Author’s Accepted Manuscript

www.elsevier.com/locate/finmar

Liquidity measures throughout the lifetime of the U.S. Treasury bond

Antonio Díaz, Ana Escribano

PII: S1386-4181(15)30130-0
DOI: http://dx.doi.org/10.1016/j.finmar.2017.01.002
Reference: FINMAR424

To appear in: *Journal of Financial Markets*

Received date: 16 December 2015
Revised date: 15 January 2017
Accepted date: 18 January 2017

Cite this article as: Antonio Díaz and Ana Escribano, Liquidity measure: throughout the lifetime of the U.S. Treasury bond, *Journal of Financial Markets* http://dx.doi.org/10.1016/j.finmar.2017.01.002

Liquidity measures throughout the lifetime of the U.S. Treasury bond☆

Antonio Díaz[*], Ana Escribano[†]
Universidad de Castilla-La Mancha, Department of Economics and Finance, Facultad de C. Económicas y Empresariales, Plaza de la Universidad, 1, 02071 – Albacete, Spain
Antonio.Diaz@uclm.es
Ana.Escribano@uclm.es

Abstract

We examine the price impact of different components of liquidity throughout the lifetime of the U.S. Treasury bond. Using the GovPX dataset, we provide a comprehensive empirical analysis of the impact of several liquidity proxies on the relative liquidity premium of these securities. The findings show that the liquidity premium has a deterministic main age-based component. This aging effect extends beyond the simple on-the-run/off-the-run effect. There is also a stochastic component of the liquidity premium that depends on the unexpected value of microstructure-based liquidity proxies and the current market- and bond-level conditions.

JEL Classification

G11; G12; G20; E43

Keywords

Liquidity; Fixed income; Pricing; Life cycle; Government bonds

1 Introduction

Liquidity is a key factor in the pricing of fixed income securities. Since the seminal work by Amihud and Mendelson (1991), there have been many studies showing that a security's liquidity is priced in Treasury markets. In this sense, Sarig and Warga (1989) show that the "on-the-run" or "just-issued" Treasury bond is by far the most

☆ We would like to express our gratitude to Tarun Chordia (the editor), an anonymous referee, and Irem Demirci, John Merrick, and Eliseo Navarro for their helpful comments and suggestions. This work was supported by the Spanish Ministerio de Ciencia y Tecnología (ECO2011-28134, ECO2014-59664-P), and Junta de Comunidades de Castilla-La Mancha (PEII-2014-019-P). Any errors are solely the responsibility of the authors.
[*] Tel.: +34 967599200x2351.
[†] Tel.: +34 967599200x2181.

highly liquid bond and is traded with a liquidity premium on prices. We emphasize that market participants take into account that the liquidity of a Treasury bond passes through different well-known stages. Therefore, the age is a relevant determinant of the current and potential liquidity of a bond.

The aim of this paper is to examine the price impact of different components of liquidity throughout the lifetime of the U.S. Treasury bond. To what extent do market players consider a liquidity term structure in the decision-making process? Does the liquidity premium depend on the aging of the bond? Is this potential dependence exclusively due to the on-the-run/off-the-run effect? What is the main driver of this potential term structure? Do the different liquidity components affect the liquidity premium? We hypothesize that liquidity has a deterministic component that should covary with the bond's age in a regular and predictable manner over time. Thus, we can model current expected liquidity as a function of the bond's age with implications for prices.

We consider a measure based on trading activity (market share) and several microstructure-based liquidity measures. In concrete terms, we analyze the proxy proposed by Bao, Pan, and Wang (2011), henceforth BPW, as an adaptation of the measure by Roll (1984), the measure by Amihud (2002) defined as the price impact of a trade per unit traded, and the price dispersion proposed by Jankowitsch, Nashikkar, and Subrahmanyam (2011). We focus the analysis on the 2-year Treasury note segment, which is by far the most actively traded segment on the market. Additionally, neither reissuance processes nor changes in the issuance programs have an impact on this segment.

A preliminary descriptive analysis of the behavior of microstructure-based illiquidity proxies throughout the lifetime of the notes shows some unexpected results. According to two of these proxies, the findings show that the on-the-run and first off-the-run notes are apparently the most highly illiquid assets on the market and that liquidity progressively improves as maturity approaches. Additionally, their average levels remain insensitive to the major instances of turmoil in the financial market during the sample period.

To determine an age-based component, we adjust a function to model the term structure of each considered liquidity/illiquidity proxy during the “liquidity life cycle.” In other words, we fit a mathematical expression from the average levels of each measure per age bracket. For a specific age, these functions provide smooth values of the expected current liquidity. Market participants may consider this expected current liquidity level and its potential future values before making trading decisions. This level should be a key input in investors’ decision-making process. In this sense, Goldreich, Hanke, and Nath (2005), henceforth GHN, observe that the current price of 2-year U.S. Treasury notes reflects the expectation of the costs and benefits of future liquidity. We find that the bond-aging process drives the time evolution of a deterministic liquidity component, which makes it possible to estimate a trading activity term structure. However, we again obtain some results for microstructure-based liquidity proxies that are seemingly inconsistent with expectations. Even controlling for current market-level and bond-level conditions, the random behavior of these illiquidity proxies is predominant. Thus, we identify two components of the current liquidity: a determinist age-based component, dominated by the trading activity facet of the liquidity, and a stochastic component.

We study the liquidity impact on prices. To compute the liquidity premium from Treasury security prices, we use the differences between the observed yield-to-maturity of a 2-year Treasury note and its theoretical yield, as given by an explicit term structure model. The theoretical yield-to-maturity is computed from discounting the original cash flows of the note by the corresponding spot rates. These daily estimates of the zero-coupon interest rate term structure are obtained by the methodology of Svensson (1994) and from our daily GovPx dataset of all the traded Treasury bills, notes, and bonds. The fitted term structures reflect the average liquidity level in the market. Thus, our yield spread can be understood as a relative liquidity premium because it reflects the yield differential with respect to a market-averaged liquid asset.[‡]

The yield spread shows a clear upward trend throughout the lifetime of the 2-year notes. Just-issued notes are traded with a negative liquidity premium that implies a higher price and therefore a lower yield-to-maturity. As a note's age increases, liquidity premiums begin to be positive, and its volatility increases. The mean yield spread ranges from -4.3 bps for the on-the-run, -2.3 bps for the first off-the-run, and 2.0 bps and 9.4 bps for the remaining notes during the first and the second year of life, respectively. On average, we find liquidity premiums among 2-year notes of approximately 10 bps in terms of yield-to-maturity during the sample period. However, this amount clearly depends on market-wide factors. For instance, the average liquidity premium of the on-the-run note was approximately -23 bps in fall 1998 after the Long-Term Capital Management (LCTM) default.

We explore the time series properties of the yield spread by regressing its value on the current value of the liquidity proxies, the note's age, and a number of control

[‡] For simplicity, this relative liquidity premium is referred to as the liquidity premium.

variables. The results indicate that a large portion of the liquidity premium follows a predictive behavior along the lifetime of the Treasury notes. The current level of three common microstructure-based measures of illiquidity has a limited impact on the liquidity premium. Only our proxy for trading activity has a relevant explanatory power.

Additionally we examine what part of the liquidity premium is determined by the expected current level of the liquidity proxies estimated from our term structures. The expected market share provides explanatory power for a relevant percentage of the yield spread, even when the age is included as an explanatory variable. The abnormal or unexpected value of three of the liquidity proxies has a statistically significant impact. In addition to the improvement in the relevant explanatory power of the model after including the control variables for market-wide liquidity levels, this result shows the important role that is played by the unexpected component of the liquidity premium.

The liquidity measures that we use are from the traditional microstructure literature. Recent papers based on these proxies show important pricing implications that are associated with corporate bond illiquidity (e.g., BPW; Lin, Wang, and Wu, 2011; Dick-Nielsen, Feldhutter, and Lando, 2012, henceforth DFL; Friewald, Jankowitsch, and Subrahmanyam, 2012). However, we find that only the unexpected component of microstructure liquidity is relevant for Treasury notes, not the level itself. We comment on several distinctive factors of Treasury securities and their market that can induce these results. First, government bonds are relatively homogeneous assets. In each maturity segment, the U.S. Treasury regularly auctions almost identical issues. These bonds share the same original term to maturity, amount outstanding, and other bond characteristics, which are all used as liquidity proxies in the literature. Age and the correlated on-the-run phenomenon may be the main determinants of both the liquidity differences among these assets and the different impacts of market conditions. Second, instances of financial turmoil, macroeconomic fundamentals, and several effects and phenomena that are related to the Treasury supply and demand effects can disrupt the performance of some microstructure-based liquidity proxies (see Li et al., 2009). Third, even the own price dataset that is used in the analysis of the U.S. Treasury market may be a relevant player in the results.

To ensure that the results are robust to alternative sub-samples, alternative specifications of the liquidity proxies, and different original terms to maturity, we conduct several robustness checks. We report the results using two sub-samples (the second period begins in August 1998 with the Russian financial crisis) and including the turnover as a proxy for trading activity, and both the Amivest liquidity ratio (see Cooper, Groth, and Avera, 1985) and Roll's (1984) measure as microstructure-based liquidity proxies. Additionally, we replicate the main analysis using the 5- and 10-year Treasury note segments. For 5-year notes, some of the liquidity proxies perform better than for the 2-year notes. The robustness checks show that the results remain similar.

Our empirical results for the liquidity life cycle and its impact on prices provide new insights into the pricing of Treasury securities. First, our results show that the liquidity premium has a deterministic main age-based component. A facet of liquidity, the trading activity, can be modeled throughout the lifetime of the Treasury notes. Market players consider a liquidity term structure in the decision-making process. This aging effect appears to be beyond the simple on-/off-the-run effect. Second, the current levels of microstructure-based liquidity measures do not explain this cycle and their impact on prices very well. The peculiarities of these securities and the market-wide liquidity behavior may distort the results of these bond-level liquidity measures. Third, the unexpected values of both the trading activity proxy and the transaction cost proxy proposed by BPW help provide explanatory power for the liquidity premium.

Our analysis has certain similarities with those provided by GHN. They examine the price difference between the first off-the-run and the on-the-run 2-year Treasury notes during the month in which both notes remain in this auction status. They explain this spread based on the current and expected future value of several trading activity measures. Although we also base the analysis on the 2-year Treasury note segment, we consider a dominant age-based predictable component of the liquidity premium and incorporate several microstructure-based liquidity measures that control for market-wide and bond-level liquidity throughout the entire lifetime of the note. Additionally, we use a yield spread measure free of tax and coupon biases and expand the study to the 5- and 10-year Treasury note segments. The use of both the market share as liquidity proxy and the bond liquidity life cycle function for obtaining the expected liquidity are inspired by Díaz, Merrick, and Navarro (2006), henceforth DMN. They compare the behavior of the current and the expected future market share in the pre- and post-European Monetary Union (EMU) periods to analyze the impact of the Spanish Treasury's tactical decision in 1997 to prepare its Treasury bond market for entry into the EMU.

Our paper is organized as follows. In Section 2, we further motivate our analysis by laying out a set of key stylized facts, drawing on the previous literature. In Section 3, we describe the specific characteristics of the U.S. debt market and the data and sample period. In Section 4, we examine the proposed liquidity proxies and estimate the term structure of their expected values. In Section 5, we define the methodology for estimating yield spreads and show the analysis of the ability of the liquidity proxies to explain the yield spreads. In addition, it includes the robustness checks. Finally, we conclude in Section 6.

2 Liquidity in debt markets

We begin by documenting the liquidity role in debt markets. We remark the different measures used to quantify liquidity and the results from previous studies in corporate bond markets. We then highlight distinctive factors of the Treasury bond market. Finally, we comment the liquidity evolution throughout the lifetime of the Treasury bonds according to the literature.

2.1 Liquidity measures

Previous studies show that liquidity depends on several factors that influence the liquidity of fixed income assets, such as the amount outstanding (e.g., Fisher, 1959), age and issue auction status (e.g., Sarig and Warga, 1989, and Warga, 1992), term to maturity (e.g., Amihud and Mendelson, 1991), and investor risk aversion (e.g., Longstaff, 2004). There are a number of measures that have been traditionally used in the literature as bond liquidity proxies. These include proxies such as the trading volume, percentage of trading days, the number of "runs,"[§] trading frequency, quoted bid-ask spread, quote size, trade size, price impact coefficient, and on-/off-the-run yield spread. For instance, Amihud and Mendelson (1991), Díaz and Navarro (2002), Houweling, Mentink, and Vorst (2005), Longstaff, Mithal, and Neis (2005), and Chen, Lesmond, and Wei (2007) conclude that traditional liquidity proxies are significant explanatory variables for credit spreads. In the case of the Treasury debt markets, Fleming (2003), GHN, Johnson (2008), Ejsing and Sihvonen (2009), DMN, and

[§] According to the terminology employed by Sarig and Warga (1989), a price "run" appears when two consecutive daily prices are identical.

Goyenko, Subrahmanyam, and Ukhov (2011) find evidence that some of these measures are useful tool for assessing and tracking Treasury market liquidity.

The availability of data has been the major driving force behind the choice of variables. The main reason is that, in most markets, the largest portion of trading activity occurs over-the-counter and some potential liquidity proxies are not directly observable. The recent availability of intraday transaction prices in the secondary U.S. corporate bond markets, i.e., the TRACE dataset, has made it possible to incorporate and adapt new liquidity measures from stock exchange markets in the analysis of fixed income liquidity.

The new set of liquidity measures inspired by the theoretical-founded microstructure literature on stock markets is applied to corporate bond market data. Among the most popular of these measures, we can highlight the Amihud's (2002) illiquidity measure, which is a proxy of the price impact, and the Roll's (1984) measure that provides a proxy of the effective bid-ask spread. Among other proposals, Jankowitsch, Nashikkar, and Subrahmanyam (2011) suggest their price dispersion measure, and DFL define a liquidity measure as an equally-weighted sum of four variables: the Amihud measure, the "imputed roundtrip trades" proposed by Feldhütter (2012) as measure of transaction costs, and the standard deviations of both previous variables.

The recent literature shows that these microstructure-based illiquidity proxies are useful for corporate bonds. Among others, BPW, Lin, Wang, and Wu (2011), DFL, and Friewald, Jankowitsch, and Subrahmanyam (2012) show that the yield spreads of corporate bonds are related to these proxies for illiquidity. These proxies have both statistical and economic significance in measuring liquidity, especially in periods of financial crisis. Regardless, two recent papers show discordant results concerning price-based illiquidity proxies. Helwege, Huang, and Wang (2014) observe a weak explanatory power of these proxies to describe the yield spread of matched pairs of corporate bonds. They suggest that the low number of daily trades often makes these proxies less reliable than their counterparts in the equity market. Schestag, Schuster, and Uhrig-Homburg (2016) find different levels of performance of some proxies in both the stock and the corporate bond markets, especially in the case of price impact measures.[**] As sources, they highlight two main peculiarities of the bond market. First, it has a decentralized market structure. Second, it is a market in which transaction costs decrease with the trade size (e.g., Chakravarty and Sarkar, 2003; Edwards, Harris, and Piwowar, 2007). Friewald, Jankowitsch, and Subrahmanyam (2012) note that conventional transaction metrics of liquidity do not have the same meaning in the OTC fixed income markets compared to exchange traded markets.

Because we analyze Treasury notes, a natural question is how well these microstructure measures work in these assets. A priori, the answer is unclear because characteristics and determining factors of the Treasury market may be very different from equities and corporate bonds. We note three distinctive factors. First, the available dataset is one point to consider. The GovPX dataset does not report information trade by trade. Some of these measures of illiquidity may be difficult to precisely measure empirically. This empirical difficulty can tend to bias against finding that bond prices and illiquidity are related.

Second, government bonds are relatively homogeneous assets. In each maturity segment, the U.S. Treasury regularly auctions almost identical issues. The outstanding

[**] They comment that "price impact measures should be employed with great caution." Nevertheless, they encourage the use of the Amihud price impact proxy because it is correlated with transaction costs.

bonds share all the characteristics but have an approximately similar size and coupon rate and a different age. By contrast, the corporate bond literature provides evidence that a number of bond fundamentals, such as maturity, issuance size, trade size, and credit rating category (e.g. Friewald, Jankowitsch, and Subrahmanyam, 2012; Acharya, Amihud, and Bharath, 2013) provide explanatory power for differing liquidity levels among corporate bonds. Nevertheless, Helwege, Huang, and Wang (2014) cast doubt on the performance of some liquidity proxies when matched pairs of homogeneous corporate bonds are examined. Given the extreme homogeneity of the 2-year Treasury note segment, the age and/or the correlated on-the-run phenomenon may be the main determinants of both the liquidity differences among Treasuries and the different impacts of market-wide liquidity factors.

Third, Treasury supply and demand and other external factors, such as the market-level illiquidity, monetary policy decisions, and macroeconomic shocks, can interfere with government bond liquidity and in the performance of microstructure-based liquidity measures. Duffie (1996), Jordan and Jordan (1997), Krishnamurthy (2002), Cherian, Jacquier, and Jarrow (2004), Krishnamurthy and Vissing-Jorgensen (2012), and Barnejee and Graveline (2013) highlight that the effects of supply and demand can have important consequences in the Treasury market. Treasury securities carry a moneyness premium based on their liquidity and safety attributes that decreases the yield to maturity. Reductions in the supply of Treasuries lower the yield on Treasuries relative to corporate securities that are less liquid and riskier than Treasuries.

Market-wide liquidity affects both corporate and government bonds but not necessarily in the same manner. In the case of corporate bonds, the literature shows the role of external factors beyond bond characteristics and microstructure-based illiquidity proxies on the pricing of these bonds. In times of financial turmoil, the time-varying liquidity risk of corporate bond returns is detected, conditional on episodes of flight-to-quality (e.g., Bernanke and Gertler, 1995; Longstaff, 2004; Vayanos, 2004; Beber, Brandt, and Kavajecz, 2009; DFL) and flight-to-liquidity (e.g., Fleming and Remolona, 1999; Longstaff, 2004; Beber, Brandt, and Kavajecz, 2009; Lin, Wang, and Wu, 2011; Friewald, Jankowitsch, and Subrahmanyam, 2012; Acharya, Amihud, and Bharath, 2013; Helwege, Huang, and Wang, 2014). These factors have a relevant impact on the liquidity premium behavior, even overshadowing the credit risk component (e.g., BPW).

In the case of Treasury bonds, Fleming (2003) and Longstaff (2004) report the existence of flight-to-quality and flight-to-liquidity phenomena that significantly affect Treasury bond prices. Investors are willing to pay a premium for the safety and liquidity of Treasuries when markets are unsettled. The premium is related to the market sentiment and the amount of the funds that flow into equity and money market mutual funds. In times of adverse economic and financial conditions, a greater demand for liquidity increases liquid Treasury security prices by more than usual. An increased perception of market risk may increase the spread between on-the-run and off-the-run government bonds. Li et al. (2009) stress that persistent market-wide liquidity shocks have pervasive impacts on government bond pricing. They comment that this effect surpasses the effect of the level of liquidity that is proxied by microstructure-based liquidity measures. Treasury bond prices drop when market-wide liquidity worsens, regardless of how bond-level liquidity fluctuates. They observe that "the microstructure-based liquidity measures could be very noisy proxies for liquidity risk." Additionally, factors related to both the on-the-run and the repo specialness phenomena are discussed in the next section.

2.2 Liquidity throughout the lifetime of the Treasury bonds

Amihud and Mendelson (1991) note that, as time passes for a given instrument, trading tends to become less active as investors who are more likely to hold the instrument for longer periods gradually acquire an increasing fraction of the issue. Bond aging reduces and even fades away the bond liquidity. Similarly, Treasury securities pass through different phases: when-issued, on-the-run, and off-the-run. Each of these stages presents different market structures. In the when-issued market, securities are traded several days before the auction. The settlement date of these transactions coincides with the auction settlement date. The most recently Treasury-issued security of a given maturity is the on-the-run security. After each auction, the just-issued bond is the on-the-run; the former on-the-run becomes the "first off-the-run;" the former first off-the-run becomes the "second off-the-run;" and so on.

The on-the-run phenomenon or on-/off-the-run cycle postulates that the on-the-run bond is the most actively traded among the issues of the same original term to maturity. These issues focus the interest of investors. Trading in the Treasury market is clearly concentrated on the on-the-run issues, which have more trades and higher trading volumes. Following Sarig and Warga (1989), on-the-run bonds are the more highly liquid securities (e.g., Brandt, Kavaiecz, and Underwood, 2007; Mizrach and Neely, 2008; Pasquariello and Vega, 2009; Graveline and McBrady, 2011).

Therefore, the on-the-run Treasury bond generally has higher prices than previous issues (off-the-run) that mature on similar dates. Some reasons are proposed as explanatory factors of the liquidity premium on the prices of the on-the-run securities: liquidity, transaction cost, and repo specialness. Amihud and Mendelson (1991) and

Warga (1992) note that differences in liquidity provide explanatory power for this phenomenon. All institutional investors wish to include this Treasury bond in their portfolios. Krishnamurthy (2002) shows that a higher demand by buy-and-hold investors for more highly liquid on-the-run Treasuries increases their price in the cash market. These investors choose to hold these liquid securities because they can sell them more quickly and without high losses. Vayanos and Weill (2008) highlight that, although off-the-run Treasury bonds are less expensive than on-the-run bonds, investors think that they are difficult to find and scarce in markets. Amihud and Mendelson (1991) and GHN report that on-the-run bonds offer low transaction costs.

Fleming (2000) and Pasquariello and Vega (2009) state that the on-the-run Treasury may trade "on special" (i.e., it can be used as collateral to borrow money at a rate below the prevailing general repo rate)[††] because it is more liquid or, alternatively, because of its scarcity due to the limited supply or short squeeze. Positive specialness is generally considered to be a signal of greater "market desirability" or a relatively scarce supply of the specific instrument used as collateral in the repo contract. Specialness in the repo market may cause on-the-run securities to trade at a premium.

On the demand side, Sundaresan (1994), Graveline and McBrady (2011), and Cherian, Jacquier, and Jarrow (2004) detail that speculators short sell the not-yet auctioned Treasury security in the when-issued market, hoping to buy it back in the auction at a lower price. To hedge the risks of this transaction, they buy existing on-the-run Treasuries, which are the closest substitutes. This behavior creates shortages for these on-the-run Treasuries before the auction and explains the higher costs, or repo

[††] In a general collateral repo, traders can choose the bond that is to be used as collateral from a pre-defined basket of Treasuries. By contrast, a special collateral repo requires traders to stipulate a unique bond as collateral at the outset of a repo transaction.

specials, that short-sellers often pay to borrow these securities. Simultaneously, long investors are willing to pay a higher price for securities that they can lend at a premium to short-sellers in the repo market.

On the supply side, Jordan and Jordan (1997) find strong support for Duffie's (1996) model in which specialness can arise when collateral owners are inhibited from supplying the collateral because of frictional costs or legal or institutional requirements. Fontaine and Garcia (2012) also stress the relevant importance of funding conditions in the repo market as an aggregate risk premium in the Treasury market. They suggest that changes in monetary aggregates and in bank reserves are key determinants of the liquidity premium.

The implication is that the current age of a Treasury note has a strong negative correlation with liquidity. A main component of our liquidity proxies should change predictably over time. Thus, this deterministic component should covary with the note's age in a regular and predictable manner over the time. If the note auction status passes through a life cycle, then we can state that the note's liquidity also passes through a similar life cycle.

In this sense, GHN examine the price differences between on-the-run and first off-the-run Treasuries and time-varying liquidity over the on/off cycle. They show that the current price of Treasuries reflects the expectation of the costs and benefits of future liquidity. DMN propose an alternative analysis. The two-stage on-/off-the-run cycle division used for U.S. Treasury debt is not suitable in the Spanish case. The Spanish Treasury has built up its issues through a series of issuance tranches.[‡‡] They use a continuous, highly non-linear function of bond age with an initial jump to explain the

[‡‡] They propose three different status stages: pre-benchmark, benchmark, and seasoned.

typical bond's changing market share of trading volume. This function is used to project each issue's future liquidity. They conclude that the expected future liquidity is much more important than the current liquidity for explaining relative Spanish Treasury bond values.

3 Data and sample period

The dataset used in the analysis of U.S. Treasury liquidity is from the GovPX database. This database contains trading information from five of the six largest majority brokers trading in the interdealer market. It was created in 1991 to meet the demands to provide greater transparency for the U.S. Treasury market. Brokers report the quote and trade information from their trading activity with participating interdealer brokers to the GovPX system. The dataset includes only the trades and quotes registered among them. The trading activity among dealers and between dealers and their customers is beyond the computational scope of the data. The posted data include the best bid and ask quotes, the quote sizes, and the price and size of the transaction. Trade-by-trade information is not available, but the dataset includes the aggregate information on all trades involving each issue during the day.

Our GovPx dataset ranges from 1996 to 2001. The GovPx daily trading volume average was almost $80 billion until 1998. Figure 1 shows the time evolution of the trading activity reported by GovPX in the U.S. Treasury bonds and notes segment. The emergence of the new electronic trading platform at the beginning of this century had a clear impact on the trading activity in the interdealer broker market and the quality of the information reported by GovPx. Among others, Fleming (2003), Mizrach and Neely (2006), and Li et al. (2009) report the gradual deterioration of the GovPX coverage of coupon securities. The GovPx dataset does not provide a reliable indicator of transactions after March 2001. Indeed, GovPx has not reported volume information since May 2001.

Our sample period is affected by these constraints. The dataset includes every trade between January 1996 and November 2000.[§§] To complement the dataset, we use information on the amount outstanding and auction details obtained from the official website of the U.S. Department of the Treasury. For the study period, there are 1,302 trading days and 251,680 observations. We consider all the traded U.S. Treasury bills and straight notes and bonds to estimate the daily coupon-zero interest rate term structures. The methodology and details of the yield curve fitting process are noted below. These term structures are used to compute the liquidity premium included in the observed transaction prices and yields-to-maturity.

Table 1 shows the total number of outstanding Treasury notes and bonds, their average trading volume, and some details of the issuance process. Several patterns can be observed. The most actively traded issues by far are the 2-year and 10-year notes. By contrast, 7-year notes and 20-year bonds can be regarded as illiquid securities because they are rarely traded. During our sample period, no new issuances of these assets occur.

We focus our liquidity analysis on the 2-year Treasury note segment, although we include the liquidity analysis of the 5- and 10-year segments in the section on robustness checks. Two main reasons justify this choice. First, the 2-year segment is the

[§§] The reported GovPx information from December 2000 is limited, causing distortion in the measures used. However, other authors such as Li et al. (2009) use the GovPx dataset until December 2002. Our liquidity proxies, which are computed until November 2000, should be relatively unaffected by changes in GovPX coverage. Indeed, we compute the market share instead of the trading volume to isolate the measure from changes on market trading activity over time.

most actively traded segment on the market. On average, a 2-year note trades 89% of the days throughout its lifetime. However, 5- and 10-year notes are only traded 50% and 27% of the days, respectively. The low or even lack of trading activity during long periods (weeks, months or even years) can affect the validity and coherence of illiquidity proxies based on prices.

Second, 2-year notes have a regular issuance program during the period of analysis. They are uninterruptedly issued and the number of simultaneous outstanding issues remains constant. The issuance schedule of 5-year (10-year) notes changes from monthly (quarterly) to semiannually in 1998 (in 2000). New 5- and 10-year notes are then issued twice a year, and they are re-issued three months later as a new tranche. Additionally, several new tranches of the seasoned 5-year notes are issued three years after their original issuance as 2-year notes.

The changing issuance programs and the re-issuance of new tranches of existing issues clearly affect the analysis of 5- and 10-year notes. Their impact on both the trading activity patterns and the on-/off-the-run cycle is evident, as shown in Figure 2. This figure depicts the market share of the different Treasury notes and bonds as a function of the security age from issuance in weeks during the first two years of the lifetime of the securities. Similar term structures of the market share can be observed for all securities, although some variations appear, depending on the issuance policy for each security. The on-/off-the-run period of 2-year notes is the clearest among all the original terms to maturity. By contrast, the trading activity of the rest of securities displays the impact of the changing issuance process.

4 Liquidity analysis

We assume that bond liquidity has two components. The main component is deterministic and depends on the bond's aging process. Market players consider the bond's age or alternatively the bond's auction status (i.e., on-the-run, first off-the-run, second off-the-run, and so on) to provide a full insight into the current expected liquidity of the bond. Additionally, liquidity also has a stochastic component that depends on both current market-level and bond-level conditions.

In this section, we analyze four liquidity/illiquidity proxies throughout the lifetime of a note. We adjust functions of the age to determine the current expected liquidity. Finally, we estimate panel models to explain the observed value of each liquidity proxy based on the current expected liquidity and several control variables.

4.1 Liquidity proxies

We consider four liquidity measures to proxy two different liquidity facets: the market impact and the price impact. In the sections above, a number of liquidity proxies widely used in the literature have been noted. We propose a measure based on trading activity as a proxy for market impact and three microstructure-based liquidity measures as proxies for price impact. Following DMN, we use market share as a proxy for trading activity because this measure is scarcely influenced by instances of market-wide turmoil. DMN prefer the market share measure to the raw volume measure because scaling individual issue volumes by total market volume both detrends the data and controls for week-to-week volume fluctuations that are unrelated to relative liquidity.[***] As proxies for price impact, we include the proxy proposed by BPW, as an adaptation of the measure by Roll (1984), the Amihud (2002) measure, defined as the price impact of a trade per unit traded, and the price dispersion proposed by Jankowitsch, Nashikkar, and Subrahmanyam (2011).[†††] These measures are computed at the individual bond level.

We calculate the measures for weekly age brackets based on daily data. The age of note *i* on day *t* is computed as the difference between trading day *t* and its issuance date in working days. Given that we consider working days, we compute weeks of five days to express the age in weeks. Thus, week 1 is the first week after issuance, and week 105 is the last week until maturity. Working with weekly brackets makes it possible to avoid reversals and reduces spurious oscillations as well. Authors of previous studies also average daily data (e.g., Cooper, Groth, and Avera, 1985, and Amihud, 2002, in the case of the stock exchange market; and BPW and DFL in the case of the corporate bond market). Schestag, Schuster, and Uhrig-Homburg (2016) conclude that many of their liquidity proxies, which are alternatively computed on a monthly, yearly or daily basis, well replicate the benchmark proxies that are obtained by trade-by-trade data.

Market share, $MS_{i,k}$, is the ratio of the individual trading volume of a *k*-weeks-old note *i* (i.e., a note *i* during the week the note has the age of *k*) to the total trading

[***] Regardless, this liquidity proxy can also have limitations in specific situations. For instance, even when bond liquidity improves, the ratio can become worse if other bonds' liquidity becomes even better.

[†††] BPW and Jankowitsch, Nashikkar, and Subrahmanyam (2011) consider their proposed γ and price dispersion measures to be proxies of the price impact and the transaction cost, respectively. However, Schestag, Schuster, and Uhrig-Homburg (2016) classify the first measure as a transaction cost proxy, the second as a price dispersion proxy, and the Amihud measure as a price impact proxy. We use a broad view of the price impact concept and include the three proxies in the same category.

volume in the entire market, including any transaction involving all the outstanding issues during the same calendar week.

The Amihud (2002) illiquidity measure is the price impact of a trade per unit traded. Intuitively, this measure tells us that an asset is illiquid if the price moves substantially given a small change in volume. We compute the Amihud measure, $AM_{i,k}$, for a k-week old note i as follows:

$$AM_{i,k} = \frac{1}{D_{i,k}} \cdot \sum_{t=1}^{D_{i,k}} \frac{|r_{i,t,k}|}{TV_{i,t,k}}, \qquad (1)$$

where $D_{i,k}$ is the number of days in which the k-weeks-old note i is traded (from 0 to 5 days); $TV_{i,t,k}$ is the par trading volume in million dollars for k-weeks-old note i on day t; and $|r_{i,t,k}|$ is the absolute return of note i on day t of week k.

BPW propose an aggregate illiquidity measure, γ, which is a variant of the Roll (1984) measure. They assume that the lack of liquidity in an asset leads to transitory components in its prices. Because transitory price movements lead to negatively serially correlated price changes, they propose the negative of the autocovariance in relative price changes as a measure of illiquidity. These authors consider that it captures the broader impact of illiquidity on prices, above and beyond the effect of the bid-ask spread (Roll's measure). We compute $Bao_{i,k}$ for note i in the last trading day t of the k-week of age as

$$Bao_{i,k} = -Cov(\Delta p_t, \Delta p_{t+1}). \qquad (2)$$

where Δp_t is the change in prices or the absolute return from day t - 1 to day t. We use a rolling window of 21 trading days.

Jankowitsch, Nashikkar, and Subrahmanyam (2011) define an illiquidity proxy as a "price dispersion" based on the dispersion of trading prices with respect to the market valuation, controlling for the effect of the trading volume on each trade. A high value indicates that investors cannot trade the bond near its fundamental value; thus, they must incur large transaction costs. Hence, this measure would indicate a bond trade transaction cost.

In their study from the U.S. corporate bond market, Jankowitsch, Nashikkar, and Subrahmanyam (2011) compare the observed transaction prices from TRACE and Markit composites from bid and ask quotations. From our perspective, we propose a more accurate measure. The price dispersion is computed from the difference between the observed trade price from GovPx and its theoretical price obtained from the zero-coupon yield curve estimated from GovPx prices. The fictitious price for each 2-year note at each date is obtained by discounting the particular cash flows of the security with the appropriate zero-coupon interest rate for each maturity extracted from the daily yield curve that we adjust (see Section 5.1). We compute the price dispersion $PD_{i,k}$ for note *i* in week *k* as follows:

$$PD_{i,k} = \sqrt{\frac{1}{\sum_{t=1}^{N_{i,k}} TV_{i,t,k}} \sum_{t=1}^{N_{i,k}} \left(p_{i,t,k} - p_{i,t,k}^{theo}\right)^2 \cdot TV_{i,t,k}}, \qquad (3)$$

where, for each note i, there are $N_{i,k}$ transactions in week k with a trading volume of $TV_{i,t,k}$ at traded prices $p_{i,t,k}$. We compute the difference between the $p_{i,t,k}$ and the theoretical price $p_{i,t,k}^{theo}$ for note *i* on each day *t* during week *k*.

A higher *MS* implies more trading activity and improved trading conditions (i.e., the note can be traded more easily and quickly) and transaction costs are lower. Thus, *MS* is a proxy for liquidity, but the other three measures are illiquidity proxies. In the case of the *Bao* measure, an illiquid note is traded with a large bid-ask spread, implying highly negative correlated consecutive prices and a high positive value of the *Bao* measure. According to the *AM* measure, higher values represent a larger price impact and transaction costs. Therefore, notes with high *AM* values are less liquid notes. Finally, a low level of the *PD* measure indicates liquidity (i.e., the note can be traded close to its fair value).

4.2 Estimating a liquidity life cycle

Following DMN, we analyze the relation between trading activity, proxied by *MS*, and the age of the security. In addition, we incorporate the three proposed proxies for price impact based on the traditional microstructure in stock exchange markets: *AM*, *Bao*, and *PD*.

In a first approximation of the problem, Figure 2 provides some insight into the *MS* behavior for a 2-year note. The line for the 2-year note reflects the auction status and clearly corroborates the on-the-run phenomenon. An average *MS* of approximately 27% for the on-the-run 2-year note means that it is not only the most actively traded security for this maturity but also the most actively traded security on the entire U.S. Treasury market. The trading activity of the remaining outstanding 2-year notes (off-the-run) remains relatively low until maturity. The first off-the-run note trades with a 4% *MS* and the second and further off-the-run notes trade with only a 0.5% *MS*. A peak in the *MS* is observed when the time to maturity of the 2-year note is approximately 12 months. This increase in trading activity may be because these securities can be used as a substitute for just-issued one-year Treasury bills, although they pay semiannual coupons, with the corresponding tax implications, and have different amounts outstanding. Indeed, the *MS* for a one-year-old 2-year note is twofold the average value in previous weeks.

This trading behavior should affect the prices at which these assets are traded on the market. Before the liquidity premium analysis that we conduct in the next section, we obtain preliminary evidence on the observed bid-ask. There is a constant reported bid-ask spread of 3.125 bps for 2-year notes with ages of up to 3 weeks. This constant bid-ask spread jumps to 6.250 bps for 2-year notes that are four weeks old or older.

In Panels A and B of Figure 3, we plot the time evolution of the weekly average and standard deviation for the four liquidity proxies, depending on the aging of the note. In Table 2, we summarize the main descriptive statistics for the full lifetime of the 2-year notes and separately identify the on-the-run, first off-the-run, and further off-the-run auction statuses. In the case of further off-the-run status, we distinguish between until and after the first year of life. The term structure of the *MS* seems to fit the expected behavior of both the liquidity and the liquidity premium according to the literature. There is a sharp fall in trading activity when the on-the-run note becomes off-the-run. This result is consistent with the result observed by Graveline and McBrady (2011), who obtain evidence that repo specials for on-the-run Treasuries tend to rise in a non-linear manner with the time since the last auction and fall after the announcement of the auction for the next new issue.

The term structure of the *AM* measure is also very consistent with the on-/off-the-run liquidity cycle. It performs as expected until the first year of life. The illiquidity progressively increases during the first off-the-run period and the following weeks. However, this price impact proxy drops when the note becomes one year old, and although it slightly worsens thereafter, it remains at a low level until maturity. Thus, the off-the-run period until the first year of life is the more illiquid period.

According to the evolution of the other two microstructure-based measures, liquidity progressively improves throughout the lifetime of the note. The temporal evolution of the average *Bao* and *PD* measures suggests that the younger the note, the higher the search and transaction costs. This result is puzzling. Moreover, the evolution of the weekly age range average of the *Bao* proxy is highly irregular.

The behavior of microstructure-based illiquidity proxies as maturity approaches also requires attention. Old bonds are typically included in inactive portfolios and are less accessible. For most investors, it can be more convenient to wait for maturity for a short period than to unwind positions. For instance, BPW observe that the older the corporate bond, the higher is its illiquidity as proxied by the proposed measure. In contrast, the level of our three illiquidity proxies shows a downward trend during the last year of the note's life that is difficult to explain. As a possible reason for this apparent increase in liquidity, we suggest that these assets can be used as a substitute for Treasury bills or in transactions that attempt to replace repo operations.

Table 2 also shows that the standard deviations of these measures for the age range show that the first year after issuance is the more volatile period for our liquidity proxies. Large standard deviations indicate that the mean is estimated with low precision. In the case of *MS*, *Bao*, and *PD*, volatility reaches the highest levels during the on-the-run and first off-the-run periods. Therefore, there are just-issued notes whose trading activity and *PD* are far from the mean level. In the case of *AM* and *Bao*, both the illiquidity level and the illiquidity risk are much higher, from the time that the note becomes off-the-run to the end of the first year of life.

One explanatory reason for the great volatility observed in Figure 3 and Table 2 may be market episodes that affect the liquidity of these assets, such as instances of financial turmoil and macroeconomic shocks. Figure 4 shows the evolution of the monthly average level of the liquidity proxies for the auction status category along our sample period, from January 1996 to November 2000. The time behavior is quite erratic, especially in the case of *Bao* and *PD*. The on-the-run phenomenon does not seem to be relevant in the monthly illiquidity level that is measured by these two proxies. The more illiquid note is alternatively the on-the-run, the first off-the-run, or the further off-the-run note, depending on the month. In addition, we are unable to identify the spikes in Treasury market liquidity reported by Fleming (2003). This author states that the bid-ask spread "increases sharply with the equity market declines in October 1997, with the financial market turmoil in the fall of 1998, and with the market disruptions around the Treasury's quarterly refunding announcement in February 2000."

Based on this evidence, we conclude that two of the three considered illiquidity proxies, *Bao* and *PD*, follow irregular and unexpected trends along the lifetime of the notes if only bond-level characteristics, such as age or term to maturity, are considered. The high volatility and unsteady pattern suggest that they are part of a stochastic component of the liquidity, in which the age is not the main determinant. The average level of these measures does not adequately address either the well-known on-/off-the-run liquidity cycle or reported financial market episodes that affect the liquidity in the market during the sample period. As previously suggested, several distinctive characteristics of the bond markets in general and the Treasury market in particular may imply that the level itself of these microstructure-based measures of illiquidity is not relevant in measuring or pricing liquidity in these concrete markets.

We hypothesize that liquidity has a main deterministic age-based component. The liquidity of a note follows different stages that are well-known by the market. Thus, we can model a current expected liquidity function of the note age with implications for prices. Our previous findings suggest that this determinist age-based component is driven by trading activity, one of the liquidity facets. Additionally, market-wide liquidity, and punctual fluctuations in bond-level liquidity proxied by both microstructure-based liquidity measures and the note's fundamentals, can also affect a liquidity premium on prices.

We model each of the four liquidity proxies as smooth, non-linear functions of the age of a 2-year note. This methodology is proposed by DMN. Based on the average values of each measure for each weekly age, we fit parsimonious functions in a manner that is merely empirical. We use exponential life cycle functions in the case of *MS* liquidity and *AM*, *Bao*, and *PD* illiquidity proxies as follows:

$$MS_{i,k} = \beta_0 + \beta_1 \exp[-\beta_2(k-\beta_3)^2] + \beta_4 \cdot \beta_5^k + \beta_6 \cdot d1y_{i,k} + u_{i,k} \tag{4}$$

$$AM_{i,k} = exp[\beta_1 + \beta_2/k + \beta_3 \cdot \log(k)] + u_{i,k} \tag{5}$$

$$Bao_{i,k} = \beta_1 \cdot exp(\beta_2 \cdot k) + \beta_3 \cdot \exp(\beta_4 \cdot k) + u_{i,k} \tag{6}$$

$$PD_{i,k} = \beta_0 + \beta_1 \exp[-\beta_2(k-\beta_3)^2] + \beta_4 \cdot \beta_5^k + \beta_6 \cdot k + u_{i,k} \tag{7}$$

where k refers to the weekly age (k = 1 to 105 weeks); $MS_{i,k}$, $AM_{i,k}$, $Bao_{i,k}$, and $PD_{i,k}$ are the average *MS, AM, Bao*, and *PD* of all the observations at the k-week age, respectively; $d1y_{i,k}$ is a dummy variable that takes the value of 1 when note i is approximately one year old (k = 52 to 54) and otherwise 0; and $u_{i,k}$ is a random error.

These liquidity functions relate a note's liquidity proxy to note age. Thus, at any point in time, these functions can be used to project the expected liquidity of any individual note. For the first proxy, we define $E[MS_{i,k}]$ as the expectation of the *MS* of note *i* during the week that note is *k*-weeks old. Using expression (4), the expected *MS* can be expressed as follows:

$$E\left[MS_{i,k}\right] = \hat{\beta}_0 + \hat{\beta}_1 \exp[-\hat{\beta}_2\left(k - \hat{\beta}_3\right)^2] + \hat{\beta}_4 \cdot \hat{\beta}_5^k + \hat{\beta}_6 \cdot d1y_{i,k}. \quad (8)$$

A similar method is used to estimate the expected values of the other three illiquidity proxies based on expressions (5), (6), and (7).

In Figure 5, we plot the actual and estimated values for the four liquidity proxies. These functions make it possible to approximate the path of these liquidity measures as a function of the note's age. From them, we can calculate the expected liquidity of a note, depending exclusively on its age. This result should be the determinist component of the liquidity of a note at a certain age.[‡‡‡] This deterministic component reflects the expectation of the current and potential future liquidity. Market participants should consider this expected liquidity to price the asset.

To examine the relation between the observed value of the liquidity proxies and the expected liquidity according to the liquidity term structures, we regress the current liquidity measures on the estimated liquidity values, computed from expression (8), the bond's characteristics, and a number of control variables. For the bond's characteristics, we use *Age* expressed in weeks, two dichotomous variables to consider the on-the-run (*OTR*) and the first off-the-run (*1stOFF*) auction statuses, the *Coupon* rate because this variable has tax implications, the log of the *Amount* outstanding, and the *Bid-Ask*

[‡‡‡] Both GHN and DMN consider the expected future liquidity, but only the latter authors estimate this variable explicitly. They use the expression of the expected current liquidity to project each issue's future liquidity as the average liquidity that the bond would have during its remaining time to maturity. The specific Spanish auction status cycle allows a richer shape for the expected future liquidity function. In our case, this expected future liquidity should be nothing more than a downward, almost linear trend.

spread. The *OTR* (*1stOFF*) dummy takes the value of one if the status of the note is on-the-run (first off-the-run) and zero otherwise.

To control for the shape of the yield curve, we compute the *Level*, *Slope*, and *Curvature* as the 2-year zero-coupon interest rate, the differential between the 10- and 2-year spot rate, and the difference between the 6-year and the average between the 10- and the 2-year spot rates, respectively. To control for the economic state and market sentiment, we use the Standard & Poor's 500 Index (*SP500*) and the S&P500 option implied volatility (*VIX*) as a measure of investor confidence. To control for credit risk, we include the *BBB-AAA* credit spread. Distinguishing between flights-to-liquidity and flights-to-quality is very difficult. Both cases have the same expected effect on the Treasury market (i.e., an increment on trading activity and price impact). As control proxies for these episodes, we consider the spread between the AAA corporate yield and the 10-year Treasury bond yield, *AAA-10yTr*, and the *Market Vol*, calculated as the log of the trading volume for the entire Treasury market reported by GovPx.[§§§]

Table 3 presents the resulting coefficient estimates of the regression analysis for each liquidity/illiquidity proxy. Although the expected liquidity based on the age of the note is statistically significant for all of the liquidity proxies, the explanatory power of the models in the case of the illiquidity proxies is much lower than in the case of the *MS*. This trading activity proxy reaches 87.8% adjusted R^2. However, the regressions for the *Bao* measures have the lowest explanatory power, represented by an adj. R^2 of 1.2%. Controlling for the bond characteristics, economic state, and market sentiment,

[§§§] Source: we use the Yahoo Finance website to obtain the S&P500 and VIX series and data from the H.15 series (Statistical Releases and Historical Data from the Federal Reserve Board) to compute the BBB-AAA spread and the AAA-10-year Treasury spread. The BBB-AAA spread is calculated as the difference of the weekly 'Moody's yield on seasoned corporate bonds for all industries' series for the rating categories BAA and AAA. The AAA-10-year Treasury spread is obtained as the difference between the AAA yield and the yield-to-maturity of the 10-year Treasury constant maturity.

the values of the adj. R^2 remain almost constant in the case of *MS* and increase by nearly 4% in the case of the illiquidity proxies. Even the loading on the expected *Bao* is not statistically significant. Because the expected liquidity is a function of age, the *Age* loading is not statistically significant in almost all of the models. The dummy variables of the status, *OTR* and *1stOFF*, are not significant either.

Based on these results, we find that market players can accurately predict the current trading activity of a note according to the aging of the note. There is a determinist main age-based component of the liquidity, which makes it possible to estimate a trading activity term structure. As an explanatory factor of the price impact and transaction cost proxies, the age of the note plays a limited role. Even controlling for current market-level and bond-level conditions, the unexpected behavior of these illiquidity proxies is predominant. Thus, we identify two components of the current liquidity: a determinist age-based component, dominated by the trading activity facet of liquidity, and a stochastic component.

5 Liquidity impact on yield spreads

In this section, we analyze yield spreads involving the trading of Treasury notes. We examine the price impact of the different components of liquidity throughout the lifetime of the U.S. Treasury notes. Our starting point is the consensus in the literature with respect to the liquidity pricing impact on fixed income securities.[****]

[****] However, some researchers are more skeptical. For instance, Elton and Green (1998) and Helwege, Huang, and Wang (2014) observe a restricted liquidity effect in the prices of Treasury securities and of corporate bonds, respectively.

5.1 Estimating liquidity premium

Early researches compute the liquidity premium as the yield-to-maturity differential between Treasury notes and bills with the same remaining maturity (e.g., Amihud and Mendelson, 1991; Kamara, 1994). Warga (1992) proposes an alternative to this method, which consists of comparing portfolios of seasoned bonds and portfolios of on-the-run securities with similar duration. Similarly, Fontaine and García (2012) match pairs of securities composed of the youngest bond in a given maturity's bin and other securities in the same maturity's bin. Krishnamurthy (2002) and GHN also use securities with different maturities. They match the on-the-run and the first off-the-run bonds and follow the pair during the month in which both bonds remain in this auction status. This method is unable to monitor liquidity throughout the lifetime of the bond. As an alternative method, Daves and Ehrhardt (1993) and Bühler and Vonhoff (2011) compare matched portfolios of STRIPS with coupon-bearing Treasury bonds. Noise may be incorporated in the analysis when comparing securities with different features and that bear different coupon rates. Most of these methods may imply tax and coupon biases, depending on the shape of the yield curve.

We use a synthetic bond to obtain the liquidity premium. Among others, this method has been applied by Fleming (2001), Babbel et al. (2004), DMN, and Gürkaynak, Sack, and Wright (2007).[††††] The liquidity premium is calculated as the yield spread of two securities with identical cash flows. We use the differences between the observed yield-to-maturity of a 2-year Treasury note and its theoretical yield, as

[††††] Babbel, Merrill, and Panning (1997), Díaz and Skinner (2001), and Díaz and Navarro (2002) use this method to obtain yield spreads for corporate bonds.

given by an explicit term structure model. The theoretical yield-to-maturity is obtained from the price of a synthetic bond constructed by discounting the original cash flows of the bond by the corresponding spot rates.

This method of computing liquidity premiums requires a daily zero-coupon interest rate term structure dataset.

Two of the most popular daily yield curve datasets can be downloaded from the websites of the Federal Reserve Board (Gürkaynak, Sack, and Wright, 2007) and the U.S. Department of the Treasury (*Daily Treasury Yield Curve Rates*). The latter interest rates also appear as "U.S. government securities. Treasury constant maturities" included in the Interest Rates H.15 series posted on the Fed's website. Different estimation methods and different security sets are used to fit these yield curves.[‡‡‡‡] Thus, the reported interest rates measure different aspects. The Gürkaynak, Sack, and Wright (2007) yield curves provide spot rates from second and further off-the-run bonds. They exclude Treasury bills. The H.15 yield curves are par yields from on-the-run bills, notes, and bonds.

We estimate our daily yield curves from the GovPx price dataset. There are two main motives behind fitting our own yield curves rather than using one of the available well-known daily yield curve datasets: to avoid potential discrepancies in prices among datasets and to use a yield curve that captures the average market liquidity. We use the exact same transaction prices that are reported by GovPx to estimate both the effective

[‡‡‡‡] Gürkaynak, Sack, and Wright (2007) use a weighted version of the method by Svensson (1994) from prices of all of the outstanding second and further off-the-run bonds. Among other securities, they exclude all Treasury bills and the on-the-run and first off-the-run issues of bonds and notes. The H.15 yield curve is obtained using a quasi-cubic hermite spline function from market bid yields on 11 on-the-run securities: the most recently auctioned 4-, 13-, 26-, and 52-week bills, as well as the most recently auctioned 2-, 3-, 5-, 7-, and 10-year notes and the most recently auctioned 30-year bond, in addition to the composite rate in the 20-year maturity range.

yield-to-maturity at which each security is traded and the term structure of the interest rates from all of the Treasuries that are traded this day. Other datasets use a price other than that reported by GovPx for the same bond on the same day. Considering different price datasets (e.g., transaction prices, quotes or bid yields) may introduce a bias in the analysis of the liquidity premium that arises from bid-ask spreads and nonsynchronous quote times.[§§§§]

Because the synthetic bonds that are used to obtain the liquidity premiums should reflect the average liquidity level in the market, we fit our yield curves from the prices at which all Treasury securities are traded during the day. As noted above, the Gürkaynak, Sack, and Wright (2007) and H.15 yield curves are estimated from partial samples of securities. Instead, we consider all of the traded bills and straight notes and bonds.[*****] We include the bills because they are much more actively traded than old off-the-run notes and bonds (e.g., Amihud and Mendelson, 1991), GovPX bill coverage is larger than bond and note coverage (e.g., Fleming, 2003), and bills improve the adjustment in the short end of the yield curve. In addition to economic concerns about the on-the-run assets that we comment on below, our yield curves should be able to monitor the average liquidity in the market. Thus, we consider all traded assets, including on-the-run assets, in the yield curve fitting process. These on-the-run securities concentrate most of the trading activity in the market. Both the on-the-run and the off-the-run securities provide relevant information on liquidity pricing in the market.

[§§§§] As input, Gürkaynak, Sack, and Wright (2007) use "Treasury quotes provided by the Federal Reserve Bank of New York," and the H.15 uses "Close of Business bid yields." As an example of a financial data provider, Bloomberg uses the "generic prices" of all outstanding (even callable) bonds.

[*****] We exclude "when-issued" assets, old callable and flower bonds, and Treasury Inflation-Protected Securities (TIPS). When two or more different securities have the same maturity, we consider only trades for the youngest security, i.e., the security with the last auction date.

An alternative to our yield curve could be a term structure that is estimated exclusively from on-the-run bonds. A priori, it should provide clear and easily interpretable liquidity premiums. However, we discard this alternative due to concerns over technical and economic issues. As a technical difficulty, the number of outstanding on-the-run assets per day is low. The H.15 yield curves provide interpolated par yields of on-the-run securities for 11 maturities.[†††††] In our analysis of liquidity premiums, the use of this dataset may imply several biases. The dataset does not provide a continuous function from which we can obtain the appropriate interest rate to discount each bond's cash flow. We would need to interpolate, or even extrapolate, yields from only five knots (i.e., the reported knots for maturities up to 3-years). Thus, we would interpolate yields from previously interpolated yield-to-maturity quotations. In addition, tax and coupon biases appear in comparing the par yields of assets with different maturities and coupon rates.[‡‡‡‡‡]

Fleming (2001) and Gürkaynak, Sack, and Wright (2007) provide economic reasons to prevent using only on-the-run assets. They highlight that on-the-run issues often trade at a large premium to other Treasury securities, particularly after Treasury auctions. In addition, the on-the-run bills are frequently traded on special in the repo market. The degree of specialness fluctuates over time (e.g., Cherian, Jacquier, and Jarrow, 2004). A new auction should affect the liquidity premium of the on-the-run asset but not the liquidity premium of an off-the-run bond with a similar maturity. Using

[†††††] The yield of the 4-week Treasury bills is not reported during our sample period; thus, the number of available maturity knots is only 10.

[‡‡‡‡‡] To avoid the noted technical difficulties of using the H.15 dataset in our analysis, we check our own alternative. We use the same method described in this section to fit the zero-coupon term structure from the actual prices of only on-the-run securities. We consider the 11 maturities that are used by the Department of the Treasury. We identify two main estimation problems. First, we use only 11 prices to fit the 6 parameters of the Svensson method. Second, we have too few points to fix the short end of the yield curve, and the shape of the curve is conditioned by the large impact of the price errors for the largest maturities. Therefore, our obtained estimates show a lack of precision and instability in the short end of the yield curve.

a yield curve that is estimated from only on-the-run assets, a new auction should lower interest rates for nearby maturities, and therefore, it should artificially raise the liquidity premium of the remaining securities. Besides these concerns, we must include the on-the-run securities to estimate our "average market liquidity level" yield curves. Regardless, most of the traded assets per day are off-the-run securities.[§§§§§]

We fit the term structure of interest rates by applying the well-known and widely used parametric and parsimonious procedure described in Svensson (1994).[******] The functional form of the model, which allows for a wide range of potential shapes of the term structure, is a function of the term to maturity. The expression is as follows:

$$r(T,\beta) = \beta_0 + \beta_1\left(\frac{1-exp\left(-\frac{T}{\tau_1}\right)}{\frac{T}{\tau_1}}\right) + \beta_2\left(\frac{1-exp\left(-\frac{T}{\tau_1}\right)}{\frac{T}{\tau_1}} - exp\left(-\frac{T}{\tau_1}\right)\right) + \beta_3\left(\frac{1-exp\left(-\frac{T}{\tau_2}\right)}{\frac{T}{\tau_2}} - exp\left(-\frac{T}{\tau_2}\right)\right), \quad (9)$$

where $r(T,\beta)$ is the zero-coupon interest rate over the time to maturity T as a function of the six parameters we estimate: $\beta_0, \beta_1, \beta_2, \beta_3, \tau_1,$ and τ_2.

In estimating the yield curve, we minimize the weighted sum of the squared errors on prices using a non-linear optimization program. As usual, we make the variance of the error term proportional to the modified duration of each security to penalize the valuation errors of the short-term securities. In this manner, we enforce a better adjustment on the short-end of the yield curve.

[§§§§§] Only eight out of the 140 Treasury securities that, on average, are included in the daily yield curve estimation are on-the-run assets. Each day, there are on-the-run 4-, 13-, 26-, and 52-week bills, 2-, 5-, and 10-year notes, and a 30-year bond. The remaining traded securities that are included in the estimation are off-the-run securities. Thus, the average level of liquidity is mostly an off-the-run liquidity level for the entire maturity spectrum.

[******] According to the Bank of International Settlements (2005), 9 out of 13 central banks used either the Nelson and Siegel (1987) or the extended version suggested by Svensson (1994) for estimating the term structure of interest rates.

From our daily estimates of the yield curve, we obtain the theoretical price at which a market-averaged liquid bond with the same characteristics as bond *i* should be traded on day *t*. This price is estimated by aggregating each of the remaining cash flows of the original bond *i* discounted by the spot interest rate corresponding to its term to maturity. We calculate the theoretical yield-to-maturity from this price. The yield spread, *YS*, of bond *i* on day *t* is computed as the difference between the observed yield-to-maturity at which the bond trades this day and its theoretical yield. Because we work with weekly brackets of age, we define a weekly yield spread of bond *i* by taking the median of the daily measures within the week.

The *YS* between the current traded yield-to-maturity and the theoretical yield-to-maturity shows the differences between two Treasury bonds with the same cash flows but different liquidities. We interpret this *YS* as a "relative liquidity premium" with respect to an identical asset with the average market liquidity.

In Figure 6, we plot the *YS* throughout the lifetime of the 2-year note. We can observe that the higher the age, the higher is the *YS*. As expected, in most cases, the youngest notes have a negative *YS*. Thus, the just-issued notes are traded with a negative liquidity premium on yields, implying a higher price and therefore a lower yield-to-maturity. As the note's age increases, liquidity premiums begin to turn positive, indicating that current and theoretical prices are very different. There is a clear upward trend in the *YS* over the lifetime of the notes. In addition, the dispersion of the *YS* around the average for each weekly age tranche increases as the note becomes older. Thus, when maturity approaches, the volatility of the *YS* increases substantially. The standard deviation per weekly age tranche "explodes" for notes that are older than 95 weeks. This final behavior corroborates the common practice observed in the literature of excluding all securities with less than a certain number of months to maturity from the analysis.[††††††]

Table 4 shows the summary statistics based on the auction status. The *YS* values are below zero for almost all of the quartiles in the on-the-run period. The mean and median values during the first month of life are -4.3 bps and -3.5 bps, respectively. Investors are paying a price higher for these securities than they would pay for an identical asset with market-averaged liquidity. In addition, the *YS* values remain negative for most observations during the first off-the-run period, with an average of over -2.3 bps. After the note becomes second off-the-run, the *YS* values are mainly positive, with an average of 5.9 bps. This average value remains at 2.0 bps during the first year of life and rises to 9.3 bps during the second year of life. When the last 10 weeks of life are excluded, the dispersion of the empirical probability distribution narrows and all reported quartiles are more centered.

Based on these results, the liquidity premium between the on-the-run and off-the-run notes is, on average, approximately 10.1 bps in terms of yield-to-maturity. This amount is computed as the difference of the *YS* with respect to the theoretical market-averaged yield-to-maturity for both assets (i.e., the 5.9 bps of the off-the-run less the -4.3 bps of the on-the-run periods). In terms of prices, this average value is 11 bps. DFL propose an alternative method of computing liquidity scores. They use the difference between the 50% (or 75%) quantile minus the 5% quantile. In our case, this method provides liquidity premiums of -9.4 bps (or -15.0 bps) for the on-the-run notes.

[††††††] Duffee (1996) suggests that these close-to-maturity securities often behave oddly, in part due to the lack of liquidity for those issues and the segmented demand for short-term securities by particular investor classes. Additionally, a slight inaccuracy in the price of these assets can lead to a large yield error. For instance, DFL, Fontaine and Garcia (2012), and both Gürkaynak, Sack, and Wright (2007) and the U.K. Debt Management Office exclude securities with less than one, two or three months to maturity, respectively, for estimating their yield curves.

In Figure 7, we plot the monthly evolution of the *YS* according to the auction status. Table 5 shows the descriptive statistics by year. We clearly identify the financial market turmoil of fall 1998, when the average *YS* of on-the-run notes dropped from -6.7 bps in August to -22.6 bps in October. The Russian financial crisis in August and September and the posterior LCTM default at the end of September increased the risk aversion, which resulted in the high level of volatility in the market in the first week of October. The statistics in Table 5 detail the turmoil of 1998.

5.2 Liquidity proxies and the liquidity premium

Differences in liquidity/illiquidity should provide explanatory power for a relevant portion of the *YS*. In this section, we analyze the liquidity impact on prices through our *YS*. These *YS* values reflect the yield differential with a market-averaged liquid asset. Additionally, we examine what part of this liquidity premium is determined by the expected level of several liquidity proxies. To determine this age-based component, we use the expected liquidity obtained from the term structure of each considered liquidity/illiquidity proxy that we fit in Section 4.2. For a specific age, the functions provide smooth values of the expected current liquidity. In the case of the trading activity proxy, the expected value works especially well to explain the observed market share.

Table 6 reports the results from the regression of the *YS* on the actual value of each liquidity/illiquidity proxy. We also run regressions for the same models, in which the note's *Age* alone and also together with the two dummy variables, *OTR* and *1stOFF*, which are included as additional explanatory factors to control for the auction status. In this manner, we attempt to distinguish between the on-/off-the-run effect in yields and the aging effect. The repo specialness is one of the main explanatory factors of the liquidity premium on the prices of on-the-run securities. For instance, Graveline and McBrady (2011) indicate a sudden drop in the price of the on-the-run Treasury note immediately after it becomes off-the-run. In contrast, GHN and DMN propose that both the current and the expected future liquidities are reflected in the current market price. From this perspective, a new auction may not have a significant impact on the price of the old on-the-run note. According to Graveline and McBrady (2011), the on-the-run phenomenon per se should provide explanatory power for the difference between on-the-run and first off-the-run bonds, independent of the aging effect. In the previous section, we find that the evolution of the trading activity is fully consistent with this view.

In the case of the models with only one liquidity proxy as an explanatory variable, *Bao* is the only proxy whose estimated coefficient is not statistically significant in explaining the *YS*. The adj. R^2 values are relatively low for all the illiquidity proxies (less than 2.3%) and slightly higher in the case of the *MS* (7.4%). The signs of the two microstructure-based illiquidity proxies with significant coefficient are counterintuitive. A higher level of illiquidity measured by *AM* and *PD* (i.e., a higher price impact and transaction cost), apparently implies lower *YS* and liquidity premium. This result remains when we consider a joint model with the four liquidity proxies as explanatory variables (see column (13) in Table 6).

The results for the models that include the *Age* show that this is a relevant factor in explaining the *YS*. The adjusted R^2 substantially improves (values above 42%). The age of the note is able to provide explanatory power for a large portion of the variation in the *YS*. The older the note, the higher the *YS*. There is a clear determinist component in the liquidity premium involved in the note prices. A large portion of the liquidity premium follows a predictive behavior along the lifetime of the Treasury notes. The current level of three common microstructure-based measures of illiquidity has a weak impact on the liquidity premium. Only our proxy for trading activity has a relevant explanatory power.

The loading of the *Bao* transaction cost proxy becomes significant and positive when *Age* is incorporated into the model. The incremental explanatory power is marginal, but the sign agrees with expectations and the literature. This result suggests a link between this popular illiquidity proxy and Treasury note prices. The component of this proxy that is unrelated to the note's age (i.e., the unexpected value according to the model obtained from expression (6)) is the only component that market participants assess.

From the models that incorporate the two dummy variables to control for the on-the-run phenomenon, *OTR* and *1stOFF*, (columns (3), (6), (9), (12), and (15) in Table 6) we show that these dummies do not have any additional explanatory power in the presence of *Age*. Even the adjusted R^2 slightly worsens in the case of the *MS* regression.[‡‡‡‡‡‡] Although the on-/off-the-run cycle does not provide additional information, the *OTR* dummy is significant and the loading has the correct sign for the three illiquidity proxies. However, the value of the loadings implies an average reduction in the yield spread of 1 bp. This result is not fully consistent with the expected sharp fall in the price of the bond that becomes first off-the-run according to Graveline and McBrady (2001). We find that trading activity collapses but there is no relevant impact on prices. We also find that the aging effect is far from a mere proxy for the on-the-run phenomenon. Instead, age remains the dominant factor in driving the *YS*.[§§§§§§]

[‡‡‡‡‡‡] As observed in previous sections, this trading activity proxy shows a strong positive correlation with the *OTR* dummy, which explains the non-significant and positive sign of the *OTR* in the *MS* model.
[§§§§§§] For the sake of brevity, we omit these dummies in the next models.

We next examine the role of the expected liquidity, as estimated in Section 4.2, to explain the observed *YS* and thus to price the asset. We run regressions of the *YS* on the expected value of the liquidity proxies and the unexpected or abnormal value (i.e., the difference between the actual and the expected values). Table 7 reports the results.

As expected, the predicted *MS* provides explanatory power for a relevant percentage of the *YS* (adjusted R^2 of 8% in column (1) in Table 7). The loadings on the expected *AM, Bao*, and *PD* have negative sign, as in the previous analysis, and are statistically significant (columns (3), (5), and (7)). Although the explanatory power of these three models based on expected values improves considerably with respect to the models based on actual values, these three variables are strongly correlated with age.[*******] Indeed, they become not significant when the model controls for age. A more interesting result is the significant loadings on the unexpected liquidity/illiquidity. The abnormal *MS, Bao*, and *PD* loadings remain significant and with similar values after including *Age* (columns (2), (4), (6), and (8)). A trading activity (proxied by *MS*) larger than expected reduces the *YS*. A price impact (proxied by *Bao*) higher than expected increases the *YS*. This result corroborates the previous result for this trading cost proxy. The unexpected *AM* is not significant, and the negative sign of the unexpected *PD* is inconsistent (i.e., transaction costs that are wider than expected diminish the *YS*). Finally, the last model includes *Age* and all of the expected and abnormal values of the liquidity/illiquidity proxies (column (10)). The adjusted R^2 is close to that observed in previous models. Only the coefficients of *Age* and the abnormal *MS, Bao*, and *PD* remain significant.

[*******] The correlation coefficients between *Age* and the expected component of *MS*, *AM*, *Bao*, and *PD* are -0.30, -0.61, -0.97, and -0.64, respectively.

These findings are robust to the inclusion of bond characteristics and control variables for market-wide factors, as shown in Table 8. These additional explanatory factors increase the adjusted R^2 approximately 6%. The results show the significant impact of factors such as the size of the issue, shape of the yield curve, market sentiment, and risk aversion. Therefore, the liquidity premium has a deterministic main age-based component and a stochastic component that depends on both current market-level and bond-level conditions. The stochastic component of the liquidity premium also plays a relevant role.

The role that is played by microstructure-based illiquidity measures in providing explanatory power for the behavior of the observed *YS* is generally not the expected role according to the literature. Although in the literature corporate bond markets assign them good performance in capturing liquidity, we find weak explanatory power and some unexpected signs. Similar results are reported by Helwege, Huang, and Wang (2014) and Schestag, Schuster, and Uhrig-Homburg (2016). They observe that some liquidity proxies (i.e., *Bao* in the first case and *AM* in the second) do a poor job of explaining corporate bond spreads and liquidity. They suggest empirical difficulties in precisely computing the proxies and some peculiarities of the bond market (i.e., the decentralized market structure) and a negative relation between transaction costs and the trade size.

Beyond these reasons, trading in the government bond market is affected by non-trivial external factors that can hinder the analysis. First, the effects of supply and demand can have important consequences for the Treasury market (see Krishnamurthy and Vissing-Jorgensen, 2012). Treasuries have some of the same features as money (i.e., liquidity and safety). These attributes lead Treasuries to have significantly lower yields than they would in frictionless asset pricing models that depend on supply and demand. Episodes of flight-to-liquidity (Longstaff, 2004), flight-to-quality (Bernanke and Gertler, 1995), market turmoil (Fleming, 2003) and overall, changes in market-level illiquidity and risk aversion affect the yields at which Treasuries are traded. Second, monetary policy decisions directly impact the Treasury bond market. For instance, the Treasury program of regular buybacks announced in February 2000 increases the on-the-run liquidity premium for the longest maturity bonds and widens the 1-year Treasury bill specialness (Fleming, 2000).[†††††††] Third, funding conditions in the repo market (Fontaine and Garcia, 2012) determine the specialness of the on-the-run security. All of these punctual episodes may erase the explanatory power of the bond-level illiquidity measures.

Although the current level and the expected age-based component of the three illiquidity proxies have a limited impact on the liquidity premium, we find two interesting results. First, an age-based component of the trading activity is the dominant factor of the liquidity premium. Despite their correlation, the age effect is far from a mere proxy for the on-the-run phenomenon. Second, the unexpected component of the *Bao* proxy has relevant pricing implications for the Treasury bond market. This result suggests that this proxy indeed captures transaction costs. A non-trivial difference between this market and both the stock exchange market and the corporate bond market is the homogeneity of the traded securities and the regular liquidity life cycle of the 2-year note, which is well known to market participants.[‡‡‡‡‡‡‡] In this sense, we obtain evidence that the prices of 2-year notes incorporate an age-based liquidity premium.

[†††††††] One of the effects on the Treasury debt market of the regular buyback program is the reduction of the issuance of the 1-year Treasury bill from every 4 weeks to every 13 weeks. In addition to the scarce impact of the measures on the 2-year notes, the yield spread between the coupon security with the maturity closest to one year and the on-the-run 1-year bill reaches 56 bps in late April and May of 2000.

[‡‡‡‡‡‡‡] The bond's age is typically included in models to explain the yield spread of corporate bonds as a liquidity-related variable but with a minor role as a control variable. Frequently, the estimated loading is not significant (e.g., DFL; Helwege, Huang, and Wang, 2014).

Thus, only the unexpected value of the microstructure-based illiquidity proxies helps provide explanatory power for the *YS* in the Treasury market. Similarly, under the efficient market hypothesis, only unexpected news affects stock prices because the investors have already discounted all other information.

5.3 Robustness checks

First, we estimate the models including the original four liquidity proxies for two different sub-samples. Second, we replace these proxies with three alternative proxies. We consider an initial sub-sample from January 1996 to July 1998. Figure 7 shows the beginning of the market turmoil initiated by the Russian financial crisis and the LTCM default in August 1998. This period is included in our second sub-sample. Third, we generalize the analysis to other segments of the Treasury bond market (i.e., the 5- and the 10-year maturities). We also check whether the observed deterministic trend in short maturity assets remains when bonds with longer maturities are examined.

5.3.1 Sub-samples and alternative illiquidity proxies

As an alternative to *MS* as a proxy for trading activity, we consider the turnover ratio, *TO*, which is computed as the trading volume of bond *i* on day *t* over the amount outstanding of bond *i*. Both quantities are expressed in dollars of par value. As a substitute for the *AM* proxy, we use the Amivest liquidity ratio, *AV*. Cooper, Groth, and Avera (1985) and Amihud, Mendelson, and Lauterback (1997), among others, use this measure as an indicator of market depth. It is considered to show how well an asset is able to absorb trading volumes without a significant move in its price. A high ratio means that large amounts of an asset can be traded with little effect on prices. We compute AV as the weekly average of the daily ratio of trading volume to absolute return for each bond *i*

$$AV_{i,k} = \frac{1}{D_{i,k}} \cdot \sum_{t=1}^{D_{i,k}} \frac{TV_{i,t,k}}{|r_{i,t,k}|}, \tag{10}$$

We also replace the *Bao* measure with the Roll (1984) proposal. Indeed, BPW simply use a modified version of the original Roll measure. Roll (1984) finds that, under certain assumptions, consecutive stock returns can be interpreted as a bid-ask bounce. Thus, the covariance in price changes provides a measure of the effective bid-ask spread.. The *Roll* measure is calculated as twice the square root of minus the auto-covariance of the transaction price change bond *i* on day *t*

$$Roll_{i,t} = 2\sqrt{-Cov(\Delta p_t, \Delta p_{t-1})}, \tag{11}$$

Following the steps described in Section 4.2, we adjust the parsimonious functions using age as the only explanatory variable to model the average values of each new liquidity proxy for each weekly age (i.e., *TO*, *AV*, and *Roll*). These functions allow the expected and unexpected values of these liquidity measures to be obtained.[§§§§§§§]

Table 9 shows the results of the models in two different periods for the original liquidity/illiquidity proxies and for the alternative proxies. The left-hand side of the table contains the results for the current and expected original liquidity proxies by the two sub-samples. The right-hand side of the table shows the results for the alternative proxies proposed in this section and distinguishes the two sub-samples. In the eight estimated models, the note's age remains the most relevant factor and the loading is

[§§§§§§§] For the sake of brevity, the details are omitted. However, they are available from the authors upon request.

very stable. The liquidity/illiquidity proxies have some significant regression coefficients that depend on the version of the proxy and the sub-sample. Therefore, the results show the main conclusions obtained in the previous sections.

5.3.2 Five- and 10-year Treasury notes

In this sub-section, we replicate the liquidity premium analysis by considering 5- and 10-year Treasury notes. We check whether the results for 2-year notes can be generalized to larger maturities. As discussed in Section 3, the trading activity in both segments is much lower than that in the 2-year case. The weekly average trading volume of a 2-year note during the on-the-run period is twice as large as that traded by 5- and 10-year notes. This difference rises up to three times during the off-the-run period. Figure 8 depicts the evolution of the number of daily observations corresponding to notes that are traded at least once per day within each weekly age bracket. The trading frequency is low from the time when the issue becomes off-the-run to the last three years until maturity. Indeed, 5- and especially 10-year notes remain without trading during long periods. The low or even zero trading activity during several age brackets implies empirical difficulties and can lead to mismeasurement in computing price-based illiquidity proxies. These measures should be interpreted with caution. Additionally, the changing auction frequency and reissuance program during the sample period clearly affect the trading activity in the on-/off-the-run cycle (see Figure 2).

The temporal evolution of the liquidity/illiquidity proxies throughout the lifetime of these securities reflects the above-mentioned concerns. After the on-the-run period, there is a low-activity period that includes the first two (three) years after issuance in the case of 5-year (10-year) notes. The weekly averages of the *MS* and *PD* measures show the on/off cycle. The *AM* and *Bao* proxies follow a clear hump along the length of this period. There is, subsequently, a four-year intermediate period in the case of the 10-year notes, in which the trading is almost null. This fact implies jumps in the prices and values of the *AM* and *Bao* proxies that are extremely volatile. The last period runs for the last three years of the lifetime of both the 5- and 10-year notes. The activity reactivates during this period, but the evolution of the average weekly values of the four liquidity proxies is almost flat.

Figure 9 shows the evolution of the average *YS* throughout the lifetime of 5- (upper panel) and 10-year (lower panel) notes. The impact of the on-the-run status on the *YS* is evident. We find a negative average *YS* during the on-the-run period, which is even more negative than in the case of 2-year notes. In addition, the *YS* jumps after the note becomes first off-the-run and remains negative for several weeks. However, the evolution is not as clear as it is in the case of 2-year notes. It is affected by changes in the length of the on-the-run and first off-the-run periods along the sample period. As shown in Table 4, the average *YS* during the clear one-month on-the-run period for 2-year notes is approximately -4 bps. In the sample of 5-year notes, the average *YS* is -3 bps during the first quarter from issuance and -8 bps during the next quarter. The negative *YS* is larger in the 10-year note sample and remains almost unchanged between the first quarter (-26 bps) and the second quarter (-24 bps).

After the note becomes off-the-run and until the last two years of life, the average *YS* remains approximately zero. This is the expected behavior according to our interpretation of the *YS* as a relative liquidity premium. For these intermediate maturities, the traded Treasuries that are used as input to fit the yield curve are almost exclusively off-the-run notes and bonds. Thus, the observed yield-to-maturity should be similar to the yield of a theoretical note with the average liquidity of the market. During the last two years to maturity, the *YS* shows the same upward trend that is observed in the 2-year note segment.

Similar to the 2-year notes, we fit new expressions in a merely empirical manner to model each of the four liquidity/illiquidity proxies as smooth non-linear functions of age in the case of the 5- and the 10-year notes (see Section 4.2). From these expressions, we obtain the expected values of the liquidity measures, depending on the age of the note.[********]

We replicate the analysis that is run for the 2-year notes in Tables 6, 7, and 8. Table 10 shows the results for the 5- (Panel A) and 10-year (Panel B) notes. These models incorporate the current values of the four liquidity proxies or, alternatively, their expected and abnormal values, the age, the bond characteristics, and the market-level control variables. We find a strong correlation between two pairs of expected values of the liquidity proxies. The expected *MS* tends to be correlated with the expected *PD*, and the expected *AM* tends to be correlated with the expected *Bao* and *Age*.[††††††††] We orthogonalize one variable with respect to the other. Although collinearity per se is not a problem in judging the models, it interferes with our ability to sensibly interpret the corresponding loadings.

We find similar relations between *YS* and the current values of the four liquidity measures that we obtained in the case of the 2-year notes (columns (1), (2), (4), (6), (7), and (9)). In general, the loadings of the *Bao* and *PD* proxies remain significant and

******** For the sake of brevity, the estimation of the expected value of the liquidity proxies and the previous tests analyzed in the case of 2-year notes are omitted. These results are available upon request.

†††††††† The correlation between the expected *MS* and the *OTR* dummy equals 74% in the 5-year note sample. We consider the expected *MS* to be the primary variable. We use the residuals of the *OTR* as an explanatory variable in the model shown in column 2 of Panel A in Table 10.

positive as expected in the *Bao* case and negative in the *PD* case. An interesting new result is that *AM* becomes positive and significant in the 5-year note sample. The current value of this price impact proxy plays a relevant role in determining the *YS* of these medium-term notes. In the models in which we consider the expected and unexpected value of the liquidity proxies (columns (3) and (8)), the sign and significance of the loading corresponding to the expected values depends on the variable that is chosen as the primary variable in the orthogonalization process. Regardless, the unexpected values of *MS* and *PD* have the sign that is observed in the case of the 2-year notes and are also statistically significant. The expected values of *MS*, *AM*, and *Bao* proxies are now significant and have the expected signs in the 5- and 10-year note samples. This result suggests that the current and the predicted values according to the note's age of the trading activity, price impact, and transaction cost proxies help to explain the liquidity premium in maturities longer than two years. All of the models show that the positive relation between *YS* and age is robust, even for medium- and long-term securities with irregular auction programs and lifetime periods with low trading activity. Our results strongly suggest that there is a main deterministic aged-based component and a stochastic component of the liquidity premium of Treasury notes.

6 Conclusions

In this paper, we examine the price impact of the different components of liquidity throughout the lifetime of a U.S. Treasury bond. We study the explanatory factors and the predictable behavior of the liquidity premium involved in the prices of 2-year Treasury notes. We consider a measure based on the trading activity (i.e., market share and several microstructure-based liquidity measures). From adjusted empirical functions of the considered liquidity proxies during the lifetime of the note, we find that the bond-aging process drives the time evolution of a deterministic liquidity component, which makes it possible to estimate a trading activity term structure. However, some patterns of the current level of microstructure-based liquidity proxies along the lifetime of the note are seemingly not the expected patterns according to the literature.

We estimate the yield spread for each note and day based on the differences between the observed yield-to-maturity and its theoretical yield, as given by an explicit term structure model. The yield spread is used as a measure of the liquidity premium with respect to a market-averaged liquid asset with the same characteristics. The mean yield spread ranges from -4.3 bps for the on-the-run, -2.3 bps for the first off-the-run, and 5.9 bps for the remaining notes. This amount clearly depends on market-wide factors. The regression analysis provides evidence of an aging effect that goes above and beyond the simple on-/off-the-run effect. A large portion of the liquidity premium follows a predictive behavior along the lifetime of the Treasury note. The current levels of three microstructure-based liquidity measures do not provide much explanatory power for the liquidity life cycle. The peculiarities of these securities and the market-wide liquidity behavior may distort the results of these bond-level liquidity measures. Additionally, we examine what portion of the liquidity premium is determined by the expected current level of the liquidity proxies estimated from our term structures. The expected market share provides explanatory power for a relevant percentage of the yield spread. The abnormal or unexpected value of microstructure-based liquidity proxies also provide explanatory power for the liquidity premium. This result, in addition to the relevant explanatory power improvement of the model after including the control variables for market-wide liquidity levels, shows the role played by the unexpected component of the liquidity premium. Therefore, the liquidity premium has a deterministic main age-based component and a stochastic component that depends on the unexpected value of the liquidity proxies and the current market-level and bond-level conditions.

References

Acharya, V. V., Amihud, Y., Bharath, S. T., 2013. Liquidity risk of corporate bond returns: conditional approach. Journal of Financial Economics 110, 358-386.

Amihud, Y., Mendelson, H., 1991. Liquidity, maturity and the yield on U.S. Treasury securities. The Journal of Finance 46, 1411-1425.

Amihud, Y., Mendelson, H., Lauterbach, B., 1997. Market microstructure and securities values: evidence from the Tel Aviv stock exchange. Journal of Financial Economics 45, 365-390.

Amihud, Y., 2002. Illiquidity and stock returns: cross-section and time-series effects. Journal of Financial Markets 5, 31-56.

Babbel, D. F., Merrill, C., Panning, W., 1997. Default risk and the effective duration of bonds. Financial Analysts Journal, 53(1), 35-44.

Babbel, D. F, Merrill, C.B., Meyer, M.F., de Villiers, M., 2004. The Effect of Transaction Size on Off-the-Run Treasury Prices. Journal of Financial and Quantitative Analysis 39 (3), 595-611.

Bao, J., Pan, J., Wang, J., 2011. The illiquidity of corporate bonds. The Journal of Finance 46, 911-946.

Barnejee, S., Graveline, J. J., 2013. The cost of short-selling liquid securities. The Journal of Finance 68, 637-664.

Beber, A., Brandt, M. W., Kavajecz, K. A., 2009. Flight-to-quantity or flight-to-liquidity? Evidence from the Euro-Area Bond Market. The Review of Financial Studies 22, 925-957.

Bernanke, B. S., Gertler, M., 1995. Inside the black box: the credit channel of monetary policy transmission. National bureau of economic research working paper.

Bank for International Settlements, 2005. Zero-Coupon Yield Curves: Technical Documentation. BIS Papers No. 25, Bank for International Settlements.

Brandt, M. W., Kavajecz, K. A., Underwood, S. E., 2007. Price discovery in the Treasury futures market. Journal of Futures Markets 27, 1021-1051.

Bühler, W., Vonhoff, V., 2011. The term structure of liquidity premia in the U.S. Treasury market. Working paper.

Chakravarty, S., Sarkar, A., 2003. Trading costs in three U.S. bond markets. Journal of Fixed Income 13, 39–48.

Chen, L., Lesmond, D., Wei, J., 2007. Corporate yield spreads and bond liquidity. The Journal of Finance 62, 119–149.

Cherian, J. A., Jacquier, E., Jarrow, R. A., 2004. A model of the convenience yields in on-the-run treasuries. Review of Derivatives Research, 7, 29–97.

Cooper, S., Groth, K., Avera, W., 1985. Liquidity, exchange listing and common stock performance. Journal of Economics and Business 37, 19-33.

Daves, P. R., Ehrhardt, M. C., 1993. Liquidity, reconstitution, and the value of U.S. Treasury STRIPS. The Journal of Finance 48, 315-329.

Díaz, A., Merrick, J. J., Navarro, E., 2006. Spanish Treasury bond market liquidity and volatility pre- and post-European Monetary Union. Journal of Banking and Finance 30, 1309-1332.

Díaz, A., Navarro, E. 2002. Yield spread and term to maturity: default vs. liquidity. European Financial Management, 8 (4), 449-477.

Díaz, A., Skinner, F. S., 2001. Estimating corporate yield curves. The Journal of Fixed Income 11, 95-103.

Dick-Nielsen, J., Feldhütter, P., Lando, D., 2012. Corporate bond liquidity before and after the onset of the subprime crisis. Journal of Financial Economics 103, 471-492.

Duffee, G. R., 1996. Idiosyncratic Variation of Treasury Bill Yields. The Journal of Finance, 51 (2), 527-551.

Duffie, D., 1996. Special repo rates. The Journal of Finance 51, 493–526.

Edwards, A. K., Harris, L. E., Piwowar, M. S., 2007. Corporate bond market transaction costs and transparency. The Journal of Finance 62, 1421-1451.

Elton, E. J., Green, T. C., 1998. Tax and liquidity effects in pricing government bonds, The Journal of Finance 53, 1533-1562.

Ejsing, J. W., Sihvonen, J., 2009. Liquidity premia in German government bonds. European Central Bank working paper.

Feldhütter, P., 2012. The Same Bond at Different Prices: Identifying Search Frictions and Selling Pressures. Review of Financial Studies 25, 1155-1206.

Fisher, L., 1959. Determinants of the risk premiums on corporate bonds. Journal of Political Economy 67, 217-237.

Fleming, M. J., Remolona, E. M., 1999. Price formation and liquidity in the U.S. Treasury market: the response to public information. The Journal of Finance 54, 1901-1915.

Fleming, M. J., 2000. Financial market implications of the Federal debt paydown. Staff Report, Federal Reserve Bank of New York, No. 120.

Fleming, M. J., 2001. Measuring Treasury market liquidity. Staff Report, Federal Reserve Bank of New York, No. 133.

Fleming, M. J., 2003. Measuring Treasury market Liquidity. Federal Reserve Bank of New York Economic Policy Review 9, 83-108.

Fontaine, J. S., García, R., 2012. Bond liquidity premia. Review of Financial Studies 25, 1207- 1254.

Friewald, N., Jankowitsch, R., Subrahmanyam, M., 2012. Illiquidity or credit deterioration: a study of liquidity in the U.S. corporate bond market during financial crises. Journal of Financial Economics 105, 18-36.

Goldreich, D., Hanke, B., Nath, P., 2005. The price of future liquidity: time-varying liquidity in the U.S. Treasury market. Review of Finance 9, 1-32.

Goyenko, R., Subrahmanyam, A., Ukhov, A., 2011. The term structure of bond market liquidity and its implications for expected bond returns. Journal of Financial and Quantitative Analysis 46, 111-139.

Graveline, J. J., McBrady, M. R., 2011. Who makes on-the-run Treasuries special? Journal of Financial Intermediation 20, 620-632.

Gürkaynak, R. S., Sack, B., Wright, J. H., 2007. The U.S. Treasury yield curve: 1961 to the present. Journal of Monetary Economics 54, 2291-2304.

Helwege, J., Huang, J. Z., Wang, Y., 2014. Liquidity effects in corporate bond spreads. Journal of Banking and Finance 45, 105-116

Houweling, P., Mentink, A., Vorst, T., 2005. Comparing possible proxies of corporate bond liquidity. Journal of Banking and Finance 29, 1331–1358.

Jankowitsch, R., Nashikkar, A., Subrahmanyam, M. G., 2011. Price dispersion in OTC markets: a new measure of liquidity. Journal of Banking and Finance 35, 343-357.

Johnson, T. C., 2008. Volume, liquidity, and liquidity risk. Journal of Financial Economics 87, 388-417.

Jordan, B., Jordan, S., 1997. An empirical investigation of the repo special rate. The Journal of Finance 52, 2051-2072.

Kamara, A., 1994. Liquidity, taxes, and short-term yields. Journal of Financial and Quantitative Analysis 29, 403-417.

Krishnamurthy, A., 2002. The bond/old-bond spread. Journal of Financial Economics 66, 463-506.

Krishnamurthy, A., Vissing-Jorgensen, A., 2012. The Aggregate Demand for Treasury Debt. Journal of Political Economy 120 (2), 233-267.

Kyle, A. S., 1985. Continuous auctions and insider trading. Econometrica 536, 1315-1335.

Li, H., Wang, J., Wu, C., He, Y., 2009. Are liquidity and information risks priced in the Treasury bond market? The Journal of Finance 64, 467-503.

Lin, H., Wang, J., Wu, C., 2011. Liquidity risk and expected corporate bond returns. Journal of Financial Economics 99, 628-650.

Longstaff, F. A., 2004. The flight-to-liquidity premium in U.S. Treasury bond prices. Journal of Business 77, 511-526.

Longstaff, F., Mithal, S., Neis, E., 2005. Corporate yield spreads: default risk or liquidity? New evidence from the credit-default swap market. The Journal of Finance 60, 2213–2253.

Mizrach, B., Neely, C. J., 2006. The transition to electronic trading in the secondary treasury market. Working paper.

Mizrach, B., Neely, C.J., 2008. The microstructure of the U.S. Treasury market. Federal Reserve Bank of St. Louis working paper.

Nelson C., Siegel, A., 1987. Parsimonious modeling of yield curves. The Journal of Business 60, 473-489.

Pasquariello, P., Vega, C., 2009. The on-the-run liquidity phenomenon. Journal of Financial Economics 92, 1-24.

Roll, R., 1984. A simple implicit measure of the effective bid-ask spread in an efficient market. The Journal of Finance 39, 1127-1139.

Sarig, O., Warga, A., 1989. Some empirical estimates of the risk structure of interest rates. The Journal of Finance 44, 1351-1360.

Schestag, R., Schuster, P., Uhrig-Homburg, M., 2016. Measuring Liquidity in Bond Markets. The Review of Financial Studies 29 (5), 1170-1219.

Sundaresan, S., 1994. An Empirical Analysis of U.S. Treasury Auctions: Implications for Auction and Term Structure Theories. Journal of Fixed Income, September, 35-50.

Svensson, L. E., 1994. Estimating and interpreting forward interest rates: Sweden 1992-1994. National Bureau of Economic Research working paper.

Vayanos, D., 2004. Flight to quality, flight to liquidity, and the pricing of risk. National Bureau of Economic Research working paper.

Vayanos, D., Weill, P., 2008. A search-based theory of the on-the-Run phenomenon. The Journal of Finance 63, 1361-1398.

Warga, A., 1992. Bond returns, liquidity, and missing data. Journal of Financial and Quantitative Analysis 27, 605-617.

Figure 1. Trading activity reported by GovPx for the full market and the 2-year note segment. This figure shows the evolution of the monthly trading volume and the number of trades for all of the traded U.S. Treasury notes and bonds reported by the GovPx dataset in trillion dollars from 1996 to 2001. The details of the trading volume for the 2-year note segment are shown in the dark color.

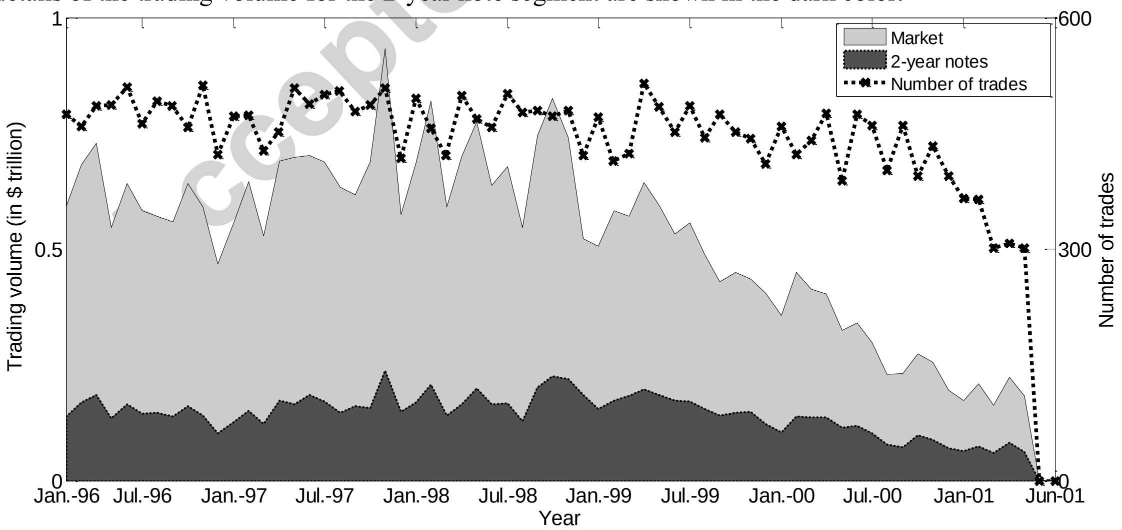


Figure 2. Average Market Share (2-, 3-, 5-, and 10-year notes and 30-year bonds). This figure shows the average daily market share per weekly age range based on current transactions for 2-, 3-, 5-, and 10-year Treasury notes and 30-year Treasury bonds. This measure is only computed for days with a positive trading volume. We only show the values for the average market share along the lifetime of the 2-year notes. The dataset includes 251,680 daily transactions during the period from January 1996 to November 2000, based on data from GovPx. For each bond, we compute its age in a trading day as the difference in working days between the issuance date and the trading day, controlling for holidays. We calculate the average market share for the weekly age brackets based on daily data.

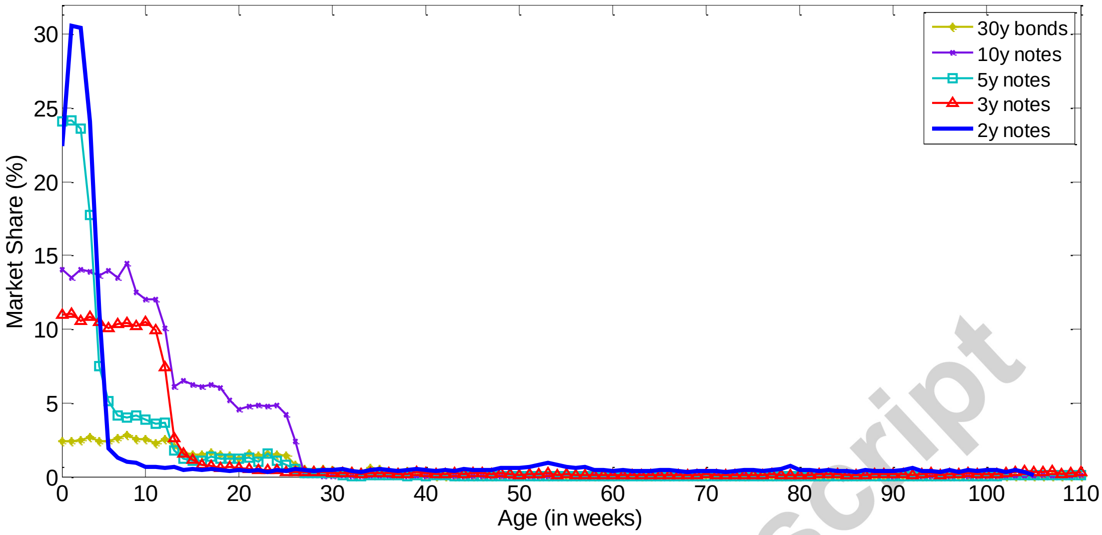
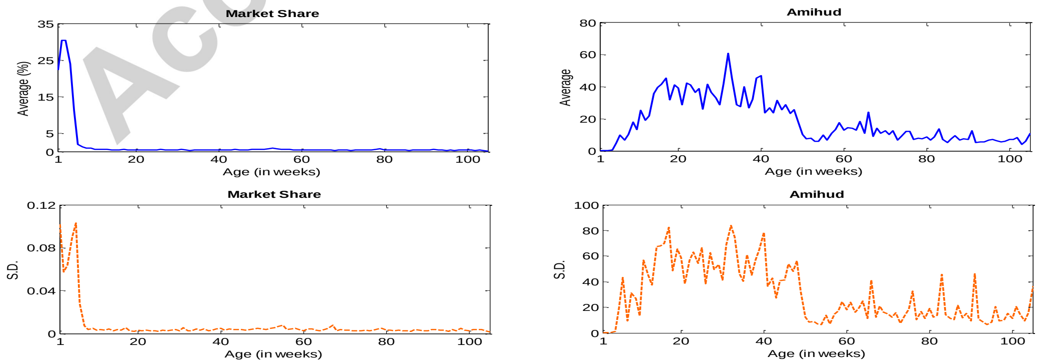


Figure 3. Average and standard deviation for market share (*MS*), Amihud (*AM*), *Bao*, and price dispersion (*PD*) measures depending on aging
This figure displays the term structure of the four liquidity proxies. Panel A shows the average and standard deviation for the *MS* and *AM* measures and Panel B shows the same for the *Bao* (x100) and *PD* measures. The dataset includes 83 2-year Treasury notes with 6,175 weekly values during the period from January 1996 to November 2000 based on data from GovPx. We winsorize the 0.5% highest values of every variable and the lowest 0.5% values, meaning that all values above the 99.5% percentile are set to the 99.5% percentile and all values below the 0.5% percentile are set to the 0.5% percentile. For each bond, we compute its age in a trading day as the difference in five business working days between the issuance date and the trading day, controlling for holidays. No exact values are rounded up in order to assign a weekly age range to each bond.

Panel A. Market share and Amihud measures



Panel B. *Bao* and price dispersion measures

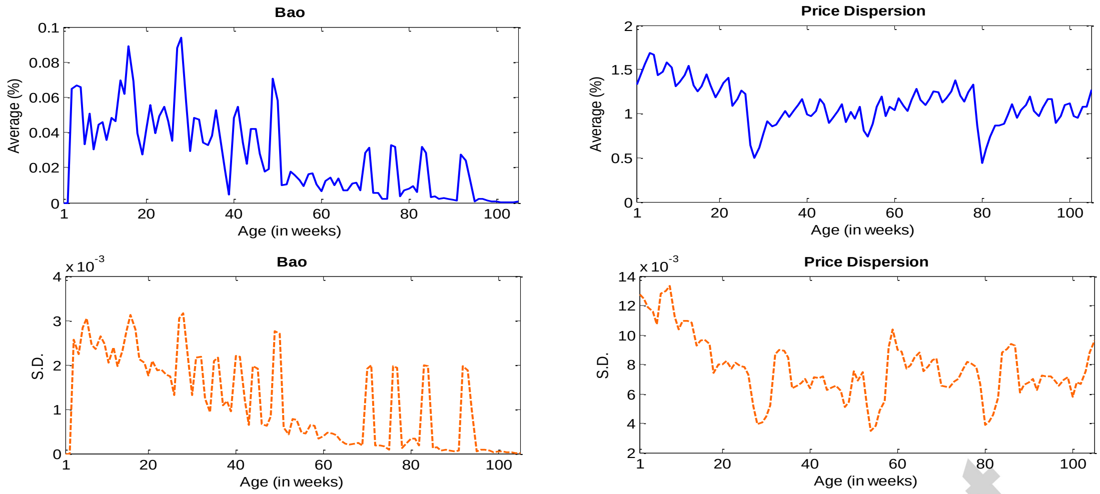


Figure 4. Monthly evolution of observed market share (*MS*), Amihud (*AM*), *Bao*, and price dispersion (*PD*) measures. This figure displays the average monthly evolution of the *MS*, *AM*, *Bao* (x100), and *PD* measures by note status. The dataset includes 83 2-year Treasury notes with 6,175 weekly values during the period from January 1996 to November 2000 based on data from GovPx. On-the-run notes are the most recently issued notes, aged from 1 to 4 weeks; first off-the-run notes represent the most recent off-the-run notes, aged from 5 to 8 weeks; and off-the-run notes represent all other notes, older securities aged from 9 to 105 weeks. The winsorization process is described in Table 2.

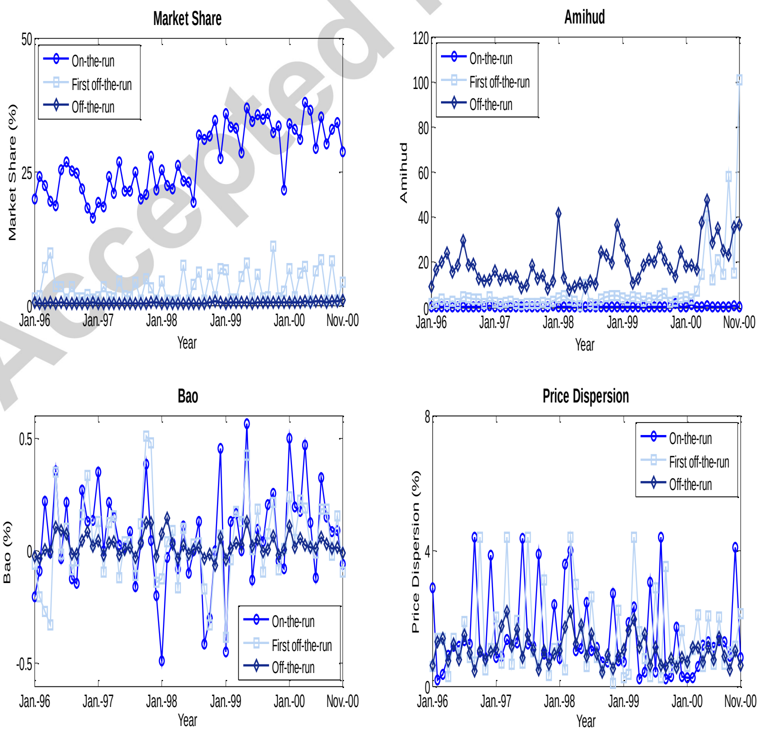
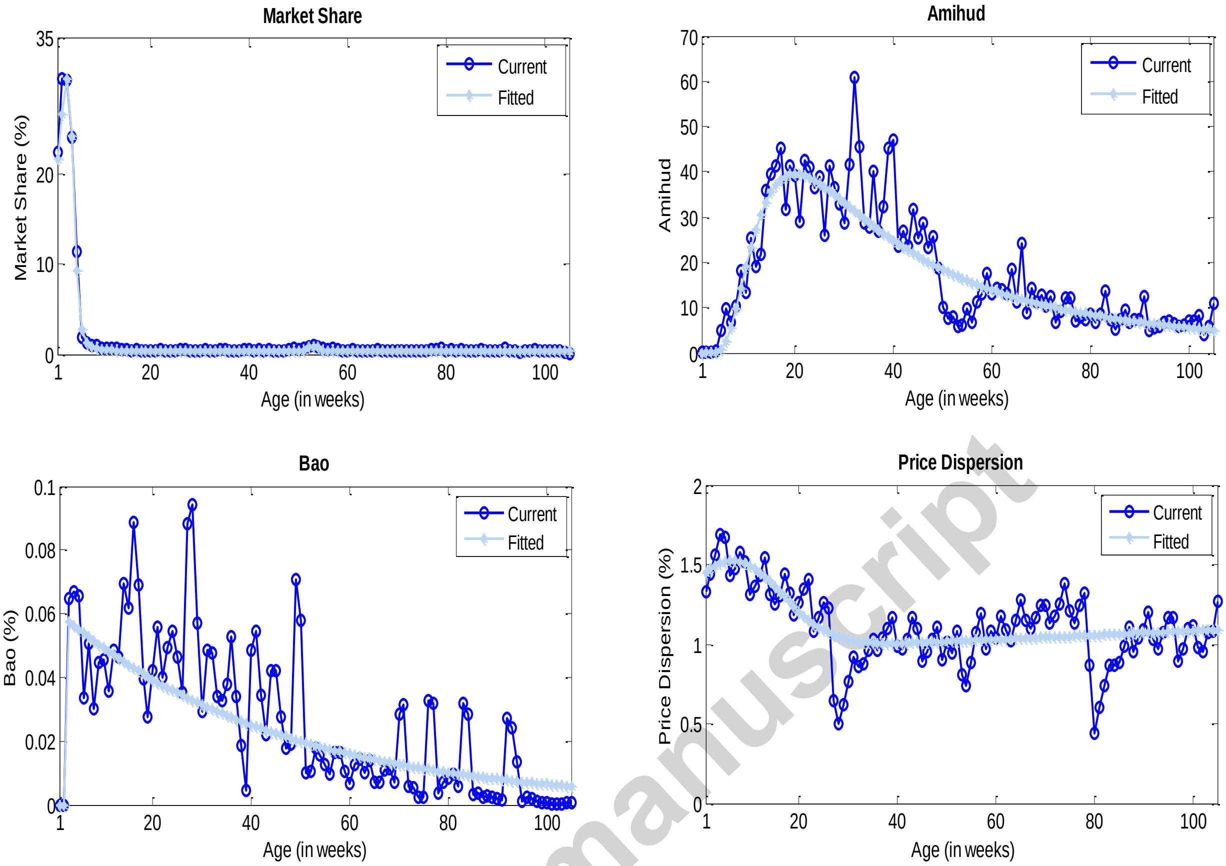


Figure 5. Average current and expected market share (*MS*), Amihud (*AM*), *Bao*, and price



dispersion (*PD*) measures

This figure displays the average current and fitted weekly *MS*, *AM*, *Bao* (x100), and *PD* measures. The fitted functions based on age are estimated according to expressions (4), (5), (6), and (7), which are described in Section 4.2. The dataset includes 83 2-year Treasury notes with 6,175 weekly values during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2.

Figure 6. Yield spread throughout the lifetime. In this figure, we plot the average weekly yield spread, *YS*, across weekly age tranches. We define a weekly *YS* of every single bond by taking the median of its daily *YS* within the week. The daily *YS* for every single note and date is estimated as the difference between the observed yield-to-maturity and the theoretical yield-to-maturity. The theoretical yield-to-maturity is obtained from the theoretical price that the note should be traded at, using the average liquidity on the market. To that end, we discount each original cash flow of the note from the corresponding zero-coupon interest rate for each maturity. The daily zero-coupon yield curve for each date is fitted following the procedure by Svensson (1994) that is described in Section 5. The continuous line depicts the average weekly *YS* and the dotted lines depict ± 2 standard deviation bands. The dataset includes 83 2-year Treasury notes with 6,175 weekly values during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2.

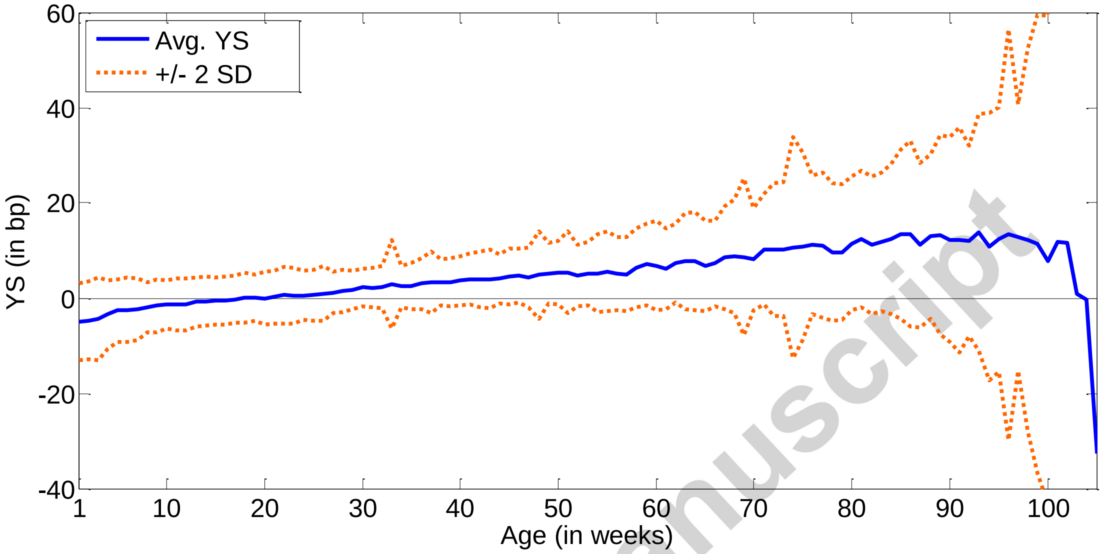


Figure 7. Monthly evolution of observed yield spreads. This figure displays the average monthly evolution of *YS* in basis points by note status. On-the-run notes are the most recently issued notes, aged from 1 to 4 weeks; first off-the-run notes represent the most recent off-the-run notes, aged from 5 to 8 weeks; and off-the-run notes represent all other notes, older securities aged from 9 to 105 weeks. The dataset includes 83 2-year Treasury notes with 6,175 weekly values during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2.

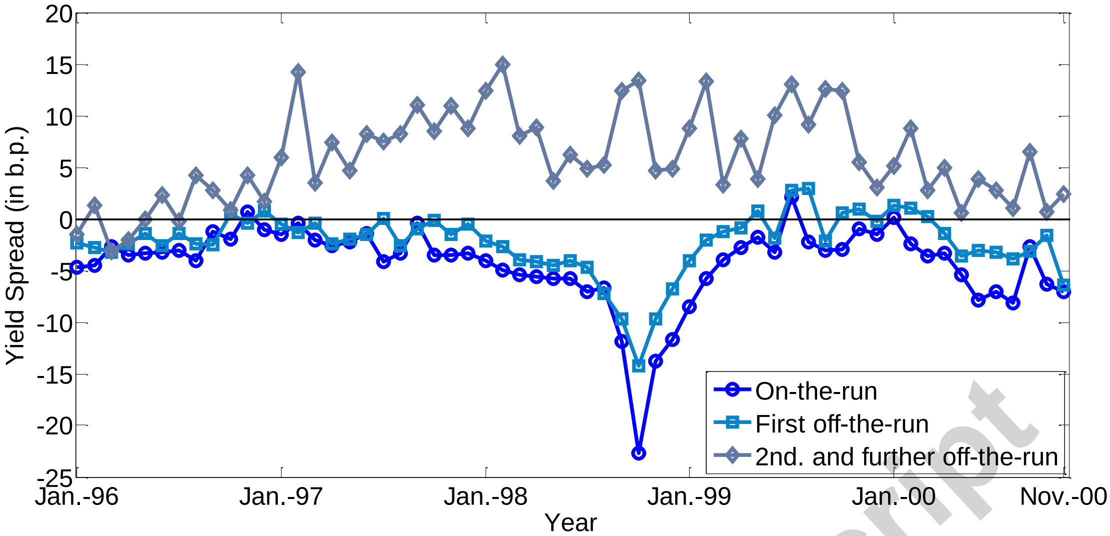


Figure 8. Number of daily observations per weekly age bracket. This figure shows the number of daily observations corresponding to notes within each weekly age bracket. They are added as a function of the security age from issuance in weeks. Each observation implies that one note is traded at least once in the day when it has the age corresponding to the weekly each bracket. For instance, the first value in the 2-year note figure is 285. This means that our sample has 285 daily observations of 1-week-old 2-year notes during the period from January 1996 to November 2000 based on data from GovPx. The dataset includes 83 2-year notes, 94 5-year notes, and 49 10-year Treasury notes. For each bond, we compute its age in a trading day as the difference in five business working days between the issuance date and the trading day, controlling for holidays.

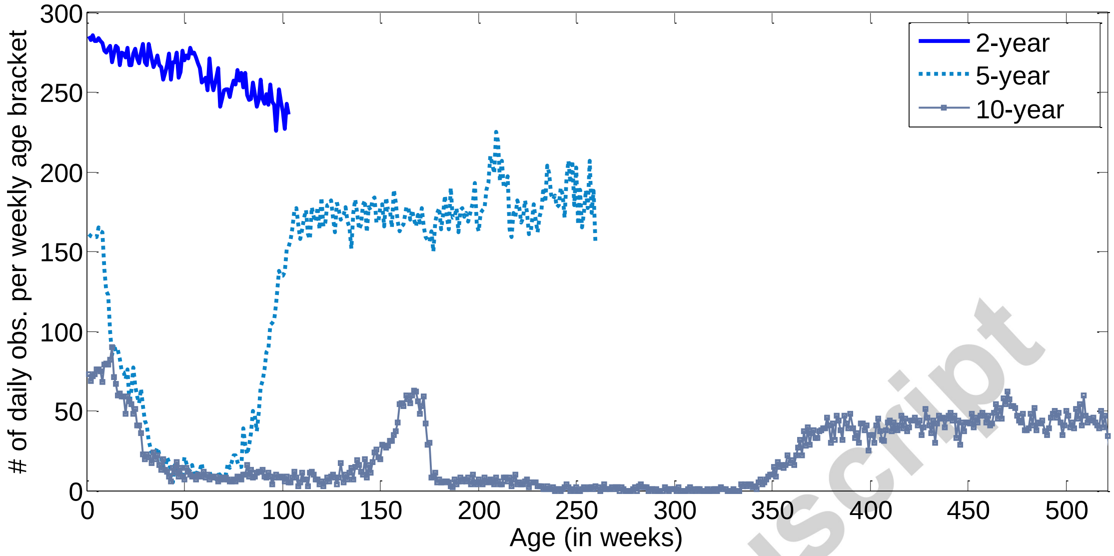
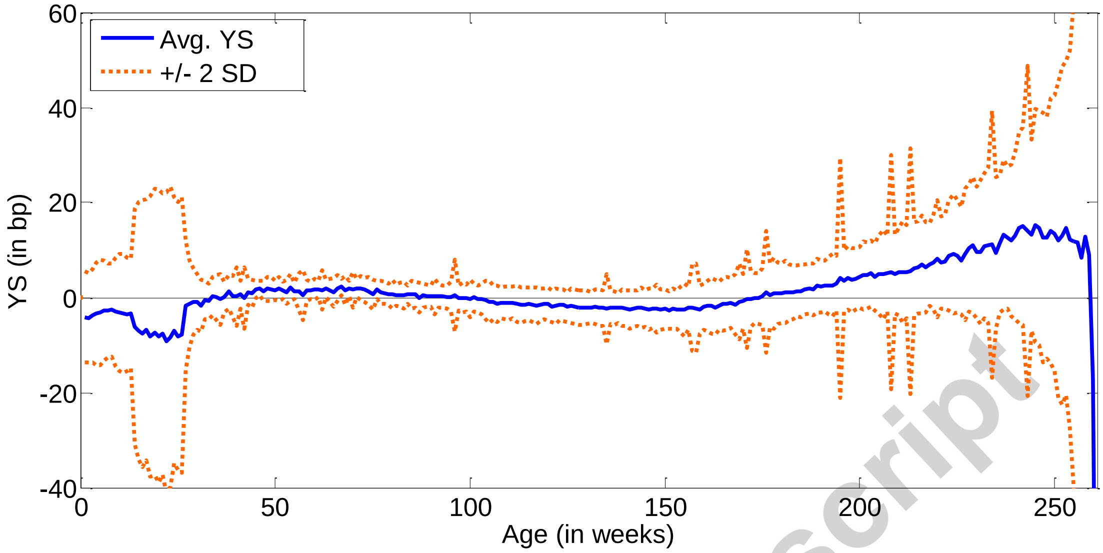


Figure 9. Yield spread of 5- and 10-year notes throughout the lifetime. In this figure, we plot the average weekly yield spread, *YS*, (continuous line) across weekly age tranches and ± 2 standard deviation bands (dotted lines). The dataset includes 94 (49) 5-year (10-year) Treasury notes with 10,410 (4,348) weekly values during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2.

Panel A. 5-year notes



Panel B. 10-year notes

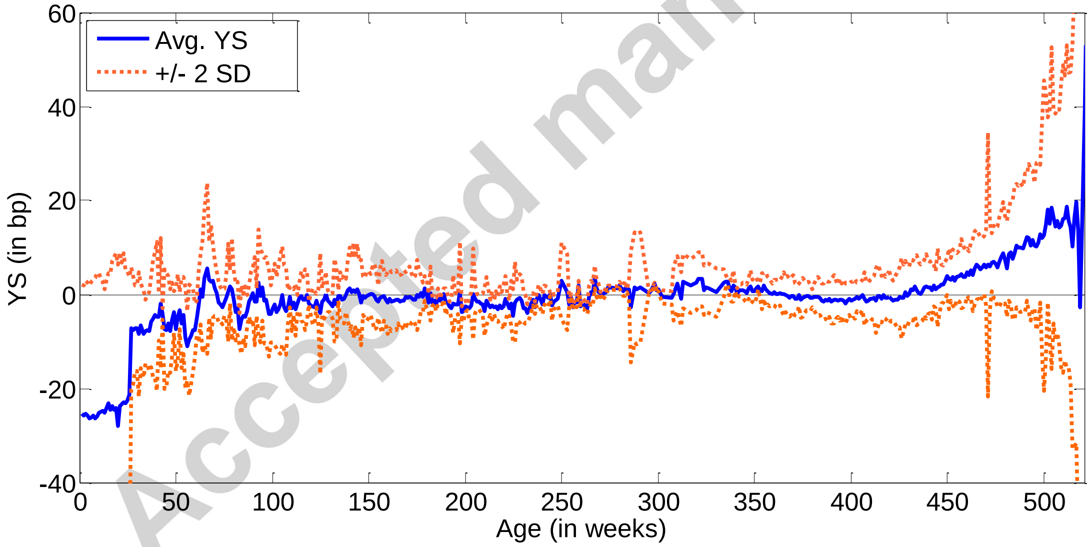


Table 1. Sample composition

This table provides information on the composition of the entire sample from the GovPx dataset by term to maturity. *New issues per year* is the number of issuances per year for each original maturity. In the case of 5-year (10-year) notes, the monthly (quarterly) issuance schedule changes to semiannually in 1998 (in 2010), and they are re-issued three months later as a new tranche. *Re-issuance as new tranche per year* is the number of new tranches of the outstanding issues that are auctioned. *Re-issuance as new asset* is the case of old original 5-year notes that are re-issued as 2-year notes when their term to maturity is 2 years. *Outstanding issues* is the number of simultaneous outstanding issues along the entire sample. *#Observations* is the number of observations in the initial sample. *% Zeros* is the percentage of observations with zero trading volume. *Issues* is the number of different issues by original term to maturity. *Aggregate Volume* is the total par trading volume in thousand dollars along the sample period. *Avg. Volume per day* is the average par trading volume per traded day in thousand dollars. *On-the-run* represent the % of the total aggregate volume traded during the on-the-run period of each bond. *Off-the-run* represent the percentage of the total aggregate volume traded in the sample during the off-the-run period of each term. The sample period included 1,302 working days ranging from January 1996 to November 2000.

	2-year	3-year	5-year	7-year	10-year	20-year	30-year
New issues per year	12	4 or ∅	12 or 2	-	4 or 2	-	4
Re-issuance as new tranche per year	-	-	∅ or 2	-	∅ or 2	-	-
Re-issuance as new asset	-	-	∅ or when 2y	-	-	-	-
Outstanding issues	24	12 or less	60 or less	18 or less	40 or less	16 or less	120 or less
# Observations	31,167	12,327	67,768	10,090	44,309	20,832	65,187
% Zeros	11.2	17.7	50.0	43.9	73.4	98.3	78.6
Issues	83	22	95	18	49	16	56
Aggregate Volume	9,007,475	2,203,020	6,167,517	128,718	4,370,513	20,832	1,409,381
Avg. Volume per day	325.8	217.1	182.1	22.7	371.1	8.4	100.8
On-the-run	72%	74%	67%	0%	67%	0%	57%
Off-the-run	28%	26%	33%	100%	33%	100%	43%

Table 2. Summary of descriptive statistics for liquidity measures

This table provides statistics for the market share, *MS*, Amihud, *AM*, BPW, *Bao*, and price dispersion, *PD*, measures. The liquidity and illiquidity proxies are described in detail in Section 4 and are calculated weekly. The results for *Bao* are multiplied by 100. The dataset includes 83 2-year Treasury notes with 6,175 weekly measures during 257 trading weeks. The period covers January 1996 to November 2000 and is based on data from GovPx. We winsorize the 0.5% highest values and the 0.5% lowest values of the weekly measures of *MS*, *AM*, and *PD*, meaning that all values above the 99.5% percentile are set to the 99.5% percentile and all values below the 0.5% percentile are set to the 0.5% percentile. *Bao* is also winsorized but previously at the daily level.

	Full lifetime (weeks 1-105)	On-the-run (weeks 1-4)	First off-the-run (weeks 5-8)	Further off-the-run (weeks 9 to 53)	Further off-the-run (weeks 54 to 105)
Panel A. Market share					
$Q_{0.05}$	0.001	0.107	0.006	0.001	0.001
$Q_{0.25}$	0.002	0.231	0.010	0.002	0.002
$Q_{0.50}$	0.004	0.270	0.013	0.004	0.003
$Q_{0.75}$	0.007	0.347	0.021	0.006	0.006
$Q_{0.95}$	0.024	0.379	0.231	0.012	0.011
Average	0.016	0.269	0.038	0.005	0.004
Std dev	0.056	0.088	0.068	0.004	0.004
#Obs	6,175	238	237	2,658	3,042
Panel B. Amihud					
$Q_{0.05}$	0.252	0.009	0.552	2.136	0.384
$Q_{0.25}$	2.312	0.078	1.629	5.635	1.627
$Q_{0.50}$	6.066	0.112	2.721	12.060	3.786
$Q_{0.75}$	16.079	0.189	5.141	29.275	9.550
$Q_{0.95}$	74.611	0.584	23.282	127.906	37.303
Average	18.209	0.235	7.989	30.669	9.524
Std dev	39.468	0.567	28.947	53.462	18.860
#Obs	6,175	238	237	2,658	3,042

Panel C. Bao					
$Q_{0.05}$	-0.117	-0.400	-0.379	-0.172	-0.016
$Q_{0.25}$	-0.005	-0.050	-0.088	-0.030	-0.001
$Q_{0.50}$	0.002	0.075	0.040	0.017	0.001
$Q_{0.75}$	0.000	0.182	0.166	0.083	0.008
$Q_{0.95}$	0.215	0.483	0.489	0.317	0.045
Average	0.027	0.066	0.045	0.043	0.010
Std dev	0.157	0.240	0.267	0.197	0.082
#Obs	6,056	119	237	2,658	3,042
Panel D. Price dispersion					
$Q_{0.05}$	0.001	0.002	0.001	0.001	0.001
$Q_{0.25}$	0.005	0.008	0.006	0.005	0.005
$Q_{0.50}$	0.009	0.010	0.011	0.009	0.009
$Q_{0.75}$	0.015	0.018	0.021	0.015	0.015
$Q_{0.95}$	0.027	0.042	0.044	0.026	0.025
Average	0.011	0.015	0.015	0.011	0.011
Std dev	0.008	0.012	0.012	0.008	0.007
#Obs	6,175	238	237	2,658	3,042

Table 3. Liquidity measures

This table reports the results from the regressions on each considered liquidity proxy in the 2-year Treasury note sample. *MS* is a liquidity proxy, and *AM, Bao*, and *PD* are illiquidity proxies. *E*[*Liq*] is the expected value of the corresponding liquidity proxy according to the age of the note (see expression 8). *Age* is expressed in weeks. *Coupon* is the coupon rate of the bond. *OTR* and *1stOFF* are dummy variables that take value one if the status of the bond is respectively 'on-the-run' or 'first off-the-run' and zero otherwise. *Amount* is the log of the amount outstanding of the issue. *Bid-ask* is the bid-ask spread. *Level* is the 2-year Treasury yield. *Slope* is equal to the difference between the 10- and the 2-year Treasury yields. *Curvature* is equal to the difference between the 6-year Treasury yield and the average difference between the 10- and the 2-year Treasury yields. *BBB-AAA* is a credit spread. *AAA-10yTr* is used as a proxy for flight to liquidity/quality and is computed as the spread between the AAA yield and the 10-year Treasury bond yield. *Market Vol* is the log of the trading volume for the entire Treasury market reported by GovPx. The dataset includes weekly observations of the 2-year Treasury notes during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2. The *t*-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	Market Share			*Amihud*			*Bao*			*Price Dispersion*		
Intercept	0.000	-0.057	-0.057	0.229	-134.333	-139.311	-0.005	-3.399	-3.568	-0.557	27.483	27.917
	(2.56)**	(-3.90)***	(-3.94)***	(0.28)	(-6.06)***	(-6.26)***	(-0.11)	(-3.30)***	(-3.36)***	(-0.24)	(3.13)***	(3.16)***
E[Liq]	1.044	1.042	1.139	1.047	1.054	1.173	1.211	0.263	0.675	1.037	1.013	0.972
	(36.63)***	(38.34)***	(9.54)***	(14.66)***	(16.81)***	(9.08)***	(4.43)***	(0.32)	(0.71)	(4.72)***	(4.47)***	(3.92)***
Age		-0.000	0.000		-0.015	0.034		-0.005	-0.004		-0.002	-0.002
		(-1.55)	(-2.09)**		(-1.01)	(0.77)		(-1.49)	(-0.99)		(-0.25)	(-0.23)
OTR			-0.025			4.530			-0.026			0.370
			(-0.85)			(0.98)			(-0.08)			(0.22)
1stOFF			-0.002			6.558			-0.196			0.352
			(-0.75)			(1.66)*			(-0.72)			(0.25)
Coupon		0.001	0.001		6.408	6.398		0.173	0.174		0.848	0.848
		(1.41)	(1.40)		(5.41)***	(5.39)***		(3.70)***	(3.72)***		(2.27)**	(2.27)**

Amount		0.006	0.006		-4.819	-4.784		0.663	0.663		-1.615	-1.617
		(1.77)*	(1.77)*		(-0.95)	(-0.95)		(2.61)***	(2.62)***		(-0.93)	(-0.93)
Bid-ask		-0.000	0.000		1.342	1.366		-0.012	-0.011		-0.101	-0.100
		(-2.28)**	(-2.38)**		(14.16)***	(13.35)***		(-1.86)*	(-1.73)*		(-0.35)	(-0.35)
Level		0.204	0.205		1069.28	1067.49		2.496	2.584		-269.77	-269.90
		(1.82)*	(1.83)*		(5.04)***	(5.03)***		(0.36)	(0.37)		(-4.31)***	(-4.31)***
Slope		0.266	0.265		1086.86	1082.54		-0.543	-0.361		-734.01	-734.27
		(0.93)	(0.93)		(2.13)**	(2.12)**		(-0.03)	(-0.02)		(-4.48)***	(-4.48)***
Curvature		0.557	0.552		-4308.79	-4299.40		243.33	242.79		1200.07	1201.02
		(0.53)	(0.53)		(-2.30)**	(-2.30)**		(3.48)***	(3.47)***		(2.39)**	(2.39)**
SP500		0.000	0.000		0.000	0.000		0.001	0.001		0.001	0.001
		(1.85)*	(1.84)*		(0.04)	(0.03)		(2.68)***	(2.69)***		(0.41)	(0.41)
VIX		0.000	0.000		0.393	0.393		0.021	0.021		-0.149	-0.149
		(1.80)*	(1.79)*		(3.19)***	(3.20)***		(2.21)**	(2.21)**		(-4.10)***	(-4.09)***

(Continued)

Table 3. Continued

BBB-AAA		0.006	0.006		26.748	26.768		-0.270	-0.270		1.933	1.932
		(1.70)*	(1.7)*		(3.39)***	(3.39)***		(-0.88)	(-0.88)		(0.94)	(0.94)
AAA-10yTr		0.007	0.007		18.917	18.890		-0.577	-0.576		-7.890	-7.892
		(2.65)***	(2.66)***		(4.45)***	(4.45)***		(-2.43)**	(-2.43)**		(-6.19)***	(-6.20)***
Market Vol		0.000	0.000		-0.819	-0.845		-0.128	-0.126		0.356	0.352
		(0.02)	(0.03)		(-0.48)	(-0.50)		(-1.90)*	(-1.88)*		(0.92)	(0.91)
Adj. R^2	0.878	0.881	0.881	0.095	0.132	0.132	0.012	0.035	0.035	0.039	0.085	0.085
#Obs	6,175	6,175	6,175	6,175	6,175	6,175	6,056	6,056	6,056	6,175	6,175	6,175

Table 4. Descriptive statistics for 2-year note yield spread according the auction status

This table shows the descriptive statistics for the 2-year yield spreads, *YS*, in bps. *YS* can be interpreted as a liquidity premium with respect to an identical asset with the average market liquidity. We estimate the *YS* for every note and date as the difference between the observed yield-to-maturity and the theoretical yield-to-maturity. The theoretical yield-to-maturity is obtained from the theoretical price that the note should be traded at, using the average liquidity on the market. To do so, we discount each original cash flow of the note from the corresponding zero-coupon interest rate for each maturity. The daily zero-coupon yield curve for each date is fitted following the procedure by Svensson (1994) described in Section 5. Weekly averages are computed from the daily observations. *OTR*, *1stOFF*, and *2nd+OFF* represent different sub-samples, depending on the auction status, i.e., 'on-the-run' (weeks 1 to 4), 'first off-the-run' (weeks 5 to 8), and 'second or further off-the-run' (full period, i.e., weeks 9 to 105), respectively. The last two column excludes notes with a maturity of less than two months (the last 10 weeks before maturity). The dataset includes weekly observations of the 2-year Treasury notes during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2.

	Full lifetime	**OTR**	**1stOFF**	**2nd+OFF**				
				Full period	1st year	2nd year	Excl. last 10 weeks	
Weeks	1 to 105	1 to 4	5 to 8	9 to 105	9 to 53	54 to 105	9 to 95	54 to 95
$Q_{0.05}$	-5.80	-11.27	-7.60	-4.19	-3.13	-9.43	-2.64	-1.20
$Q_{0.25}$	-0.04	-5.71	-3.52	0.74	-0.25	3.63	0.92	4.40
$Q_{0.50}$	3.58	-3.58	-1.95	4.26	1.92	8.84	4.14	8.75
$Q_{0.75}$	9.11	-2.01	-0.44	9.76	4.16	15.32	8.96	13.96
$Q_{0.95}$	24.40	-0.02	1.65	25.06	8.05	31.90	20.11	24.93
Avg	5.23	-4.33	-2.32	5.94	2.04	9.35	5.77	9.75
Std	14.28	4.05	3.13	14.59	3.55	19.06	7.34	8.21
Min	-75.22	-29.32	-16.85	-75.22	-13.02	-75.22	-18.25	-18.26
Max	127.43	3.36	5.28	127.43	34.68	127.43	86.43	86.43
#Obs	6,175	238	237	5,700	2,658	3,042	5,142	2,484

Table 5. Descriptive statistics per year **for 2-year note yield spreads according to the auction status**

This table shows the statistics for the 2-year yield spreads, *YS*, in bps, for each year of the sample period. We estimate the *YS* as described in Table 4 and Section 5. The dataset includes weekly observations of the 2-year Treasury notes during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2. *OTR*, *1stOFF*, and *2nd+OFF* represent different sub-samples, depending on the auction status, i.e., "on-the-run" (weeks 1 to 4), "first off-the-run" (weeks 5 to 8), and "second or further off-the-run" (weeks 9 to 105), respectively.

	1996			1997			1998			1999			2000		
	OTR	1st OFF	2nd+ OFF	OTR	1st OFF	2nd+ OFF	OTR	1st OFF	2nd+ OFF	OTR	1st OFF	2nd+ OFF	OTR	1st OFF	2nd+ OFF
$Q_{0.05}$	-5.26	-3.56	-12.07	-4.76	-2.79	-2.03	-20.80	-14.07	-4.69	-7.57	-3.61	-0.98	-9.18	-6.25	-6.55
$Q_{0.25}$	-3.68	-2.56	-0.60	-3.32	-2.00	1.35	-11.24	-7.59	0.99	-4.09	-1.83	2.67	-7.31	-3.97	0.18
$Q_{0.50}$	-2.94	-1.94	1.62	-2.30	-1.13	5.43	-6.25	-4.95	5.78	-2.52	-0.63	5.88	-5.11	-2.57	3.25
$Q_{0.75}$	-1.49	-0.66	4.45	-1.20	-0.35	12.12	-5.61	-3.83	12.61	-1.36	1.37	11.20	-3.53	-0.04	7.90

$Q_{0.95}$	0.35	0.77	13.83	-0.35	0.52	29.63	-3.95	-2.13	28.46	1.62	3.25	27.38	0.17	1.75	20.14
Avg	-2.70	-1.69	0.91	-2.35	-1.14	8.15	-8.84	-6.14	8.27	-2.74	-0.31	8.59	-5.06	-2.25	3.56
Std	1.69	1.48	13.02	1.48	1.11	14.27	5.63	3.70	15.01	2.61	2.23	14.12	2.81	2.52	14.84
Min	-6.04	-5.69	-75.22	-6.12	-3.60	-75.22	-29.32	-16.85	-75.22	-8.87	-4.96	-75.22	-10.60	-7.12	-75.22
Max	1.31	1.31	91.11	-0.04	0.96	127.43	-3.59	-1.68	127.43	3.36	5.28	127.43	0.64	2.10	127.43
#Obs	48	47	1,152	49	49	1,154	49	49	1,173	48	48	1,156	44	44	1,065

Table 6. Yield spread and current liquidity

This table reports the results from the panel regressions of the yield spread, *YS*, as the dependent variable on the actual value of each liquidity/illiquidity proxy and the age of the note. *MS* is a liquidity proxy, and *AM, Bao*, and *PD* are illiquidity proxies. *OTR* and *1stOFF* are dummy proxies that take value one if the status of the bond is respectively "on-the-run" or "first off-the-run" and zero otherwise. *YS* can be interpreted as a liquidity premium with respect to an identical asset with the average market liquidity. We estimate the *YS* as described in Table 4 and Section 5. The dataset includes weekly observations of the 2-year Treasury notes during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2. The *t*-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Intercept	0.056	-0.034	-0.035	0.054	-0.037	-0.035	0.052	-0.037	-0.037	0.065	-0.029	-0.028	0.075	-0.027	-0.027
	(20.34)***	(-10.29)***	(-9.33)***	(17.83)***	(-12.22)***	(-9.00)***	(18.73)***	(-11.97)***	(-9.90)***	(16.40)***	(-7.36)***	(-6.33)***	(18.29)***	(-6.20)***	(-5.98)***
MS	-0.354	-0.052	-0.063										-0.359	-0.040	-0.078
	(-16.25)***	(-2.50)**	(-1.91)*										(-14.25)***	(-1.92)*	(-2.37)**
AM				-0.189	0.002	-0.009							-0.260	-0.026	-0.024
				(-6.69)***	(0.10)	(-0.53)							(-9.37)***	(-1.67)*	(-1.51)
Bao							-0.000	0.003	0.003				0.001	0.003	0.003
							(-0.33)	(5.17)***	(5.20)***				(1.04)	(5.34)***	(5.37)***
PD										-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
										(-5.94)***	(-3.49)***	(-3.42)***	(-5.71)***	(-3.74)***	(-3.83)***
Age		0.002	0.002		0.002	0.002		0.002	0.002		0.002	0.002		0.002	0.002
		(19.	(18.		(21.	(18.		(20.	(18.		(20.	(18.		(19.	(18.

		68)***	41)***		45)***	22)***		81)***	64)***		91)***	33)***		32)***	28)***
OTR			0.004			-0.013			-0.010			-0.011			0.013
			(0.50)			(-2.27)**			(-1.78)*			(-1.89)*			(1.51)
1stOFF			0.002			-0.000			0.001			0.002			0.005
			(0.52)			(-0.01)			(0.13)			(0.50)			(1.07)
Adj. R^2	0.074	0.436	0.435	0.010	0.434	0.435	-0.000	0.420	0.420	0.023	0.439	0.439	0.080	0.425	0.425
#Obs	5,617	5,617	5,617	5,617	5,617	5,617	5,498	5,498	5,498	5,617	5,617	5,617	5,498	5,498	5,498

Table 7. Yield spread and expected liquidity

This table reports the results from panel regressions of the yield spread, *YS*, as the dependent variable on the expected and unexpected or abnormal (*Abn*) value of each liquidity proxy and the age of the note. *MS* is a liquidity proxy, and *AM, Bao*, and *PD* are illiquidity proxies. $E[\cdot]$ is the expected value of the corresponding liquidity proxy based on the age of the note (see expression 8). *Age* is expressed in weeks. *YS* can be interpreted as a liquidity premium with respect to an identical asset with the average market liquidity. We estimate the *YS* as described in Table 4 and Section 5. The dataset includes weekly observations of the 2-year Treasury notes during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2. The *t*-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Intercept	0.057	-0.034	0.088	-0.042	0.131	-0.046	0.275	-0.041	-0.000	-0.060
	(20.48)***	(-10.11)***	(14.45)***	(-10.05)***	(26.11)***	(-1.62)	(24.65)***	(-2.24)**	(-0.00)	(-1.40)
E[MS]	-0.404	-0.046							0.059	-0.043
	(-19.45)***	(-2.25)**							(2.18)**	(-1.39)
AbnMS	-0.096	-0.075							-0.092	-0.089
	(-2.27)**	(-1.95)*							(-2.23)**	(-2.21)**
E[AM]			-2.087	0.157					0.299	0.068
			(-9.79)***	(1.44)					(1.55)	(0.46)
AbnAM			-0.015	-0.009					-0.017	-0.021
			(-0.66)	(-0.56)					(-1.05)	(-1.37)
E[Bao]					-0.326	0.020			-0.472	0.024
					(-22.97)***	(0.37)			(-11.14)***	(0.14)
AbnBao					2.526	2.690			2.926	2.885
					(4.43)***	(5.17)***			(5.28)***	(5.39)***
E[PD]							-0.020	0.000	0.014	0.001
							(-23.00)***	(0.23)	(5.38)***	(0.23)
AbnPD							-0.587	-0.623	-0.741	-0.705
							(-2.95)***	(-3.57)***	(-4.18)***	(-3.94)***
Age		0.002		0.002		0.002		0.002		0.002
		(19.46)**		(22.42)**		(5.61)**		(14.99)**		(2.53)**

		*		*		*		*		
Adj. R^2	0.080	0.436	0.102	0.435	0.389	0.420	0.195	0.439	0.420	0.426
#Obs	5,617	5,617	5,617	5,617	5,498	5,498	5,617	5,617	5,498	5,498

Table 8. Yield spread and current and expected liquidity including control variables

This table reports the results from panel regressions of the yield spread, *YS*, as the dependent variable on the expected and unexpected or abnormal, *Abn*, value of each liquidity proxy and the age of the note. *MS* is a liquidity proxy, and *AM, Bao*, and *PD*, are illiquidity proxies. *E*[·] is the expected value of the corresponding liquidity proxy based on the age of the note (see expression 8). *Age* is expressed in weeks. *Coupon* is the coupon rate of the bond. *Amount* is the log of the amount outstanding of the issue. *Bid-ask* is the bid-ask spread. *Level* is the 2-year Treasury yield. *Slope* is equal to the difference between the 10- and the 2-year Treasury yields. *Curvature* is equal to the difference between the 6-year Treasury yield and the average difference between the 10- and the 2-year Treasury yields. *BBB-AAA* is a credit spread. *AAA-10yTr* is used as proxy for flight to liquidity/quality and is computed as the spread between the AAA yield and the 10-year Treasury bond yield. *Market Vol* is the log of the trading volume for the entire Treasury market reported by GovPx. Weekly averages are computed from the daily observations. We estimate the *YS* as described in Table 4 and Section 5. The dataset includes weekly observations of the 2-year Treasury notes during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2.The *t*-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

Intercept	-0.114	-0.118	-0.110	-0.114	-0.099	-0.113	-0.086	-0.101	-0.071	-0.110
	(-2.21)**	(-2.29)**	(-2.13)**	(-2.20)**	(-1.87)*	(-1.96)*	(-1.66)*	(-1.88)*	(-1.32)	(-1.69)*
MS	-0.055								-0.036	
	(-2.50)**								(-1.58)	
E[MS]		-0.041								-0.036
		(-1.87)*								(-1.14)
AbnMS		-0.121								-0.117
		(-2.80)***								(-2.38)**
AM			0.018						0.004	
			(1.53)						(0.26)	
E[AM]				0.132						0.105
				(1.12)						(0.66)
AbnAM				0.019						0.011
				(1.16)						(0.68)
Bao					0.002				0.002	
					(3.62)***				(3.71)***	
E[Bao]						0.032				0.013
						(0.62)				(0.09)
AbnBao						2.047				2.151
						(3.62)***				(3.76)***
PD							-0.001		-0.001	
							(-3.53)***		(-3.65)***	
E[PD]								0.001		0.002
								(0.51)		(0.47)
AbnPD								-0.615		-0.683
								(-3.72)***		(-4.02)***
Age	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
	(20.63)***	(20.48)***	(22.59)***	(22.83)***	(21.68)***	(6.10)***	(21.83)***	(15.96)***	(20.17)***	(2.70)***
Coupon	-0.004	-0.004	-0.004	-0.004	-0.005	-0.005	-0.003	-0.004	-0.005	-0.005
	(-1.00)	(-0.98)	(-1.11)	(-1.07)	(-1.45)	(-1.47)	(-0.94)	(-0.97)	(-1.30)	(-1.34)
Amount	0.055	0.055	0.055	0.055	0.055	0.055	0.053	0.053	0.053	0.054
	(4.16)***	(4.18)***	(4.18)***	(4.15)***	(4.08)***	(4.11)***	(4.04)***	(4.07)***	(3.96)***	(4.03)***
Bid-ask	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.73)	(0.68)	(0.67)	(0.81)	(0.74)	(0.66)	(0.94)	(0.56)	(1.02)	(0.37)
Level	-1.506	-1.492	-1.553	-1.541	-1.606	-1.608	-1.668	-1.679	-1.767	-1.786
	(-3.16)***	(-3.13)***	(-3.26)***	(-3.23)***	(-3.34)***	(-3.35)***	(-3.49)***	(-3.53)***	(-3.63)***	(-3.69)***
Slope	-1.332	-1.313	-1.390	-1.375	-1.418	-1.424	-1.816	-1.849	-1.905	-1.962

	(-0.96)	(-0.95)	(-1.00)	(-0.99)	(-1.02)	(-1.02)	(-1.31)	(-1.33)	(-1.36)	(-1.40)
Curvature	17.438	17.477	17.537	17.498	16.725	16.722	18.204	18.240	17.595	17.718
	(4.40)***	(4.41)***	(4.42)***	(4.41)***	(4.14)***	(4.14)***	(4.64)***	(4.65)***	(4.41)***	(4.44)***
SP500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(2.70)***	(2.72)***	(2.65)***	(2.66)***	(2.40)**	(2.37)**	(2.66)***	(2.63)***	(2.42)**	(2.40)**
VIX	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
	(5.19)***	(5.21)***	(5.08)***	(5.11)***	(5.22)***	(5.20)***	(4.86)***	(4.84)***	(4.88)***	(4.83)***
BBB-AAA	-0.035	-0.034	-0.036	-0.036	-0.035	-0.035	-0.035	-0.035	-0.035	-0.035
	(-1.96)*	(-1.93)*	(-2.03)**	(-2.01)**	(-1.99)**	(-1.99)**	(-1.95)*	(-1.95)*	(-1.94)*	(-1.94)*
AAA-10yTr	-0.017	-0.017	-0.018	-0.018	-0.015	-0.015	-0.022	-0.022	-0.019	-0.020
	(-1.25)	(-1.22)	(-1.31)	(-1.30)	(-1.10)	(-1.10)	(-1.57)	(-1.58)	(-1.41)	(-1.42)
Market Vol	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.011	0.011
	(3.62)***	(3.62)***	(3.59)***	(3.60)***	(3.68)***	(3.68)***	(3.76)***	(3.77)***	(3.84)***	(3.85)***
Adj. R^2	0.491	0.491	0.489	0.490	0.478	0.478	0.493	0.493	0.482	0.483
#Obs	5,617	5,617	5,617	5,617	5,498	5,617	5,617	5,617	5,498	5,617

Table 9. Robustness checks: two sub-samples and alternative liquidity proxies

This table reports the results from the panel regressions of the yield spread, *YS*, as the dependent variable on the actual, expected, and unexpected or abnormal, *Abn*, value of each liquidity proxy and the age of the note. *MS* is a liquidity proxy, and *AM, Bao*, and *PD* are illiquidity proxies. *TO*, *AV*, and *Roll* are the turnover, Amivest, and Roll measures, respectively. The liquidity and illiquidity proxies are described in detail in Sections 4 and 5.3 and are calculated weekly. $E[\cdot]$ is the expected value of the corresponding liquidity proxy based on the age of the note (see expression 8). *Age* is expressed in weeks. Weekly averages are computed from the daily observations. We estimate the *YS* as described in Table 4 and Section 5. The control variables are described in Table 8. The dataset includes weekly observations of the 2-year Treasury notes during the period from January 1996 to November 2000 based on data from GovPx. The winsorization process is described in Table 2. The *t*-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	January 1996 - July 1998		August 1998 - November 2000			January 1996 - July 1998		August 1998 - November 2000	
Intercept	0.015	-0.084	-0.353	-0.332	Intercept	0.022	-0.188	0.083	0.131
	(0.08)	(-0.44)	(-2.68)***	(-2.29)**		(0.11)	(-0.86)	(0.58)	(0.84)
MS	0.016		0.246		TO	-0.036		-0.058	
	(0.66)		(2.00)**			(-2.89)***		(-1.60)	
E[MS]		-0.051		0.255	E[TO]		-0.044		-0.043
		(-1.36)		(1.67)**			(-1.09)		(-0.63)
AbnMS		-0.139		0.280	AbnTO		-63.21		-50.63
		(-3.06)*		(2.19)**			(-3.53)***		(-1.33)
AM	-0.008		0.013		AV	0.003		-0.002	
	(-0.27)		(0.64)			(2.69)***		(-2.32)**	
E[AM]		0.062		0.199	E[AV]		0.002		-0.006
		(0.34)		(0.78)			(0.53)		(-0.96)
AbnAM		0.015		0.013	AbnAV		0.003		-0.003
		(0.54)		(0.70)			(2.50)**		(-2.24)**
Bao	0.001		0.005		Roll	0.027		-0.032	
	(1.16)		(3.70)***			(2.65)***		(-0.92)	
E[Bao]		0.117		-0.146	E[Roll]		4.784		-0.097
		(0.56)		(-0.70)			(2.90)***		(-0.06)
AbnBao		0.679		4.714	AbnRoll		0.032		-0.032
		(1.16)		(3.73)***			(3.23)***		(-0.92)

PD	-0.000		-0.001						
	(-2.04)**		(-3.55)***						
E[PD]		0.001		0.004					
		(0.14)		(0.71)					
AbnPD		-0.538		-0.909					
		(-2.51)**		(-3.44)***					
Age	0.002	0.002	0.002	0.001	Age	0.002	0.004	0.002	0.002
	(15.10)***	(2.50)**	(15.88)***	(1.41)		(16.43)***	(5.55)***	(15.21)***	(2.57)**
Coupon	-0.016	-0.016	0.006	0.006	Coupon	-0.016	-0.016	0.004	0.004
	(-3.30)***	(-3.30)***	(1.13)	(1.14)		(-2.79)***	(-2.93)***	(0.82)	(0.80)
Amount	0.074	0.076	0.044	0.044	Amount	0.074	0.077	0.048	0.048
	(3.67)***	(3.83)***	(2.87)***	(2.86)***		(3.45)***	(3.78)***	(3.59)***	(3.59)***
Bid-ask	0.000	0.000	7.209	6.766	Bid-ask	0.000	0.000	-6.784	-8.110
	(1.46)	(0.79)	(2.30)**	(2.02)**		(0.75)	(0.29)	(-1.90)*	(-2.02)**
Level	-2.084	-1.898	1.809	1.813	Level	-1.823	-1.668	1.932	1.926
	(-1.03)	(-0.96)	(2.09)**	(2.10)**		(-0.83)	(-0.79)	(2.66)***	(2.65)***
Slope	3.937	4.043	1.831	1.857	Slope	3.586	3.156	4.932	4.899
	(1.22)	(1.26)	(1.07)	(1.09)		(0.82)	(0.73)	(2.76)***	(2.74)***
Curvature	-1.887	-1.808	21.239	21.238	Curvature	-4.770	-5.182	14.868	14.957
	(-0.14)	(-0.13)	(5.24)***	(5.24)***		(-0.29)	(-0.32)	(3.10)***	(3.13)***
SP500	0.000	0.000	-0.000	-0.000	SP500	0.000	0.000	0.000	0.000
	(2.95)**	(3.05)***	(-4.05)***	(-4.04)***		(2.20)**	(2.20)**	(-4.01)***	(-4.02)***
VIX	0.002	0.002	-0.001	-0.001	VIX	0.002	0.002	-0.001	-0.001
	(3.41)***	(3.40)***	(-1.43)	(-1.45)		(4.02)***	(4.02)***	(-1.73)*	(-1.77)*
BBB-AAA	-0.126	-0.126	0.027	0.027	BBB-AAA	-0.141	-0.133	-0.026	-0.026
	(-2.49)**	(-2.47)**	(1.13)	(1.13)		(-2.31)**	(-2.16)**	(-1.29)	(-1.27)
AAA-10yTr	-0.082	-0.075	0.042	0.042	AAA-10yTr	-0.107	-0.106	0.091	0.091
	(-1.54)	(-1.41)	(2.31)**	(2.33)**		(-1.71)*	(-1.67)*	(4.85)***	(4.80)***
Market Vol	0.008	0.008	0.017	0.017	Market Vol	0.010	0.011	0.026	0.026
	(3.14)***	(3.06)***	(3.57)***	(3.60)***		(3.29)***	(3.52)***	(4.44)***	(4.41)***
Adj. R^2	0.546	0.551	0.478	0.478	Adj. R^2	0.561	0.571	0.456	0.455
#Obs	2,864	2,864	2,634	2,634	#Obs	1,947	1,947	1,843	1,843

Table 10. Robustness check: Yield spread of 5-year and 10-year notes and current and expected liquidity including control variables

This table reports the results from panel regressions of the yield spread, *YS*, as the dependent variable on the expected and unexpected or abnormal (*Abn*) value of each liquidity proxy and the age of the note. *MS* is a liquidity proxy, and *AM*, *Bao*, and *PD* are illiquidity proxies. $E[\cdot]$ is the expected value of the corresponding liquidity proxy based on the age of the note (see expression 8). *Age* is expressed in weeks. *OTR* and *1stOFF* are dummy proxies that take value one if the status of the bond is respectively 'on-the-run' or 'first off-the-run' and zero otherwise. $E[MS]^{\perp}$, $E[Bao]^{\perp}$, and $OTR^{\perp}$ are the variables orthogonalized to the $E[PD]$, to the $E[AM]$ and *Age*, and to the *MS* in the 5-year note sample, respectively. $E[AM]^{\perp}$ and $E[PD]^{\perp}$ are the variables orthogonalized to the $E[Bao]$ and *Age* and to the $E[MS]$ in the 10-year note sample, respectively. We estimate the *YS* as described in Table 4 and Section 5. The control variables are described in Table 8. The winsorization process is described in Table 2. The dataset includes weekly observations of 94 5-year notes, and 49 10-year Treasury notes during the period from January 1996 to November 2000 based on data from GovPx. The *t*-statistics are based on the Newey-West estimate of the covariance matrix and are presented in parentheses. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively.

	Panel A. 5-year notes					Panel B. 10-year notes					
	(1)	(2)	(3)	(4)	(5)		(6)	(7)	(8)	(9)	(10)
Intercept	-0.069	-0.076	-0.478	0.209	-1.083	Intercept	-0.070	-0.065	-0.121	0.814	0.595
	(-	(-	(-	(0.49)	(-3.02)***		(-	(-	(-8.15)***	(1.57)	(1.16)
MS	-0.148	-0.150		-0.127		MS	-0.291	-0.072		-0.282	
	(-1.49)	(-1.83)*		(-1.33)			(-2.87)***	(-0.57)		(-2.90)***	
$E[MS]^{\perp}$			-0.934		-0.932	E[MS]			-0.649		-0.730
			(-8.29)***		(-7.93)***				(-2.72)***		(-3.15)***

AbnMS			-0.798 (-4.53)***		-0.837 (-4.96)***
AM	6.086 (8.71)***	7.158 (9.72)***		6.606 (8.84)***	
E[AM]			71.616 (21.87)***		76.322 (22.75)***
AbnAM			0.044 (0.06)		0.808 (1.09)
Bao	0.048 (1.96)*	0.054 (2.07)**		0.053 (2.08)**	
E[Bao]$^{\perp}$			4.405 (11.35)***		4.372 (10.40)***
AbnBao			-0.007 (-0.32)		-0.003 (-0.13)
PD	-0.153 (-1.03)	-0.272 (-2.05)**		-0.213 (-1.43)	
E[PD]			24.758 (17.42)***		25.678 (18.07)***
AbnPD			-0.447 (-3.90)***		-0.475 (-4.16)***
Age (x1000)	0.576 (17.70)***	0.618 (17.66)***	1.220 (24.18)***	0.571 (14.12)***	1.273 (24.00)***
OTR$^{\perp}$		0.093 (2.74)***			
1stOFF		0.043 (5.10)***			
Coupon				0.003 (1.11)	0.002 (0.89)
Amount				-0.017 (-0.63)	0.035 (1.55)
Bid-ask				0.063 (0.28)	0.164 (1.00)
Level				-1.324 (-2.62)***	-1.570 (-3.89)***
Slope				-0.737 (-0.56)	0.199 (0.19)
Curvature				10.892 (2.74)***	11.924 (3.72)***
SP500				0.000 (0.94)	0.000 (2.65)***
VIX				0.001 (2.49)**	0.001 (4.07)***
BBB-AAA				-0.020 (-1.07)	-0.009 (-0.61)
AAA-10yTr				-0.013 (-1.06)	-0.020 (-2.00)**
Market Vol				0.009 (1.81)*	0.009 (2.19)**
Adj. R^2	0.306	0.328	0.490	0.321	0.515
#Obs	9,649	9,649	9,560	9,649	9,560

AbnMS			-0.105 (-0.80)		-0.076 (-0.61)
AM	0.245 (0.65)	0.053 (0.14)		0.443 (1.18)	
E[AM]$^{\perp}$			30.419 (3.34)***		29.41 (3.38)***
AbnAM			-0.467 (-1.08)		-0.497 (-1.11)
Bao	0.011 (1.30)	0.009 (1.15)		0.013 (1.82)*	
E[Bao]			0.428 (4.56)***		0.418 (4.36)***
AbnBao			0.007 (0.75)		0.007 (0.97)
PD	-0.187 (-13.31)***	-0.184 (-13.60)***		-0.194 (-12.98)***	
E[PD]$^{\perp}$			-0.297 (-4.34)***		-0.321 (-4.93)***
AbnPD			-0.174 (-12.49)***		-0.177 (-12.44)***
Age (x1000)	0.260 (14.29)***	0.247 (13.06)***	0.368 (9.19)***	0.197 (5.79)***	0.298 (5.58)***
OTR		-0.056 (-2.34)***			
1stOFF		-0.033 (-2.41)**			
Coupon				0.004 (0.87)	0.005 (1.11)
Amount				-0.056 (-1.86)*	-0.046 (-1.52)
Bid-ask				-0.442 (-0.96)	-0.321 (-0.73)
Level				0.465 (0.69)	0.149 (0.22)
Slope				-5.187 (-2.43)**	-5.160 (-2.45)**
Curvature				12.121 (2.08)**	14.324 (2.52)***
SP500				0.000 (-1.27)	-0.000 (-1.47)
VIX				0.001 (2.08)**	0.001 (2.04)**
BBB-AAA				-0.018 (-0.57)	-0.017 (-0.54)
AAA-10yTr				-0.011 (-0.62)	-0.009 (-0.55)
Market Vol				0.013 (1.56)	0.014 (1.77)*
Adj. R^2	0.665	0.668	0.681	0.676	0.693
#Obs	3,994	3,664	3,994	3,994	3,994

Highlights

A term structure of each considered liquidity proxy during the 'life cycle' is adjusted

Liquidity premiums are estimated from yield differentials with respect to market-averaged liquid assets

Large portion of the liquidity premium follows a predictive behavior along the lifetime

The aging effect extends beyond the simple on-the-run/off-the-run effect

There is a stochastic component of the liquidity premium that depends on the unexpec ted value of microstructure-based liquidity proxies