Agency-based LP term spread and Treasury term spread.** We regress the LP term spread on the Treasury yield term spread of the same maturity. Here, LP is measured as the spread between agency STRIPS and Treasury STRIPS. The k-year term spread is defined as the yield spread between the k-year value and the 3-month value. Newey-West standard errors with 12 lags are shown in the parentheses.

	Term Spread of LP (Agency/Treasury)			
	1Y	5Y	10Y	20Y
	(1)	(2)	(3)	(4)
Treasury term spread 1Y	−0.02			
	(0.06)			
Treasury term spread 5Y		0.05		
		(0.03)		
Treasury term spread 10Y			0.04	
			(0.04)	
Treasury term spread 20Y				0.003
				(0.04)
Observations	250	250	250	250
Adjusted R^2	0.001	0.04	0.04	0.0004



(a) Variations Explained by PCs



(b) Loadings of First Three PCs

Figure B.II: **Principal component analysis of agency/Treasury spread across maturities**. We conduct a principal component analysis of the agency/Treasury LP with maturities from three-month to 20-years. The sample spans from August 1999 to May 2020.

B.3 Descriptive statistics of LP based on daily data

Table B.III shows the summary statistics of LP at a daily frequency. We further show in Table B.IV that at a daily frequency, the Treasury term spread still has quite low power in explaining the LP term spread, and the R^2s are quite low for different maturities. Therefore, the results further confirm that the variations of the LP term spread are largely orthogonal to the term structure of Treasury yields.

Table B.III: **Summary statistics of daily liquidity premium.** We calculate the difference (in percent) between the yield of Treasury STRIPS and the yield of Refcorp STRIPS of the same maturity at a daily frequency. The sample spans from 1991-04-01 to 2020-05-01.

Maturity	N	Mean	St. Dev.	Pctl(10)	Pctl(25)	Pctl(75)	Pctl(90)
3M	7,587	0.27	0.30	0.01	0.09	0.38	0.60
6M	7,587	0.25	0.29	0.01	0.07	0.37	0.58
1Y	7,587	0.23	0.27	0.01	0.06	0.37	0.57
2Y	7,587	0.22	0.23	0.01	0.05	0.36	0.54
3Y	7,587	0.25	0.25	0.02	0.07	0.39	0.62
4Y	7,587	0.25	0.24	0.03	0.07	0.37	0.55
5Y	7,587	0.25	0.23	0.03	0.07	0.36	0.53
10Y	7,587	0.28	0.20	0.09	0.12	0.42	0.53
20Y	7,587	0.27	0.16	0.10	0.14	0.35	0.49

Table B.IV: **LP term spread and Treasury yield term spread at a daily frequency.** We regress the *daily* LP term spread on the *daily* Treasury yield term spread. The k-year term spread is the spread between the k-year value and the three-month value. Newey-West standard errors with 12 lags are shown in the parentheses. Data are at a daily frequency from 1991-04-01 to 2020-05-01.

	Term Spread of LP (Refcorp/Treasury)			
	1Y	5Y	10Y	20Y
	(1)	(2)	(3)	(4)
Treasury Term Spread 1Y	−0.27			
	(0.05)			
Treasury Term Spread 5Y		−0.05		
		(0.02)		
Treasury Term Spread 10Y			−0.05	
			(0.01)	
Treasury Term Spread 20Y				−0.04
				(0.01)
Observations	7,587	7,587	7,587	7,587
Adjusted R^2	0.20	0.04	0.07	0.05